Survey of Biomass Resource Assessments
and Assessment Capabilities
in APEC Economies

Energy Working Group

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Preface

This survey of biomass resource assessments and assessment capabilities in Asia-Pacific Economic Cooperation (APEC) economies took place from September 2007 until May 2008. Various sources were considered: academic and government publications, media reports, and personal communication with contacts in member economies. The inventoried literature was not reviewed for accuracy or modified, but simply cataloged, with the published characteristics and limitations noted. It is reasonable to assume that additional information exists for some economies, yet it was not made available due to language or access constraints.

Abbreviations and Acronyms

APEC - Asia-Pacific Economic Cooperation

BTF – Biofuels Task Force (APEC)

CRP - conservation reserve program

ETBE - ethyl tertiary butyl ether

FAO - Food and Agriculture Organization

GIS – geographic information system

GPS – global positioning system

MTBE - methyl tertiary butyl ether

MSW - municipal solid waste

NREL - National Renewable Energy Laboratory (of the U.S. Department of Energy)

PNG - Papua New Guinea

RS – remote sensing

R&D - research and development

SVO - straight vegetable oil

Units of Measure

dam^3 – cubic decameter or 1,000 m^3 or 10^6 L, described in some sources as a ML (Megaliter)

EJ – Exajoule (10^{18} joule)

Gg – Gigagram (1,000 tonnes)

ha – hectare

hm^3 – cubic hectometer or 1,000,000 m^3 or 10^9 L, described in some sources as a GL (Gigaliter)

kt – kilotonne (1,000 tonnes)

L – liter (decimeter or dm^3)

m^3 – cubic meter

Mt – Megatonne (10^6 tonnes)

MW – Megawatt

Odt – oven dry ton = bone dry ton

Tg – Teragram, a unit of mass = 1 Megatonne

TJ – Terajoule (10^{12} J)

Tonne - metric ton

TOE - tonne of oil equivalent, the amount of energy released by burning one tonne of crude oil, approximately 42 GJ (Gigajoule = 10^9 J); Mtoe – Million TOE

Conversions

1 metric ton of wood = 1.4 cubic meters (solid wood)

1 metric ton of ethanol = 1,265 liters; average ethanol density: 0.79 g/cm^3 (= tonne/m^3)

1 metric ton of biodiesel = 1,136 liters; average biodiesel density: 0.88 g/cm^3 (= tonne/m^3)

1 metric ton of gasoline = 1,356 liters; average gasoline density: 0.73 g/cm^3 (= tonne/m^3)

1 metric ton of diesel = 1,177 liters; average diesel density: 0.85 g/cm^3 (= tonne/m^3)

1 metric ton of lignocellulosic biomass yields approximately 300 liters of ethanol

1 metric ton of grains yield approximately 360 liters of ethanol

Glossary of Plant Names

Chinese pistachio (*Pistacia Chinensis*)

Chinese tallow tree (*Sapium Sebiferum*)

Corn (*Zea Mays)* commonly known as maize

Indian mustard (*Brassica Juncea*)

Jatropha *(Jatropha Curcas)*

Maravilla (*Flourensia Thurifera)*

Miscanthus (a genus of about 15 species, e.g. *Miscanthus Sinensis* and *Miscanthus giganteus)*

Pongam (*Pongamia Pinnata*) also known as Karanj

Rapeseed (*Brassica Napus*) also known as Canola in the United States and Canada

Executive Summary

Given the steady growth in the demand for transportation fuels and declining oil production within their region, the APEC economies are concerned over energy supply security and are looking for alternative options. APEC members have identified biofuels as one option for diversifying sources of energy for transport.

Biomass resource assessment is essential in evaluating the bioenergy potential in a given location, as well as the social, environmental, and economic impacts associated with resources production and use. Biomass resource assessments guide industry development strategies and support decision-making processes.

This survey aims to catalog current and planned biomass resource assessments throughout the APEC region, increasing awareness of the resource availability and identifying future needs. It also aims to understand the capability of APEC economies to undertake such assessments. It is intended to deepen and expand on the preliminary resource assessments that were presented in the APEC Biofuels Task Force (BTF) report at the Eight Energy Ministers Meeting (EMM) in Darwin, Australia in May 2007.

The results of this survey revealed that most of the APEC economies have assessed their biomass resources at an economy-wide level. Many have completed biomass resource assessments by state/province, and few at a finer geographic level – county/district or local.

Additionally, the survey found that all APEC economies have what is necessary to conduct biomass resource assessments - scientific knowledge, tools, and data. However, not all of them have used their full capabilities in existing assessments. Some members have used their advanced capabilities, such as geospatial technologies and simulation modeling to develop detailed analyses of resource potential. For others, the survey identified products that are not direct examples of biomass resource assessments, but they indicate existing capabilities that could be applied to future resource assessment projects, thus enabling them to achieve fine geographic presentation of resources and project potential.

A summary of findings is presented below.

Economies with Good Resource-Assessment Capabilities and Detailed Resource Assessments: Australia, Canada, Chile, Indonesia, Korea, Mexico, the Philippines, Thailand, United States

Economies with Good Resource-Assessment Capabilities and Medium Scale (state/province) Resource Assessments: China, New Zealand

Economies with Good Resource-Assessment Capabilities and Broad (Economy-Wide) Resource Assessments: Japan, Malaysia, Chinese Taipei, Viet Nam

Economies with Good Resource-Assessment Capabilities and Limited or No Resource Assessments: Papua New Guinea, Peru, Russia

Economies with Limited Biofuel Resources: Brunei Darussalam, Hong Kong, Singapore

With respect to resource potential for ethanol production in the APEC region, the study concluded that a significant amount of second generation feedstock (particularly crop and forest residues) is available. This feedstock could be utilized when the technology for conversion of this material to ethanol becomes cost-effective. The feedstock amounts to about 1,700 million tonnes (Mt), which would yield some 509 hm^3 [1] of ethanol or 245 Mt gasoline equivalent. Such a volume would displace about two-fifths of the region's current gasoline consumption and one-fifth of its crude oil import. Many economies could substitute a substantial volume of their current gasoline consumption with ethanol from second generation feedstock, while others such as China, Thailand, and Viet Nam could substitute their entire consumption. The table below summarizes these findings.

Regarding first generation feedstock for ethanol production, the study evaluated the contribution of 20% of the economies' current starch and sugar crops production. The 20% figure is purely illustrative but would be consistent with trend-based hypotheses regarding the potential for increased agricultural yields to render a fifth of production surplus to food needs over time. If the equivalent of one-fifth of current agricultural production could actually be spared for biofuels production, the first-generation resource potential would amount to some 252 Mt of feedstock and 92 hm^3 of ethanol or 44 Mt of gasoline equivalent. This would be sufficient to displace only 7% of current gasoline consumption and 3.5% of crude oil imports in the region.

With respect to resource potential for biodiesel production, only first generation feedstock was considered. Data on second generation feedstock (non-edible crops, such as Jatropha and

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[1] hm^3 – cubic hectometer or 1,000,000 m^3 or 10^9 L, described in some sources as a GL (Gigaliter)

Pongam, or from algae) was insufficient to provide meaningful results. If 20% of APEC economies' current vegetable oil supply could be spared for biofuel production and if all waste oils and fats could be practically gathered for such production, it would yield about 22 Mt of biodiesel. This would be sufficient to displace about 7% of current petroleum-based diesel consumption and 2% of crude oil imports. Economies with the highest resource availability include China, Indonesia, Malaysia, and the United States. It is expected that the resource potential for biodiesel production in APEC economies will increase significantly over the next years with the development of second generation feedstock.

Second-generation Resource Availability for Ethanol Production in APEC Economies

Economy	Feedstock Type	Resource Availability ('000 tonnes)	Ethanol Potential (hm3)	Gasoline Equivalent ('000 tonnes)	Gasoline Consumption ('000 tonnes)*	Share of Gasoline Consumption (%)	Crude Oil Import ('000 tonnes)*	Share of Crude Oil Import (%)
Australia	crop, forest, and primary mill residues; urban wood waste	36,700	11.0	5,299	14,520	36.5	20,070	26.4
Brunei					196			
Canada	crop, forest, and primary mill residues; hog fuel piles	71,000	21.3	10,261	29,751	34.5	45,336	22.6
Chile	primary mill residues	3,254	0.9	434	2,081	20.8	10,219	4.2
China	crop, forest, and primary mill residues	788,000	236.0	113,689	46,097	246.6	126,817	89.6
Hong Kong					325		352	
Indonesia	crop residues; sugar cane bagasse; oil-palm, rubber, and coconut residues	74,000	22.2	10,695	12,942	82.6	20,829	51.3
Japan	crop and forest residues; urban wood waste	15,000	4.5	2,168	44,391	4.9	207,266	1.0
Korea	crop and forest residues	13,100	3.9	1,879	6,969	27.0	113,234	1.7
Malaysia	crop residues; sugar cane bagasse; oil-palm and wood-processing residues	32,392	9.7	4,673	7,756	60.2	7,885	59.3
Mexico	crop, logging, and primary mill residues	74,500	22.4	10,767	27,704	38.9		
New Zealand	crop, logging, and primary mill residues; horticultural and urban wood waste	5,500	1.7	795	2,325	34.2	4,488	17.7
PNG	logging, oil-palm, and coconut residues; sugar cane bagasse	N/A	N/A	N/A	N/A	N/A	435	N/A
Peru	crop, logging, and oil-palm residues; sugar cane bagasse	N/A	N/A	N/A	771	N/A	4,809	N/A
The Philippines	crop, logging, and coconut residues; sugar cane bagasse	18,000	5.4	2,601	4,111	63.3	10,681	24.4
Russia	crop and forest residues	100,000	30.0	14,452	26,260	55.0		
Singapore					727		54,786	
Chinese Taipei	crop residues	1,900	0.6	275	7,845	3.5	54,035	0.5
Thailand	crop residues; sugar cane bagasse; oil-palm and coconut residues	47,800	14.3	6,889	5,280	130.5	39,815	17.3
United States	crop, forest, primary mill, and secondary mill residues; urban wood waste	324,448	97.3	46,873	373,930	12.5	538,651	8.7
Viet Nam	crop, wood-processing, and coconut residues; sugar cane bagasse	93,000	27.9	13,440	2,546	527.9		
APEC Total		**1,698,594**	**509.0**	**245,189**	**616,527**	**39.8**	**1,259,708**	**19.5**

Note: Possible additional resources from dedicated energy crops are not included.

Introduction

Biomass energy is derived from plant-based material and residues whereby solar energy has been converted into organic matter. Biomass can be used in a variety of energy-conversion processes to yield power, heat, steam, and fuel. Biomass energy sources include:

- agricultural crops and residues;
- dedicated energy crops (herbaceous and tree species);
- forestry products and residues;
- residues and byproducts from food, feed, fiber, wood, and materials processing plants [sawdust from sawmills, black liquor (a byproduct of paper making), cheese whey (a byproduct of cheese-making processes), and animal manure];
- post-consumer residues and wastes, such as fats, greases, oils, construction and demolition wood debris and other urban wood waste, municipal solid wastes and wastewater, and landfill gases.

Agricultural and forestry resource production is dependent on adequate sun, rainfall, and nutrient conditions. Depending on the climate and crop-harvesting schedule, there can be seasonal constraints on this type of resource availability and significant annual variability in resource yields at a local level. Adverse environmental conditions (e.g., hail, drought, flooding, insects, and fire) can have significant negative or positive impacts on resource availability from year to year. The concentration of population and activities in urban areas is responsible for the generation of industrial processing residues, municipal solid waste, and other urban discards. These resources may have some seasonal variability, but typically remain at consistent levels in most areas. They also tend to be more spatially concentrated.

There are competing uses for biomass resources because of their economic and environmental value for a variety of purposes. As mentioned earlier, biomass material is used to generate power, heat, steam, and for producing transportation fuels. Biomass is also used by the food processing industries, 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.

Biomass Resources for Liquid Transportation Fuels

During the past few years, there has been an increased interest in biomass resources as a feedstock for transportation fuels production. These fuels can be produced from all biomass resources listed earlier; however, the conversion technologies are at different points in their development.

First-generation feedstocks refer to currently available biomass resources converted to biofuels via well-established technologies. For ethanol production, these include starches from grains (cereals and feed) and tubers (cassava and sweet potatoes), sugars from crops (such as sugar beets, sugar cane, and sweet sorghum), and from food-processing byproducts (molasses, cheese whey, and beverage waste). First-generation biodiesel (Fatty acid methyl ester of FAME) feedstocks include vegetable oil (such as soybean, rapeseed, and palm oil), used cooking oil, and animal fat (tallow, cat fish oil, etc.).

Second-generation feedstocks refer to biomass resources either available, but not used for biofuels production at a commercial level; or resources currently not available, but proven (through R&D activities) to have potential for biofuels production. For ethanol production, these include lignocellulosic material, such as crop and forest residues, municipal solid waste (MSW), and dedicated energy crops. The structural complexity of lignocellulosic biomass is what makes this feedstock a challenge to break down into simple sugars that can be converted to ethanol. Most plant matter consists of three key polymers: cellulose (35 to 50%), hemicellulose (20 to 35%), and lignin (10 to 25%). These polymers are assembled into a complex, interconnected matrix within plant cell walls. Cellulose and hemicellulose are carbohydrates that can be broken down into fermentable sugars. Lignin is not a carbohydrate and cannot be converted into ethanol. The technical challenge is associated with separating and breaking down these different polymers. Significant R&D efforts are under way in many APEC economies to advance this technology and use abundant lignocellulosic biomass. Lignocellulosic resources can also be catalytically processed into alcohols and Fischer Tropsch hydrocarbons via gasification to syngas, a mixture of carbon monoxide and hydrogen.

Second-generation feedstocks for biodiesel production include oils from non-edible plants, such as jatropha and pongam. More R&D is needed to better understand these plants' biofuel potential, including their characteristics, cultivation, socio-economic, and environmental benefits. Another advanced biodiesel feedstock is microalgae, which has oil content considerably higher

than that of oil-palm or rapeseed. However, significant technical and economic barriers need to be overcome to finish the laboratory phase, test the conversion process, develop and commercialize biodiesel from algae.

Biofuels yield per unit of land is an important consideration when choosing appropriate feedstock and making decisions for production expansion. APEC economies in the tropical biome have the advantage of growing crops with significant solar energy and rainfall input, yielding the highest biofuels per land unit compared with those in the temperate biome and its seasonal limitations. Two tropical crops, sugar cane and oil-palm, which can be used to produce ethanol and biodiesel respectively, have the highest yield per hectare among the first-generation feedstocks (Figures 1-2). APEC economies are among the world's leading producers of these crops. China, Mexico, Thailand, Australia, and Indonesia are well established sugar cane producers and among the top 10 suppliers in the world. Indonesia, Malaysia, and Thailand are the world's largest palm oil producers. The Philippines are the world's largest coconut oil producer. Given the favorable climate conditions and significant labor availability, Southeast Asian economies have announced feedstock production expansion and large-scale biofuels programs.
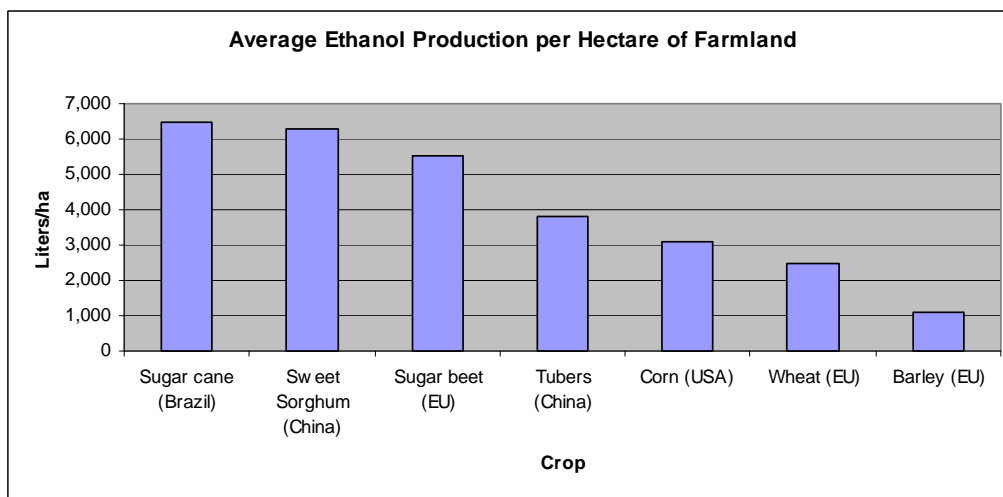
Source: Worldwatch Institute, 2007; USDA, GAIN Biofuels Report for China, 2007

Figure 1. Average Ethanol Production per Hectare of Farmland Yield by Crop

Figure 2. Average Biodiesel Production per Hectare of Farmland Yield by Crop

Project Background and Objectives

Accounting for about 60% of world energy demand, the APEC region is a net energy importer with its annual consumption exceeding domestic production. Energy imports to APEC economies are projected to increase by approximately 92% between 2000 and 2020 driven by economic growth, industrialization, and urbanization. According to the Asia-Pacific Energy Research Center, APEC's transport energy demand is projected to double from 2002 to 2030, and the transport sector is expected to account for more than 70% of APEC's incremental oil-demand growth. Given the steady growth in the demand for transportation fuels and declining oil production within the region, the APEC economies are concerned over supply security and are looking for alternative options. APEC members have identified biofuels as one option for diversifying sources of energy for transport.

The Seventh APEC EMM in Gyeongju, Korea, (October 2005) endorsed a three-pronged approach to cope with increasing oil prices and oil-import dependency, including enhanced exploration and development, improved fuel economy in transport, and increased use of alternative fuels including biofuels. The APEC Biofuels Task Force, established in May 2006 at ministers' direction, has a remit to examine issues related to biofuel resources, infrastructure requirements, economics and trade. The task force reported to EMM-8 in Darwin, Australia, in May 2007 that biofuels from a variety of feedstocks are cost-competitive with petroleum-based fuels, that biofuels can reduce greenhouse gas emissions, and that biofuels can displace a

significant percentage of petroleum use over time, especially as advanced technologies are developed for use of lignocellulosic biomass such as crop and forest residues. This survey is intended to deepen and expand on the preliminary resource assessments that were presented in that report.[2]

The project aims to understand what biomass resource assessments have been undertaken in APEC economies, as well as the capability of APEC economies to undertake such assessments. Considering that every economy maintains statistics on grain, sugar, and oil crops they produce - and the controversy surrounding the use of these crops for biofuels production - the project pays particular attention to assessments of alternative (non-food) biomass resources, including lignocellulosic biomass, waste vegetable oil and animal fats, and dedicated energy crops.

Many APEC economies have completed biomass resource assessments, but are not aware of the range of resource assessments conducted in other APEC economies. Furthermore, industry developers may be unaware of resource assessments that have been conducted in their area of interest. As interdependency increase among the APEC members, this information is critical to moving forward the biofuels technology in the region. The project aims to catalog current and planned biomass resource assessment products throughout the APEC region, increasing awareness of their availability and identifying future needs.

Some APEC economies have extensive capabilities to assess biomass resources – methods, tools, data, and scientific knowledge – but, there is no common understanding of such capabilities in others. The project gives APEC economies a shared view of their capabilities to systematically assess biofuel resources and suggest practical ways to improve these capabilities so that the resource potential can be better understood.

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[2] APEC BTF Report to the Eight Energy Ministers Meeting, Darwin, Australia, May 2007, http://www.ewg.apec.org/assets/documents/apecinternet/Biofuelsreport%5FEMM820071011104537%2Epdf

Biomass Resource Assessment Products and Assessment Methodologies

Biomass resource assessment is essential in evaluating the bioenergy potential in a given location, the social and environmental impacts associated with resources production and (most important) the economic feasibility of biomass utilization scenarios. Biomass resource assessments guide industry development strategies and support decision-making processes.

Biomass resource assessment products have different information characteristics and applicability. These products can be presented in a different format: tabular, graphic (charts or graphs), geographic (maps), or as analytical tools and software products. 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: power, heat, steam, or transportation fuel. There are three types of biomass resource potential: theoretical, technical, and economic, that build on each other in providing a comprehensive view of biomass energy opportunities.

- *Theoretical* - Illustrates the ultimate resource potential based on calculation or measurement of the net primary productivity of the biome.
- *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* – It is a subset of technical resource potential that applies economic parameters, which estimate 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).

The level of detail varies between biomass resource assessments. High-level, aggregated information - such as assessments at economy-wide, 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 level of detailed required dictate the method employed to assess biomass resources. The current evaluation methods include geospatial technologies, field surveys, and modeling.

Geospatial Technologies. These include remote sensing (RS), geographic information systems (GIS), and global positioning systems (GPS). Remotely sensed images, such as aerial and satellite images, provide an efficient and reliable way to monitor biomass resources over time. Remote sensing images have relatively fine spatial and temporal resolutions, similar to the data obtained by field surveys. These products range in spatial resolution from as coarse as every degree of latitude and longitude to as fine as every six meters, and can be at repeatable time scales. RS is the only technique available to monitor biomass resources at local, regional and global scales. This technique is used to estimate growing stock of biomass and forecast its productivity. RS provides a cost-efficient way to collect the required information at areas that are remote and poorly accessible. Remote sensing images are also the only practical approach to analyze land use and land cover change at economy-wide, regional, and global scales. Their patterns can be studied by comparing images acquired at different times. Figure 3 illustrates an example of high-resolution remote sensing images.

Data derived from remote sensing images, such as land use/cover, elevation, and surface temperature, is further used in geographic information systems (GIS). GIS is a computer-based information system used to create, manipulate, analyze, and visualize geographically referenced information. It is a powerful tool for assessing biomass potential: It integrates many different types of data and provides a means of examining their spatial relationships. The concept of data overlaying in GIS is shown in Figure 4. GIS is particularly useful in estimating technical biomass resource potential by integrating various datasets such as crop/forest production statistics, land use, terrain, transportation infrastructure, and protected areas. It also can identify areas where the agro-climatic conditions are suitable for growing a particular crop or assess biomass resources available within a certain radius from a processing facility.

Source: NASA/GSFC/METI/ERSDAC/JAROS and U.S./Japan ASTER Science Team[3]; Aster sensor, multi-spectral, 15m
Each ASTER sub-image covers an area of 10.5 x 12 km; 1- Minnesota, USA; 2 – Kansas, USA; 3 - Northwest Germany;
4 – Santa Cruz, Bolivia; 5 – Bangkok, Thailand; 6 – Cerrado, Southern Brazil.

Figure 3. Agricultural Fields Around the World
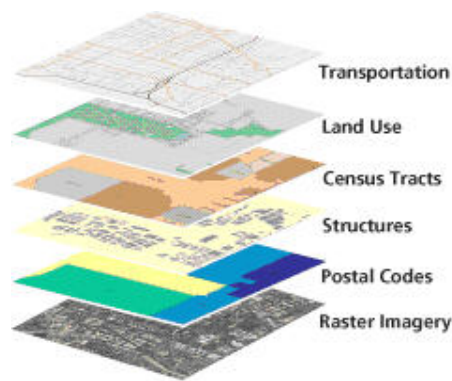
Source: Fire Program Analysis (FPA), http://www.fpa.nifc.gov

Figure 4. Conceptual Model of GIS

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[3] ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is an imaging instrument flying on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System, http://asterweb.jpl.nasa.gov/gallery-detail.asp?name=agmontage

Surveys. Field surveys are used to collect data as part of site-specific evaluation. Usually, a field plot (the size can vary) is selected as representative of the vegetation type in a study area, and parameters such as stem diameter, tree height, or crown dimensions for forest resources and density, height, and phenological development for crops are easily measured. The results are further extrapolated over a larger area and used to develop equations that predict biomass availability. This sampling technique provides the most accurate estimate of biomass resources at a given location; however, it is not practical for broad scale inventory. It is a time-consuming, labor-intensive, and therefore costly procedure, even with today's satellite communication technology (GPS). Data collected by the GPS operations can be automatically recorded with a GIS program to further analyze the data or validate model-derived estimates. Currently, field surveys in biomass resource assessments are used when other methods prove insufficient or when capabilities to use other methods don't exist.

Another way of collecting field data is sending questionnaires to farmers and cooperatives and asking them to report information such as planted acres, harvested yield, harvesting methods, and water management (irrigation or no irrigation). But this method of collecting field data relies on voluntary participation, creating a potential for informational gaps. Information can also be collected by face-to-face and telephone interviews, which are only applicable to local surveys; otherwise, it could be a time-consuming process. The "paper" survey method is often used for collecting crops-related information while the sampling technique described above is usually applied in forest resource estimates.

Modeling. Models are simplified frameworks designed to illustrate a system or process often using mathematical techniques to facilitate calculations or predictions. The complexity of a model and the modeling technique depend on the needs of the assessment and data availability. Models can be as simple as extrapolating measured data using statistical methods, or as complex as balancing numerous processes (organized in separate modules) to derive resource characteristics.

Both, static (analytical) and dynamic (simulation) models are used in biomass resource assessments. Static models describe a system mathematically, in terms of equations, and can be built in a spreadsheet. An example is estimating the amount and cost of crop residues (rice straw for example) by specifying values (usually averages) for several variables such as crop production, residue generation, labor cost, and prices (chemical, fertilizer, fuel, and planting).

Simulation models describe a system dynamically over time and are built using specific software. While static models ignore time-based variances and the synergy of the components of the system, dynamic models explore "what-if" scenarios and the sensitivity of a system to variations in its different components as time progresses. For example, simulation techniques can be used in a crop-simulation model to examine the effects of climate, soil, and management practices on crop production. Another example is the use in biomass resource elasticity studies to examine the effect of land use change, market price, and policy measures on feedstock supply. When combined with optimization algorithms, simulations can indicate what policy choices or other decisions may lead to particular desired outcomes.

A more advanced, and perhaps the most comprehensive, type of modeling is the integration of simulation techniques with GIS to capture temporal and spatial perspectives of a system together. For example, incorporating soil type, climate, land use and road network information with advanced transportation and economic models, it is possible to predict both where dedicated energy crops could be grown and their marginal cost. Depending on the purpose of the model and input data resolution, the GIS system allows visualization of the outcome at different geographic levels – regional, sub-regional, economy-wide, state, provincial, municipal, or site specific.

In the past, using the modeling method for biomass resource assessments has been criticized for relying on highly simplified assumptions. Today however, simulation models allow examining the theoretical consequences of more complex assumptions. Increased computational power and speed of today's computers has vaulted dynamic modeling ahead of static modeling as the method of choice, and made it possible to improve intuition about the feedback and interaction among regions, sectors, and other components of the biomass "landscape". Moreover, data are becoming organized into common databases at finer levels of granularity and sharing data has never been easier. Micro-data can now support micro-simulations. It is possible to compute large-scale micro-simulation models that would not have been possible just a few of years ago.

Australia

Economy-Wide Biomass Resource Assessments

Australia has developed a number of biomass resource assessments considering conventional and advanced biofuels feedstock. The most recent study was developed by Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) for the Rural Industries Research and Development Corporation (RIRDC) in May 2007. The study calculated the amount of ethanol and biodiesel from first- and second-generation feedstocks, as well as the percentage of petroleum products they could replace. The study looked at different scenarios: all domestic crop production converted to biofuels, export fraction of domestic crop production converted to biofuels, and potential ethanol production from lignocellulosic biomass. The study also investigated the implications of an economy-wide E10 (blend of 10% ethanol with gasoline) target. This is a study at an economy-wide level with no finer geography.

First-Generation Biofuels Potential

Ethanol: Ethanol in Australia is produced mainly from sorghum, wheat, and sugar cane. Feedstock supply regions are primarily the grain belt (primarily the south and southeast) and the east coast, where the sugar cane is grown. The study by CSIRO evaluated the feedstock availability in Australia and estimated the volume of ethanol that could be produced under two scenarios: first, if all grains and sugars are converted to ethanol and second, if the export portion of these crops is used. Table 1 provides the results of CSIRO's study.

If 20% of Australia's current starch and sugar crops production could be used for biofuels (about 9 Mt in 2005), it would yield about 3.11 hm^3 of ethanol or 1.5 Mt gasoline equivalent. This volume would replace 10.3% of Australia's current gasoline consumption and 7.5% of crude oil import.

Biodiesel: Animal fats, used cooking oil, and canola are the available biodiesel feedstock in Australia. The study by CSIRO evaluated the availability of these resources and similarly to ethanol estimated the biodiesel production potential under the two scenarios (Table 2).

If 20% of Australia's current vegetable oil production (about 39,000 tonnes in 2005), as well as the export portion of waste oils and fats, are used for biofuels, it would yield about 379 Mt of

biodiesel. This volume would replace 5% of the economy's current diesel consumption and 2% of crude oil import.

Table 1. Upper Limits to Ethanol Production Using Current Domestic Feedstock Supply Systems in Australia

Feedstock	Conv (L/t)	Scenario I — All domestic crop production converted to ethanol			Scenario II — Export fraction of domestic crop production converted to ethanol		
		Australian production (Mt)	Ethanol all feedstock (ML)	Blend (% 04–05 petrol replacement[F])	Export (Mt)	Ethanol export feedstock (ML)	Blend (% 04–05 petrol energy[F])
Sugar	560[E]	5.0 (4.2–5.5)[A]	2 800 (2 352–3 080)	E14 (9 %)	3.8 (3.1–4.2)[A]	2 128 (1 736–2 352)	E11 (7 %)
C-molasses	270–290[D]	0.6–1.2[B]	280	< E2 (0.9 %)	0.5[B]–0.82 E	140 - 220	< E1 (0.05 %)
Wheat	360[D]	20.6 (10.1–26.1)[A]	7 419 (3 648–9 408)	E38 (24.5 %)	14.8 (9.1–17.9)[A]	5 337 (3 278–6 432)	E27 (18 %)
Coarse grain	360	11.3 (6.9–15.6)[A]	4 083 (2 493–5 637)	E20 (14 %)	5.5 (3.8–7.2)[A]	1 978 (1 355–2 587)	E10 (7 %)
TOTAL			14,857	E78 (50 %)		9 690 (6 509–11 771)	E50 (E33–E60) (22–40 %)

[A] ABARE Australian Commodity Statistics 2005, 2000–01 to 2004–05 data used; [B] Beer et al 2003; [D] Rutowitz 2005; [E] Australian Cane growers Council 2005; [F] 2004–05 petrol usage of 19 500 ML. Note: The first figure reported describes the ethanol blend that could be supported, while the bracketed figure corrects for the lower energy content of ethanol relative to petrol (0.66). Source: CSIRO, 2007

Table 2. Upper Limits to Biodiesel Production Using Current Domestic Feedstock Supply Systems in Australia

Feedstock	ConvL/t	Scenario I — All domestic crop production converted to biodiesel			Scenario II — Export fraction of domestic crop production converted to biodiesel		
		Australian production (kt)	Biodiesel all feedstock (ML)	Biodiesel blend supported[B]	Export (kt)	Biodiesel feedstock No domestic use (ML)	Biodiesel blend supported[B]
Waste cooking oil - Australia	870[A]	90–105 [A]	90–105 A	B0.6		90–105 [A]	B0.6
Tallow - Australia	894 [A]	500 Lo grade 260 Hi grade 240 [A]	447	B2	340 [A]	304	B2
Oilseed crops (incl. canola, cottonseed and others)	400	2 533 (1 532–3 094)[A]	1 013 (613–1 238)	B7	1 498 (887–2 189) [A]	599 (355–876)	B4
TOTAL for Australia			1,538 (1 132–1 769)	B10		903 (659–1 180)	B6 (4–8 %)

[A] Beer et al (2005); [B] A correction for energy content is not required for biodiesel; Note: B10 equates to 10 % replacement of 2004–05 diesel energy. Source: CSIRO, 2007; Note: the tabulated values are taken directly from the source – the unit ML means 10^6 L or 1 dam^3

Second-Generation Biofuels Potential

Ethanol: The study by CSIRO evaluated the potential for ethanol production from second-generation feedstock in Australia. It estimated the amount of lignocellulosic biomass generated annually in Australia as well as the reasonable amount that could actually be collected (Table 3). The "reasonable available fraction" of biomass resources amount to about 36.7 Mt per year. These include 30 Mt of crop residues, 1.2 Mt of urban wood waste, 0.65 Mt of wood processing residues, 1 Mt of plantation residues, 1.35 Mt of forest residues, and 2.5 Mt of forest thinning. This amount would yield 11 hm^3 of ethanol or 5.2 Mt gasoline equivalent, and it would replace 36% of current gasoline consumption and 26% of crude oil import.

Biodiesel: Alternative oilseed crops, such as pongam, jatropha, and Indian mustard, have been considered for biodiesel production in Australia, particularly for marginal lands.

Researchers from the Faculty of Agriculture, Food and Natural Resources at the University of Sydney assessed the marginal lands in Australia and found that 20–30 million hectares are potentially suitable for the production of exotic biofuel crops, namely pongam, jatropha, and Indian mustard. The authors estimate that even if a small fraction of the marginal lands is used for these crops production, it will provide enough feedstocks to supply up to 50% of the economy diesel needs (Odeh and Tan 2007). The marginal agricultural regions of mainland Australia are illustrated in Figure 8. These marginal regions are outside the grain belt in southern Australia and tropical rainforests in northern Australia. The criteria used to delineate these regions include a plant productivity index, as derived by the Australian Greenhouse Office. The "productivity index" model is based on the relationship between the amount of photosynthetically active radiation absorbed by plant canopies (APAR) and the various productivity modifiers that affect plant growth (e.g., temperature, soil water content, frost). The model used a monthly time-step to derive both a long-term average monthly productivity index (~250 m resolution) and a monthly productivity index for 1970 to 2002 (1 km resolution) (Kesteven et al. 2004). Table 4 illustrates the location and extent of the areas suitable for exotic biofuel crops. It should be noted, however, that this is a theoretical study and in dept analysis would be needed to determine the marginal land that could actually be developed for biofuels. Moreover, jatropha is declared a highly invasive weed and it is banned in parts of Australia. Considering the uncertainty surrounding the alternative oilseed crops cultivation in the economy they have not been considered in this study.

Table 3. Upper Limits to Biofuels Production Using Second-generation Feedstock Resources in Australia

Feedstock	Conv. (L/t)	Australian production (Mt)	Ethanol from all feedstock (ML)	Reasonable available fraction (Mt)	Ethanol from reasonable available fraction (ML)	Ethanol blend (% 04–05 petrol energy)	Electricity (TWh)
Crop residues	300	53.1 (23.4–79.1)[A]	13,148 (5 852–19 561)[A]	30[B] (28–37)	9,000 (8 400–11 100)	E43–E57 (28–37 %)	
Annual and perennial grasses	300	10–20[B]	3 000–6 000	NAD but have assumed 5 % as there is already an existing market	150–300	E0.7–E1.5 (< 1 %)	
Sawlogs and pulpwood	200–280	14 (9–19)[C]	3,300 (1 800–5 200)	NAD but assume biomass currently exported as woodchip could be available	1,400 (900–2 000)	E5–E10 (3–7 %)	28 (13–120)
Urban wood waste	200–280	3.3–4[D]	660–1 200	No data but assume 30 % recovery	200–360	E1–E1.7 (< 2 %)	
Waste from wood processing facilities	200–280	1.3 (1–5)[E]	700 (400–1 000)	NAD but assume 50 % could be available	350 (200–500)	E1.8 (1)	1.3 (1.0–1.5)
Firewood	200–280	5.0 (4–22)[F]	1,200 (1 000–5 500)	NAD but assume 10 % as there is already an existing market	100–550	E0.5–E2.8 (< 2 %)	0.5 (0.1–2)
Plantation residues - current	200–240	2.1 (1.5–2.8)[G]	500 (300–700)	No data but assume 50 % can be colleted economically	250 (150–350)	E0.7–E1.7 (< 2 %)	3.1 (1.7–13.1)
Native forest residues	200–300	2.7 (1.6–3.7)[H]	300–1 100	No data but assume 50 % can be collected	150–500	E0.7–E2.6 (< 2 %)	4.1 (1.4–17.2)
Native forest thinning	200–300	2.5 (1–4)[H]	250–1 300	No data but assume 100 % would be used for biofuels	250–1 300	E1.3–E6.8 (1-4 %)	4 (1–20)
Black liquor		0.25 m³	NAD				
New oilseed species eg *Pongamia, Moringa*		NAD	NAD	NAD	NAD	NAD	
Algae		NAD	NAD	NAD	NAD	NAD	
Future mallee-eucalypt crop	200–300[I]	(2–100)	(400–30 000)	NAD – assume all available	(400–30 000)	E2–E85+ (3–100 %)	18 (2–500)
Future hardwood plantation growth	240–300[J]	14 (7–24)	3,800 (2 000–7 000)	NAD – assume 25 % of pulpwood and 50 % of harvesting residue could be available	1,000 (500–2 000)	E2.5–E10 (1.7–7 %)	6 (2–31)

[A] CSIRO estimate from APSIM modeling *unpublished data*; [B] Higgins 2006 9; [C] ABARE 2006; [D] FWPRDC 2006, MBAC 2004; [E] MBAC 2004, Raison 2006; [F] Freudenberger et al 2004; [G] CSIRO, Ensis unpublished data; [H] Raison 2006; [I] Foran 1999, Bartle 2001, 2006, Grove etg al 2005; [J] Based on future expected harvest and residue amounts minus current harvest and residue amounts; NAD = No Appropriate Data
Source: CSIRO, 2007; Note: the tabulated values are taken directly from the source – the unit ML means 10^6 L or 1 dam³
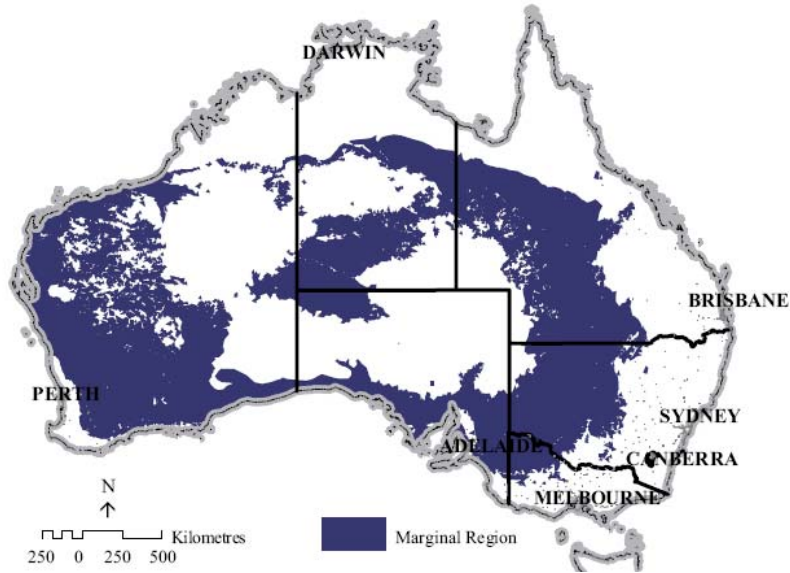
Source: Odeh and Tan 2007

Figure 5. The Marginal Agricultural Regions of Australia

Table 4. Marginal Lands for the Production of Exotic Biofuel Crops in Australia

	Approximate Locations of Suitable Regions	Area (Mha)	% Australia's Land Mass
Pongam	Mostly in central north Queensland (QLD) near Mt Isa and Longreach, and areas north of Tennant Creek in the Northern Territory (NT). There is a substantial area east of Port Hedland in northwest Western Australia (WA).	20.06	2.6
Physic nut	Substantially in the area east of Mt Isa, extending north-west of the town to north-east of Tennant Creek in NT. There is a considerable area between Port Hedland and Newman in WA that is suitable for this crop.	23.47	3.1
Indian mustard	While some suitable areas for Indian mustard found in central north QLD and north-west WA overlap with the areas suitable for both pongam and physic nut, Indian mustard can be grown in areas as far south as southern New South Wales around Hay, extending into Victoria.	31.7	4.2

Source: Odeh and Tan 2007; Note: the area unit of Mha identified in the table is from the original source and is considered to be 10^6 ha or a unit of 10,000 km^2

Regional and Local Biofuels Resource Assessments

A finer level of detail is achieved with the online Bioenergy Atlas of Australia, an interactive tool that provides access to maps and information on existing and potential biomass resources as well as existing industry locations, infrastructure and other key data. The project was undertaken jointly by the Bureau of Rural Sciences and University of Adelaide with funding provided by the Rural Industries Research and Development Corporation under the Joint Venture AgroForestry Program and the Australian Greenhouse Office. The Atlas uses GIS technology to illustrate the quantity and spatial distribution of biomass resources. It provides estimates for the following biomass categories:

Agricultural residues. This includes in-field resources remaining after harvesting, and post-processing resources (biomass material remaining at the facility after the processing of sown pastures, rice, cottonseed, etc.). The estimates are presented within a Statistical Local Area (SLA) region, distributed using land use patterns (at 1 km resolution), or at processing sites. These estimates are based on 1996 crop production statistics. An example of the agricultural resources presented in the Atlas is shown in Figure 5.

Source: Bioenergy Atlas of Australia, 2004
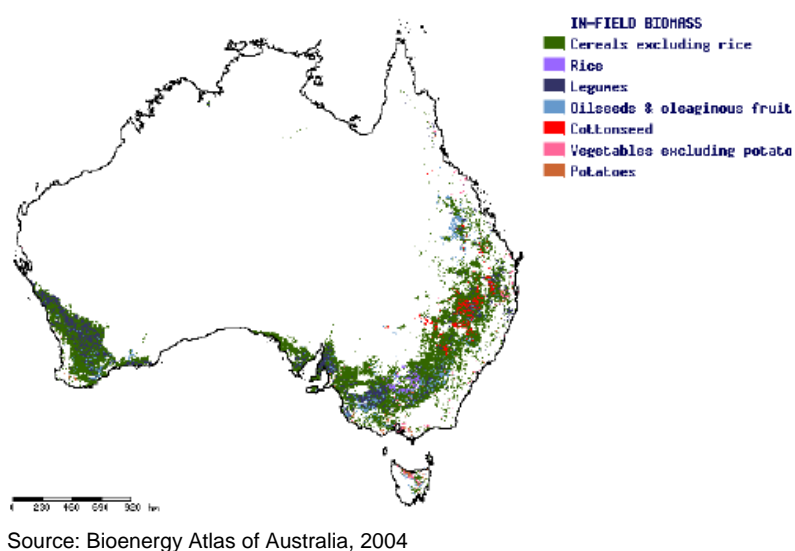
Figure 6. In-field Biomass Resources in Australia

Forest residues. This includes resources from native forests and plantations, as well as estimates of potential production from plantations on capable and suitable land. The estimates are presented within a SLA region, distributed using land use patterns (at 250 meter and 1 km

resolution), or at processing sites. These estimates are based on 1999-2001 statistics. An example of the agricultural resources presented in the Atlas is shown in Figure 6.
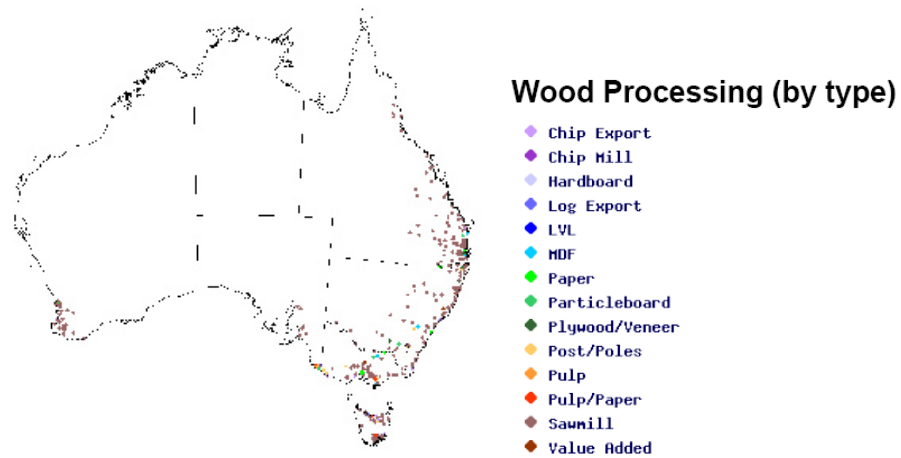
Source: Bioenergy Atlas of Australia, 2004

Figure 7. Wood Processing Mills in Australia

Potential tree crops for salinity hazard reduction. This dataset shows potential tree growth on cleared private land where a salinity hazard exists. It is designed to show where revegetation may provide benefits for salinity hazard reduction. The estimates were developed by analysis of climate, land use (at 250 meter resolution), and potential productivity of suitable species. Figure 7 depicts the location of salinity hazard lands and their tree production potential.
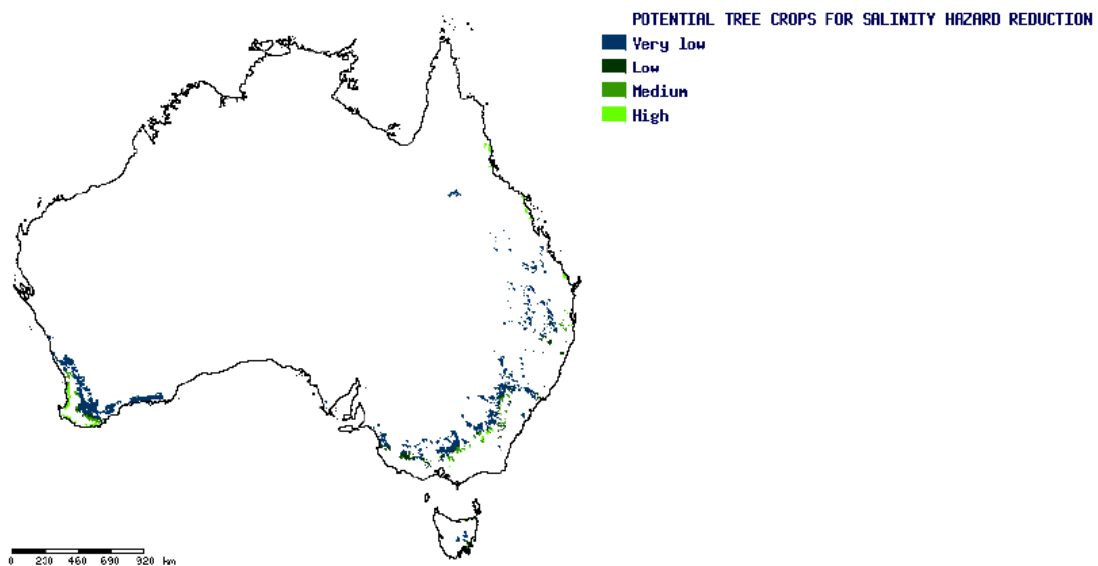
Source: Bioenergy Atlas of Australia, 2004

Figure 8. Potential Tree Crops for Salinity Hazard Reduction in Australia

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Biomass Resource Assessment Capabilities

Australia has strong capabilities in assessing biomass resources as illustrated above. The economy has used the full range of resource assessment methods: geospatial technologies, modeling, and survey techniques. In addition, spatial and temporal data are readily available to support future work in the area.

Geospatial technologies such as remote sensing and GIS are extensively used by the academic, government, and private institutions in Australia. A direct example of applying these technologies in assessing biomass resources is the Bioenergy Atlas of Australia, described above. In addition to the Atlas, the Bureau of Rural Sciences (BRS) has produced other interactive tools and models to help agricultural, fishing, and forestry industries make decisions. These include the *National Agricultural Monitoring System (NAMS),* which contains a range of climatic and production information for dry land/ broad acre and irrigated industries, for more than 600 regions throughout Australia; the *Integrated Vegetation Online* tool which illustrates the distribution of major vegetation cover types in Australia (native forests and grasslands and non-native vegetation); and the *Rainfall Reliability Wizard,* which uses data since January 1900 to estimate rainfall reliability, rainfall means, and rainfall variability. The full list of products by BRS can be viewed at http://www.daff.gov.au/brs/data-tools.

Remote sensing and GIS techniques are also largely used by the Australian Greenhouse Office (AGO) and CSIRO's Terrestrial Mapping and Monitoring group in estimating and monitoring vegetation productivity and land use/cover change for carbon accounting. AGO developed the *National Carbon Accounting System (NCAS)* which estimates the greenhouse gas emissions from land-based sectors. This GIS-based system integrates various datasets (remotely sensed land cover change, land use and management, climate and soil data), tools (greenhouse gas accounting tools), and ecosystem modeling. NCAS determines carbon stock changes at a fine spatial (25m resolution) and temporal scale (10 sequences of land cover change from 1972 to 2000) nationally. A list of products and technical reports developed by AGO is provided at http://www.greenhouse.gov.au/ncas/publications/index.html.

Dynamic modeling is largely used in Australia. In 1990, the Queensland State Government and CSIRO established a joint research team, the Agricultural Production Systems Research Unit (APSRU) that combines expertise in the computer simulation of farming systems and facilitates agricultural production research. One simulation model designed by APSRU is the

Agricultural Production Systems sIMulator (APSIM). The model simulates biophysical processes in farming systems, particularly in relation to the economic and ecological outcomes of management practices in the face of climate risk. APSIM is structured around plant, soil, and management modules. It resulted from a need for tools that provide accurate predictions of crop production in relation to climate, genotype, soils, and management factor while addressing the long-term resource management issues. APSIM can simulate more than 20 crops and forests (e.g., alfalfa, eucalyptus, cowpea, pigeon pea, peanuts, cotton, lupin, maize, wheat, barley, sunflower, sugar cane, chickpea, and tomato). Key outputs include crop and pasture yields, yield components, and soil erosion losses for different climate change scenarios. APSIM outputs are site specific but can be linked to GIS for spatial analysis at different geographic scales - economy-wide, state, and regional. Other agricultural simulation models developed by APSRU are listed at http://www.apsru.gov.au/apsru/.

Surveys and Data Availability. Sample survey techniques are used by CSIRO to generate the Biomass Database, a project funded by the AGO and the Joint Venture Agroforestry Program (JVAP), which is supported by three R&D corporations — Rural Industries Research and Development Corporation (RIRDC), Land & Water Australia (L&WA), and Forest and Wood Products Research and Development Corporation (FWPRDC), together with the Murray-Darling Basin Commission (MDBC). The database provides fuel and energy characteristics for biomass material sourced from agriculture (wheat straw, cotton trash, bagasse, poultry litter, etc), municipal (municipal solid waste in various forms including some involving sewage, refuse-derived fuel, green waste, wood waste), woody (from different forestry operations including some irrigated by effluent), and industrial sources (timber mills, etc). Representative samples of biomass were collected and analyzed in terms of their ultimate, proximate, ash, combustion (fouling and corrosion), and gasification characteristics, as well as their suitability for ethanol (liquid fuel) production. The database is available through the *Bioenergy Atlas*, which will allow the resource (t/ha) to be linked with fuel characteristics (MJ/kg), providing energy density information on different regions in Australia. The biomass database can be accessed at http://www.det.csiro.au/science/energyresources/biomass.htm

Paper surveys are used by government agencies in Australia to collect information related to agricultural commodities: cereals and other broad-acre crops, vegetables, fruits, vineyards, and livestock. The most relevant agencies are the Australian Bureau of Statistics (ABS) and Australian Bureau of Agricultural and Resource Economics (ABARE). These agencies provide

time-series data at different geographic levels. ABS conducts an Agricultural Survey (AS) annually; and approximately every fifth year, an Agricultural Census is conducted in place of the AS. The Agricultural Survey collects area and production data for a wide range of agricultural commodities at the establishment level. The collected information can be further aggregated to larger geographic units such as Statistical Local Area (SLA), Statistical Division (SD), or State/Territory. The spatial extent of these units varies. More information on these spatial units can be found at http://www.abs.gov.au/.

ABARE has conducted surveys of selected Australian agricultural industries since the 1950s. ABARE surveys collect detailed financial, physical, and socioeconomic information from farm businesses across Australia. Surveys include the Australian agricultural and grazing industries survey (AAGIS) and Australian dairy industry survey (ADIS). AAGIS includes the following five broad-acre industries: wheat and other crops (farms engaged mainly in growing cereal grains, coarse grains, oilseeds, and/or pulses), mixed livestock–crops, sheep, beef, and sheep-beef industries. The ADIS survey includes primarily dairy farms. The data collected is presented interactively by region, agricultural zone, or state in *AGsurf* (http://www.abare.gov.au/interactive/agsurf/). ABARE also has been collecting irrigation data as part of its annual broad-acre and dairy industries surveys since 1987-88.

Information about Australia's forests is collected by many different organizations, including Commonwealth, state and territory land management agencies and private companies. The scale at which such information is collected and the methodology used often differ between agencies, the tenure of land and the purpose of collection. To standardize these data sources and to allow them to be combined and directly compared, a National Forest Inventory (NFI) partnership was developed between the Commonwealth and all state and territory governments. The states and territories undertake on-the-ground collection of forest data, while the Commonwealth provides funding for the data integration and dissemination. The NFI encompasses a wide range of forest-related data, from the most detailed site data to the broadest Australia-wide summaries. It covers public and private forests, and native and plantation forests. It collates information about a wide range of forest characteristics such as their type, location, distribution, height, crown density, growth stage and/or planting date, ownership, and protection status. The NFI holds datasets on other forest attributes including soils, administrative boundaries, climate, mineral deposits, topography, rare and endangered species, and social and economic aspects. NFI is based in Canberra at the Bureau of Rural

Sciences, a research bureau of the Commonwealth Department of Agriculture, Fisheries and Forestry (DAFF). BRS also maintains two other inventories - the National Farm Forest Inventory and the National Plantation Inventory - both relying on reported information by farm forest and plantation owners. More information on the BRS products related to forest, plantation, and vegetation resources is available at http://www.daff.gov.au/brs/forest-veg. A list of agencies and organizations involved in forestry research is maintained by the DAFF at http://www.daff.gov.au/forestry/contacts.

Overall Biomass Resource Assessment Capabilities. It is evident from the summary above that Australia has very strong capabilities in conducting biomass resource assessments: relevant data is collected systematically, various methods and tools are applied in existing resource assessments or in relevant fields, and knowledgeable personnel is available through many agencies and organizations to undertake such efforts. However, continued work is needed to improve the quality of existing products. The study completed by CSIRO in May 2007 uses up-to-date statistics, but it is a nationwide study with no finer geography. Finer geography is achieved in the Bioenergy Atlas of Australia, but the data on feedstock quantity is out of date (1996). To address this knowledge gap, the economy is launching a new initiative called Sustainable Biomass Production for Bioenergy and Biofuels in Australia. This effort plans to coordinate all biomass resource assessment activities in the economy and provide detailed and up to date products.

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Brunei Darussalam

Despite being a significant regional producer of oil and natural gas, Brunei Darussalam is considering diversifying its energy portfolio and following the global trend in search of alternative energy sources such as biofuels. No biomass resource assessment was identified at the time this survey took place. Statistical information on crop and forestry production in Brunei is provided annually by the Department of Agriculture and the Forestry Department (also includes monthly reports). Considering some general information on land use, however, it is unlikely that Brunei will produce biofuels feedstock domestically. The economy is more than 527,000 ha - about 2.3% (12,000 ha) is arable land and about 53% (278,000 ha) is forest. Rice production is low (only about 1,000 tonnes per year), and Brunei imports more than 80% of its requirements. Other crops grown, mostly for home consumption, include banana, sweet potato, cassava, coconut, pineapple, and vegetables. The timber industry is well established and the harvest volume is carefully controlled by the Forestry Department on a planned renewable basis. Timber production has been limited to just 100,000 cubic meters a year. The economy most likely will pursue overseas investments in feedstock production and import either the raw material or fuel.

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Canada

Economy-Wide and Provincial Biofuels Resource Assessments

First-Generation Biofuels Potential

Ethanol: In Canada, ethanol is produced almost entirely from cereals (corn and wheat). Corn accounted for 77% of all ethanol feedstock in 2006. This percentage is expected to decrease in coming years due to more wheat-based plants under construction. Corn production was about 9 Mt in 2006, 7% of which was used for ethanol production. The majority of domestically produced and imported corn is used by the livestock industry. Wheat production in Canada is much higher, more than 20 Mt annually. Being the world's second-largest exporter of wheat, after the United States, the majority of this production goes for export (about 17 Mt annually). Less than 1% was used for ethanol production in 2006.

If the equivalent of 20% of Canada's current starch and sugar crops production could be made available for biofuels, for example through increase in crop yields over time, it would yield about 2.18 hm^3 of ethanol or 1 Mt gasoline equivalent per annum. This volume would be sufficient to replace 3.5% of Canada's current gasoline consumption and 2.3% of its crude oil imports.

Biodiesel: The Canadian Canola Growers Association (CCGA) estimated that Canada could produce about 500 million litres (approximately 440,000 tonnes) of biodiesel from domestic feedstock in the 2007-2010 timeframe (Table 5). This volume would replace more than 3% of the current diesel consumption, based on the International Energy Agency (IEA) estimate of 12.5 Mt of diesel consumed in 2005. CCGA's estimate is at a economy-wide level with no finer geography presented.

If the equivalent of 20% of Canada's current vegetable oil production could be spared for biofuels production, as well as all waste oils and fats, it would yield about 0.55 Mt of biodiesel per annum. Such an amount could displace 4.4% of the economy's current diesel consumption and 1.2% of its crude oil imports.

Table 5. Potential Biodiesel Production in Canada, 2007-2010

Source	Biodiesel Production
Tallow	160 million litres
Yellow Grease	80 million litres
Canola	220 million litres
Soybeans	40 million litres
TOTAL FORECAST	500 million litres

Source: CCGA 2006

Second-Generation Biofuels Potential

BIOCAP Canada Foundation estimated agricultural crop residues in 2001 (BIOCAP 2003). Total crop production was about 78.3 Mt in 2001, of which 70% was wheat, barley, or tame hay. Crop residues (straw and stover) were estimated at 56.1 Mt (using crop-to-residue ratio), some of which must be left on the field to maintain soil fertility and carbon content. Residues recoverable and sustainably removable were estimated at 29.3 Mt annually; however, some of this goes to traditional uses such as animal bedding and mulching. The study concluded that agricultural biomass available for energy may be 18 Mt annually (Table 6).

An analysis by Climate Change Solutions in 2007 estimated the harvest residues available in the key forest provinces (Table 7). In some provinces, much of this material is burned at roadside, both to prevent uncontrolled forest fires and also to clear more land for forest renewal. British Columbia (BC) has the largest harvest, at 87 million m^3 (~ 62 Mt), and slash residues. BC is followed by Quebec in harvest, with 40 million m^3 (~ 29 Mt). In most of the provinces slash is 9-14% of the harvest volumes; however, in BC slash volumes are currently 20-40% of harvest, a phenomenon of the massive harvest of mountain pine beetle (MPB) wood. The MPB population has undergone an unprecedented explosion in BC, spreading from 25,000 hectares (ha) in 1994 to more than 7 million ha in 2004. Of this area, 26% suffered moderate mortality and 11% suffered severe mortality. As a result of the outbreak, dead timber in 2004 is estimated at 170 million m^3 (~ 121 Mt). The annual kill is projected to peak in 2008 at 70 million m^3 (~ 50 Mt) with more than 450 million m^3 (~ 321 Mt) projected to be killed by this time. The outbreak may last for 10 years and kill 80% of merchantable pine (Climate Change Solutions 2006).

Table 6. Biomass from Crop Residues in Canada, 2001

Crop	Yield of Crops and Crop Residues						Currently Available Residues		
	Total Production	Straw/ Stover	Sustainably Removable Residues (SRR)[1,2,3,4]	Recoverable SRR[5]		Energy Potential of SRR[8]	Amount Available[6]	C Content[7]	Energy Potential[8]
	M ODT/yr	M ODT/yr	M ODT/yr	M ODT/yr	M tC/yr	EJ/yr	M ODT/yr	Mt C/yr	EJ/yr
Wheat	20.6	26.7	21.4	14.97	6.74	0.241	7.49	3.37	0.120
Barley	10.8	10.8	8.68	6.07	2.73	0.098	3.04	1.37	0.049
Oats	2.7	2.7	2.15	1.51	0.68	0.024	0.75	0.34	0.012
Grain corn	8.3	8.3	6.65	3.33	1.50	0.054	3.33	1.50	0.054
Canola	4.9	4.9	3.94	2.76	1.24	0.044	2.76	1,24	0.044
Soybeans	1.6	1.6	0.33	0.16	0.07	0.003	0.16	0.7	0.003
Flaxseed	0.72	0.72	0.57	0.40	0.180	0.006	0.20	0.9	0.003
Rye	0.23	0.23	0.18	0.13	0.57	0.002	0.06	0.29	0.001
Fodder corn	5.2	0	0	0	0.26	0.009	0.26	0.12	0.004
Tame hay	23.1	0	0	0	1.157	0.041	1.16	0.52	0.019
Totals	78.27	56.09	43.89	29.33	14.62	0.523	17.79	8.64	0.309

[1]Assumes that straw to grain ratio for wheat is 1.3:1 (Levelton, 2000 Assessment of net emissions of GHG from EtOH-blended gasolines in Canada; lignocellulosic feedstocks, R-2000-2 AAFC). This ratio represents the lower end of Levelton's proposed range of 1.3 - 1.7:1.

[2]Assumes a straw to grain ratio of 1:1 for all other cereal grains (Helwig *et al.,*2002).

[3] Stover from grain corn production in Eastern Canada averages 2.5 ODT/ha and equals the quantity of corn grain harvested in OTDs (Helwig *et al., 2002*). Statistics Canada, however, shows that harvested yield averages just over 6 ODT/ha which is substantially different... it is unclear whether the Stats can figure includes fodder and grain corn, or grain corn alone. A 1:1 ratio of harvested crop to stover is assumed.

[4] Assumes an average sustainable removal rate of 80% (Klass, 1998; Helwig *et al.,* 2002) for all crops except soybean. Soybean stover is not generally considered harvestable except on conservation tillage soil, which constitutes approximately 20% of soybean land, where they may be completely removed. Hence, yield of sustainably removable soybean residues is assumed to be 20% of stover.

[5] Assumes that not all sustainably removable residues may be retrieved, and reduces these by 30% to account for difficulties during recovery, except for grain corn and soybeans, which are reduced by 50% to account for late harvest.

[6] Assumes that biomass will continue to be diverted to traditional uses, leaving available: 50% of cereal straws; 100% of recoverable grain corn stover, canola, and soybean stover; 5% of fodder corn, and tame hay which is unused in an average year (Helwig *et al.,* 2002). This assumption overestimates availability of straw in NB and PEI, where production is quite low, and underestimates availability in MB and SK where production is higher on average.

[7] Carbon content is based on an average yield for agricultural residues of 45% C in OD biomass (Bioenergy Conversion Factors_ .

[8] Assumes that 35.76 GJ of energy may be derived from each tonne of carbon from dried biomass. This conversion factor has been tested against upper and lower heating values, both theoretical and measured, for a variety of biological feedstocks and is accurate to 5% in every case. Comparative figures from Klass, 1998, were used to derive this conversion factor.

M ODT – million oven-dry tonne; Source: BIOCAP 2003

Table 7. Forest Residues in Canada

	Harvest Roundwood Mil M3	Slash %	Slash Mil M3	Slash 000 BDt	Roadside %	Roadside 000 BDt	Stump 000 BDt
BC	87.0	25%	29.0	11,600	80%	9,280	2,320
Alberta	23.5	10%	2.6	1,044	95%	992	52
Ontario	24.2	14%	3.9	1,576	95%	1,497	79
Quebec	39.6	9%	3.9	1,567	60%	940	627
New Brunswick	10.4	9%	1.0	411	35%	144	267
Nova Scotia	5.7	9%	0.6	225	0%	0	225
	190.4			16,424	78%	12,853	3,571

Source: Climate Change Solutions 2007; BDt - Bone-Dry tonne= Oven-Dry tonne

A 2004 mill residue survey of Canadian pulp mills and sawmills (BW McCloy & Associates and Climate Change Solutions 2005) indicated annual production of bark, sawdust, and shavings of 21.2 Mt as shown in Table 8. Major producers were BC, Quebec, Ontario, and Alberta. Much of this biomass is committed to produce onsite energy, or sold to independent power producers, board and pellet manufacturers, farmers for animal bedding, and landscapers for garden beds. The study estimated that after considering domestic consumption and exports, there was a surplus of 2.7 Mt.

Table 8. Canada Surplus Mill Residues, 2004

| Province	Prod'n 000 BDt	Consump.	Exports	Surplus 000 BDt
BC	6,554	4,389	350	1,815
Alberta	2,406	1,924	0	481
Saskatchewan	580	416	0	164
Manitoba	225	212		13
Ontario	2,602	2,480	0.54	121
Quebec	6,669	6,400	169	100
New Brunswick	1,373	1,223	150	0
Nova Scotia	601	588	0	13
PEI	24	23		1
Nfld & Lab.	195	166	0	30
Total	21,229	17,821	669	2,738

Source: Climate Change Solutions 2007
BDt - Bone-Dry tonne = Oven-Dry tonne

The mill residue survey also estimated that the excess bark and sawdust not used by sawmills or pulp mills, simply piled up on the mill site. This is the case in some provinces; however, in BC, Alberta, and Manitoba the approved method of residue disposal is incineration. Until recently, bark piles were considered an environmental problem, not a revenue source. Many

piles were too contaminated, or moisture contents were considered too high for energy use. With annual residue production almost completely committed, companies are looking at these piles with renewed interest. Some are experimenting with methods to remove contaminants, or mixing wet with drier residues to produce a fuel with low average moisture content. Different companies assess the usable portion of bark piles between 50-100%. The study estimated the dry biomass available from bark piles in Canada at 15.9 Mt in 2005. Leading provinces are Ontario (6.7 Mt), Quebec (5.6 Mt), and Saskatchewan (2.9 Mt) (Climate Change Solutions 2006).

Summing together sustainably recoverable crop residues of 17.79 Mt (Table 6), slash forest residues of 16.4 Mt (Table 7) and mill residues of 21.2 Mt (Table 8), overall farm and forest residues could sum to as much as 55 Mt per annum. Adding in hog pile residues of 15.9 Mt, it would bring overall second generation feedstock in Canada (crop, forest, primary mill residues and hog fuel piles) to about 71 Mt per year yielding 21.3 hm^3 of ethanol or 10 Mt gasoline equivalent. This volume would replace 35% of current gasoline consumption and 23% of crude oil imports.

Local Biofuels Resource Assessments

Agriculture and Agri-Food Canada (AAFC) developed a Web-based biomass inventory tool, called Biomass Inventory Mapping and Analysis Tool (BIMAT). The tool uses GIS to illustrate the quantity and geographic distribution of agricultural and wood residues (logging, mill, and urban) at a fine spatial resolution, as illustrated in Figure 9.
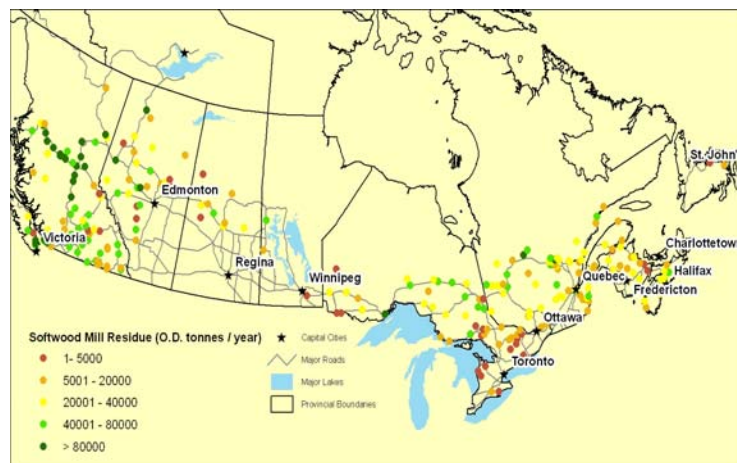
Source: Stumborg, M., Agriculture and Agri-Food Canada, 2008; http://www.agr.gc.ca/nlwis/

Figure 9. Softwood Mill Residues in Canada

Biomass Resource Assessment Capabilities

Canada has extensive biomass resource assessment capabilities. These include geospatial technologies, modeling, surveying, and statistical information available through various agencies.

Geospatial technologies, as illustrated above, have been used by the AAFC to develop the biomass inventory tool (BIMAT). These technologies are also used by the Canadian Forest Service (CFS), in partnership with the Canadian Space Agency, to create products for forest inventory, forest carbon accounting, monitoring sustainable development, and landscape management. It launched a project titled Earth Observation for Sustainable Development of Forests (EOSD) to aid in developing techniques for these products. Initially, the initiative will work in partnership with the provinces, territories, universities, and industry to develop an economy-wide map of the forested land cover of Canada with the long-term goal of producing not only land cover maps, but maps of forest composition, change over time, and biomass. Overview of methods for mapping biomass resources employed by EOSD is available at http://www.pfc.forestry.ca/eosd/biomass/methods_e.html. Inputs from EOSD will be an important data source in the National Forest Carbon Accounting Framework and will also be used to enhance Canada's new National Forest Inventory. EOSD data and products are available at no charge to the public and accessible through the National Forest Information System (NFIS) and SAFORAH (System of Agents for Forest Observation Research with Automation Hierarchies). The NFIS provides various geospatial products (tools and maps) that illustrate Canada's forests, vegetation, protected areas, imagery, etc. at an economy-wide and provincial/territory level (http://nfis.org/index_e.shtml).

Integrated Techniques and Data Availability. CFS, which is responsible for disseminating forestry statistics, compiles Canada's forest inventory by collecting data from provincial, territorial and other forest management inventories. Provinces and territories apply a set of methods in collecting forest data: field surveys, aerial photography, GIS, and other modeling techniques as illustrated in Figure 10. The data provided by the provincial and territorial management agencies are converted to an economy-wide classification scheme, and then aggregated to the map sheet, provincial and economy-wide levels for storage, analysis and reporting. Economy-wide inventories are compiled about every five years, currently in 1981, 1986, 1991, and 2001.

Step 1: Plot sampling

Step 2: Aerial photography

Step 3: Photo interpretation using stereoscope

Step 4: Tracing boundaries from photo

Step 5: Output from traced photo

Step 6: Computer model

Source: Natural Resources, Government of Newfoundland and Labrador, Canada

Figure 10. Forest Inventory Process in Canada

Canada National Forest Inventory (CanFI) 2001 is the most recent inventory collected for Canada. The current approach to an economy-wide inventory is based on existing data making it is cost-effective. The process is well-established and accepted by the contributing agencies, and provides detailed information about Canada's forests that is consistent with forest management information. The inventory also contains location-specific information on the characteristics and quantity of the forest resource, providing mapping and spatial analysis capabilities. While this periodic compilation has many advantages, CanFI data can be up to 25 years old and collected using variable data standards. CanFI does not allow tracking of the rate and nature of changes to the resource over time, nor does it necessarily reflect the current state of the forests. It also generally lacks information on non-timber attributes and is of unknown precision. A new design for Canada's forest inventory has been developed and is being implemented to address weaknesses of CanFI. Instead of a periodic compilation of existing information from across the country, the National Forest Inventory (NFI) is a plot-based design consisting of permanent observational units located on an economy-wide grid. This new design tracks changes such as land cover, forest area, and volumes, and supports additional forest resource information. It will replace the current CanFI approach and allow comparisons with time. More information about NFI and its progress is available at http://nfi.nfis.org/ (CFS).

Numerical and geospatial modeling has been used by the Agriculture and Agri-Food Canada (AAFC). A biomass production model estimates the amount of crop residues available after a portion of it is left on the field to meet soil protection and animal feed requirements. Further, GIS is used to illustrate the geographic distribution of these resources. Figure 11 illustrates an example - potential surplus wheat straw production in the Western Canadian prairies (Stumborg et al. 2004).
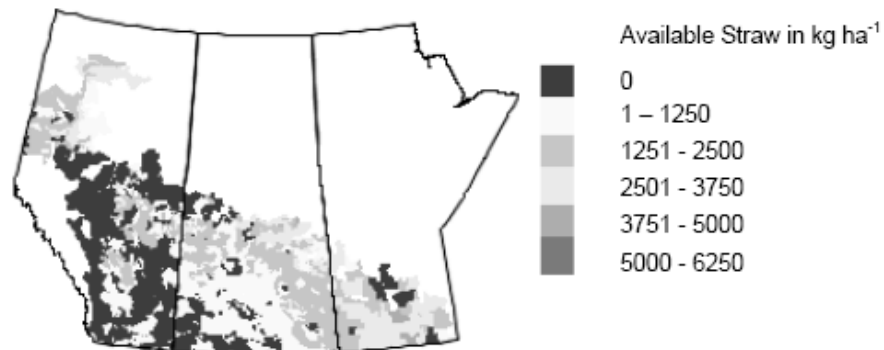
Source: Stumborg 2004

Figure 11. Areas of Potential Surplus Wheat Straw in Western Canada

The Census of Agriculture (CA), part of Canada's National Statistical Agency, is the main provider of agricultural statistics at an economy-wide, provincial/territorial, regional, divisional, and sub-divisional level. The census has been taken every five years since 1956, the most recent being developed in 2006. Data is collected using paper surveys (questionnaires) mailed to farmers. Samples are used for making agriculture estimates between census years. Provinces/Territories' Departments of Agriculture also provide agricultural statistics collected via paper and field surveys.

In addition to the agencies mentioned above, many of the leading colleges and universities in Canada with agricultural or engineering programs have the potential to contribute to biomass resource assessments efforts. Several universities, including Moncton, Sherbrooke, Guelph, Manitoba, Saskatchewan, Alberta, and BC have extensive experience in a range of agricultural disciplines. Others including McGill, Ottawa, Queen's, Toronto, McMaster, Waterloo, Saskatchewan, and Alberta have significant experience in engineering sciences that are important to the development of bio-products. Still others have strong environmental or forestry programs that could provide valuable expertise. Even universities without strengths in these

applied disciplines may have the potential to contribute through expertise in biology, physics, chemistry, and geospatial technologies.

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Chile

Economy-Wide, Provincial and Local Biofuels Resource Assessments

First-Generation Biofuels Potential

Ethanol: Chile produces corn, wheat, and sugar beet, all of which could be used as feedstock for ethanol production. However, given the limited land available in Chile and the current need to import significant quantities of food, second-generation biofuels, particularly from forestry resources, appear to be more promising.

If the equivalent of 20% of Chile's current starch and sugar crops production could be made available for biofuel production, for example through increase in crop yields over time, it would yield about 0.26 m^3 of ethanol or 0.12 Mt gasoline equivalent. This would be enough to replace 6% of Chile's 2005 gasoline consumption and 1.2% of its 2005 crude oil imports.

Biodiesel: The Ministry of Agriculture, Office of Agrarian Studies and Policies (ODEPA), completed a study in January 2007 looking at available feedstock for biodiesel production. The project estimated that about 44,500 m^3 (39.2 kt) of biodiesel could be produced from rapeseed and maravilla, and about 52,338 m^3 (46.1 kt) from animal fat. This is a nationwide study with no finer geography represented, and it is based on statistical analysis of reported information.

If 20% of Chile's current vegetable oil production, as well as all waste oils and fats, could be used for biofuels, it would yield about 54,000 tonnes of biodiesel per annum. This could replace 1.7% of Chile's current diesel consumption or 0.5% of its crude oil imports.

Second-Generation Biofuels Potential

A study by the National Energy Commission (Comisión Nacional de Energía), Instituto Forestal (INFOR), and GTZ evaluated the primary mill residues at regional, provincial, and municipal levels in some cases for 2005 (CNE/INFOR/GTZ 2007). Data for this study was provided by INFOR, which collects it via surveys of sawmills. In addition to statistical analysis, the project uses GIS to map the residues available in each region, as shown in the example in Figure 12. The study concluded that about 5.5 million m^3 or 3.25 Mt of primary mill residues were available

in Chile in 2005. This corresponds roughly to about 0.98 hm^3 of ethanol or 0.43 Mt gasoline equivalent. This volume could displace 21% of Chile's current gasoline consumption and 4.2% of its crude oil imports. Crop residues have not been estimated; if included, the amount of ethanol that could be produced in Chile would be higher.
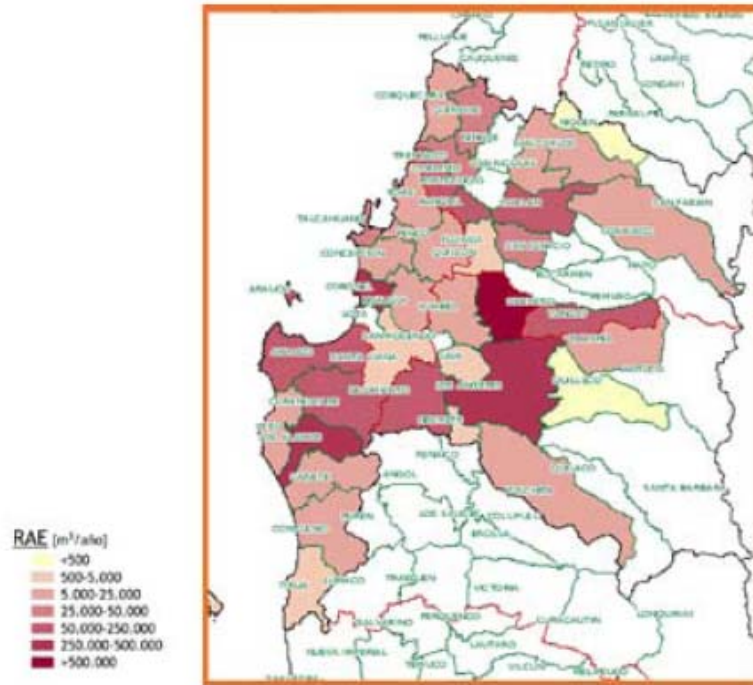
Source: CNE/INFOR/GTZ 2007; RAE – Residues Available for Energy (m^3/year)

Figure 12. Distribution of Primary Mill Residues in the Region of Bio-Bio, Chile

A study by the National Energy Commission (Comisión Nacional de Energía) and GTZ in January 2008 estimated forest biomass (harvest and pruning waste) in select regions, power generation potential, and cost of electricity. The study focused on residues generated at pine and eucalyptus plantations in the regions of O'Higgins, Bio-Bio, and Maule. It excludes residues from native forests due to their small contribution to the overall forest residue potential and lack of access in some areas. The project estimates the available tree plantation residues in 2004 and projects availability by 2017 for each region. The projections are based on 32 years of data collected for the project. The data was collected from the plantation owners and is complemented by analyses on the future availability of pine and eucalyptus carried out by the Chile Forestry Institute. The study uses a set of methods to assess biomass resources – statistical analysis, simulation modeling, and GIS. Figure 13 illustrates an example of the maps generated under this project.

Figure 13. Plantation Forests in the Region of Bio-Bio, Chile

The study concluded that residues generated at pine and eucalyptus plantations could support between 310 and 470 MW of power generation capacity (considering residue use of 50-75%, respectively), concentrated in the regions between Valparaiso and Aysen. No numbers for total volume of residues were presented. The paper only outlines the methodology used and gives an example of only one region. Thus, it was not possible to estimate the amount of ethanol that could be produced from these resources in Chile.

The government is conducting a biomass resource assessment specifically for biofuels production, and will evaluate various feedstocks. The project began in April 2008 and will be completed by early 2009. The project will estimate crop and forest residues for ethanol production, as well as investigate feedstock other than oil crops for biodiesel production.

Biomass Resource Assessment Capabilities

It is evident from the examples above that Chile has very good biomass resource assessment capabilities. It has used various assessment methods and it maintains excellent statistics. The National Energy Commission (CNE), Department of Agriculture, and the Forestry Institute (INFOR) are leading government agencies in biomass resource assessments. These agencies provide data and expertise in their relevant field. INFOR has used geospatial technologies beyond the regular map-making services they offer. It used advanced GIS techniques to develop an interactive Web based application illustrating the primary mill residues by province, as well as the location of sawmills. Figure 14 shows the graphical interface of this application.
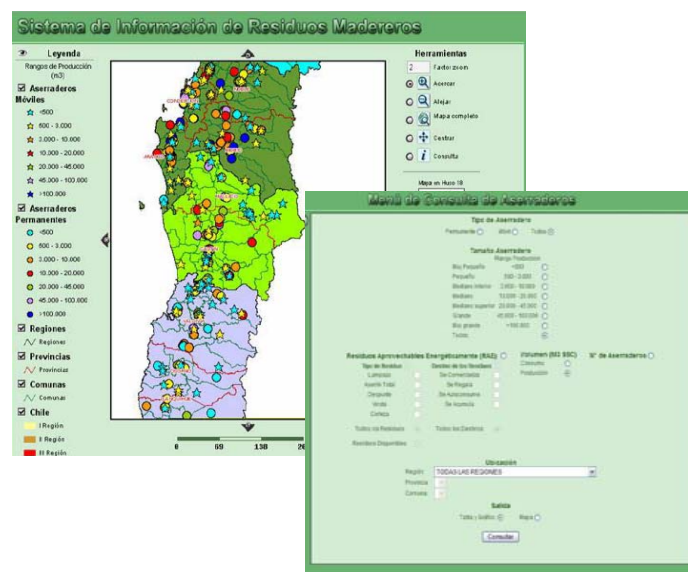
Source: INFOR 2008

Figure 14. Chile Primary Mill Residues Information System

Agricultural, forestry, and industry statistics are also provided by the National Statistics Institute (INE). INE collects information through paper or phone surveys and provides regional reports on a regular basis. Some of the universities involved in biomass research include Universidad de Concepción, Unidad de Desarrollo Tecnológico of the Universidad de Concepción, Universidad de la Frontera, and Universidad de Chile (Facultad de Agronomía and Facultad de Ciencias Forestales).

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China

Economy-Wide, Provincial and Local Biofuels Resource Assessments

First-Generation Biofuels Potential

Ethanol: About 80% of the fuel ethanol in China is made from corn, the rest from wheat. However, concerns about food supply and high prices have led the industry to look at other, non-grain feedstock, such as cassava, sweet sorghum and sweet potato. China's current cassava production is estimated at 7.5 Mt per year (USDA 2006). China's sweet potato production of about 105 Mt accounted for 82% of global output in 2005 (100 million tones).

The Ministry of Agriculture estimated about 200 million mu (13.3 million hectares) of land is available for cassava and sweet potato cultivation in the southern provinces. The ministry has noted that if only one-fifth of this land were used for cassava and sweet potato as biofuel feedstock, it could produce about 13 hm^3 of fuel ethanol per year. Eighteen provinces north of the Yellow and Huaihe rivers were identified by the ministry as suitable for sweet sorghum production. The ministry has noted that if one-fifth of the saline lands in China were used for sweet sorghum production, they could yield about 19 hm^3 of ethanol per year. Thus counting both cassava and sweet potato on agricultural lands and sweet sorghum on marginal lands, some 32 hm^3 ethanol per year might be produced.

Looking more systematically at China's overall starch and sugar crop production – including cassava, corn, rice, sorghum, sugar cane, sweet potato and wheat – one-fifth of current production would amount to some 96.6 Mt. If this amount could be made available for biofuels production, for example through increase in productivity over time, roughly 32 hm^3 of ethanol could be produced each year. (By coincidence, this is the same figure cited in the previous paragraph for cassava, sweet potato and sweet sorghum alone; sweet sorghum is not an agricultural crop.) This would yield some 15.4 Mt of gasoline equivalent, enough to displace 33% of China's current gasoline consumption and 12% of China's current crude oil imports.

Biodiesel: Almost all biodiesel in China is produced from used cooking oil and animal fat. About 3 Mt of waste oil and grease are produced in China annually. A key barrier to using these resources is collection since their use is highly decentralized.

Rape is the most widely planted oil-bearing crop in China, which has the world's highest output. The Institute of Oil Crops Research of the Chinese Academy of Agricultural Sciences announced in 2006 that it bred a new kind of rapeseed with record high oil content in a move to develop China's biodiesel industry. The new rapeseed has an oil content of 54.72%, nearly 2% higher than conventional rapeseed. The institute estimated that the Yangtze River Valley, which accounts for nearly one-third of the world's rape output, could eventually produce up to 40 Mt of biodiesel per year. That would amount to 85% of China's current annual consumption of diesel fuel. But this must be regarded as highly speculative in view of competing uses for the land in question.

Focusing on China's current vegetable oil production, including both rapeseed and soybean, one fifth of output would amount to 2.2 Mt per annum. If this amount could be made available for biodiesel production, for example through an annual increase in productivity, and if the 3 Mt of waste oil and grease produced each year could also be collected, there would be a potential for 5.2 Mt of biodiesel production per year. That would be enough to displace 11% of China's current diesel production and 4% of China's current crude oil imports.

Second-Generation Biofuels Potential

Agricultural and forest residues are the primary bioenergy resource generated in China, so assessments of their type, quantity, and location are most abundant. Most of the biomass resources in China are assessed at economy-wide and provincial levels. Several studies have assessed the resources at a finer level (see the example in Figure 15), using more advanced tools and methods, such as remote sensing and GIS. However, these studies are narrow in scope, assessing a particular resource at an economy-wide level or various resources in a small study area. The majority of biomass resource assessments in China are based on statistical analysis of reported information, applying product to residue coefficient.
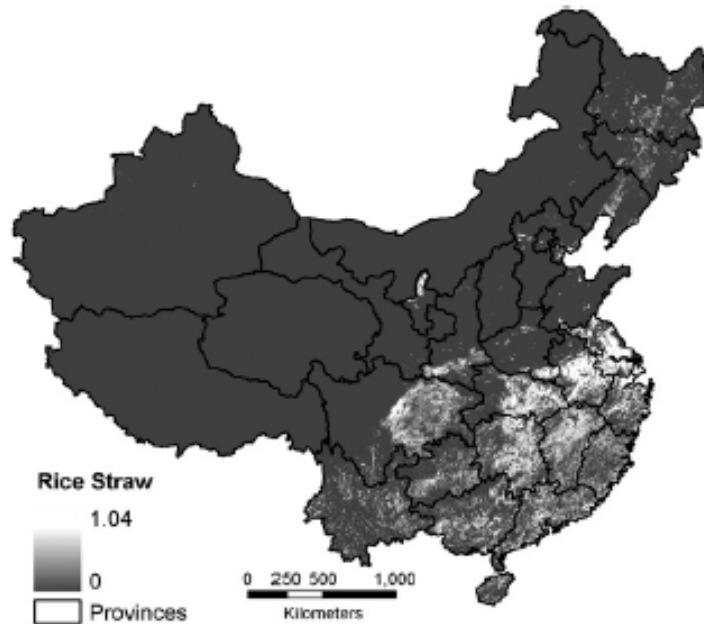
Source: Elmore, A. et al. 2007

Figure 15. Rice Straw Production in 2004, Gg per 1 km pixel.

Ethanol: It is difficult to directly compare the different biomass resource assessments completed in China. Despite using similar methodologies to assess crop and forest residues, each study includes different feedstock, which needs to be considered when comparing results. Tables 9-10 summarize agricultural and forest residues estimated in the main biomass resource assessments completed in China. Focusing on the studies completed in 2007, which are among the most comprehensive, Liu, Jiang and others assess the potential from crop residues at 627 Mt per annum, while ERI and DTI assess the potential from forest residues at 161 Mt per annum. Totaling these, we would arrive at a potential as high as 788 Mt of biomass, equivalent to 236 hm^3 of ethanol per year. That could be sufficient to displace 247% of China's current gasoline use and 90% of China's crude oil imports.

Biodiesel: For long-term development of biodiesel, China is considering woody oil plants, such as jatropha, Chinese pistachio, and Chinese tallow tree. Research on their selection and cultivation just started in recent years. The State Forestry Administration plans to develop 12 million mu (800,000 ha) of oil-bearing tree nuts, principally in Sichuan, Yunan, Guizhou, Chongqing, Hebei, Shaanxi, Anhui, Henan, Hubei, and Jiangxi as part of its 11th five-year plan (2006-2010). It is estimated that these trees will take more than five years to provide a sustainable feedstock supply and they could support as much as 6 Mt of biodiesel production.

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If this should come to pass, it would amount to an extra potential of some 13% of current diesel consumption and 5% of crude oil imports.

Table 9. Summary of Agricultural Residue Assessments in China

Source	Statistical Year	Crop Residues - straw, stalks, stems and leaves	Amount (Mt per year)
(Li Jingjing 1998)	1995	Rice, wheat, corn, soybeans, tubers, oil-bearing crops, cotton, sugar cane, other miscellaneous	605
(Li Junfeng 2005)	1997	Rice, wheat, corn, beans, tubers, sorghum, coarse grains, oil bearing, cotton, sugar cane	639
(Li Jingjing 2001)	1998	Rice and wheat straw; rice husk; bagasse	719
(Liao, Yan et al. 2004)	1999	Rice, wheat, corn, soybeans, sorghum, cotton, hemp, rapeseed, sunflower, sugar cane	551
(Zeng, Ma and Ma 2007)	2002	Rice, wheat, corn, beans, tubers, oil-bearing crops, cotton, hemp, sugar crops, other crops	620
(Liu, Jiang et al. 2007)	1995-2004	Rice, wheat, corn, beans, tubers, oil-bearing crops, cotton, sugar crops, fiber crops, other crops	627
(ERI & DTI 2007)	2006	Rice, wheat, corn, legume, potato, cotton, oil-bearing crops	498

Table 10. Summary of Forest Biomass Resource Assessments in China

Source	Statistical Year	Forest Residues	Amount (Mt per year)
(Li Jingjing 1998)	1995	Residues from felling areas and wood processing factories	26
(Li Jingjing 2001)	1998	Mainly logging residues and forest maintenance operations. A small contribution from fuelwood plantations is also included	110
(Liao, Yan et al. 2004)	1999	Forest residues, shrubbery and orchards*	104
(ERI & DTI 2007)	2006	Residues from fuelwood forests, felling remainders, processing remainders, shrubbery, and other forests (economic forests and bamboo groves)	161

* The study includes residues from the following forest types: Protection forests: forests, trees and bushes mainly aimed at protection, inclusive of water source storage forests, forests for water and soil conservation, wind protection and sand bind forests, forests for farmland and grassland protection, river bank protective belts and road protection belts; Timber stands: forests and trees mainly aimed at timber production, including bamboo groves mainly aimed at bamboo production; Economic forests: trees mainly aimed at the production of fruits, edible oils, soft drinks and ingredients, industrial raw materials, and medicinal materials; Firewood forests: trees mainly aimed at the production of fuels; Forests for special uses: forests and trees mainly aimed at national defense, environmental protection and scientific experiments, inclusive of national defense forests, experimental forests, parent stands, environmental protection forests, scenic beauty forests, trees for sites of historical interests and the forests of natural protection areas.

Biomass Resource Assessment Capabilities

In China, biomass resource assessments have been completed by university researchers and the Energy Research Institute (ERI), a department of the National Development and Reform Commission (NDRC). In some cases, these assessments were developed with technical support from foreign agencies and institutions predominately in the United States, Japan, Canada, and Australia.

University Expertise. Any university with agricultural and forestry departments, or chemical and engineering departments with biomass orientation, would be able to provide knowledge and expertise in the biomass field and contribute to resource assessment efforts. Likewise, geography, GIS, RS, and informational technology departments would offer expertise in geospatial science. Often, agricultural and forestry programs offer geospatial studies as part of the curriculum to provide awareness of GIS and RS as useful research tools. The survey identified two institutions that have been heavily involved in biomass resource assessment activities in the past. These are the Chinese Academy of Forestry (CAF) and the Chinese Academy of Sciences (CAS). CAF's Research Institute of Forest Resource Information Techniques is one of China's leading scientific institutions, especially in the field of GIS, RS, and theoretical modeling in forest resources management - including the development of growth models of forest stands and quantitative evaluation techniques of forest-management activities. Two other research institutes – the Research Institute of Forestry (RIF) and the Forest Ecology, Environment and Protection (RIFEEP) - provide research related to plant science, forest management, ecology, protection, monitoring, etc. More information on CAF and its research institutes is available at http://www.forestry.ac.cn/newcaf/home.cfm. CAS's institutes and laboratories involved in biomass resource assessment include: Institute of Geographical Sciences and Natural Resources Research; Laboratory of Biomass Energy - Guangzhou Institute of Energy Conversion; Laboratory of Quantitative Vegetation Ecology - Institute of Botany; and Laboratory of Remote Sensing Information Science - Institute of Remote Sensing Application. There are other institutions that have been involved in biomass resource assessments, which are listed below:

- School of Geography and Planning, Sun Yat-sen University, Guangzhou
- Guangzhou Institute of Geography, Guangzhou
- College of Forest Resources and Environment, Nanjing Forestry University, Nanjing
- Department of Resource and Environmental Science, Chongqing University, Chongqing

- College of Resource and Environment Engineering, East China University of Science and Technology, Shanghai
- Agronomy Department, Shandong Agricultural University, Tai'an, Shandong Province
- Shandong Academy of Sciences, Ji'nan, Shandong Province
- Department of Ecology, College of Environmental Sciences, and Key Laboratory for Earth Surface Processes of the Ministry of Education, Peking University, Beijing
- Ecology Program, Northeast Forestry University, Harbin, Heilongjiang
- College of Life Science, Beijing Normal University, Beijing
- Thermal Energy Research Institute, Tianjin University, Tianjin
- International Institute for Earth System Science, Nanjing University, Nanjing
- College of Resources and Environmental Science, China Agricultural University, Beijing
- College of Engineering, Nanjing Agriculture University, Nanjing
- Institute of Agricultural Remote Sensing & Information Application, Zhejiang University, Hangzhou

Geospatial technologies - RS and GIS - have not been widely used for resource assessments in China, although many universities appear to have the capabilities. Remote sensing and GIS have been used to estimate crop residues, net primary productivity (NPP)[4] of forests, forest density, and change in forest density.

Geospatial techniques will be used in China's second economy-wide land survey to obtain up-to-date and accurate land data for policy making. The survey will be completed by October 2009. China conducted its first economy-wide land survey in 1996 but, given the substantial changes that have taken place in urban and rural areas, the data collected 11 years ago are now out of date. The purpose of the 1996 nationwide survey was to gather systematic county-level data on the types, area, and location of land use as well as information on land ownership. The survey was primarily based on the reading, verification, classification, and measurement of different land use from the most recent aerial photos, satellite images, and maps available. The second land use survey will use advanced geospatial technologies and GIS. It will build an electronic database for the survey findings and determine statistical and monitoring methods to track changes in land resources and a system to update the information on a regular basis. The

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[4] Net primary productivity (NPP) is defined as the net flux of carbon from the atmosphere into green plants per unit time.

survey will also look at the situation of basic farmland that is widely seen as critical to the country's food security.

Modeling. As mentioned earlier, most of the completed resource assessments in China are based on statistical analysis of reported information. To assess lignocellulosic biomass availability, these analyses apply crop-to-residue ratios and forest-residue generation per land unit to production data reported at economy-wide or provincial level in statistical yearbooks. Advanced modeling techniques - linear and simulation modeling - have not been used as often in resource assessments. Models' input data are based on direct field measurements at sample plots or information obtained from paper surveys.

Data Availability. Agricultural and forestry data is readily available in China to support biomass resource assessments. The Ministry of Agriculture (MOA) and the State Forestry Administration (SFA), formerly the Ministry of Forestry, along with the National Bureau of Statistics (NBS) are the major statistical agencies in China.

MOA is responsible for conducting the nationwide sampling survey. Under this scheme, the province selects counties, the county selects villages and the village selects plots or farm households. The sample counties account for 20% in one province and for the small province no fewer than seven counties must be selected. The sample villages account for 3-5% in one county and the sample households account for 20%. It generally selects 7-10 sample plots in the north and 15 plots in the south. More information on the agricultural survey, structure, and process is available from FAO at http://faorap-apcas.org/rdes/PPT/china_metadata.pdf.
MOA and NBS work together to disseminate agricultural statistics. These include area planted; average yield; production of grains, cotton, oil-bearing crops, and sugar crops; as well as information on forest products and animal husbandry by province for 1996-2005. NBS provides this information via its Web site in both Chinese and English at
http://www.stats.gov.cn/english/statisticaldata/yearlydata/.   MOA publishes China's Agricultural Statistics Report in Chinese annually.

China's State Forestry Administration (SFA) has been conducting a National Forest Inventory (NFI) every five years since 1973: first (1973–1976), second (1977–1981), third (1984–1988), fourth (1989–1993), fifth (1994–1998), sixth (1999-2003), and seventh (in progress). These NFIs apply different methods and techniques in collecting forest resources information. During

the first NFI, most provinces used a random sampling method, which made it difficult for comparison of a field over time. Thus, a network of permanent sample plots was developed during the second NFI. During the third NFI, computers were first introduced to forest inventory, which significantly improved the efficiency of data processing and analysis. Remote sensing sample plots (measured from aerial and satellite imagery) were used in the fourth NFI to complement ground sample plots, and GIS and GPS were widely used during the fifth NFI. Today, the NFI uses a combination of field survey and geospatial techniques to collect forest resources information. SFA uses paper surveys (at the township level) to collect information on forestry products, such as non-wood forest products, timber harvested by villagers, industrial logging, wood processing and forest chemical products. Information on forest resources is released in *China Forestry Yearbook* (first published in 1986) and *China Forestry Resources* (first published in 2005), providing data from the sixth NFI. Publications on forestry products include *China Forestry Statistics 1949-1987*, *China Forestry Statistics* (published annually since 1988, this publication has the most extensive forestry data), *China Agricultural Yearbook* (published in both Chinese and English), and the *Rural Statistical Yearbook of China*. More information of the forestry statistics, collection methodologies, and dissemination is available from the Center for International Forestry Research (CIFOR) at

http://www.cifor.cgiar.org/publications/pdf_files/WPapers/WP36Dachang.pdf.

Overall Biomass Resource Assessment Capabilities. It is evident from the summary above that China has the capabilities to achieve a finer than province level biomass resource assessment. Geospatial technologies have been used in the forestry field and by academia for many years. Applying these techniques to the agricultural sector would ensure an efficient way of evaluating and monitoring crop production. Close coordination of activities between the government and academia, as well as sharing knowledge and expertise with relevant entities abroad, would provide a successful outcome of future biomass resource assessment efforts.

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Hong Kong, China

Hong Kong is a small metropolitan city with very high population and vehicle density. Rapid urbanization in the past two decades had led to serious air pollution problems. To cope with the situation, the government of Hong Kong has adopted many programs and measures focused on improving the fuel quality and efficiency, one of which is blending petro-diesel with biodiesel.

Hong Kong has no natural resources and the only biodiesel feedstock available domestically is waste oil - recycled and grease trap oils from restaurants and food processing industries. According to Dynamic Progress Ltd., the only licensed biodiesel manufacturer in Hong Kong, there were about 25,000 liters of used cooking oil produced and collected per day in 2007. Of that, about 3,500 liters per day are recycled domestically and the rest (about 21,500 liters per day) are exported. Trap grease collected and disposed of at landfills is approximately 8,000 liters per day. If the export portion of used cooking oil and trap grease are used for biodiesel production domestically, it would yield more than 10 million liters (9,000 tonnes) of biodiesel per year (assuming waste oil generation stays the same). Diesel consumption in Hong Kong was about 1,500 million liters (1.3 Mt) in 2005 (IEA 2005), so biodiesel would displace less than 1% of petro-diesel consumption.

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Indonesia

Economy-Wide Biofuels Resource Assessments

First-Generation Biofuels Potential

Ethanol: Currently, fuel ethanol in Indonesia is produced mainly from sugar cane molasses. The economy is among the top 10 sugar cane producers in the world with about 30 Mt per year. Another feedstock considered for ethanol production in Indonesia is cassava with annual production of about 17 Mt. Indonesia plans to expand current production of sugar cane and cassava and dedicate more than 1.5 million ha to growing these crops for biofuels production in the next few years. The Ministry of Energy and Mineral Resources released maps illustrating areas suitable for growing these crops, developed to support decision making and planning activities (Figures 16 and 17).
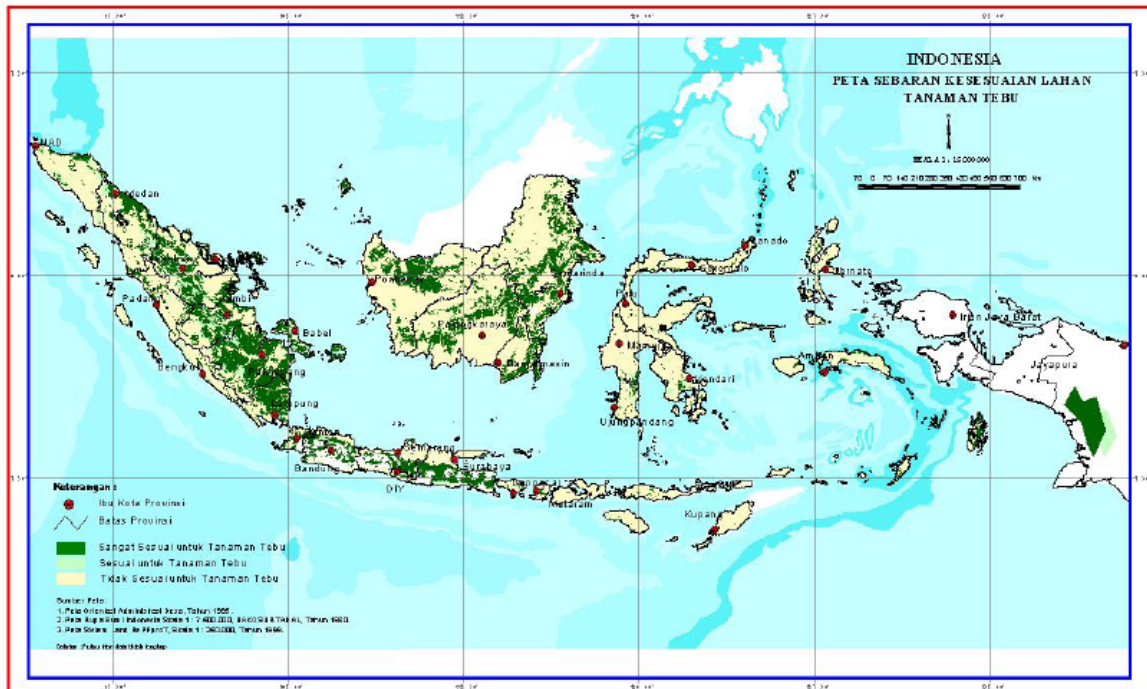
Source: Legowo 2007; Total land suitable for sugar cane production is 500,000 ha; Dark green – very suitable land; light green – suitable land; yellow – not suitable land.

Figure 16. Land Suitable for Sugar cane in Indonesia
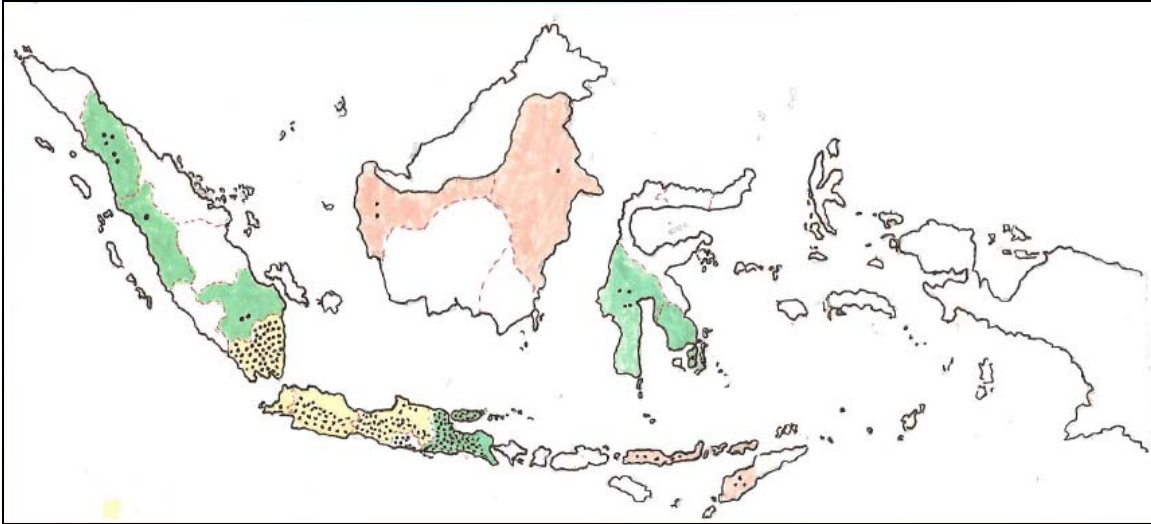
Source: Legowo 2007; Suitable land: white (less than 75 ha), yellow (75-200 ha), green (200-400 ha), red (400-1.800 ha). Each dot represents production potential of 100 tonnes.

Figure 17. Land Suitable for Cassava in Indonesia

If the equivalent of 20% of Indonesia's current starch and sugar crops production could be made available for biofuel production, for example through increase in crop yields over time, it would yield about 6.7 hm^3 of ethanol or 3.2 Mt gasoline equivalent. Such a volume would replace about 25% of Indonesia's current gasoline consumption and 16% of its current crude oil imports.

Biodiesel: The main biodiesel feedstock in Indonesia is palm oil, due to the well-established industry and potential for increase in production. Indonesia surpassed Malaysia in palm oil production in 2007 and is now the world leader. Together, Malaysia and Indonesia provide 90% of the world's palm oil. Indonesia produced 17.4 Mt in 2007; up from 15.9 Mt in 2006 (about 12 Mt were exported). There are about 6 million ha of oil-palm plantations with another 3 million ha suitable for this crop (Figure 18). Another potential biodiesel feedstock in Indonesia is coconut oil, of which production amounted to nearly 0.9 Mt and exports to about 0.5 Mt in 2006.

If the equivalent of 20% of Indonesia's current vegetable oil production were available for biofuels, it would yield about 3.4 Mt of biodiesel. This could replace 34% of the economy's current diesel consumption and 16% of its current crude oil imports.

53
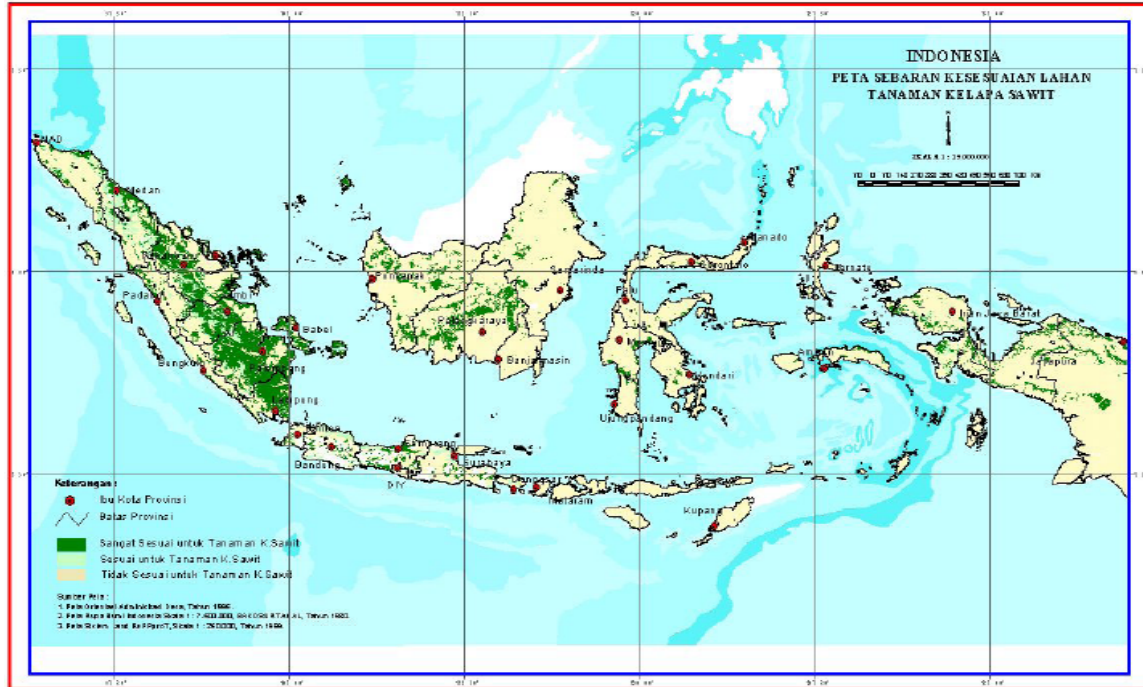
Source: Legowo 2007; Additional land suitable for oil-palm production is 3 million ha; Dark green – very suitable land; light green – suitable land; yellow – not suitable land.

Figure 18. Land Suitable for Oil-Palm in Indonesia

Second-Generation Biofuels Potential

Ethanol: An economy-wide biomass resource assessment was completed by the Agency for the Assessment and Application of Technology (AAAT), which appears to be the main government entity involved in this type of analysis. Table 11 summarizes the most recent statistics on lignocellulosic biomass provided by AAAT. This information was further used to estimate the electric potential of these resources by province (Privanto 2007).

As shown in Table 11, second generation feedstock (excluding Palm Oil Mill Effluent or POME) amounts to about 74 Mt per year. This would yield 22 hm^3 of ethanol or 10.7 Mt gasoline equivalent per annum. Such a volume would displace 83% of Indonesia's current gasoline consumption and 51% of its current crude oil imports.

Table 11. Agricultural and Wood Residues in Indonesia

Biomass Residues	Quantity (million tonnes/yr)
Sugar industry	
Baggase	8.5
Leaf cane	1.3
Palm Oil Industry	
Shell	3.5
Fibre	6.7
Empty fruit bunch	12.9
Palm Oil Mill Effluent	31.0
Rubber	
Rubber wood	2.8
Coconut	
Shell	3.0
Fibre	6.7
Paddy	
Rice husk	13.5
Cassava waste	7.3
Wood waste	8.3
Total	**105.5**

Source: Febijanto 2007; Priyanto 2007

Biodiesel: A potential biodiesel feedstock considered in Indonesia is jatropha. Jatropha is still in the very early stage of development and efforts appear to be focused on small scale plantations. Figure 19 illustrates areas suitable for growing jatropha in Indonesia.

Source: Legowo 2007; green - suitable, yellow – more suitable, orange – very suitable; the table shows hectares identified as suitable for jatropha under each of these land categories

Figure 19. Land Suitable for Jatropha Curcas in Indonesia

Biomass Resource Assessment Capabilities

Geospatial Techniques. It is evident from the examples above that Indonesia uses GIS to identify lands suitable for growing different crops. In addition to the Ministry of Energy and Mineral Resources (http://www.esdm.go.id), GIS has been used by the Ministry of Forestry (http://www.dephut.go.id). In the summer of 2008, AAAT's Center of Technology for Natural Resources Inventory and the Japanese Earth Remote Sensing Data Analysis Center began a collaborative project in agricultural analyses using remote sensing techniques. This is the first time these techniques have been used in Indonesia. The output of this cooperative work will be the development of a crop prediction model (AAAT 2008).

Data Availability. Statistics Indonesia - BPS (Badan Pusat Statistik) is the main agency that compiles and disseminates statistics related to agriculture, forestry, industry and other areas. Data is collected via paper and sample ground surveys on an annual basis. Detailed information on BPS and its data-collection methods is provided by FAO's Regional Data Exchange System (RDES 2006). Other agencies that provide agricultural and forestry data by province include the Ministry of Forestry (http://www.dephut.go.id/) and the Ministry of Agriculture (http://www.deptan.go.id). The Indonesian Palm Oil Association (GAPKI) provides statistics on current and historic palm oil production in Indonesia (http://www.gapki.org/).

Institutions with research programs related to biomass that could provide expertise in the field include Indonesian Institute of Sciences (Lembaga Ilmu Pengetahuan Indonesia), which has been involved in research of new and renewable energy, earth science, and provides information technologies services; and the Institute of Technology Bandung with its School of Life Sciences and Technology and the Faculty of Earth Sciences and Technology offering RS and GIS programs.

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Japan

Economy-Wide Biofuels Resource Assessments

This survey identified several biomass resource assessments in Japan. All of them are at an economy-wide level, although statistics are available at prefecture and, in some cases, municipal level. Japan appears to have very good geospatial capabilities to assess the resources at a finer level. It is possible that such assessments exist, but are inaccessible due to language or status constraints. The assessments are based on statistical analysis of reported information.

First-Generation Biofuels Potential

Ethanol: Japan's potential for production of ethanol from conventional agricultural crops is extremely limited. Even if 20% of Japan's current starch and sugar crop production could be spared for biofuels, it would only yield about 0.75 hm^3 of ethanol or 0.36 Mt gasoline equivalent. Such a volume of ethanol would displace just 0.8% of Japan's current gasoline consumption and 0.2% of its crude oil imports.

Biodiesel: Japan produces a small amount of oil crops, and biodiesel is produced from used cooking oil in limited quantity. Table 12 illustrates the amount of waste oil and fats generated in 2000, which totaled some 0.5 Mt. If 20% of Japan's current vegetable oil production were devoted to biofuels, it would yield less than 0.3 Mt of biodiesel. Together with the waste oil and fats, this would provide less than 0.8 Mt of biodiesel. This amount would replace just 2.8% of the economy's diesel consumption and 0.4% of its crude oil imports.

Table 12. Quantity of Waste Oil and Fats Generated in Japan

Section	Oil supply[a] (kt)	CF			Quantity of waste oil/fat (kt)
		(1) Wastes per person (gcaput^{-1})	(2) Rate of wastes (%)	(3) Rate of return (%)	
Household	650	950	40	—	124[b]–261
Restaurant	710	—	30	—	212
Food industry	689	—	10	—	21
Oils/fats industry	429	—	—	5	69
Total	2479	—	—	—	426–563

Source: Minami, E., and Saka, S., (2005); a - Ministry of Agriculture, Forestry and Fisheries (MAFF), 2000;
CF - conversion factor of the wastes from (1) number of the population, and (2, 3) oil supply;
b - Estimated assuming that the population of Japan is about 130,000,000.

Second-Generation Biofuels Potential

Agricultural residues were estimated by Matsumura et al. using statistics from 2000. The study considered residues from all major crops grown in Japan and evaluated their energy potential as shown in Table 13. The agricultural residues identified in the table sum to just under 30 Mt in all.

Table 13. Annual Agricultural Residue Production in Japan

	Production (t year[-1])	Residual ratio (−)	Residue production (t year[-1])	Moisture content (−)	Ash content (−)	Energy potential (PJ year[-1])
Rice	9,472,000	1.43	13,544,960	0.2	0.22	157.2
Wheat	688,200	2.53	1,741,146	0.28	0.14	20.1
Barley	192,200	2.5	480,500	0.09	0.15	6.9
Sweet potato	1,008,000	1.14	1,149,120	0.89	0.1	2.1
Potato	2,844,000	1.14	3,242,160	0.89	0.1	6.0
Soybean	235,000	2.14	502,900	0.6	0.15	3.2
Sugarcane	1,395,000	0.52	725,400	0.8	0.16	2.3
Corn	5,287,000	1.1	5,815,700	0.47	0.1	51.6
Sorghum	1,625,000	1.57	2,551,250	0.6	0.16	15.9

Source: Matsumura, Y., et al. in 2005-B

Forest residues were estimated by Yoshioka et al. using statistics from 1999 (waste paper and black liquor are excluded from the analysis). The study estimated that about 32 Mt of woody residues are available annually in Japan. The different types of residues assessed are shown in Table 14.

Table 14. Annual Potential Amount of Woody Biomass in Japan (dry weight)

Item	Amount (Tg y[-1])
Logging residues[a]	3.0
Trees to be thinned from coniferous forests which are behind in tending[b]	5.0
Coppice forests, i.e., broad-leaved forests[c]	9.0
Bamboo[d]	0.3
Bamboo grass[e]	3.0
Mill residues[f]	0.4
Wood-based waste material[g]	8.0
Trimmings of park trees, roadside trees, and garden trees[h]	3.0
Total	31.7

Source: Yoshioka, T., et al. (2005); [a] Includes thinned trees that are left in forests because the logging costs are higher than the timber price; [b] Cutting the forests which should have been thinned with the thinning rate of 20%; [c] Cutting the broad-leaved forests (excluding the forests for logs and bed-logs for shiitake mushroom production) less than 500m from forest roads with the cutting cycle of 30 years.; [d] Harvesting 30% of the annual amount of 1.0 Tg/yr dry-weight basis; [e] Harvesting the grass less than a certain distance from forest roads.; [f] Covering all of the wood industries; [g] Consisting of demolition woods, wastes from new construction, and old materials of pallets and packages; [h] Net primary production of the park, roadside, and garden trees; Tg (Teragram) = 1 Megatonne

A more up to date analysis on biomass resources is provided by the Ministry of Agriculture, Forestry and Fisheries (MAFF). In addition to estimating the total amount of resources available in Japan, the agency provided the utilized and unutilized portions of these resources as presented in Table 15. Crop and wood residues amount to about 26.3 Mt, but only 15 Mt are not utilized and therefore available for biofuels production in Japan. These surplus residues would yield 4.5 GL of ethanol per year or 2.2 Mt gasoline equivalent, enough to replace 5% of gasoline consumption and 1% of crude oil imports.

Table 15. Utilization of Biomass Resources in Japan, 2006
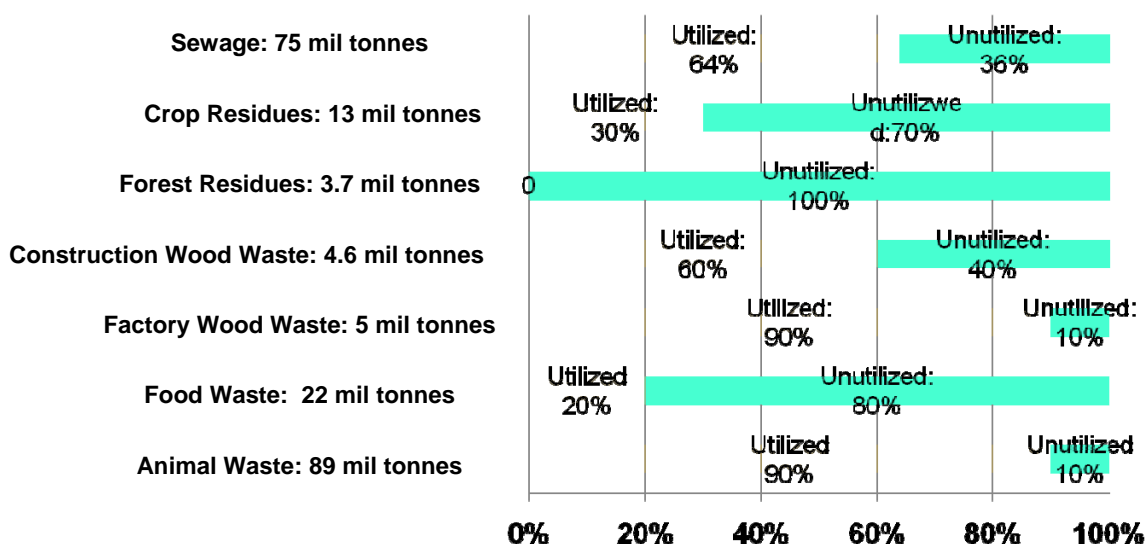
Source: Takao Ikeda, 2008, http://www.maff.go.jp/j/biomass/pdf/riyou_jyokyou.pdf

To further promote domestic ethanol production, the government hopes to use abandoned arable land. In 2005, Yamamoto et al. estimated the land available for growing dedicated energy crops, but the study does not specify the types of energy crops that could be grown. It concludes that about 400,000 ha of unused arable land are available in Japan for growing energy crops and that another 1.2 million ha could be used for double-cropping with conventional crops. If such land were cultivated, the potential for second-generation biofuels to displace petroleum would be enhanced.

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Biomass Resource Assessment Capabilities

Japan appears to have advanced modeling and geospatial capabilities; however, no analysis of biomass resources using these methods was identified during this survey. MAFF has been using mathematical modeling to estimate crop yield and predict production. The Forestry Agency has been promoting the use of GIS/GPS as efficient tools for collecting, recording, and updating data to the prefectural governments. GIS and RS have also been used by several universities to support research activities.

Academic institutions that have been involved in analyses of agricultural and forestry resources include:

- Department of Mechanical System Engineering, School of Engineering, Hiroshima University
- Department of Forest Science and Resources, College of Bio-resource Sciences, Nihon University, Fujisawa
- School of Agriculture, Kyoto University
- Natural Resources and Energy Division, Mizuho Information & Research Institute Inc., Tokyo
- Forestry and Forest Products Research Institute
- Biomass Recycle Research Laboratory, National Institute of Advanced and Industrial Science and Technology, Hiroshima
- Biomass Technology Research Laboratory, National Institute of Advanced Industrial Science and Technology, Chugoku
- Research Institute of Energy Utilization, National Institute of Advanced Industrial Science and Technology, Ibaraki
- Global Warming Research Department, Mitsubishi Research Institute Inc., Tokyo
- Technical Institute, Kawasaki Heavy Industries Ltd, Hyogo
- Socioeconomic Research Center, Central Research Institute of Electric Power Industry, Tokyo
- Seikei University, Fukuoka
- Ehime University, Matsuyama

Institutions with geospatial capabilities include:

- Center for Spatial Information Science, University of Tokyo
- Center for Environment Remote Sensing (CEReS), Chiba University
- Japanese Earth Remote Sensing Data Analysis Center (ERSDAC), Tokyo
- Institute of Industrial Science, University of Tokyo
- National Institute for Rural Engineering

Data Availability. MAFF (http://www.maff.go.jp/) is in charge of Japan's agricultural and forestry statistics. It provides annual data on crop acreages and production, livestock, and forestry products by prefecture and, in some cases, municipality. The agricultural data is collected through direct interviews with farm owners. Due to the different climate and types of agriculture among Hokkaido, Okinawa, and the other prefectures, three sets of farm household questionnaires were used, in the simplified and detailed format, reporting different items (FAO 2000). The Forestry Agency established the Forest Resources Monitoring System in 1999 to monitor changes in quality and quantity of forests in Japan. Under the system, data are collected on about 15,700 permanent monitoring plots, 10,500 of which are located in private forests and the rest in national forests. The plots have been chosen systematically on 4km x 4km grid points covering forests throughout Japan. The system is designed so that data is collected on about 3,100 plots (or one-fifth of the total number of plots) annually with each plot visited every 5 years in rotation (Imaizumi 2001).

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Korea

Economy-Wide, Regional, and Local Biofuels Resource Assessments

First-Generation Biofuels Potential

Ethanol: Korea's potential for production of ethanol from conventional agricultural crops is considered to be quite limited. Even if 20% of Korea's current rice production could be spared for conversion to biofuels, it would only yield about 0.33 hm^3 of ethanol or 0.16 Mt gasoline equivalent. This amount of ethanol could displace just 2.3% of Korea's current gasoline consumption and 0.1% of its current crude oil imports.

Biodiesel: Biodiesel is considered the primary biofuel in Korea since the economy consumes twice as much diesel as gasoline and has real domestic production potential. About 70-80% of biodiesel in Korea is produced from imported soybean oil and 20-30% from used cooking oil. Several biodiesel plants have the capability of using palm oil. Due to increasing soybean and palm oil prices, biodiesel producers are considering alternative feedstocks such as jatropha oil produced in Southeast Asia.

Used cooking oil in Korea amounts to some 0.2 Mtoe annually (Lee and Park 2006), which could yield about 0.23 Mt of biodiesel.[5] If 20% of Korea's current soybean oil production were also devoted to biodiesel production, it could yield about another 0.03 Mt. The overall potential of 0.26 Mt of biodiesel from soybean and cooking oil would replace just 1.8% of the economy's current diesel consumption and 0.2% of its current crude oil imports.

Second-Generation Biofuels Potential

Ethanol: KIER's Bioenergy Research Laboratory is developing a National Biomass Resources Atlas. The project, which began at the end of 2006, includes maps of forest and agricultural residues at an economy-wide, regional, and county level. The estimates are based on statistical information collected through paper surveys. Field surveys are conducted occasionally in

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[5] Assuming 1 tonne of biodiesel = 0,86 toe

assessing and monitoring agricultural and forest residues. The atlas and its underlying data are available to the public via the Internet, but only in Korean.

Table 16 notes that agricultural residues in Korea amount to about 11.8 Mt. Additionally, about 1.3 Mt of logging residues are generated annually (Park S. et al 1993), thus second generation feedstock in Korea amounts to about 13.1 Mt. This amount could produce 3.9 hm^3 of ethanol or 1.9 Mt gasoline equivalent. Such a volume of ethanol could displace 27% of current gasoline consumption and 1.7% of current crude oil imports in Korea.

Table 16. Agricultural Residues in Korea

Residues	Amount produced (1000MT)
Rice straw	8,228
Rice hull	1,487
Barley straw	560
Misc. grain residue	141
Pulse residue	444
Special crop residue	328
Potatos residue	187
Fruit production residue	468
Misc.	–
Total	11,843

Source: Park S. et al., KIER 1993

Biodiesel: The Korea Institute of Energy Research (KIER) is researching the potential for growing winter canola domestically as a biodiesel feedstock. The coastal regions were identified as suitable for production of this crop (Figure 20) and about 300,000–500,000 ha were estimated to be available for planting. Expected canola production would be between 0.45 Mt and 0.75 M t per year. These amounts could displace an additional 3% to 5% of the economy's current diesel consumption and an extra 0.3% to 0.5% of crude imports.
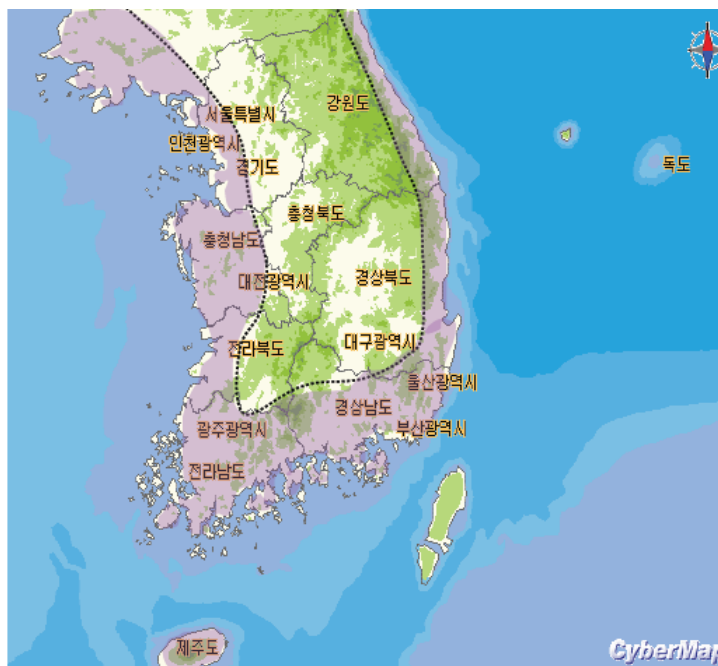
Source: KIER, 2006

Figure 20. Areas Suitable for Winter Canola in Korea

Biomass Resource Assessment Capabilities

KIER appears to be the main institution involved in biomass resource assessment activities. A few other organizations are involved in agricultural or forestry research so may have the potential to contribute to resource assessment efforts. These include the National Institute of Agricultural Science and Technology, Korea Forest Service, Korea Forest Research Institute, and Korea Rural Economic Institute.

Several universities have been involved in research related to forestry monitoring and assessment using remote sensing and GIS. These include Kyungil University, Chungbuk National University, Kyungpook National University, Ewha Womans University, Seoul National University, and Korea University.

The Korea National Statistical Office (KNSO) provides statistical information on agriculture and forestry. The data is collected via surveys with questionnaires prepared and sent out to farmers. KNSO has been conducting agricultural and forestry surveys every five years since 1960.

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Malaysia

Economy-Wide Biofuels Resource Assessments

First-Generation Biofuels Potential

Ethanol: Ethanol from first generation feedstock is currently not considered viable in Malaysia. Grain production in the economy (rice in particular) totals just 1.4 Mt. If 20% of this amount could be made available for biofuel feedstock, for example through increase in productivity over time, the resulting ethanol would amount to just 0.10 hm^3 or 0.048 Mt gasoline equivalent. That would be sufficient to displace 1% of the economy's current gasoline consumption or 0.6% of its current crude oil imports.

Biodiesel: Malaysia concentrates primarily on biodiesel production, particularly from palm oil. Malaysia was the world's largest palm oil producer for many years but was surpassed by Indonesia in 2007. Together, these economies produce about 90% of the world's palm oil. In Malaysia, nearly 11% of the total land area (about 62% of the economy's agricultural land) is devoted to oil palm. Production more than doubled in a little over a decade, from 8 Mt in 1995 to 16 Mt in 2006. Malaysian government policy currently allows only 6 Mt of palm oil to be converted into biodiesel, and a large portion of this production is intended for export. If 20% of Malaysia's current palm oil production were used for biofuels, it would yield about 3.2 Mt of biodiesel. This amount would replace 64% of the economy's current diesel consumption and 41% of its crude oil imports.

Second-Generation Biofuels Potential

Ethanol: Abundant biomass resources are generated from oil palm, paddy, sugar, and wood-processing industries. The National Energy Research Center, Pusat Tenaga Malaysia (PTM), estimated the amount of these resources as illustrated in Table 17 (Rahman 2007). The study states that bagasse is already in use by the sugar mills for power and steam generation, and that wood waste residues are declining due to the use of modern equipment (which generates fewer residues) or are used for the manufacture of charcoal, briquettes and processed heat through gasification. Based on the results presented in Table 17, Malaysia generates more than

32 Mt of oil palm, paddy, wood residues, and bagasse annually. If all used for biofuel, this would yield roughly 9.7 hm³ of ethanol or 4.6 Mt gasoline equivalent. That would displace about 60% of current gasoline consumption and 59% of crude oil imports.

Table 17. Biomass Residue Generation in Malaysia

Type of Industry	Production (Thousand Tonne)	Residue	Residue product Ratio (%)	Residue Generated (Thousand Tonne)	Potential Energy PJ	Potential Elec MWe
Oil palm	74,272	EFB	21.14	15,701	74	**714**
		Fiber	12.72	9,447	140	**1,353**
		Shell	5.67	4,211	71	**683**
	Total			29,360	285	**2,750**
	Others(POME)			51,990	30	**428**
Paddy	2,141	Rice Husk	22	471	7.6	**72**
		Paddy Straw	40	856	8.8	**80**
Sugar	1,111	Bagasse	32	356	356	**314**
Wood	2,937,679 m3	Sawn timber	0.5-0.6	1,692,718 m3	5.2	**50**
	523,336	Plywood and veneer	0.18-0.65	121,000m3	0.374	**4**
	147,813	Moulding	0.2-1.0	75,600 m3	0.232	**2**

Source: PTM, 2007; EFB – Empty Fruit Bunches; POME - Palm Oil Mill Effluent

Biodiesel: A potential biodiesel feedstock considered in Malaysia is jatropha. Jatropha is still in the very early stage of development and efforts appear to be focused on small scale plantations.

Biomass Resource Assessment Capabilities

Although this survey didn't yield any detailed biomass resource assessments, it appears that these capabilities are present in Malaysia. Institutions that have been involved in assessing biomass resources include the National Energy Research Center - Pusat Tenaga Malaysia (PTM); the Forest Research Institute Malaysia (FRIM), University Putra Malaysia (UPM); and the School of Mechanical Engineering - University Science Malaysia, Pulau Pinang.

Geospatial Techniques. RS and GIS technologies started to advance in Malaysia in the 1980s, particularly in the natural resources field. The effective use of these technologies in assessing and monitoring forest resources - at a reduced cost, time, and labour compared to conventional

practices - prompted the government to establish the Malaysian Centre of Remote Sensing (MACRES) in 1988 (UMS 2008). MACRES established an operational remote sensing-based integrated natural resource and environmental database at the economy-wide level to support planning and decision making. While MACRES is the leading agency for remote sensing applications, research on the subject is also carried out by universities such as University Technology Malaysia (UTM), University Putra Malaysia (UPM), University Kebangsaan Malaysia (UKM), and University Malaysia Sabah (UMS). Remote sensing user agencies include the Malaysia Agriculture Research and Development Institute (MARDI) and the Forest Research Institute of Malaysia (FRIM). Remote sensing for forestry applications undertaken by FRIM includes forest inventory, mapping, rehabilitation, and monitoring. Microwave remote sensing is expected to improve the coverage of critical areas. At MARDI, past research included crop surveillance and a land resource inventory; while current research activities cover, among other things, spatial modeling for regional agricultural development and characterization of plant species (Global Security 2008).

Data availability. Malaysia maintains very good agricultural and forestry statistics provided by the following agencies: forestry statistics by state is available from the Forestry Department, Peninsular Malaysia (FDPM) at http://www.forestry.gov.my/stat_kand.html; the Ministry of Agriculture and Agro-Based Industry (MOA) collects and reports data on agricultural products at http://www.moa.gov.my/. The Malaysian Timber Council provides statistics on timber products at http://www.mtc.com.my and the Malaysian Palm Oil Board (MPOB) provides statistics on the palm oil production (http://mpob.gov.my/).

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Mexico

Economy-Wide Biofuels Resource Assessments

First-Generation Biofuels Potential

Ethanol: Mexico grows several crops that could be used as feedstock for ethanol production, including grain sorghum, corn, wheat, and sugar cane. However, sugar cane is considered the most feasible feedstock due to the opportunity for co-locating ethanol refineries with existing sugar mills. Also, Mexico is a sugar exporter, while it imports large amounts of the other crops mentioned above.

A study by the Energy Secretariat (SENER), the Inter-American Development Bank (BID), and the German Agency for Technical Cooperation (GTZ) in 2006 analyzed the potential of the main crops in Mexico for ethanol production, concluding that three of them (corn, grain sorghum, and sugar cane) could be considered. These crops today use a significant area, as seen in Table 18.

Table 18. Areas and Production for Select Crops in Mexico, 2004

Crops	Rain fed M ha	Irrigated M ha	Total M ha	Production M t / year
Corn (annual)	7.08	1.33	8.41	21.70
Sorghum (annual)	1.60	0.35	1.95	7.00
Sugar cane (perennial) (1)	0.24	0.37	0.61	47.80

Source: SENER-BID-GTZ, 2006; (1) – 2003/04

The study also illustrates the approximate areas needed to support ethanol production in three scenarios:

        Scenario 1: Substitute MTBE with ETBE as oxygenate in gasoline

        Scenario 2: Total replacement of ethers with ethanol at 5.7%

        Scenario 3: Ethanol 10% blend becomes the standard gasoline in Mexico

Two crops (sugar cane and sugar beets) would require less than 1 million ha to produce enough ethanol for 10% of gasoline substitution (Scenario 3). This seems to be within the possibilities today, because agriculture uses only 21.8 million ha (2003) out of about 30 million ha "available" area; and pasture land (27.7 million ha) in some regions (South-Southeast) could be partly used

for energy crops. Corn also would be in this range, while cassava and sorghum would require much larger areas (SENER-BID-GTZ). Table 19 summarizes the results of this analysis.

Table 19. Areas Needed for Ethanol Production in Mexico

	Productivity, t/ha		Conversion, l ethanol / t (8)	Areas needed, 2010 M ha (4)		
	Average today	Expected (1)		Scenario 1	Scenario 2	Scenario 3
Sugar Cane	74	65 (2)	83 (3)	0.08	0.21	0.85
Corn	2.8	9.1 (5)	400	0.11	0.32	1.26
Sorghum (grain)	2	2 (6)	400	0.51	1.44	5.73
Cassava		10.6 (10)	170	0.23	0.64	2.54
Wheat	6.0	6.0 (7)	440	0.16	0.44	1.73
Sugar beets	40	85- 60 (9)	86 (12)	0.06-0.09	0.16- 0.11	0.63-0.89

(1) For the conditions (irrigation or rain fed, etc) proposed in the scenarios

(2) For rain fed areas (indicated for expansion to produce ethanol). Except for Tabasco and some areas of Chiapas and Veracruz (sufficient rain) all other areas will need at least two water applications to reach ~70 t cane / ha (Lazcano 2006b)

(3) New distilleries; from the average in Brazil (2002) corrected by the pol% cane.

(4) Scenario 1:   0. 412 M m³ ethanol / year

    Scenario 2:   1.153 M m³ ethanol / year

    Scenario 3:   4.582 M m³ ethanol / year

(5) With irrigation; Mar de Cortés, Center-North of Sinaloa; as proposed (Lazcano 2006b)

(6) Rain fed; as proposed, in the San Fernando Tamps, Pacifico Norte (Lazcano 2006b)

(7) With irrigation; Valles de Mexicali, del Yaki and B.C. (Lazcano 2006b)

(8) In all cases (when applicable) the use of cellulosic residues to produce ethanol   from hydrolysis is not considered in this table, although it is included (with the necessary restrictions) in the study.

(9) With irrigation; as proposed, in the Valle de Mexicali and may be the Valle del Fuerte, Sinaloa (Lazcano 2006b) the value of 85 would be achieved. The second value (~60) is the average 5- year productivity (2000-2004) for the best producers in Europe (France, Germany, Belgium), (F O Lichts 2005).

(10) Rain fed; Bajo Papaloapan, Peninsular

(11) This was the world average in 2000; in many conditions higher values can be obtained (soils, water) (FAO 2002)

(12) See (El Sayed, Matthews and Mortimer 2005)

Source: SENER-BID-GTZ, 2006

If the equivalent of 20% of Mexico's current starch and sugar crop production could be spared for biofuels production, for example through increase in crop yields over time, it would yield

about 3 hm^3 of ethanol or 1.5 Mt gasoline equivalent. This volume would displace 5% of Mexico's current gasoline consumption. Alternatively, if Scenario 3 in the SENER analysis could be realized, with 4.6 hm^3 of annual ethanol production, about 8% of gasoline consumption could be displaced.

Biodiesel: Biodiesel in Mexico is produced from animal fat and used cooking oil. Because of the existing import dependency for animal and recycled oils/fats, the SENER-BID-GTZ study concluded that these feedstocks are going to play a minor role in domestic biodiesel production.

The economy is highly dependent on imports of oilseeds and products (about 90 % oilseeds and approximately 35 % fodder). However, the SENER-BID-GTZ study analyzed the possibility of producing more vegetable oils domestically to support biodiesel production. Accounting for the biodiesel yields per hectare for the different oil crops, the study estimated the acreages needed to support different biodiesel-blend scenarios (Table 20). The study states that if Mexico wants to achieve a self-sufficient supply of biodiesel feedstock considering currently planted and needed land, an intensive agricultural supporting scheme needs to be established. Figure 21 shows areas suitable for growing these crops.

If the equivalent of 20% of Mexico's current vegetable oil production were used for biofuels, it would yield about 0.23 Mt of biodiesel per annum. This volume would displace less than 2% of the economy's current diesel consumption.

Table 20. Agricultural Land Needed to Support Biodiesel Feedstock Production in Mexico

Crop	Yield (L/ha)	Agricultural Land (ha) Needed to Support:			Current Growing Area (ha)	Potential Area (ha)
		B5	B10	B20		
Oil Palm	3,390	304,881	609,762	1,219,524	15,000	2,500,000
Jatropha	730	1,415,717	2,831,434	5,666,868	N/A	1,000,000
Sunflower	665	1,554,095	3,108,190	6,216,381	900	N/A
Canola	619	1,669,585	3,339,171	6,678,341	10,500	N/A
Safflower	409	2,526,830	5,053,659	10,107,319	224,000	N/A
Soybeans	289	3,576,032	7,152,065	14,304,129	110,000	> 1,000,000

Source: SENER-BID-GTZ, 2006

Figure 21. Suitable Areas for Biodiesel Feedstock Production in Mexico

Second-Generation Biofuels Potential

Ethanol: A study sponsored by the National Forest Commission (CONAFOR) and the National Association of Solar Energy (ANES) estimated the amount of logging, primary mill, and crop residues (CONAFOR/ANES 2006) in Mexico. This is a nationwide study based on statistical analysis of reported information in 2001 – 2003. Crop residues evaluated in this analysis include those from sugar cane, rice, corn, wheat, grain sorghum, barley, and beans production. Total residues are estimated at 74.5 Mt per year (Table 21), which could generate 22 hm^3 of ethanol or 10.7 Mt gasoline equivalent. Mexico consumed about 27.7 Mt of gasoline in 2005, so second-generation ethanol could displace about 39% of its gasoline consumption.

Table 21. Lignocellulosic Biomass Potential in Mexico

Feedstock	Quantity (million tonnes/year)
Logging Residues	2
Primary Mill Residues	1.5
Crop Residues	71
Total	74.5

Source: CONAFOR, 2006

Biodiesel: A potential biodiesel feedstock considered in Mexico is jatropha. Jatropha is still in the very early stage of development and efforts appear to be focused on small scale plantations.

Regional and Local Biofuels Resource Assessments

The Institute of Electrical Investigations (IIE) estimated and mapped the biomass resources available by Basic Geostatistical Area (BGA). These are territorial divisions, smaller than the municipalities, developed by the National Institute for Statistics and Geography (INEGI) to collect statistics. The study assessed the amount of residues available in each BGA using crop-to-residue ratio as well as their energy potential in GJ (Figure 22). The following six crops are considered: beans, corn, wheat, rice, barley, grain sorghum, and sugar cane. IIE has also estimated and mapped animal manure by BGA and its energy potential.

Source: IIE, 2008
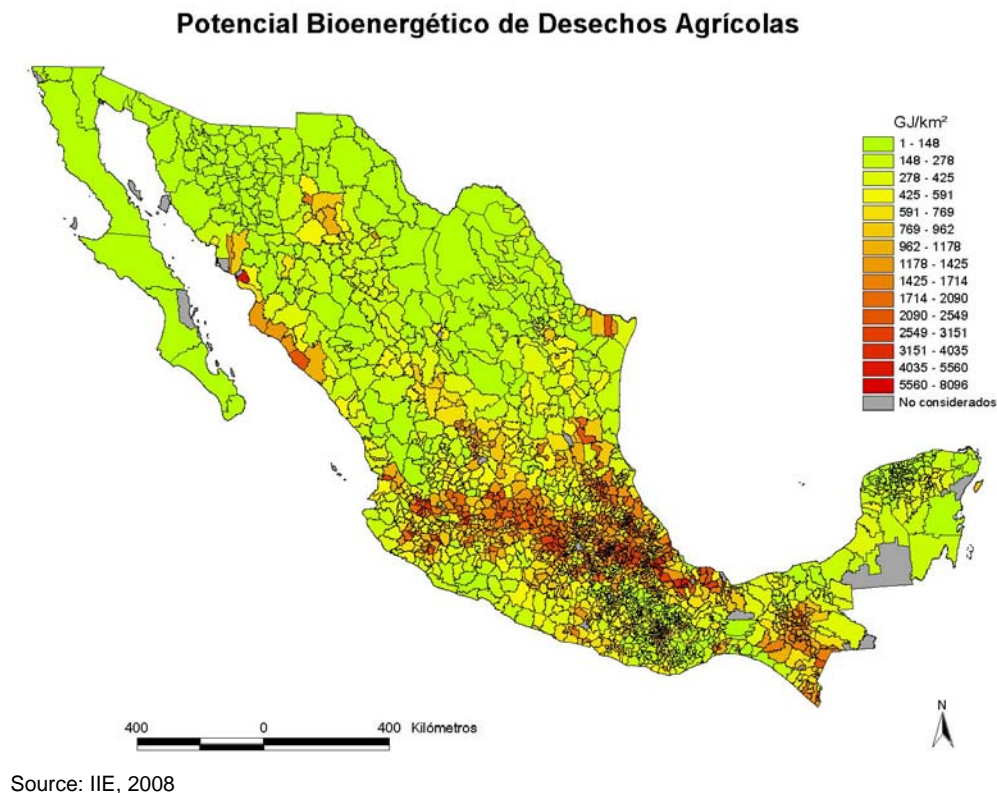
Figure 22. Energy Potential of Crop Residues in Mexico

Biomass Resource Assessment Capabilities

It is clear from the examples above that Mexico has very good biomass resource assessment capabilities. The primary agencies providing expertise in agriculture and forestry include the National Forest Commission (CONAFOR); the Secretariat of Agriculture, Livestock, Rural Development, Fishes and Feeding (SAGARPA); and the Mexican National Institute of Forestry, Agriculture, and Livestock Research (INIFAP). Two other agencies analyze biomass resources as feedstock for power generation – the Institute of Electrical Investigations (IIE) and the Secretariat of Energy (SENER).

Integrated Techniques. GIS and RS have been used by all agencies listed above for mapping cropland areas and monitoring crop production. Additionally, the National Autonomous University of Mexico (UNAM)'s Center for Ecosystems Research has been working in the field of forestry resources using geospatial techniques. UNAM conducted a wood-fuel supply and demand spatial analysis to identify high-priority (or hot spot) areas where actions to ensure the sustainability of fuelwood use are urgently needed. The approach used in the Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) model is illustrated in Figure 23.
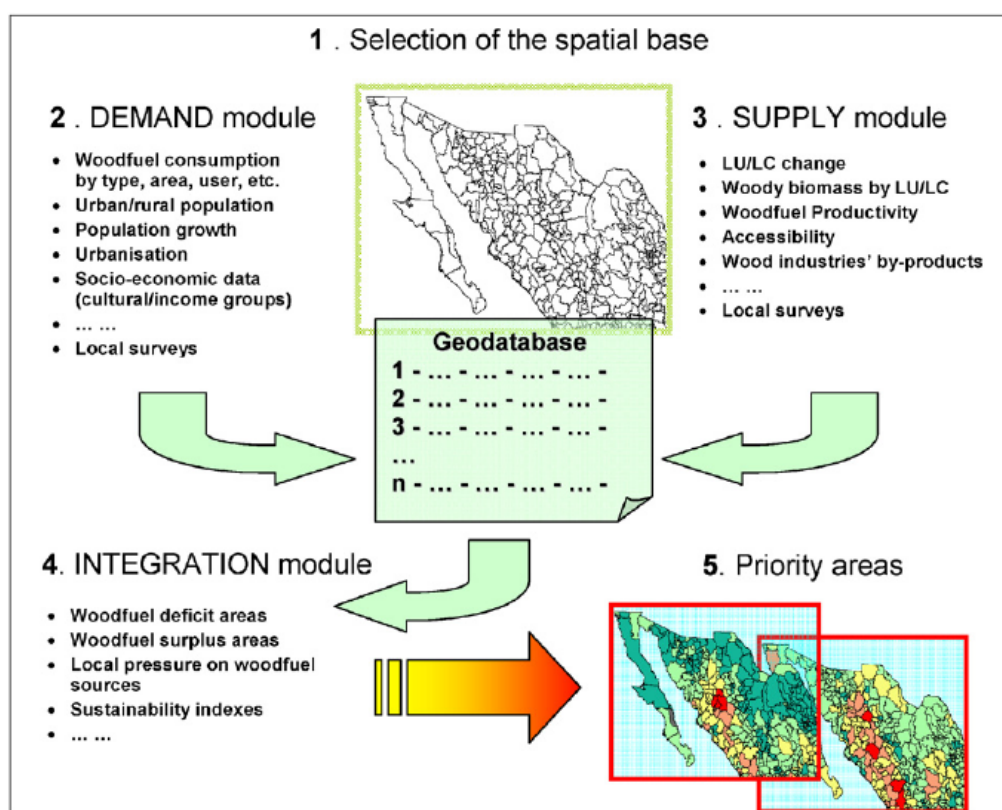
Source: Ghilardi, A., et al. 2007

Figure 23. WISDOM Analysis Steps

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As noted in Figure 23, the WISDOM approach combines geospatial techniques and sample surveys. A combination of different methods has been used by the INIFAP in crop yield prediction and by SAGARPA for collecting crop information. INIFAP uses a set of simulation models with input data taken on-site at sample plots as well as remotely sensed data. The different levels of government agencies – federal, state and municipal – are already benefiting from timely information on the condition of agricultural crops, including the relationship with climatic effects and other potentially adverse factors as well as the impact on crop production. SAGARPA collects agricultural information via sample ground and paper surveys as well as remote sensing. The study by CENER-BID-GTZ conducted an economic analysis using numeric modeling to estimate the cost of producing ethanol and biodiesel from different feedstock.

Data Availability. SAGARPA and Mexico State's Institute of Agriculture, Livestock, Water, and Forestry Research and Training (ICAMEX) provide crop and livestock statistics by state, district and municipality. Additionally, the National Institute for Statistics and Geography (INEGI) provides agricultural and forestry statistics at the BGA level, collected via paper surveys.

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New Zealand

Economy-Wide Biofuels Resource Assessments

A comprehensive biomass resource assessment was completed at an economy-wide and regional level by the New Zealand Crown Research Institute Scion (formerly known as Forest Research) in 2007. The project examined crops and crop residues; woody biomass (logging residues, wood processing residues, horticultural prunings, and short rotation forestry); municipal and industrial wastes (sewage bio-solid effluents; solid waste; animal manures; and industrial wastes from dairy, fruit, vegetable, and meat processing); and algae. A summary of the findings is presented below.

First-Generation Biofuels Potential

Ethanol: New Zealand produces ethanol from whey, a byproduct of the dairy industry and it is estimated that the production will increase (USDA 2007). Ethanol produced from whey amounts to about 15 million liters per year, which meets 0.3% of the economy's gasoline needs and 0.2% of crude oil imports.

New Zealand has about 109,900 ha of grain crops planted: approximately 20,600 ha of corn (predominantly in the Waikato/Central North Island), 39,400 ha of wheat and 49,900 ha of barley (predominantly in Canterbury). However, the use of these grains for energy production is likely to lead to competition with food uses. The Scion study states that there are about 915,950 ha of pasture land that could physically and economically (based on current gross marginal returns in dollars per ha) be switched to grain for ethanol production if demand for the resource increases sufficiently. This area of land could potentially produce enough corn to make 4,100 million liters of ethanol (40% of current total liquid fuels demand). However, the net carbon balances would need to be examined in light of the value of pastureland as a carbon store.

Sugar crops (cane and beet) are not currently grown in New Zealand. However, sugar beet can be produced in Tasmania (Australia), where similar growing conditions exist. Successful sugar beet trials were undertaken in Southland, but the economics did not support development.

Biodiesel: Biodiesel feedstocks in New Zealand include used cooking oil and tallow. Scion reports that about 5-6 million liters of used cooking oil is generated per year, largely sourced

from major population centers. New Zealand produces sufficient tallow (a by-product of the meat industry) to produce 132,000 tonnes of biodiesel per year, which could replace 7.6% of the economy's current diesel consumption and 2.9% of its crude oil imports.

Rapeseed has been targeted as another source of biodiesel in New Zealand. Farmers in South Canterbury are being encouraged to grow the crop, supplying a biodiesel production plant with a target capacity of 70 million liters of biodiesel per year by 2011. The land area required to meet this level of production would be around 50-55,000 ha, in a region that has more than 100,000 ha of arable cropland. Some competition with land for growing food crops and animal grazing is inevitable if the stated levels of production are to be achieved. However, the use of the residual cake from the processed oil seed can be used as a stock food. This largely offsets the loss of grazing area.

Second-Generation Biofuels Potential

Ethanol: The Scion study estimated that about 5.5 Mt of crop and woody residues are available annually in New Zealand as illustrated in Table 22. These second-generation feedstocks could yield about 1.7 hm^3 of ethanol or 0.8 Mt gasoline equivalent per annum. Such a volume could displace 34% of current gasoline consumption and 18% of crude oil imports.

Table 22. Lignocellulosic Biomass Available in New Zealand, 2005-2010

Residues	Quantity (dry tonnes)
Logging	3,600,000
Primary Mill	800,000
Horticultural Wood	46,000
Municipal Wood	500,000
Crop	500,000
Total	**5,446,000**

Source: Scion, 2007; Note that logging residue availability
will increase over time as the harvest of plantation forest increases in the next 20 years

Fast-growing tree species such as eucalyptus, acacia and willow have potential as dedicated energy crops for New Zealand. Currently, these short-rotation forestry (SRF) crops are not commercially used for bioenergy production, with a small area (<20 ha) established as trials. Some expansion of the willow SRF resource is planned for the Lake Taupo area, with the development of a 20 ha nursery to provide planting stock for a planned 1,200-1,500 ha planting program in 2009. The study states that it is unlikely that there will be any commercial SRF

harvesting operations in New Zealand in the next 3 years because there is currently no resource to harvest.

Biodiesel: Second-generation biodiesel feedstock considered in New Zealand is algae. Algal biomass is not produced commercially; however, existing municipal waste streams offer significant potential and this route is being actively researched by government and private organizations, with research on growth and conversion underway. As shown in Table 23, wastewater and poultry waste could provide as much as 1,787 dry tons of algae per day or 652,000 tonnes per year. This amount would yield about 125,000 – 326,000 tonnes of oil, considering that oil yield is between 0.2 - 0.5 tonne per tonne of algae (NREL 2008).

Table 23. Algae Potential from Existing Waste Streams in New Zealand

Municipal wastewater:	The potential daily algal biomass yield from each existing WSP in New Zealand was calculated from wastewater flow data to give a total of 41 tonnes per day (dry weight). By converting all existing WSP in New Zealand to HRAP the potential daily algal biomass yield could increase to 164 tonnes dry weight/day. If all municipal wastewater was treated in HRAP with addition, the potential daily algal biomass yield could be further increased to 475 tonnes dry weight/day.
Dairy farm wastewater:	The daily algae production potential from dairy farm wastewater in NZ using HRAP with CO_2 addition would be 1093 tonnes dry weight/day. This is more than double that which could be produced from all municipal wastewater, however, with the production spread over many farms, cost-effective small-scale harvesting and processing technology will be required to realise this potential.
Pig farm wastewater:	There are approximately 250 commercial pig farms in New Zealand, each with an average of 1000 pigs. As all of the daily manure production is treated, the daily algae production potential from piggery wastewater in NZ using HRAP with CO_2 addition would be 83 tonnes dry weight/ day. The high and concentrated wastewater flows of commercial piggeries compared to those of the largest dairy farms makes piggeries attractive potential sites for algae biomass production.
Poultry waste:	Poultry farming is gaining popularity in New Zealand with approximately 350 laying hen and broiler chicken farms with a total of 24 million chickens. The daily algae production potential from chicken farm manure in NZ using HRAP with CO_2 addition would be 136 tonnes dry weight/ day. However, as most poultry farms have solid manure collection systems, often with 100% export of the manure, the potential for algae production may be harder to realise that for other agricultural manures.

Source: Scion, 2007

Regional Biomass Resource Assessments

The Scion study used GIS to assess the lignocellulosic biomass at a regional level. Figure 24 illustrates an example of the series of maps presented in the report, and Table 24 shows the results in a tabular format, for the case of primary mill residues. Other types of residues considered at regional level, for which data are also provided in the study, include logging residues, municipal wood waste, horticultural wood residues, crop residues, fruit, and vegetable residues.

Table 24. Regional Production and Use of Primary Mill Residues in New Zealand

Based on processing 13.9 million m³ roundwood			
Wood supply region	Residue production	Estimated residue used as bioenergy	Residues available
Northland	288	288	0
Auckland	256	91	164
CNI	2,139	1,508	631
East Coast/Hawke's Bay	373	299	74
SNI	267	130	137
Nelson/Marlborough	316	357	-41
West Coast	73	69	4
Canterbury	149	83	66
Otago/Southland	263	241	23
Total	4,123	3,066	1,099
Existing markets		Estimated residue used	
Wood pellets		200	
Landscaping and other uses		100	
Estimate of residue available			799

Source: Scion, 2007
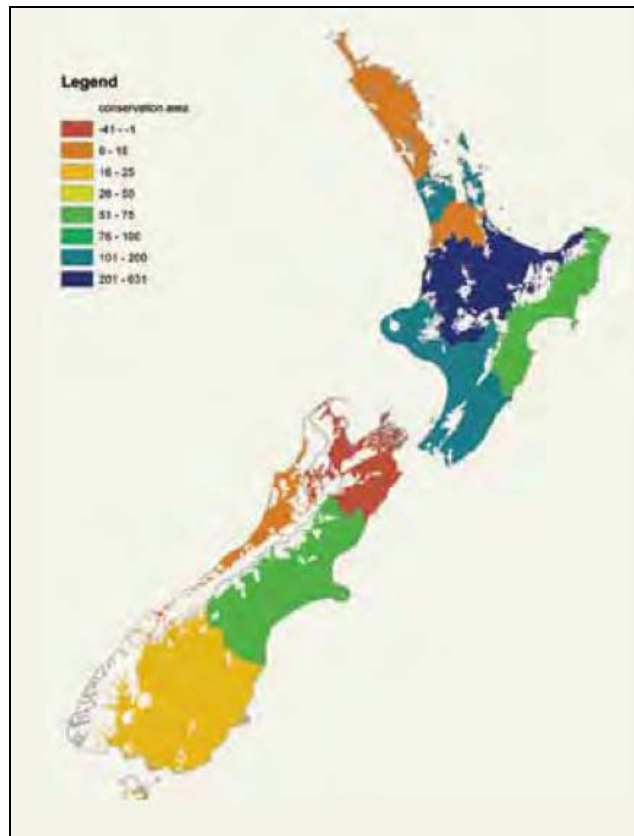
Source: Scion, 2007; '000 green tonnes

Figure 24. Primary Mill Residues in New Zealand by Region, 2005

Biomass Resource Assessment Capabilities

New Zealand has very good biomass resource assessment capabilities. Leading agencies include the New Zealand Crown Research Institutes' Scion and AgResearch; Landcare Research, Crop & Food Research; the Ministry of Agriculture and Forestry (MAF); the Energy Efficiency and Conservation Authority (EECA); and Massey University.

Geospatial techniques and GIS, in particular, have been used by Scion, Landcare Research, and MAF to map agricultural and forestry products and residues. A GIS model for estimating potential volumes and costs for delivering forest derived biomass to a chosen site has been developed. A forest productivity database has also been developed in a geospatial format.

Modeling. Numeric modeling has been used by MAF in crop, forest industry, and wood availability forecasts. Bioenergy researchers at Scion have developed a range of user-friendly calculation tools (based on numeric modeling) to assess wood waste, cost of recovery, transportation costs, CO_2 emissions, and return on investment to support decisions relating to bioenergy. More information about these tools is available at
http://www.scionresearch.com/BKC/index.html.

Data Availability. Two agencies are responsible for collecting and reporting crop, livestock, and forestry statistics in New Zealand – the MAF and Statistics New Zealand (SNZ). Both agencies use a combination of data-collection methods – paper and ground sample surveys. Information is collected at the farm or processing facility; aggregated; and reported by territory, region or nationwide.

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Papua New Guinea

Economy-Wide Biofuels Resource Assessments

First-Generation Biofuels Potential

Ethanol: Papua New Guinea (PNG) produces small amounts of sugar cane. Ramu Sugar Ltd (RSL) is a registered private enterprise, the only PNG company specializing in sugar cane production. Sugar cane is grown on 8,500 ha, with production at more than 500,000 tonnes in 2002 (NAIS 2006). The main by-product of the RSL sugar mill is molasses. About 12% of total output is sold locally, primarily as cattle feed. The balance of about 15,000 tonnes per year is pumped to the distillery adjacent to the sugar mill for conversion into alcohol. In 1995, the distillery was upgraded from producing industrial grade alcohol to producing potable grade alcohol. The bulk of the annual production of more than 2 million liters of potable alcohol is exported (Pacific Magazine 2003).

If 20% of PNG's sugar cane production is used for biofuels, it would yield about 0.06 hm^3 of ethanol per year (29,000 tonnes gasoline equivalent). This volume would displace 6.6% of the economy's crude oil import.

Biodiesel: There is no information on biodiesel production and consumption in PNG. However, there is a widespread use of straight vegetable oil (SVO) or mixture of SVO and petro-diesel. Domestic biodiesel feedstocks include palm and coconut oil. Oil palm has been a widely cultivated cash crop since the 1960s, and today it is the economy's leading agricultural export. PNG is the world's sixth-largest producer and the third-largest exporter of palm oil, behind Malaysia and Indonesia. Crude palm oil (CPO) production in 2007 was 380,000 tonnes, almost entirely for export. The coconut oil industry is relatively small (about 60,000 tonnes in 2007), of which 43,000 tonnes or 73% was exported (USDA 2008).

If 20% of PNG's current vegetable oil production is used for biofuels, it would yield about 82,000 tonnes of biodiesel. This volume would replace 48% of the economy's current diesel consumption and 19% of crude oil import.

Second-Generation Biofuels Potential

No assessment of lignocellulosic biomass was identified during this survey. Considering PNG's agricultural and forestry industries a significant waste material could be available for ethanol production. These include logging, oil-palm and coconut residues, as well as sugar cane bagasse.

Biomass Resource Assessment Capabilities

Although some of the products mentioned below are not direct examples of biomass resource assessments, they are indicators of existing capabilities - methods, tools, scientific knowledge and data - that could be applied to future resource assessment projects.

Leading agencies and institutions providing expertise in agriculture and forestry include the National Agricultural Research Institute (NARI), Department of Agriculture and Livestock (DAL), PNG Forest Authority (PNGFA), Forest Industries Association (FIA), and PNG University of Technology (Department of Agriculture and Department of Forestry).

Geospatial techniques (GIS and RS) have been used by the University of Papua New Guinea (UPNG) and NARI in various projects. The UPNG Remote Sensing Center (in conjunction with the Australian National University) recently released a report on the state of forests in PNG (UPNG/ANU 2008). The study used satellite images and GIS to illustrate the loss in forest cover between 1972 and 2002 (Figure 25). It found that at current rates, 53% of forest is at risk of being destroyed by 2021. The study also found that even in conservation areas, trees have been logged or cut down by local subsistence farmers unabated. Papua New Guinea has the world's third-largest tropical forest but it was being cleared or degraded at a rate of 362,000 hectares (895,000 acres) a year. UPNG also developed a Resource Information System (PNGRIS), which is a computer-based inventory of PNG natural resources, land-use, and population information. The system provides a series of maps and data on climate, elevation, relief, geology, soil, population and inundation, useful for natural resource planning, development, and conservation. The Land Use Section in DAL uses PNGRIS in combination with other data to develop crop suitability maps. Additionally, NARI uses GIS to map crop production, land use, and socio-economic information related to farming systems.
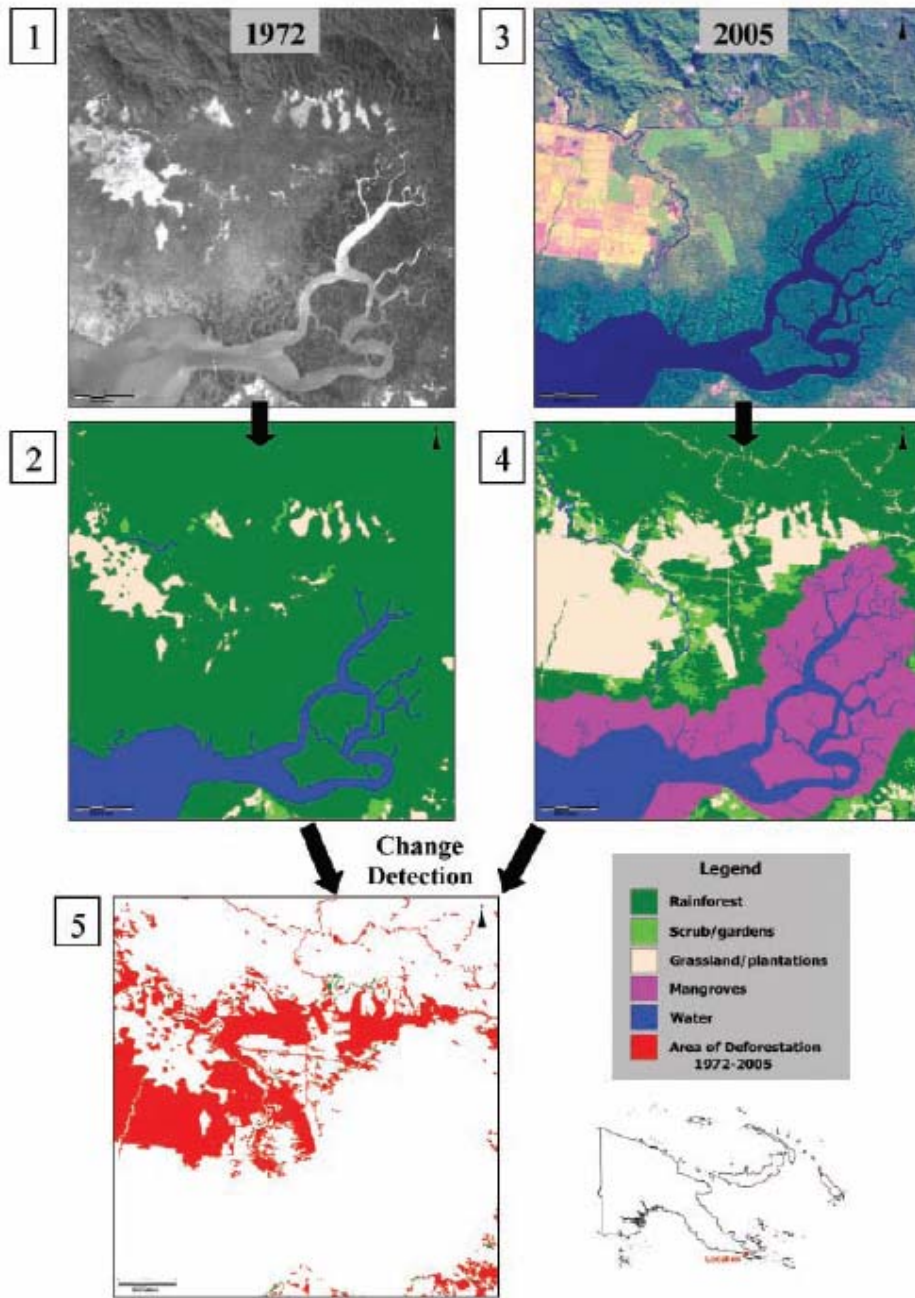
Source: UPNG/ANU, 2008

Figure 25. Estimating Area of Deforestation in Papua New Guinea

Data Availability. The survey didn't find any agricultural and forestry statistics by domestic agencies in electronic format. In most cases, this type of information is provided by FAO and the United States Department of Agriculture (USDA) at an economy-wide level via their Web sites. The Forest Authority (PNGFA) is the government body responsible for monitoring and

controlling the wood- and forest-based industries and the management of forest resources. NARI is responsible for collection and maintenance of agricultural statistics. However, no data is provided via NARI and FA Web sites. Without this information, the survey found it difficult to assess data-collection methods and frequency, as well as geographic scale.

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Peru

Economy-Wide Biofuels Resource Assessments

First-Generation Biofuels Potential

Ethanol: Peru has a number of crops that can be used for ethanol production, including sugar cane, grain sorghum, corn, cassava, potatoes, and rice. The economy is particularly competitive in sugar cane, boasting the highest yield per hectare in the world. According to the Ministry of Agriculture (MINAG), the Peruvian sugar cane industry in 2006 produced 110 tonnes per ha compared to just 85 tonnes per ha in Brazil. Sugar cane production was 7.2 Mt in 2006, with about 80% going to sugar production. The rest is used for production of alcohol used by the beverage, pharmaceutical, and chemical industries. Sugar cane production in Peru is cultivated in five regions along the coast and 77% of the production is concentrated in the North. The region La Libertad provided 46% of total production in 2006, followed by Lambayeque (23%), Lima (22%), Ancash (8%), and Arequipa (1%). Potential for expanded production of sugar cane and other crops remains to be assessed.

If 20% of Peru's current starch and sugar crops production could be spared for biofuels, it would yield about 1 hm^3 of ethanol or 0.48 Mt gasoline equivalent per annum. This volume would be sufficient to replace 62% of Peru's current gasoline consumption and 10% of its crude oil imports.

**Biodiesel:** A study by the Soluciones Prácticas-ITDG in 2007 evaluated the resource potential for biodiesel in Peru. The study states that there are a variety of raw materials available - vegetable oils, used cooking oil, fish oil, and animal fats; however, there is not sufficient quantity to satisfy a potential industry demand. Peru is a net vegetable oil importer with about 60% in 2002.

Primary feedstock for biodiesel production is palm oil. Production is concentrated in the provinces of Ucayali, San Martin, and Loreto. There are 21,200 ha planted with oil palm. Productivity varies between 1.7 and 5.7 tonnes of crude palm oil per ha. According to MINAG, approximately 1.4 million ha are available for capacity expansion. The National Institute of Natural Resources (INRENA) estimated that there are 4.8 million ha available, 510,000 (about

10%) of which are in non-forested areas. However, there is the emergence of concerns regarding the social and environmental impacts of expanding oil palm plantations in regions of high biodiversity.

Other feedstocks available in Peru include used cooking oil and fish oil. Used cooking oil could have interesting niche applications and environmental benefits; however, logistics of collection would be daunting. Peru is a large producer and exporter of fish oil, but there is little experience in using this oil as biodiesel feedstock worldwide.

There is a program to promote planting of canola on 20,000-200,000 ha in the Peruvian highlands.

Table 25 summarizes the resources available for biodiesel production in Peru. If 20% of Peru's current palm oil production, as well as all waste oils and fats, were used for biofuels, it would yield about 303,000 tonnes of biodiesel per annum. This amount would replace 14% of Peru's current diesel consumption and 6% of its crude oil imports.

Table 25. Biodiesel Resources in Peru, 2005

Resource	Quantity (tonnes per year)
Palm oil	48,000
Used cooking oil	3,680
Fish oil	290,000
Total	341,680

Source: Castro, 2007

Second-Generation Biofuels Potential

No assessment of lignocellulosic biomass was identified during this survey. Potential materials for ethanol production include sugar cane bagasse, crop residues, logging, and oil-palm residues. There are several plantation trails of jatropha in San Martin (Tarapoto) and Amazonas (Bagua Chica).

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Biomass Resource Assessment Capabilities

Peru appears to have good capabilities to conduct a detailed level of biomass resource assessments. Leading agencies with knowledgeable staff in agriculture and forestry are the MINAG and INRENA. These two institutions have been using GIS to map crop and forest resources. Additionally, INRENA has been using RS for forest monitoring. Figure 26 illustrates a geospatial tool developed by MINAG showing land use.
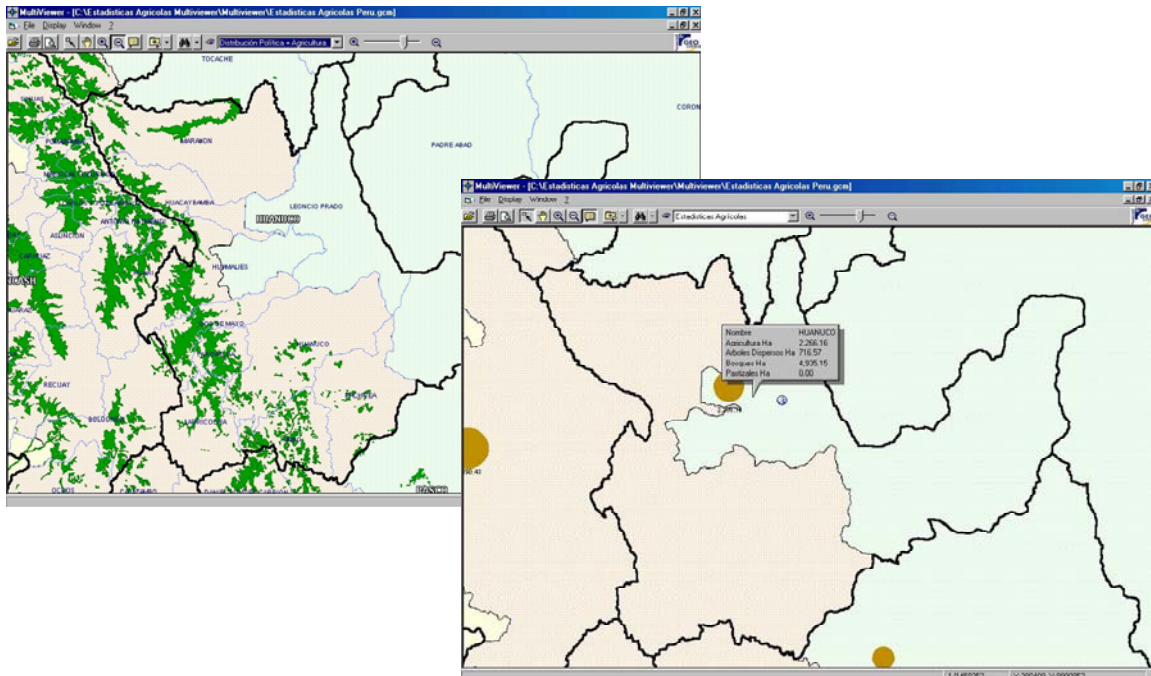
Source: MINAG, 2008

Figure 26. Atlas of Agricultural Lands in Peru

MINAG collects and provides monthly and annual statistics on crop production; acreages; and yield at an economy-wide, regional, provincial, and district level. Data is collected via sample paper and field surveys. INRENA manages forest resources and provides forest and timber product statistics annually at a regional level.

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The Philippines

Economy-Wide and Regional Biofuels Resource Assessments

First-Generation Biofuels Potential

Ethanol: In the Philippines, sugar cane is considered a primary feedstock for ethanol production. The government sees it as the most reliable feedstock due to its well-established farming technologies and the highest yield per hectare compared to other feedstock (corn, cassava, and sweet sorghum). Sugarcane production in the Philippines is expected to increase to meet the requirements of the Biofuels Act. At present, the sugar industry can only supply 79% of the needs of the 5% ethanol blend. So the current area of 344,700 ha devoted to sugar cane would have to expand to meet ethanol demand. To produce 120,000 litres of ethanol daily, sugar cane plantations need 7,000 to 8,000 ha aside from the 10 to 20 ha for each ethanol-processing plant. The Sugar Regulatory Administration (SRA) has already identified 237,748 ha of new sugar fields, mostly in Mindanao, that can be tapped to produce fuel ethanol (Bulatlat 2007).

Additional ethanol feedstocks considered in the Philippines are sweet sorghum and cassava. A study completed by the Department of Agriculture- Bureau of Agricultural Research (DA-BAR) and International Society for Southeast Asian Agricultural Sciences (ISSAAS) in 2007 evaluated the potential of sweet sorghum for ethanol production in the Philippines. It concluded that the crop is comparable with other types of feedstock in terms of yield, bioethanol productivity, and cost. The ethanol yield of sweet sorghum per hectare is comparable with corn and cassava but lower than sugar cane. However, in terms of bioethanol productivity (the ethanol yield per ton of feedstock), sweet sorghum is the most productive with a production of 425 liters/ha (50 liters per ton from stalk and 375 liters per ton from grains). The study also states that sweet sorghum is cost- competitive compared to molasses, corn, and cassava; and also with sugar cane for cane-extracted alcohol, but not for grain-extracted alcohol.

Cassava has long been cultivated in the Philippines, planted predominantly in Mindanao (Bukidnon) and Eastern Visayas. The Bureau of Agricultural Statistics (BAS) reports very low yields, around 8 tonnes per ha per year. Tests done at the Leyte State University in Baybay,

Leyte, have shown, however, that yields of 35 tonnes per ha can be achieved with new varieties that can produce 4,900-6,545 liters per ha per year of ethanol.

If the equivalent of 20% of the Philippines' current starch and sugar crops production could be used for biofuels, fro example through a mix of increased grain yields and dedicated sugar cane plantations, it would yield about 0.33 hm^3 of ethanol or 0.16 Mt gasoline equivalent per annum. This volume would replace 4% of the Philippines' current gasoline consumption and 1.5% of its crude oil imports.

Biodiesel: Primary feedstock for biodiesel production in the Philippines is coconut oil. The Philippines is one of the largest producers of coconut oil in the world, netting some 1.5 million tonnes per year. About 20% of this production is used for domestic consumption while the balance of 80% is exported. Mindanao accounts for almost 60% of the economy's total coconut oil production. If 20% of the Philippines' coconut oil production were used for biofuels, it would yield about 0.31 Mt of biodiesel per year. This would be sufficient to displace 7% of the economy's 2005 diesel consumption and 3% of its crude oil imports.

Second-Generation Biofuels Potential

Ethanol: A biomass resource assessment study was conducted in 2000 by the University of the Philippines - Biomass Energy Laboratory in collaboration with the National Renewable Energy Laboratory of the U.S. Department of Energy (Biomass Atlas of the Philippines 2000). Six biomass resources were evaluated and mapped at an economy-wide, regional, provincial, and municipal level, in some cases. These resources include: rice hull, bagasse, coconut residues, animal manure, forestry wastes, and urban refuse. The assessment is based on statistical analysis of reported information, applying product-to-residue ratios. The study uses GIS and GPS technologies to generate a series of maps illustrating each biomass feedstock potential at different administrative levels, as shown in the example in Figure 27. Table 26 provides a summary of the lignocellulosic biomass resources in the Philippines, totaling about 17.7 Mt in 1999. These crop, logging, and coconut residues, along with sugar cane bagasse, would yield 5.4 hm^3 of ethanol or 2.6 Mt gasoline equivalent per annum. This volume would be sufficient to replace 63% of the economy's current gasoline consumption and 24% of its crude oil imports.
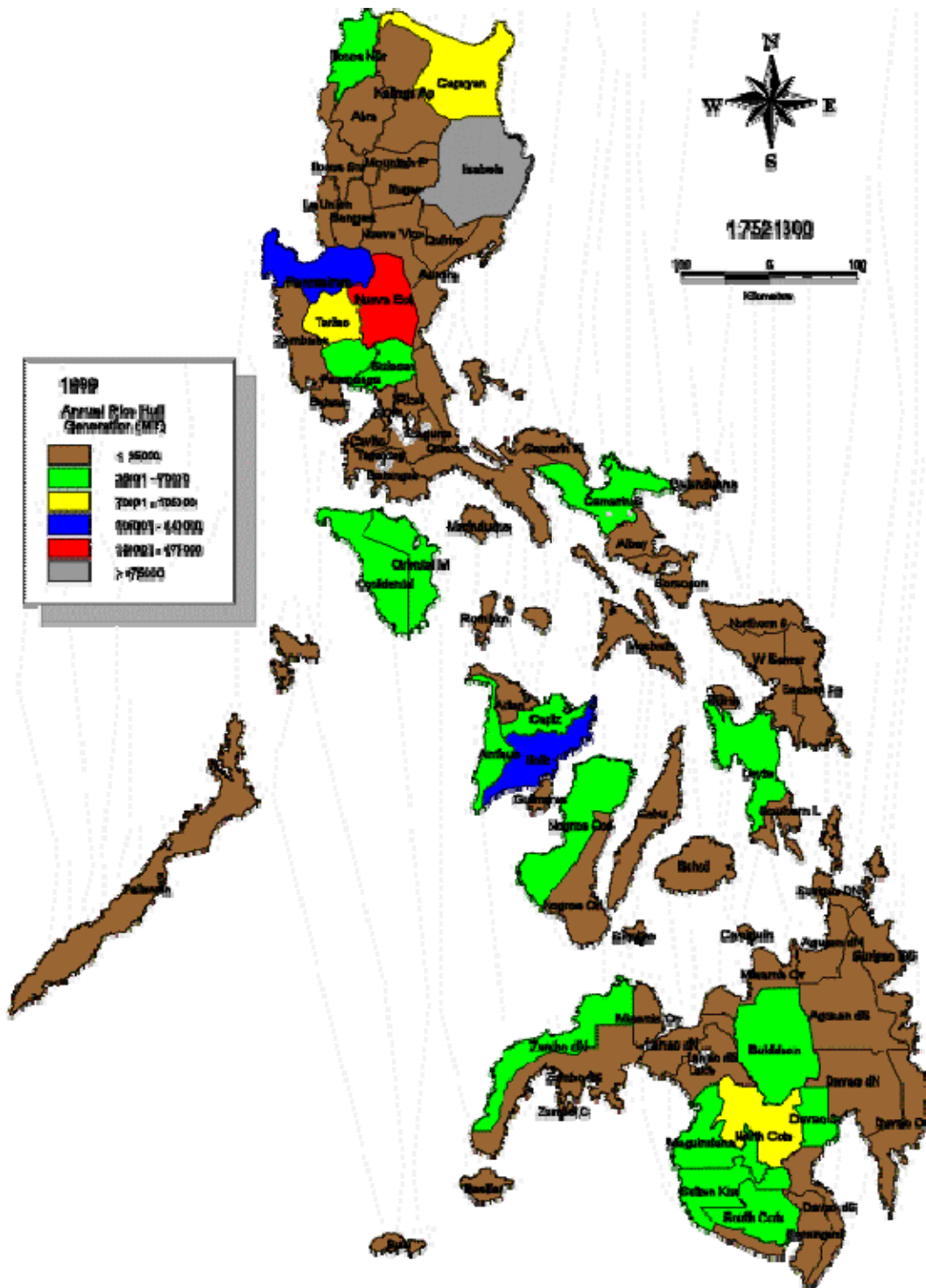
Source: Biomass Atlas of the Philippines, 2000

Figure 27. Annual Rice Hull Production by Province in the Philippines, 1999

Table 26. Lignocellulosic Biomass Resources in the Philippines, 2000

Biomass Resources	Annual Generation (tonnes)
Rice hull	2,357,325
Coconut shell	1,948,867
Coconut coir	3,031,570
Coconut husk	4,330,814
Bagasse	5,985,840
Logging residues*	75,000
Total	17,729,416

Source: Biomass Atlas of the Philippines, 2000; * Logging residues include damaged wood, tops and branches, stumps, abandoned logs, and butt trimmings. Total logging residues are estimated at 104,450 cubic meters or 75,000 tonnes (assuming 1 metric ton = 1.4 cubic meters).

Napier grass (*Pennisetum purpureum*) is one of the few dedicated energy crops being examined for biomass production in the Philippines. According to a study completed in 2001 (Samson et al.), productivity levels of 20 tonnes per ha could be achieved. If 100,000 ha were planted (representing a land area of about 4% of the maize acreage) about 2 Mt of biomass could be produced. This is about seven times the available biomass that could be supplied from sugar cane trash if harvesting occurs only after the final ratoon crop. A ratoon crop is the new cane that grows from the stubble left behind are harvesting. It enables farmers to get three or four more crop harvests before they have to replant.

Biodiesel: Potential biodiesel feedstock in the Philippines is jatropha. The Department of Science and Technology (DOST) has identified about 2 million ha of unproductive and idle land nationwide suitable for jatropha cultivation. If farmers plant in field boundaries and hedges, or practice intercropping, 5 million ha could be available, producing 25 Mt of biodiesel feedstock. This would be sufficient to displace the economy's current diesel consumption of 4.2 Mt per annum several times over. A total of 360 ha are planted with jatropha in the Philippines: 200 ha in General Santos; 27 ha in Camarines Sur; 120 ha in Fort Magsaysay, Nueva Ecija; 5 ha in

Dacong Cogon, Negros Occidental; and small plantations in Quezon Province (Philippines Department of Agriculture 2008).

Biomass Resource Assessment Capabilities

Geospatial technologies have been used by the National Mapping and Resource Information Authority (NAMRIA), an agency of the government under DENR. It is responsible for providing geospatial services and acting as the central mapping agency, depository, and distribution facility of natural resources data in the form of maps, charts, texts, and statistics.

Data Availability. The Biomass Energy Laboratory at University of the Philippines at Los Baños (UPLB) has been compiling biomass resource data since its establishment in 1997. The laboratory was established by the Department of Energy, Non-Conventional Energy Division, and biomass resource assessment is one of its major tasks. A list of other agencies providing data and expertise related to agriculture and forestry is provided below:

- The Department of Agriculture (DA) provides expertise and statistics on agricultural production and trade
- The Forest Management Bureau (FMB) of the Department of Environment and Natural Resources (DENR) provides forestry expertise and annual statistics (since 1990) by region and province; data is collected through sample field survey
- Department of Science and Technology (DOST) – Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD) and Forest Products Research and Development Institute (FPRDI)
- The National Statistics Office (NSO) provides an accurate estimate of the acreage of the major commodities at a municipal level; data is collected through sample paper surveys
- The Bureau of Agricultural Statistics (BAS) provides annual production data for major commodities; data is collected through sample paper surveys
- The National Food Authority (NFA) updates data on rice mills and their capacities
- The Sugar Regulatory Administration (SRA) reports sugar cane production and wastes data including operational sugar mills
- The United Coconut Association of the Philippines provides annual data on coconut production, coconut oil mills, and oil trade

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Russia

Economy-Wide Biofuels Resource Assessments

No comprehensive biomass resource assessment was identified during this survey. The results below are a compilation of government officials' speeches, foreign agencies' analyses, and economy-wide statistics.

First-Generation Biofuels Potential

Ethanol: Russia is one of the world's largest producer and exporter of grains, particularly wheat, barley, rye, oats, and corn. Russia produced about 82 Mt of grains in 2007 of which it exported 13.6 Mt (predominately wheat). An additional feedstock for ethanol production in Russia is sugar beet molasses. The economy produced about 29 Mt of sugar beet in 2007 and is among the top five producers in the world. If the equivalent of 20% of Russia's current starch and sugar crop production could be spared for biofuels production as crop yields improve over time, about 5 hm^3 of ethanol or 2.3 Mt gasoline equivalent could be refined per annum, enough to replace 9% of Russia's current gasoline consumption.

Biodiesel: Russia is also a major producer and exporter (mostly to the EU) of vegetable oils from sunflower, rapeseed, and soybean. In 2007, Russia produced about 2.4 Mt of vegetable oils, predominately sunflower, and exported 450,000 tonnes (USDA 2008). If 20% of this vegetable oil production were devoted to biofuels, it would yield 0.5 Mt of biodiesel yearly. This could replace 3.7% of the economy's current diesel consumption.

Second-Generation Biofuels Potential

Considering the scale of Russia's agricultural and forestry industries, a large amount of waste material exists for ethanol production including residues from crop production, logging, wood processing, and pulp and paper mill industries. The Russian Biofuels Association reports that about 100 Mt of crop and wood residues are available in Russia annually (Ablaev 2008), which would yield about 30 hm^3 of ethanol or 14.4 Mt gasoline equivalent. This volume would be sufficient to replace 55% of Russia's current gasoline consumption.

During a televised conversation with Russians in October 2007, Prime Minister Vladimir Putin mentioned that for the production of bioenergy, Russia would use its land not suitable for the production of food crops, that is the vast taiga and tundra, where a range of productive herbaceous and woody biomass crops can be grown (Check Biotech 2007). The International Institute for Applied Systems Analysis (IIASA) assessed the land suitable for energy crops production (miscanthus, willow and poplar species), outside forest, urban areas and land highly suitable for cereals in Russia. However, the analysis doesn't quantity these resources (Fischer et al. 2005).

Biomass Resource Assessment Capabilities

Russia has very good capabilities – GIS/RS, significant scientific and engineering staff capacity in the forestry and agricultural sector, and extensive statistical information to conduct comprehensive biomass resource assessments.

Geospatial Capabilities. The Russian Academy of Sciences, in collaboration with the International Institute for Applied Systems Analysis (IIASA), completed two geospatial products containing a series of maps and tables on forestry and agricultural resources: Russian Forestry Analysis and Land Resources of Russia. Figure 28 illustrates two examples of these products. More information about these products can be found at
http://www.iiasa.ac.at/Research/FOR/.

The Space Research Institute (SRI) of the Russian Academy of Science provides expertise in remote sensing. In collaboration with the Center for Forest Ecology and Productivity and a number of other leading research institutions, the SRI has a number of methodological and technological developments aimed at providing reliable and regularly updated information on the status and dynamics of Russian forests (FAO 2007). RS and GIS have been used by several leading Russian research institutions under the leadership of the Global Forest Watch, and in collaboration with the World Resource Institute, to develop an Atlas of Russia's Intact Forest Landscapes. More information about the atlas can be found at
http://archive.wri.org/publication_detail.cfm?pubid=3717.

The Federal Forestry Agency has also been using RS for forest monitoring.

Dominant Crops

No feature
beet growing
flax growing
forage production
fruit growing
grain crops (wheat)
improved hay-and grasslands
perennial grasses
potatoes growing
rice growing
soy-bean
subsidiary farming
subtropical fruit crops
sunflowers
tobacco growing
vegetable growing
viticulture
Water & Glaciers

Dominant Forest Species

pine
spruce
fir
cedar
larch
aspen
birch
other deciduous
shrub
non-forest

Source: IIASA/RAS, 2002

Figure 28. Maps of Crops and Forest Resources in Russia

Modeling. Moscow State Forest University (MSFU) is a major educational and scientific center related to the forest industry in Russia. Researchers at the university, in collaboration with IIASA, have developed models to simulate forest ecosystem dynamics and to assess biological productivity of forests. These models could be used in different ecological applications, in forest inventory, and forest management as reference information on the growth and productivity of Russia's forests.

Data Availability. Leading agencies for agricultural and forestry statistics are the Ministry of Agriculture, Federal Forestry Statistics and the National Statistics Institute. Crop production,

acreages, and yield are provided annually at an economy-wide level; and forestry statistics are available by region and province.

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Singapore

Singapore is a highly urbanized and industrialized economy with a land area of 697 sq km and a population of 4.2 million. The biomass resources available in Singapore are municipal wastes, including wood waste, horticultural waste, food waste, and waste paper. These wastes are used to generate power in waste-to-energy or cogeneration plants. Singapore generated about 5.6 Mt of waste in 2007 (its composition is illustrated in Table 27).

Biodiesel feedstock available domestically is waste oil, including recycled and grease trap oils from restaurants and food-processing industries. However, no estimates of their quantity were available at the time this survey took place.

Singapore is trying to position itself as a major biofuels processing and trading hub in Asia, rather than a feedstock producer. The economy has a well-established trading market and infrastructure already in place, and its shipping terminals would allow transportation of biofuels to many places throughout the world. It also has proximity to feedstock suppliers (such as Malaysia and Indonesia for palm oil) and emerging high-demand centers (India and China for example).

Table 27. Municipal Waste Generation in Singapore, 2007

Waste Stream	Amt of Waste Generated (mil tons/yr)	Amt of Waste Recycled (mil tons/yr)	Recycling Rate (%)
Used Slag	0.53	0.52	99
Construction Debris	0.78	0.76	98
Ferrous Metal	0.74	0.67	91
Scrap Tyres	0.03	0.02	96
Non-ferrous Metal	0.09	0.08	82
Wood	0.25	0.13	52
Paper/Cardboard	1.20	0.62	51
Horticultural Waste	0.22	0.09	41
Plastics	0.66	0.08	11
Glass	0.07	0.01	9
Food	0.56	0.05	9
Textiles	0.11	0.01	7
Others	0.25	0.01	6
Sludge	0.12	0.00	0
Total	**5.60**	**3.03**	**54**

Source: MEWR, 2008

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Chinese Taipei

Economy-Wide Biofuels Resource Assessments

First-Generation Biofuels Potential

Ethanol: Crops in Chinese Taipei have the largest share of total agricultural production, about 45.81%, followed by livestock (31.33%), fishery (22.72%), and forestry (0.14%). Rice is the most valuable crop in the economy, with more than 1.56 Mt produced in 2006 from 263,000 ha of land. Sweet potato is next on the list with about 235,000 tonnes. The production of corn (83,000 tonnes), grain sorghum (5,000 tonnes), wheat, and cassava is relatively small. Chinese Taipei imports large quantities of wheat, corn, and cassava for domestic food consumption and it exports very small amount of the crops it produces.

Chinese Taipei was formerly one of the world's leading sugar exporters. In the 1950s and 1960s, more than 100,000 hectares of land were dedicated to sugar cane production, with more than 1 Mt of sugar produced annually. However, increasing labor costs and steadily declining prices during the following decades dealt a heavy blow to the industry. By 2006, only 10,390 hectares were under cultivation (GIO 2008).

If the equivalent of 20% of Chinese Taipei's current starch crops production were devoted to biofuels owing to increased yields over time, about 0.08 hm^3 of ethanol (39,000 tonnes gasoline equivalent). This volume would only be enough to replace 0.5% of Chinese Taipei's current gasoline consumption and 0.1% of its crude oil imports.

Biodiesel: Chinese Taipei produces small amount of vegetable oils (soybeans, peanuts, and sesame, in particular), thus it relies on imports to satisfy domestic consumption. A study on biodiesel potential in Chinese Taipei (Tsai 2007) estimated the amount of vegetable oil, used cooking oil, and animal fat available in 2000 at about 608,000 tonnes: vegetable oil (mostly soybean) – 419,000 tonnes, used cooking oil – 140,000 tonnes, and animal fat (lard) – 49,200 tonnes. Used cooking oil will be the main feedstock for the planned biodiesel production facilities in Chinese Taipei.

If 20% of Chinese Taipei's current soybean oil production, as well as all waste oils and fats, were refined into biofuels, it would yield about 0.27 Mt of biodiesel per annum. This amount would replace 7.3% of the economy's current diesel consumption and 0.5% of its crude oil imports.

Second-Generation Biofuels Potential

Lignocellulosic biomass available in Chinese Taipei includes crop, forest, and wood-processing residues. A study by Tsai et al. in 2004 assessed the crop residues (rice straw, rice husk, corn con, corn stover, and groundnut shells) available during 1990-2000. The study estimated that there were about 1.9 Mt of crop residues available in 2000 (mostly rice straw). This amount would yield about 0.57 hm^3 of ethanol or 0.28 Mt gasoline equivalent – enough to displace just 3.5% of the economy's current gasoline consumption and 0.5% of its crude oil imports.

No estimates on logging or wood-processing residues were identified during this survey. According to the Forestry Bureau, forestland occupied about 2 million ha, about 59% of the total island area (3.6 million ha). The total forest volume of the island is 359 million m^3. The average forest volume per hectare is 287 m^3 for conifers, 119 m^3 for hardwoods, and 254 m^3 for mixed forests.

Biomass Resource Assessment Capabilities

Although no detailed biomass resource assessment was found for Chinese Taipei, the economy appears to have good capabilities to conduct this type of analyses.

Leading agencies providing expertise in agriculture and forestry are the Agricultural Research Institute and Forest Research Institute. Several universities also have been involved in analyzing biomass resources. They include:

- Department of Forestry, National Chung-Hsing University, Taichung
- School of Forestry and Resource Conservation, National Taiwan University, Taipei
- Department of Environmental Engineering and Science, Chia Nan University of Pharmacy and Science, Tainan

Geospatial Techniques. The Center for Space and Remote Sensing Research at the National Central University provides expertise in geospatial technologies. Researchers at the Department of Resource and Environment Studies-Leader University have used GIS to estimate and map areas suitable for growing sugar cane. GIS is also used by the Forestry Bureau to map forest resources, soils, land use, and other parameters for their analysis, as illustrated in Figure 29.
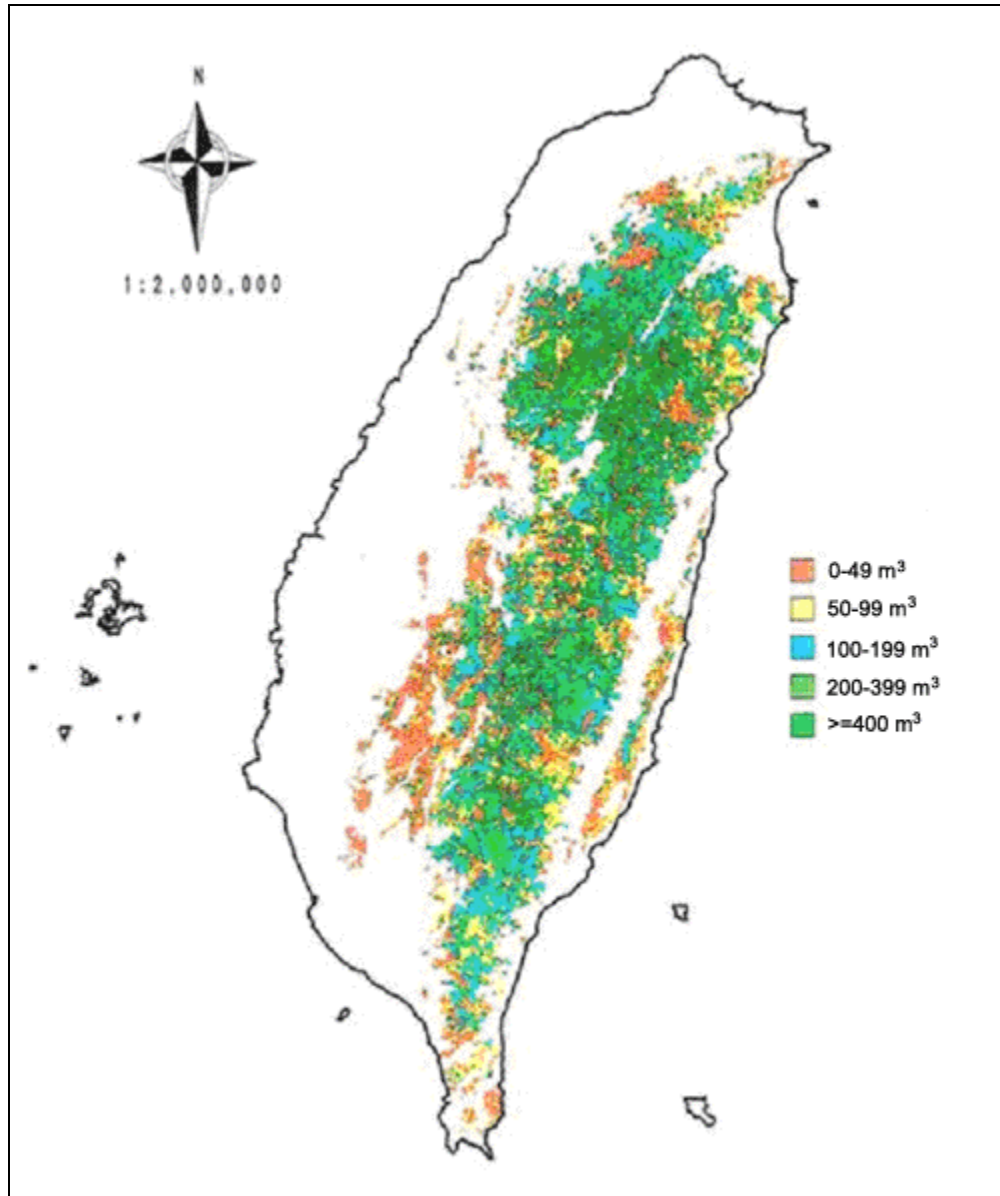
Source: Forestry Bureau, 2005

Figure 29. Map of Timber Volume of National Forest in Chinese Taipei

Data Availability. Chinese Taipei collects agricultural and forestry statistics on a regular basis. The Council of Agriculture, Executive Yuan-Agriculture and Food Agency (AFA) provides annual and monthly statistics on area planted, area harvested, production, and yield per hectare for all crops grown in Chinese Taipei since 1946, at an economy-wide and county level. Another Council of Agriculture, Executive Yuan–the Forestry Bureau provides statistics on forest area and type by county, as well as natural and plantation forest acres and volumes by Forest District Office. Both agencies collect data via sample paper and field surveys.

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Thailand

Economy-Wide Biofuels Resource Assessments

First-Generation Biofuels Potential

Ethanol: Almost 90% of ethanol currently produced in Thailand is from sugar cane molasses, with the remaining 10% from cassava; however, the proportion is expected to shift over time in favor of cassava. Other crops suitable for ethanol production in Thailand include rice and corn. A study by the Metal and Materials Technology Center (MTEC) estimated that, in 2002, there were about 3 Mt of molasses and 9 Mt of cassava remaining after domestic consumption and export. The study estimates that this amount can produce about 2 million liters of ethanol, enough to supply the current production of gasohol (blend of 10% ethanol with gasoline). Thailand produces about 20 Mt of cassava per year, which translates into roughly 3 million liters of ethanol. If 20% of Thailand's current starch and sugar crops production could be used to produce ethanol, it would yield 2.7 hm^3 or 1.3 Mt gasoline equivalent per annum – enough to replace 25% of the economy's current gasoline consumption and 3% of its crude oil imports.

Biodiesel: In Thailand, palm oil is the main raw material used for biodiesel. The economy ranks third in the world after Indonesia and Malaysia for total crude palm oil output with about 1 Mt a year (about 800,000 tonnes goes to the food sector). About 420,000 tonnes are needed to make B2, and at least 600,000 tonnes are required to make B5. The government plans to expand the palm oil cultivation area by 2.5 million Rai (1 hectare = 6.25 Rai) during the next five years. Thailand also grows coconut, soybeans, and a small amount of sunflower. If 20% of Thailand's current vegetable oil production could be spared for biodiesel production, it would yield about 0.22 Mt per annum, replacing 1.7% of current diesel consumption and 0.5% of crude oil imports.

Second-Generation Biofuels Potential

Ethanol: A study by the Department of Alternative Energy Development and Efficiency (DEDE) estimated the amount of agricultural residues and their energy potential in crop year 2002-2003. This is a nationwide study with no finer geography, and it uses crop-to-residue factors to assess the available crop residues. Table 28 illustrates the results of this analysis. About 46 Mt of crop residues, sugar cane bagasse, oil-palm and coconut residues were available in Thailand during

the year studied. Another study, conducted by the Energy Policy and Planning Office of the Ministry of Energy and Black & Veatch Corporation (Pletka 2001), estimated the amount of available unused wood residues at 1.8 Mt per year. The study considered sawdust and other residues from the wood-processing industry. The total amount of crop and wood residues in Thailand comes to about 47.8 Mt, which would yield about 14 hm^3 of ethanol or 6.9 Mt gasoline equivalent – enough to replace 130% of current gasoline consumption and 17% of crude oil imports.

Table 28. Agricultural Residues in Thailand, 2002-2003

Major Crops	Crop [1] Output (ktons)	Types of Residue	Conversion factor*			Residue Amount (10^6 tons)	Total Energy (10^6 GJ)	Crude Oil Equivalent (10^6 toe)
			Residue Ratio	Surplus Available Factor	Heat Content (MJ/kg)			
Sugar Cane	74,258	-Bagasse	0.29 [2]	0.01 [2]	8.31	0.215	1.79	0.04
		-Top & Trashes	0.30 [2]	0.98 [2]	16.42	21.83	358.45	8.48
Paddy	26,057	-Husk	0.23 [7]	0.45 [2]	15.56	2.70	42.01	0.99
		-Stalk	0.45 [2]	0.78 [2]	15.51	9.15	141.92	3.36
Maize	4,230	-Corn Cob	0.27 [2]	0.58 [2]	16.63	0.66	10.98	0.26
Cassava	16,868	-Stalk	0.09 [3]	0.70 [3]	13.38	1.06	14.18	0.34
		-Rhizome	0.49 [3]	0.98 [3]	10.61	8.10	85.94	2.03
Palm Oil	4,001	-Bunches	0.43 [4]	0.58 [4]	19.41	1.00	19.41	0.46
		-Fiber	0.15 [4]	0.13 [4]	19.94	0.078	1.56	0.04
		-Kernel Shell	0.05 [4]	0.04 [4]	21.13	0.008	0.17	0.004
Coconut	1,418	-Husk	0.362 [5]	0.59 [5]	16.23	0.303	4.92	0.116
		-Shell	0.160 [5]	0.38 [5]	17.93	0.086	1.55	0.037
		-Bunches	0.049 [5]	0.84 [5]	15.40	0.058	0.90	0.021
Soybean	260	-Stalk, leave,shell	2.663 [5]	0.76 [6]	19.44	0.526	10.23	0.24
Total Residues (Million tons)						45.77		
Total Energy (Million GJ)							694.01	
Total Oil Equivalent (Million toe)								16.43

Source:(1) Center for Agricultural Information, Agricultural Statistics of Thailand Crop Year, 2002/03

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Source: DEDE, 2004

Biodiesel: For biodiesel production, Thailand considers jatropha as an alternative feedstock, and several trial plantations have been developed in the past few years.

Regional and Local Biomass Resource Potential

Researchers at the King Mongkut's University of Technology Thonburi have developed an Atlas of Agricultural Residues in Thailand (Chanthunyagarn et al. 2004). The atlas uses GIS to illustrate the geographic distribution of residues including rice husk, sugar cane bagasse, oil-palm residues, and forest residues. It also provides data related to land use, crop production, water resources, soils, infrastructure, and other related information. Figure 30 shows crops and crop residues in one of Thailand's provinces as an example.
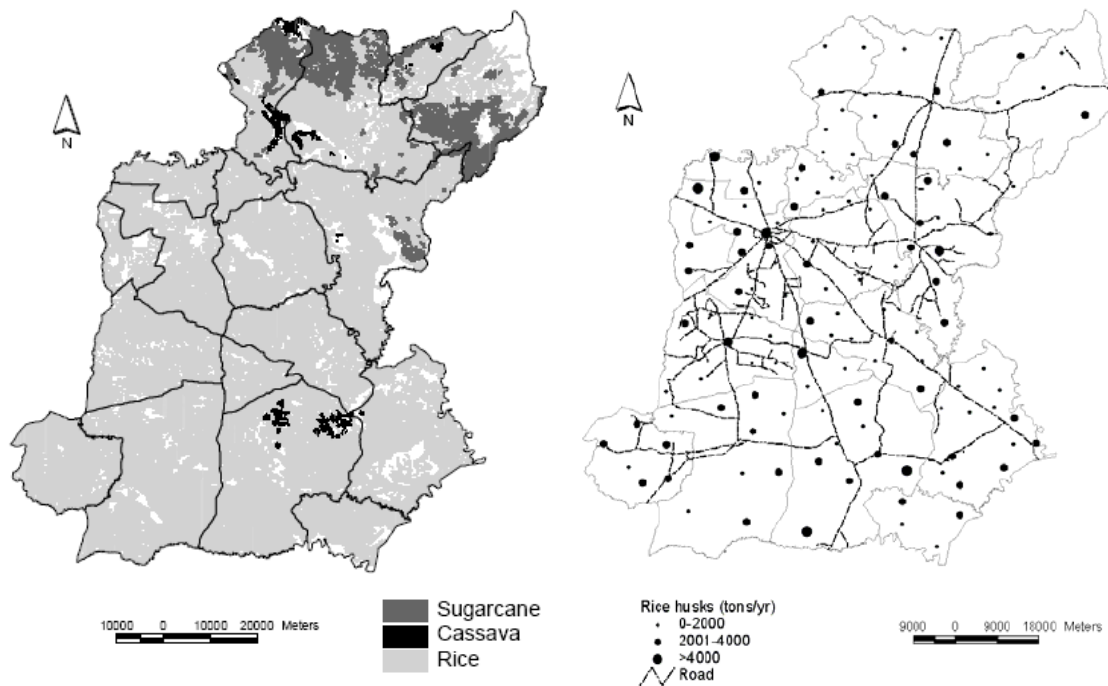
Source: Chanthunyagarn, S. et al., 2004

Figure 30. Crops and Crop Residues in Roi-Et Province, Thailand

Biomass Resource Assessment Capabilities

Thailand appears to have very good biomass resource assessment capabilities including agricultural and forestry expertise, and use of geospatial technologies, modeling, and systematically collected statistics.

Leading agencies providing agricultural and forestry expertise include the Department of Agriculture and Royal Forestry Department. Several universities also have been involved in assessing biomass resources such as the Faculty of Forestry at the Kasetsart University, Department of Mechanical Engineering and Department of Industrial Biotechnology at the Prince of Songkla University, and Joint Graduate School of Energy and Environment at King Mongkut's University of Technology Thonburi. As with other economies, a university or college with relevant programs would offer expertise in the field.

Geospatial Capabilities. In addition to the example illustrated earlier, GIS and RS have been used by the Department of Agriculture to assist in the differentiation of major agricultural crops, estimation of crop acreage, and yield forecasting. Moreover, remotely sensed data have been effectively used in assessment of damage on crops resulting from severe weather such as drought and flood. The Royal Forest Department uses RS and GIS in combination with sample ground surveys to assess existing forest land, and identify shifting cultivation and watershed areas, as well as areas of cut forest.

Modeling. Researchers at the Department of Mechanical Engineering, Prince of Songkla University, in collaboration with Kyoto University have developed mathematical models to determine the fuel cost and optimum capacity of rubber wood-fired power plants based on fuel availability. Further, the models were integrated with GIS to locate the appropriate sites and sizes of the power plants (Krukanont and Prasertsan 2004). The Department of Agriculture and the Royal Forest Department also have been using advanced modeling techniques to assess and forecast crop and forest productivity.

Data Availability. The Office of Agricultural Economics (OAE) is the prime office responsible for collection and dissemination of agricultural statistics. It collects data on crop area planted, harvested, production, and yield annually at an economy-wide and provincial level. OAE uses several methods for data collection including sample paper and ground surveys, face-to-face interviews, statistical models, and geospatial techniques. Various methods for data collection are also used by the Royal Forest Department, which provides forestry statistics at a national, regional, and provincial level annually.

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United States

Economy-Wide Biofuels Resource Assessments

First-Generation Biofuels Potential

Ethanol: Today, nearly all ethanol in the United States is made from corn grain. Production grew 24% in just one year, from 268 Mt in 2006 to 332 Mt in 2007. About 20% of U.S. corn went into ethanol production in 2007, and the United States Department of Agriculture (USDA) has projected that in 2008, the total use of corn for ethanol will approach 30% of the U.S. crop. About 29 million ha were planted with corn in 2006, which increased in 2007 to 35 million ha. The United States is not only the world's top corn producer, but also the top exporter. On average, about 20% of U.S. corn is exported. During the government's fiscal year 2007 (October 2006 – September 2007), the United States exported about 64 Mt of corn. Ethanol also provides a rapidly growing environment for other grains, such as sorghum. Ethanol production consumed approximately 26% of the nation's sorghum crop in 2006 (10 Mt).

The USDA completed a study that investigates the economic feasibility of producing ethanol from sugar feedstocks in the United States (USDA 2006). These sugar feedstocks include sugar cane juice, sugar beet juice, cane or beet molasses, raw sugar, and refined sugar. The study concluded that it is economically feasible to make ethanol from molasses, considering the lower production cost in comparison to ethanol from corn. Producing ethanol from the remaining sugar feedstocks in the United States is not cost competitive with corn – they are more than twice the production cost of converting corn into ethanol.

If 20% of the United States' current starch and sugar crops production were used for biofuels, they would yield about 30 hm^3 of ethanol (14 Mt gasoline equivalent). This volume would replace about 4% of current gasoline consumption and 3% of crude oil imports. In fact, such a volume is close to actual ethanol production in 2007, which exceeded 26 hm^3. The Energy Independence and Security Act (EISA) of 2007 will require about a five-fold increase in biofuels production to 132 hm^3 by 2022, of which it is anticipated that up to 56 hm^3 would come from the starch component of corn and other grains. If such an expansion of corn production from

ethanol were achieved, it would displace 28 Mt of gasoline equivalent, amounting to 7% of gasoline demand and 5% of crude oil imports in the economy in the year 2005.

Biodiesel: Approximately 90% of biodiesel produced in the United States is made from soybean oil. Some experts estimate that if the biodiesel industry keeps its current momentum, more than 10% of U.S. soybean oil could be used for biodiesel production in the next few years. The United States is the world leader in soybean production with about 10 Mt of oil produced in 2007 (USDA 2008); about 1 Mt was exported.

A study by the National Renewable Energy Laboratory (NREL) estimated the amount of fats and waste oils available in the United States per year (Tyson et al 2004). Table 29 illustrates the results of this analysis.

Table 29. Fat and Waste Oil Supplies in the United States, 2001

Fats and Oils	Tonnes/yr
Edible tallow	211,000
Lard	39,000
Inedible tallow & greases	1,286,000
Other fats & oils	181,000
Poultry fat	100,000
Fish oils	12,700
Yellow grease	184,000
Trap grease	1,727,000
Total	3,740,700

Source: Tyson et al, 2004

If 20% of the United States' current vegetable oil production were used for biofuels, it would amount to some 1.98 Mt per year. Adding the 3.74 Mt of waste oils and fats that might be collected each year, a total of 5.72 Mt of biodiesel could be produced per annum. This volume would displace 4% of 2005 U.S. diesel consumption and 1% of 2005 U.S. crude oil imports.

Second-Generation Biofuels Potential

There are many resource assessment products of lignocellulosic biomass in the United States serving different purposes (theoretical, technical and economic assessments) and at various geographic scales (nationwide, regional, state, and local). A comprehensive list of these assessments is provided in Table 30 (at the end of this section) and the most recent nationwide efforts are outlined below.

Theoretical Assessment. An economy-wide biomass assessment completed by the Oak Ridge National Laboratory (ORNL) and the United States Department of Agriculture (USDA) is referred to as the "Billion Ton Study" (Perlack et al. 2005). This report examined whether the land resources of the United States are capable of producing a sustainable supply of biomass sufficient to displace 30% or more of the economy's petroleum consumption – the goal set by the Biomass R&D Technical Advisory Committee (a panel established by Congress) in its vision for biomass technologies. Accomplishing this goal would require approximately 1,000 million dry tons of biomass feedstock a year. The study found that this goal could be met with resources from forest and agricultural lands (Figure 31). Forest resources – fuel wood harvested from forests, residues from wood- processing mills and pulp and paper mills, urban wood residues including construction and demolition debris, logging residues, and forest fuel treatment materials – could provide 367 Mt of biomass. Agricultural resources – residues from major crops, perennial crops, grains, and processing residues – could provide 997 Mt. Excluding grains, the second-generation cellulosic potential from perennial crops, farm and forest residues would amount to some 1,277 Mt. With a process yielding 300 liters per tonne, this would convert to 383 hm^3 of ethanol or 185 Mt of gasoline equivalent, an amount sufficient to displace 49% of 2005 U.S. gasoline consumption or 34% of 2005 U.S. crude oil imports.

These estimates of future biomass potential are based on assumptions of high crop yield increase with changes in land use, as well as agricultural and forestry practices that could significantly increase the biomass resources available for energy conversion. The study is based on regional USDA data and contains tabular summaries of the potential future sustainable biomass resources that could be supplied from agricultural and forest lands. In 2008, ORNL is pursuing the second phase of this study, updating assumptions and data where needed, as well as looking at finer regional breakouts.
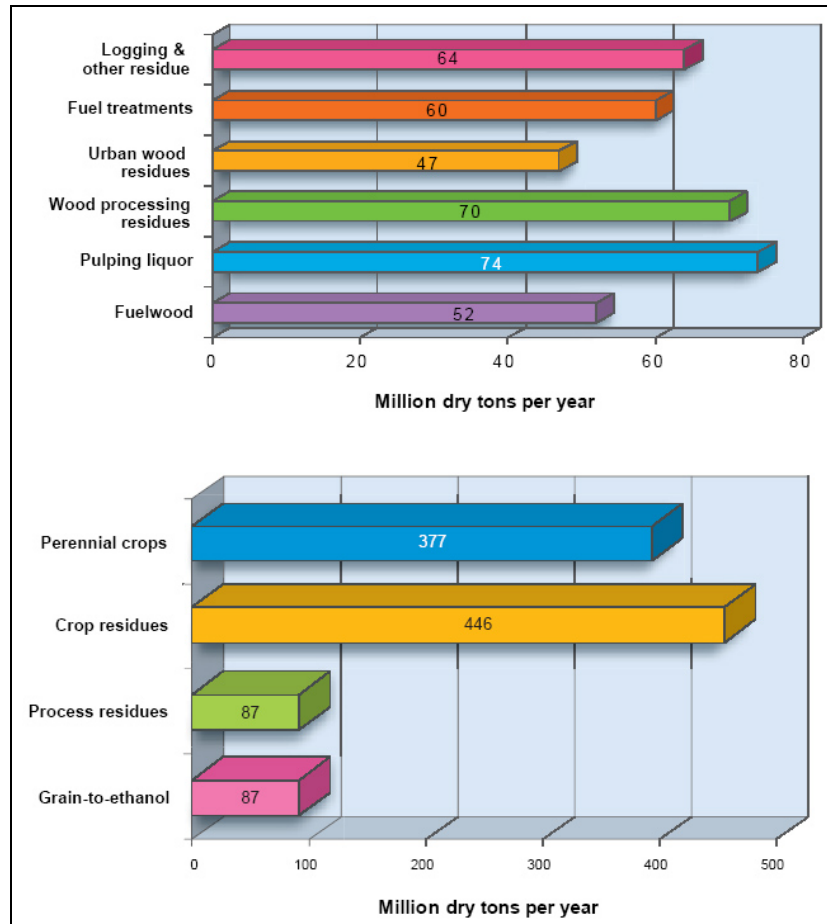
Source: Perlack et al., 2005

Figure 31. Potential Forest and Agricultural Resources in the United States

Technical Assessment. While the "high crop yield increase with land use change" scenario of the "Billion Ton Study" illustrates future potential biomass resources, a baseline summary of the same study illustrates current feedstock availability. Resources catalogued in the baseline include 113 Mt of agricultural residues, 136 Mt of forest residues, and 60 Mt of waste products. The baseline second-generation biofuel potential is thus estimated to total some 309 Mt, which converts to 93 hm^3 of ethanol or 45 Mt of gasoline equivalent. This would be sufficient to displace about 12% of 2005 gasoline consumption or 8% of net 2005 crude oil imports in the United States.

A study developed by the National Renewable Energy Laboratory (NREL) also focuses on currently available biomass (Milbrandt 2005). The study estimates resources at a county level and it illustrates their geographic distribution in a series of maps for each resource type.

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Analyzed feedstocks include crop residues (from 18 crops), forest residues, primary mill residues, secondary mill residues (wood scraps and sawdust from woodworking shops), urban wood (MSW wood, utility tree trimming, and construction/demolition wood), and methane emissions from manure management, landfills, and domestic wastewater treatment. It also estimates dedicated energy crops (switchgrass) that could be grown on Conservation Reserve Program (CRP) lands. The study uses GIS to collect, manipulate, analyze, and visualize the resource information, which is based on county-level statistics reported by the USDA, EPA, and the Census Bureau in 2002. The results of this analysis show that an estimated 324 Mt of lignocellulosic biomass (crop and wood residues) could be collected in the United States annually, similarly to the results of the baseline scenario of the "Billion Ton Study". Assuming a conversion factor of 300 liters per tonne, this could provide 97 hm^3 of ethanol or 47 Mt gasoline equivalent, enough to displace 12.5% of gasoline use or 8.7% of crude oil imports in 2005. Figure 32 shows the amounts of these resources by type, while Figure 33 illustrates their distribution by county. NREL is in the process of updating this analysis with more recent data (2006-2007 statistics) and presenting it at a finer geographic resolution (1km or 250m).
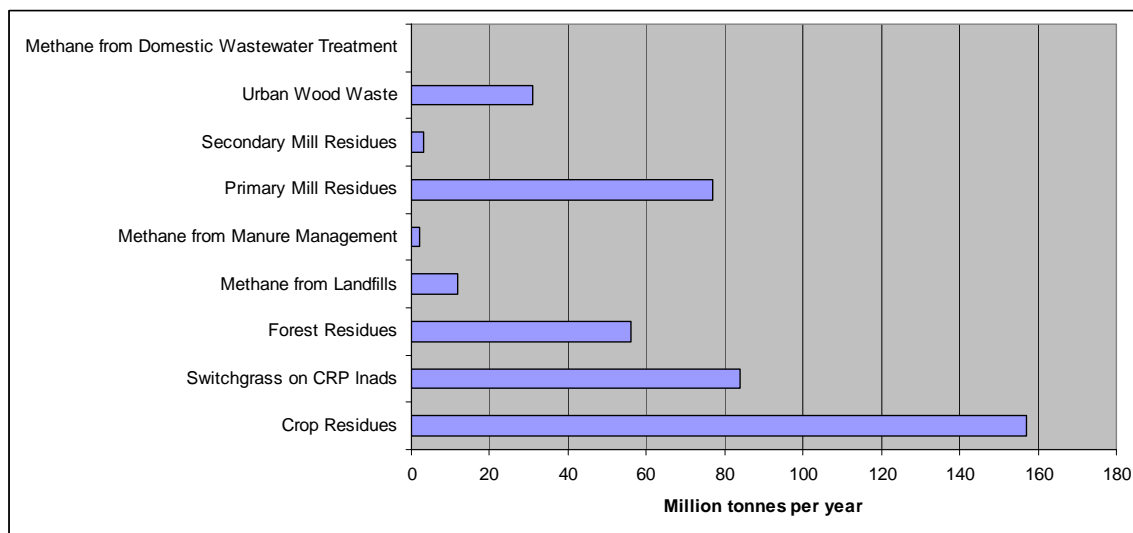
Source: Milbrandt, 2005; Methane emissions are shown in tonnes per year. Crop, forest and other solid residues are shown in dry tonnes per year.

Figure 32. Technically Available Biomass Resources in the United States

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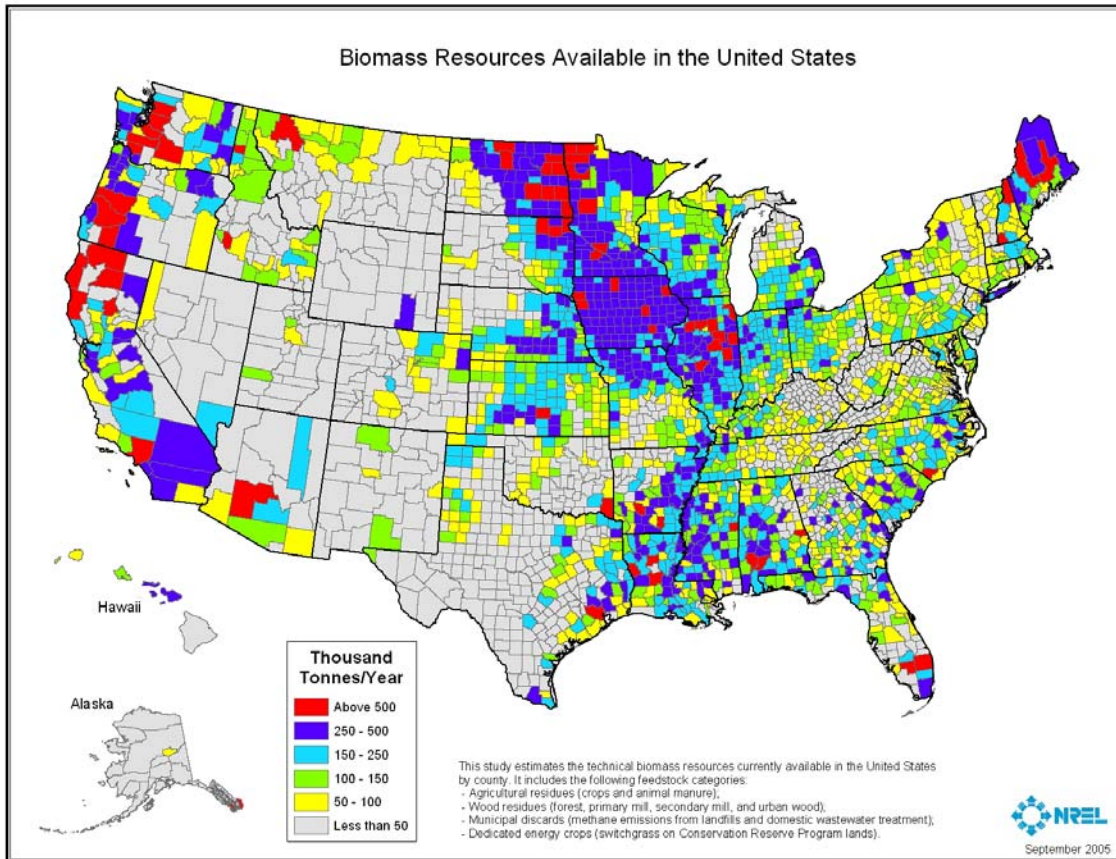
Figure 33. Biomass Resources Available in the United States by County

Economic Assessment. An economic biomass resource assessment was completed by ORNL in 1999 and updated in 2000 (Walsh et al. 2000). The assessment contains economy-wide and state-level quantities for agricultural residues (corn and wheat only), forestry residues, primary mill wastes, and urban residues that are available at specific delivered price. These supply curves are in units of US$/dry ton[6] at farm-gate or mill-gate. The estimates are derived from simulation models and analysis of various published data sources. The study found that 322 million dry tons of biomass is available annually at prices below US$50/dry ton, and about 105 million dry tons are available at prices below US$30/dry ton. More resources are available at a higher price due to larger collection radius leading to higher transportation costs.

Dedicated Energy Crops. ORNL has done extensive research on dedicated energy crops, including short-rotation woody crops (SRWC) such as hybrid poplars and hybrid willows, and

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[6] Short ton, equal to 907.18 kg

herbaceous crops (switchgrass). It developed a County-Level Energy Crop (ORECCL) database in 1996, which is in Excel spreadsheet format. However, it is no longer available from the ORNL's Web site, but is being updated (there is no defined date for the new release). The database presents a median, optimistic and pessimistic yield value for each switchgrass or SRWC production region. This yield value represents the average annual yield over the lifetime of the energy crop. Lifetime is the number of years between original planting and final harvest. For hybrid poplar, the lifetime is the same as the rotation length for the stand that will be replanted after each harvest. For willow, the lifetime is presumed to be 22 years, with the first harvest occurring at the end of the fourth growing season and a harvest occurring every three years thereafter. For switchgrass, the lifetime is assumed to be 10 years. Because it takes two years for a switchgrass stand to reach mature annual production and there is no harvest in the first year of the stand, the average annual yield of switchgrass is less than that of the stand at full annual production. Figure 34 shows potential switchgrass production on Conservation Reserve Program (CRP) lands (as of July 2003) using median yield value from ORNL's energy crop database.

The economic assessment mentioned earlier (Walsh et al. 2000) estimates the quantities of energy crops that could potentially be produced at various prices. About 188 and 66 million short tons could be available at prices below US$50/dry ton and US$40/dry ton respectively.

Due to large uncertainties associated with energy crops production potential in the United States, these estimates are not considered in this study.

Regional and Local Biofuels Resource Assessments

Many other biomass resource assessments have been completed by individual states, such as California, Colorado, Florida, Georgia, Hawaii, Ohio, South Carolina, Washington, etc. There are also regional biomass resource assessments, such as the ones completed by the Northeast Regional Biomass Program (NRBP) for several states in the Northeast region, and the Western Governors Association (WGA) studies of biomass resource potential for both power and biofuels generation in 18 member states. Most of these assessments are based on statistical analysis of reported information and many of them use GIS to illustrate the resource's geographic distribution. Additionally, there are assessments focused on a particular feedstock with varied spatial coverage (national, regional, state, county, or city). For example, an urban wood waste assessment was completed for 30 metropolitan areas using phone interviews (Appel

Consultants Inc. 1998). A detailed inventory of the main resource assessment products in the United States is provided in Table 30. The inventory excludes numerous articles published in academic and professional journals such as *Biomass & Bioenergy, Biomass Magazine, Ethanol Producer,* and *Biodiesel Producer.*
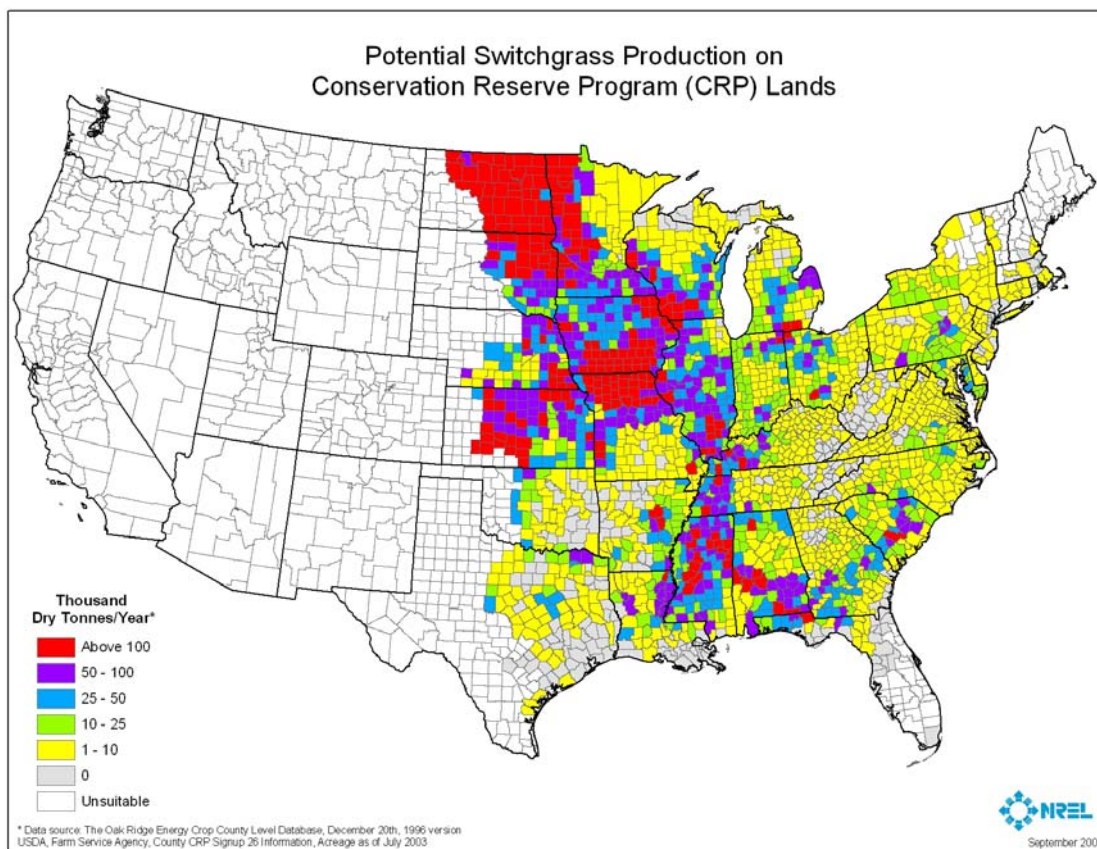
Figure 34. Potential Switchgrass Production on CRP Lands

Biomass Resource Assessment Capabilities

The United States has very strong capabilities in assessing biomass resources as illustrated above. The economy has used the full range of resource assessment methods: geospatial technologies, modeling, and survey techniques. In addition, spatial and temporal data are readily available to support future work in the area.

Leading agencies in biomass resource assessments include USDA and USDOE (ORNL and NREL, in particular). Several universities with agricultural programs are also capable of conducting resource assessments and have been involved in regional, statewide, or small-scale studies. These include University of California-Davis, Kansas State University, University of

Minnesota, Ohio State University, Washington State, and others. In addition, a few private companies, such as Antares Group and McNeil Technologies, have been historically involved in biomass assessments.

USDA is the main source of agricultural and forestry statistics and analytical products. An abundance of information is available through several agencies, particularly the National Agricultural Statistics Service (NASS) and Forest Service (FS). NASS uses remote sensing for crop-condition monitoring, particularly in assessing the effects of severe weather on crop production. It uses a biweekly composite of the normalized difference vegetation index (NDVI) from the advanced very high resolution radiometer (AVHRR) on polar orbiting weather satellites operated by the National Oceanic and Atmospheric Administration (NOAA). The EROS Data Center of the U.S. Geological Survey archives the AVHRR data and creates a biweekly composite of the NDVI. NASS procures the biweekly composites, compares the images over time, and links them to the Weekly Crop and Weather Report issued weekly by NASS and the Joint Agricultural Weather Facility (JAWF) of USDA and NOAA. AVHRR NDVI data have one square kilometer resolution (about 250 acres). This resolution can provide substantial detail when viewing a large area such as a state, region, or country, but it can't routinely provide crop-specific information because of varying crops in the same region, field-size limitations, and alternating crop and fallow field patterns. Occasionally, remote sensing is used by NASS for estimating crop yield. However, in most cases, NASS uses two survey techniques for crop yield forecasting and estimation: the frame-based sample surveys of farm operators and field observation. Forecasts for each crop season begin with a winter wheat and rye seeding report in early January followed by a March report that gives a first look at what farmers intend to plant. This is followed in late June by a report of the acreage actually planted. Monthly yield and production forecasts begin in May for winter wheat, in July for spring wheat and other small grains, in August for other spring-planted crops, and conclude with estimates of actual production at the end of the harvesting season. NASS also conducts quarterly surveys of grain and soybeans stored on and off farms. According to NASS, AVHRR-based crop yield estimates are not nearly as precise as NASS's existing survey system for crop yield data. However, in areas with no survey or ground data systems, AVHRR-based data can provide limited year-to-year interpretations of changes in yield levels. More on the survey techniques used by NASS is available at http://www.nass.usda.gov/Data_and_Statistics/Foundation_of_Estimates/index.asp.

The USDA Forest Service (FS) also uses remote sensing in monitoring and evaluating forest resources. It uses aerial survey, also known as aerial sketch mapping, a remote sensing technique of observing forest change events from an aircraft and documenting them manually onto a map. Aerial surveys are used as the first step of a multitiered process, together with other remote sensing and ground-sampling techniques to gather forest resource data. As with all remotely sensed data, some amount of ground-truthing is required before the data can be considered reliable. The Forest Service considers all information a draft until the ground-truthing is complete. The results of this survey are entered into GIS for further analysis.

USDA's NASS and FS agencies provide time-series statistical and spatial data at different geographic level (economy-wide, state, county, 1km, and 250m), as well as many analytical tools. The USDA FS developed forest inventory reporting tools, including tools for querying the National Woodland Owner Survey database and the Timber Products Output database. Another tool, the Forest Inventory Data Online (FIDO) allows users to create reports and maps using information such as tree volume, growth, and tree removals by state. More information on the tools developed by these agencies is available at

http://www.fia.fs.fed.us/tools-data/default.asp

The ORNL specializes in economic analysis of biomass resources, and has developed many models to support it. The Policy Analysis System (POLYSYS) is an economy-wide simulation model of the U.S. agriculture sector, which can incorporate agricultural supply and demand and related modules to estimate agricultural production response, resource use, price, income, and environmental impacts of projected changes from an agricultural baseline. The framework recursively incorporates linear programming, econometric, and process models to estimate an impact path resulting from changes imposed on a baseline scenario and its underlying assumptions. POLYSYS estimates crop production and supply at a disaggregated regional level, whereby the 48 contiguous states are subdivided into 305 geographic regions with relatively homogeneous production characteristics. POLYSYS is capable of estimating a wide range of policy alternatives and economic and environmental conditions and simulations may be tailored to a variety of specific analytical needs.

Oak Ridge Integrated Bioenergy Analysis System (ORIBAS) is a GIS-based modeling system for predicting delivered feedstock costs across a state. It provides county-level estimates of suitable acres, yields, and farm-gate prices of energy crops (switchgrass, hybrid poplar, willow)

for all 50 states. The latter estimates delivered feedstock prices and quantities within a state at a fine resolution (1 km2) and considers the interplay between transportation costs, farmgate prices, cropland density, and facility demand. It can be used to examine any type of feedstock given the appropriate input parameters.

Another product developed by ORNL is BIOCOST, which estimates the cost of producing hybrid poplars and switchgrass in seven regions of the United States. It is an Excel-based program with a graphical interface that lets the user select a region and then specify values for several variables including expected yields; land rents; labor costs; and prices of chemicals, fertilizers, fuel, and planting. The user can also choose among several key management options. BIOCOST generates a report that includes yearly cost estimates by cost category as well as per-acre and per-ton costs.

Although conversion technologies are the main focus of the biomass program at NREL, resource assessment work has been supported over the years. The laboratory has been involved in conducting technical resource assessments for private companies, government organizations, and nongovernment organizations within the United States and abroad.

NREL's biomass resource assessment mentioned above was used to develop an interactive Web tool, composed of geographic and analytic components, that illustrates biofuels potential and petroleum displacement by state (Figure 35). The Potential Production maps show the biomass resources within counties, as well as the existing and under-construction biodiesel and ethanol production facilities. The Potential Use maps show the Flexible Fuel Vehicle (FFV) registrations by zip code and the location of refueling stations offering ethanol and biodiesel. The analytic component has three different calculation areas: current situation, potential production, and potential use. The current situation is static for each state and shows important fuel use, infrastructure, and biomass resources data. The potential production and use calculation areas are dynamic and are used to project various production and use scenarios based on user input. The tool can be accessed at http://www.eere.energy.gov/afdc/sabre/.
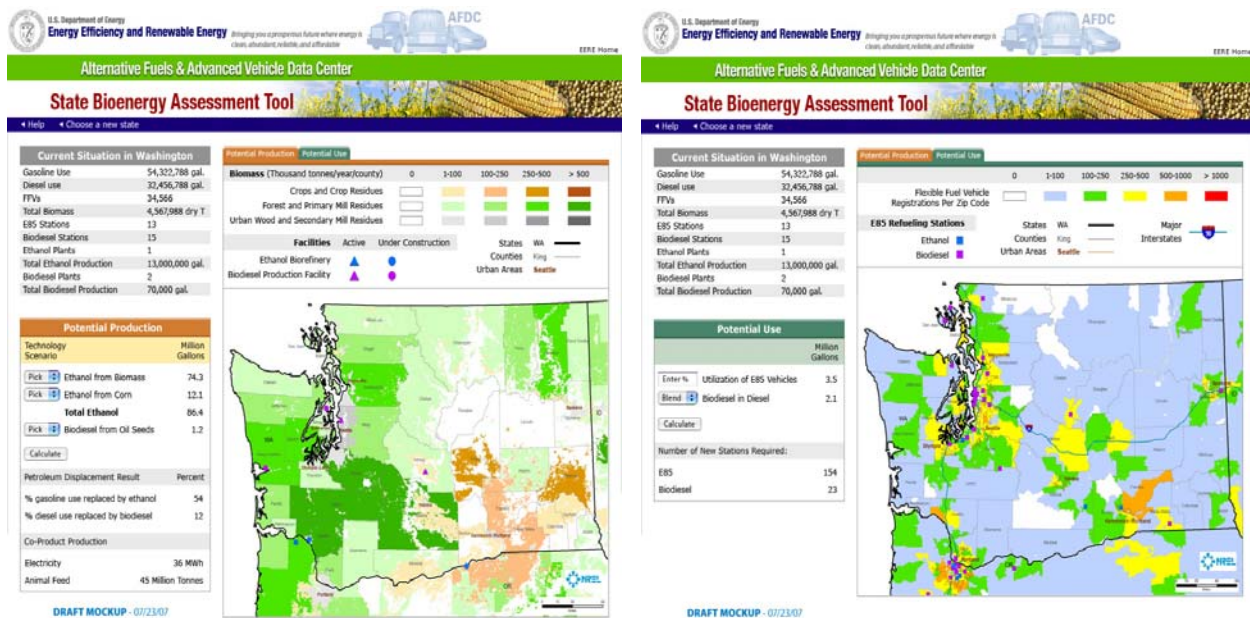
Figure 35. United States Bioenergy Assessment Tool

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Table 30. United States Biomass Resource Assessments Inventory as of May 2008

Name	Author	Publication Date	Spatial Coverage	Spatial Scale or Resolution	Temporal Scale or Resolution	Methodology Used	Units	Link	Abstract/Comments/Notes
Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply	ORNL	April, 2005	National	National	Annual Potential	Statistical analysis and modeling	dry ton/yr	http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf	This report determines whether the land resources are capable of producing a sustainable supply of biomass sufficient to displace 30% or more of the country's present petroleum consumption by examining the potential resource availability of agricultural and forest lands for biomass energy production.
A Geographic Perspective on the Current Biomass Resource Availability in the United States	NREL	December, 2005	National	County	Annual	Statistical analysis and GIS	dry tonnes/year for solid biomass; tonnes/yr for gaseous	http://www.nrel.gov/docs/fy06osti/39181.pdf	Resource availability based on county level statistics gathered from U.S. Department of Agriculture, U.S. Forest Service, and other organizations. Analyzed feedstock include: crop residues, forest residues, primary and secondary mill residues, urban wood waste, and methane emissions from manure management, landfills and domestic wastewater treatment.
Biomass Feedstock Availability in the United States: 1999 State Level Analysis	ORNL	January, 2000	National	State	Annual	Statistical analysis and modeling	$/dry ton	http://bioenergy.ornl.gov/resourcedata/index.html	Estimates of biomass quantities and prices for each state in the continental U.S., with links to a spreadsheet containing estimates of biomass quantities potentially available in five categories: mill wastes, urban wastes, forest residues, agricultural residues and energy crops. Availabilities are sorted by anticipated delivered price.
WGA CDEAC Biomass Task Force Report, Supply Addendum	WGA	January, 2006	WA, OR, ID, MT, WY, CO, NM, AZ, UT, NV, CA, TX, ND, SD, NE, KS, AK and HI	State or County	Annual	Statistical analysis and modeling	$/dry ton, tons, gallons	http://www.westgov.org/wga/initiatives/cdeac/Biomass-full.pdf	Estimates of quantities of various biomass resources throughout the WGA region on a county basis for use as feedstocks for power generation. The study analyzes the following feedstock: forest resources, agricultural residues and products, and resources from the municipal waste stream including solid wastes, biosolids, sewage, and waste buried in landfills.

Name	Author	Publication Date	Spatial Coverage	Spatial Scale or Resolution	Temporal Scale or Resolution	Methodology Used	Units	Link	Abstract/Comments/Notes
WGA CDEAC Biomass Resource Assessment and Supply Analysis	WGA	March, 2008	WA, OR, ID, MT, WY, CO, NM, AZ, UT, NV, CA, TX, ND, SD, NE, KS, AK and HI	State or County	Annual	Statistical analysis and modeling	$/dry ton, pounds, tons	N/A	Estimates of quantities of various biomass resources throughout the WGA region on a county or city basis for use as feedstocks for liquid biofuels. The study includes: crop residues (corn stover and small-grain straws), animal fats and waste greases (beef tallow, yellow grease), forest biomass resources, energy crops (short-rotation woody crops and herbaceous), orchard and vineyard trimmings (apples, almonds, grapes, etc.), biosolids, and grain and oilseeds (corn, soy, and canola).
Assessment of Biomass Resources and Power Generation Potential in California	University of California - Davis	February, 2004	California	State or County	Annual	Statistical analysis	dry ton/yr	http://biomass.ucdavis.edu/materials/reports%20and%20publications/2006/2006_Biomass_Resource_Assessment.pdf	California's gross and potential technically available biomass resources were quantified and compiled into statewide and county level inventories.
Colorado Agriculture: Land, Water, Energy Use and Bioenergy Potential	Resource Analysis, Inc. for Colorado Office of Energy Management and Conservation	April, 2004	Colorado	County	Annual	Statistical analysis	tons/yr or cubic ft/day	http://www.state.co.us/oemc/biomass/reports/2004_doe_report.pdf	County-level estimates of the gross available and maximum net available residue for five Colorado crops and livestock manure in 2001.
Biomass Resource Assessment and Utilization Options for Three Counties in Eastern Oregon	McNeil Technologies for Oregon Dept. of Energy	December, 2003	Eastern Oregon	Three counties in Eastern Oregon - Baker, Union and Wallowa	Annual	Statistical analysis and modeling	Dry tons/yr	http://www.oregon.gov/ENERGY/RENEW/Biomass/docs/EOBRA/FullText.pdf	The assessment focused on the use of biomass for electric power generation or conversion to ethanol fuel in Baker, Union and Wallowa Counties. The objectives were to identify how much biomass is generated in the region; how much is available, where it is located, its physical and chemical characteristics and the cost; provide information on best locations for a potential biomass site in each county; evaluate the economic and environmental impacts of biomass use; and provide an overview of biomass energy technologies, feedstock requirements, and the economic potential to convert biomass to electricity or ethanol.

Name	Author	Publication Date	Spatial Coverage	Spatial Scale or Resolution	Temporal Scale or Resolution	Methodology Used	Units	Link	Abstract/Comments/Notes
Potential for Biomass Energy Development in South Carolina	USDA Forest Service and the SC Forestry Commission.	September, 2004	South Carolina	County and State	Annual	Statistical analysis	Green tons, dry tons	http://www.scbiomass.org/Publications/Potential%20Biomass%20Energy%20in%20SC.pdf	This report quantifies the amount of forestry and agricultural biomass that is available for energy production on a sustainable basis in South Carolina. It also includes an analysis of the economic impacts of transferring out-of-state costs for coal to in-state family forest landowners and biomass processors.
Biomass and Bioenergy Resource Assessment for the State of Hawaii	State of Hawaii Department of Business, Economic Development and Tourism	December, 2002	Hawaii	County and State	Annual	Statistical analysis	Tons/yr or Dry Tons/yr	http://www.hawaii.gov/dbedt/info/energy/publications/biomass-assessment.pdf	An assessment of current and potential biomass and bioenergy resources for the State of Hawaii. It includes the following feedstock: animal wastes, forest products residues, agricultural residues, and urban wastes
Biomass Wood Resource Assessment on a County-by-County Basis for the State of Georgia	State Government - Georgia Forestry Commission	November, 2005	Georgia	County and State	Annual	Statistical analysis	Dry tons	http://www.gfc.state.ga.us/ForestMarketing/documents/BiomassWRACountybyCountyGA05.pdf	A biomass wood resource assessment on a county level basis for the State of Georgia: forest, primary mill, urban wood, pecan shells, paper mill sludge, and black liquor. It also analyzes the CRP Program potential.
Securing a Place for Biomass in the Northeast United States: A Review of Renewable Energy and Related Policies	Northeast Regional Biomass Program (NRBP)	Mar-03	CT, DE, ME, MD, MA, NH, NJ, NY, PA, RI, VT	State	Annual	Statistical analysis	Dry tons/yr	http://www.nrbp.org/pdfs/nrbp_final_report.pdf	A survey of biomass resources, power potential, and policies in the 11 states encompassing the Northeast Regional Biomass Program (NRBP): CT, DE, ME, MD, MA, NH, NJ, NY, PA, RI, VT.
Biomass from Crop Residues: Cost and Supply Estimates.	USDA	Feb-03	National	State, Region	Annual	Statistical analysis	lbs/acre, lbs, $/ton	http://www.usda.gov/oce/reports/energy/AER819.pdf	The analysis estimated the supply of harvested crop residues as a feed stock for energy products. The estimates account for economic and environmental factors governing residue supply. The supply results span major agricultural crops in four distinct cropping regions of the United States, taking into account local variation in cost-determining factors such as residue yield, geographic density of residues, and competition for livestock feed use.

Name	Author	Publication Date	Spatial Coverage	Spatial Scale or Resolution	Temporal Scale or Resolution	Methodology Used	Units	Link	Abstract/Comments/Notes
Florida Biomass Resources	Florida International University	Jun-05	Florida	County, Locations	Annual	GIS - ArcIMS		http://hcetgis.hcet.fiu.edu/website/FL_Biomass/Disclaimer/about.htm	Interactive map showing the biomass resources in Florida. The goal is to provide open access to information related to available biomass resources in the state for potential energy production. It not only maps these resources, but provides a means by which their potential can be assessed by region and available technologies.
Biomass Residue Supply Curves for the United States	Antares Group Inc.	Jun-99	National	State	Annual	Statistical analysis	dry tons/yr	N/A	The project estimated the availability of biomass resources and built supply curves for each state. It focused on woody biomass resources such as forestry, mills, and urban residues.
Urban Wood Waste Resource Assessment	Appel Consultants,Inc.	Nov-98	National	30 metropolitan areas	Annual	Statistical analysis	tons/yr	http://www.p2pays.org/ref/19/18947.pdf	This study collected and analyzed data on urban wood waste resources in 30 randomly selected metropolitan areas in the United States. The metropolitan areas ranged in size from Bismarck, North Dakota (83,831) to Washington, DC (3,923,574). Three major categories of urban wood wastes were considered in this study: MSW wood, industrial wood, and Construction/Demolition debris.
Lignocellulosic Feedstock Resource Assessment.	NEOS Corporation	Sep-98	National	State	Annual	Statistical analysis	Dry tons	http://www.nrel.gov/docs/legosti/fy98/24189.pdf	This study describes the distribution, quantity, availability, competing uses, and current market value of select lignocellulosic feedstock in the United States. It provides feedstock data at a state level.

Name	Author	Publication Date	Spatial Coverage	Spatial Scale or Resolution	Temporal Scale or Resolution	Methodology Used	Units	Link	Abstract/Comments/Notes
Biomass Inventory and Bioenergy Assessment An Evaluation of Organic Material Resources for Bioenergy Production in Washington State	Washington State University and Washington State Department of Ecology	Dec-05	Washington State	County	Annual	Statistical analysis	Dry tons	http://www.ecy.wa.gov/pubs/0507047.pdf	This project geographically identified, categorized, and mapped 45 potential sources in Washington at a county level. The categories included field residues, animal manures, forestry residues, food packing/processing waste, and municipal wastes. The biomass inventory was then converted to potential energy production using anaerobic digestion and simple combustion as representative conversion technologies.
Secondary Mill Residues and Urban Wood Waste Quantities in the United States	Jeffrey E. Fehrs, P.E. Williston, Vermont	Dec-99	National	National	Annual	Statistical analysis	Tons/year	http://www.nrbp.org/pdfs/pub21.pdf	This study focuses on secondary mill residues and urban wood wastes, and estimates quantities and prices based on seven national wood waste assessments completed by others.
Biomass Energy Data Book	ORNL	Sep-06	National	State	Annual	Statistical analysis	Acres/Dry Tons	http://cta.ornl.gov/bedb/pdf/Biomass_Energy_Data_Book.pdf	The book represents an assembly and display of statistics and information that characterize the biomass industry, from the production of biomass feedstocks to their end use. It inlcudes the following feedstocks: grains and oilseed crops, some crop residues (orchard trimmings and nut hulls), forest residues, secondary mill residues and urban wood waste (construction and demolition wood debris, municipal solid wastes, and landfill gases).
Assessing Ohio's Biomass Resources for Energy Potential Using GIS	Ohio State University	Oct-04	Ohio	County	Annual	Statistical analysis and GIS	Dry tons/yr	http://www.puc.state.oh.us/emplibrary/files/media/biomass/bioenergyresourceassessment.pdf	This study estimates crop and wood residues, methane from livestock manure, and food processing waste

Name	Author	Publication Date	Spatial Coverage	Spatial Scale or Resolution	Temporal Scale or Resolution	Methodology Used	Units	Link	Abstract/Comments/Notes
The Economic Feasibility of Ethanol Production from Sugar in the United States	USDA	Jul-06	National	National, Regional, and Select State	Annual	Statistical analysis	tons, $/ton, $/gallon	http://www.usda.gov/oce/Eth anolSugarFeasibilityReport3. pdf	This study investigates the economic feasibility of producing ethanol from sugar feedstocks in the United States. These sugar feedstocks include: sugarcane juice, sugar beet juice, cane or beet molasses, raw sugar, and refined sugar. Estimated costs of producing ethanol from these feedstocks are presented along with a discussion of other factors that may influence the economic feasibility of converting sugar feedstocks into ethanol.

Viet Nam

Economy-Wide Biofuels Resource Assessments

First-Generation Biofuels Potential

Ethanol: The existing ethyl alcohol industry in Viet Nam is already using starches (predominately rice) and sugar cane molasses as feedstock. Rice is the economy's main crop with production of more than 35 Mt annually. Sugar cane production has been consistent during the past six years, about 15 Mt annually. Another feedstock considered by the industry is cassava. The production has grown rapidly from 2 Mt in 2000 to about 8 million in 2006.

If 20% of Viet Nam's current starch and sugar crops production could be used for biofuels, it would yield about 4.57 hm^3 of ethanol or 2.2 Mt gasoline equivalent. This volume could replace 86% of Viet Nam's current gasoline consumption.

Biodiesel: Catfish oil and used cooking oil are the primary biodiesel feedstocks in Viet Nam. The Vietnamese Academy of Science and Technology (VAST) estimates that there were 60,000 tonnes of catfish oil produced in 2005, primarily for exports to the United States and Europe, and about 73,800 tonnes of used cooking oil. The economy produces oil crops such as coconut, peanuts, and soybeans mainly for domestic use by the food industry.

If 20% of Viet Nam's current coconut oil production, as well as all waste oils and fats, could be used for biofuels, it would yield about 164,000 tonnes of biodiesel. This volume would replace 4.6% of the economy's current diesel consumption.

Second-Generation Biofuels Potential

Ethanol: Viet Nam is very rich in lignocellulosic biomass. As illustrated in Table 31, the economy produced about 93 Mt of crop and wood residues in 2002, which translates to about 28 hm^3 of ethanol or 13.4 Mt of gasoline equivalent. This volume is more than enough in displacing the economy's current gasoline consumption.

Table 31. Wood and Crop Residues Available in Viet Nam, 2002

Wood residues & fire wood	Million tonnes	Energy Content (TJ)
Saw dust	0.27	3,132
Wood chip	1.33	19,950
Firewood	12.4	186,000
Crop residues		
Paddy straw	64.7	905,800
Rice husk	6.81	77,634
Maize husk	5.8	72,500
Cassava stem	1.25	15,625
Cane trash	1.68	21,000
Bagasse	5.5	39,655
Peanut shells	0,12	1,500
Coconut shells & leaves	5	90,000
Coffee husk	0.28	4,359

Source: Nguyen Le Truong, Tran Quang Cu, 2004; TJ – Terajoule (10^{12} J)

Dedicated energy crops (particularly elephant grass) are also seen as an opportunity in Viet Nam. Pilot elephant grass plantations have been set up in Dongthap province (67 ha), BacKan (100 ha), and TuyenQuang (200 ha). Viet Nam is also exploring the opportunity to produce ethanol from seaweed.

Biodiesel: The Institute of Applied Materials & Science and Institute of Tropical Biology in HCMC is researching the biodiesel production from rubber seed oil and other oil-bearing crops (jatropha). The Department of Agriculture & Rural Development has a jatropha trial plantation of 5,000 ha. Eco-Carbone has identified four regions in Viet Nam for jatropha development, and will partner with local farmers and communities for a minimum of 30,000 ha.

Regional and Local Biomass Resource Potential

VAST estimated the main agricultural residues available in Viet Nam by region as illustrated in Table 32. No finer analysis of biomass resources (by province or municipality) was identified during this survey.

Table 32. Main Agricultural Residues Available by Region in Viet Nam, 2006

Areas of country	Agriculture by production [million tons]			
	After processing		After harvesting	Total by product
	Rice husk	Bagasse	Straw & cane leaf	
The North mountain and midland	0.54	0.32	3.12	3.98
The Red river delta	1.30	0.04	5.19	6.53
The North central	0.58	0.76	2.79	4.13
The Central coast	0.35	0.67	2.83	3.85
Central Highlands	0.15	0.35	0.84	1.32
The South - East	0.33	0.76	2.78	3.87
The Mekong river delta	3.55	1.55	16.51	21.25

Source: Tran Dinh Man, 2007

Biomass Resource Assessment Capabilities

Although no detailed biomass resource assessments were identified at the time of this survey, it appears that Viet Nam has capabilities to improve the quality of existing analyses.

The Institute of Biotechnology and Institute of Environmental Technology at the Vietnamese Academy of Science and Technology (VAST) are the main agencies involved in biomass resource assessment. Several other entities provide expertise in agriculture and forestry such as the Faculty of Forestry, Nong Lam University (formerly University of Agriculture and Forestry), the Forest Science Institute of Vietnam (FSIV), Institute of Agricultural Technologies and Science, and Ministry of Agriculture and Rural Development (MARD).

Geospatial Technologies. The General Statistics Office (GSO) of Viet Nam and FAO jointly published an Agricultural Atlas of Vietnam in 2007. The atlas is the first product in Viet Nam to illustrate agricultural statistics in a spatial format. It used GIS to analyze and map a variety of 2001 Census variables related to agriculture and forestry in Viet Nam at commune level. The atlas's broad range of agricultural statistics is designed to provide a comprehensive overview of the geography of agricultural production in rural Viet Nam. Figure 36 illustrates an example of the series of maps presented in the atlas.

GIS and RS have also been used by the Viet Nam Environment Protection Agency (VEPA) in its environmental-monitoring activities, and in the development of an atlas on Viet Nam's environment. The Ministry of Natural Resources and Environment (MONRE) maintains land use and land cover data.

Modeling. No information on modeling techniques used for agricultural and forestry analysis in Viet Nam was identified during this survey. However, the Information Center for Agriculture and Rural Development (AGROINFO) reported in 2007 that there is an agreement between the Economic Research Service-United States Department of Agriculture (ERS-USDA) and AGROINFO's Institute of Policy and Strategy for Agriculture and Rural Development (IPSARD) to exchange knowledge in modeling and other operating mechanisms for agricultural market analyses and forecasts, particularly for rice commodity.

Data Availability. The General Statistics Office (GSO) of Viet Nam is the main agency that collects and provides agricultural and forestry statistics. Data on crop-planted area, yield, production, and forest area and wood production is available by province. Information is provided annually (since 1995) in electronic format via the GSO Web site at http://www.gso.gov.vn. Detailed farm and agricultural and forestry enterprise data, at the level of the household, are only collected through censuses. Data is collected via sample paper and ground surveys.

Figure 36. Forest Cover – Viet Nam
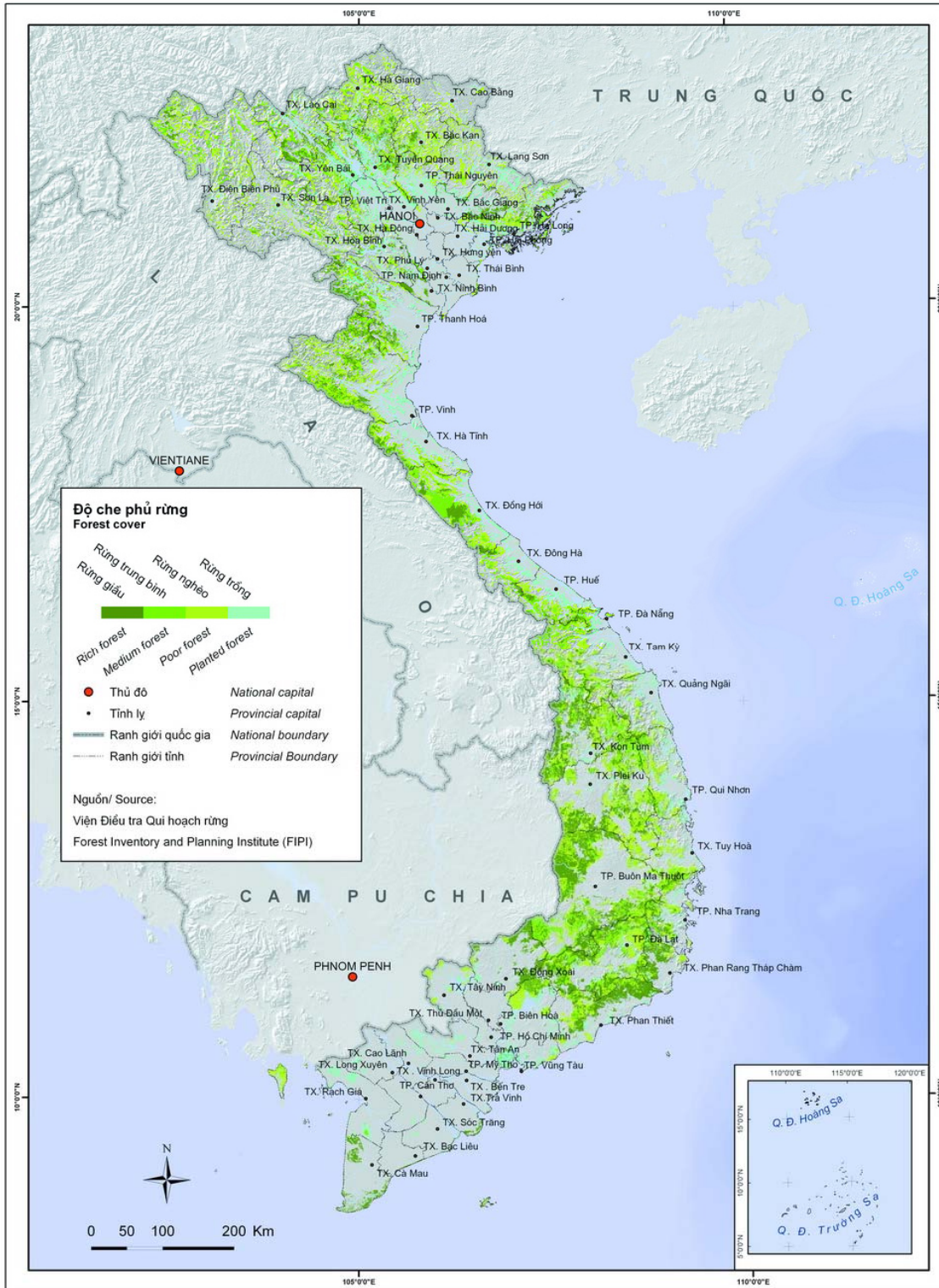
Source: GSO-FAO, 2007

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Conclusions

Biomass Resource Assessments. This analysis revealed that most of the APEC economies have assessed their biomass resources at a broad, economy-wide level. Many have completed biomass resource assessments by state/province, and few at a finer geographic level – county/district or local. Table 33 illustrates these findings.

Table 33. Biomass Resource Assessments in APEC Economies

Economy	Biomass Resource Assessments			
	Economy-Wide	State/Province	County/District	Local
Australia	X	X	X	X
Brunei Darussalam	~	~	~	~
Canada	X	X	O	O
Chile	X	X	X	X
China	X	X	O	O
Hong Kong, China	X	~	~	~
Indonesia	X	X	X	X
Japan	X	N/A	N/A	N/A
Korea	X	X	X	N/A
Malaysia	X	N/A	N/A	N/A
Mexico	X	X	X	X
New Zealand	X	X	N/A	N/A
Papua New Guinea	X	N/A	N/A	N/A
Peru	X (biodiesel only)	N/A	N/A	N/A
The Philippines	X	X	X	N/A
Russia	N/A	N/A	N/A	N/A
Singapore	X (urban wood only)	~	~	~
Chinese Taipei	X	N/A	N/A	N/A
Thailand	X	X	X	X
United States	X	X	X	X
Viet Nam	X	N/A	N/A	N/A

N/A - Information not available; "~" Not applicable; "O" - Under development

Biomass Resource Assessment Capabilities. The survey found that all economies have the necessary capabilities to conduct biomass resource assessments - scientific knowledge, tools, and data. However, not all of them have used their full capabilities in existing products. Some members have used their advanced capabilities, such as RS/GIS and simulation modeling, to develop detailed analyses of resource potential. For others, the survey identified products that are not direct examples of biomass resource assessments, but they indicate existing capabilities that could be applied to future resource assessment projects, enabling economies to achieve fine geographic presentation of resources and project potential. Table 34 illustrates these findings.

Table 34. Biomass Resource Assessment Capabilities in APEC Economies

Economy	Biomass Resource Assessment Capabilities			
	Remote Sensing/GIS	Modeling		Field/Paper Survey**
		Static/Numeric*	Dynamic/Simulation	
Australia	X	X	X	X
Brunei Darussalam	X	X	N/A	X
Canada	X	X	X	X
Chile	X	X	N/A	X
China	X	X	N/A	X
Hong Kong, China	X	X	N/A	X
Indonesia	X	X	N/A	X
Japan	X	X	X	X
Korea	X	X	N/A	X
Malaysia	X	X	N/A	X
Mexico	X	X	X	X
New Zealand	X	X	N/A	X
Papua New Guinea	X	X	N/A	X
Peru	X	X	N/A	X
The Philippines	X	X	N/A	X
Russia	X	X	X	X
Singapore	X	X	N/A	X
Chinese Taipei	X	X	N/A	X
Thailand	X	X	N/A	X
United States	X	X	X	X
Viet Nam	X	X	O	X

* In most cases, applying product to residue ratio; ** Used mostly for collecting agricultural and forestry statistics
N/A - Information not available; "~" - Not applicable; "O" - Under development

The overall survey findings are presented below.

Economies with Good Resource Assessment Capabilities and Detailed Resource Assessments:
Australia, Canada, Chile, Indonesia, Korea, Mexico, the Philippines, Thailand, United States

Economies with Good Resource Assessment Capabilities and Medium Scale (state/province) Resource Assessments: China, New Zealand

Economies with Good Resource Assessment Capabilities and Broad (Economy-Wide) Resource Assessments: Japan, Malaysia, Chinese Taipei, Viet Nam

Economies with Good Resource Assessment Capabilities and Limited or No Resource Assessments: Papua New Guinea, Peru, Russia

Economies with Limited Biofuel Resources: Brunei Darussalam, Hong Kong, Singapore

Resource Availability for Ethanol and Potential Gasoline Displacement. Considering the controversy surrounding the use of conventional crops for biofuels production, this project paid particular attention to assessments of alternative (non-food) biomass resources, such as crop and forest residues. The resource availability in the APEC region is estimated at about 1,700 Mt, which would yield 509 hm^3 of ethanol or 245 Mt gasoline equivalent. This volume would

replace 40% of the region's current gasoline consumption and just below 20% of crude oil import. Many economies could substitute a substantial volume of their current gasoline consumption with ethanol from second generation feedstock, while others such as China, Thailand, and Viet Nam could substitute their entire consumption (Table 36). A note should be made, however, that this estimate doesn't account for current uses of these resources by other industries such as power/heat generation and bioproducts (plastics, chemicals, etc.). Therefore, more detailed analyses are needed to evaluate the resources that are actually available for biofuels production.

With respect to first generation feedstock, the study evaluated the contribution of 20% of the economies' current starch and sugar crops production. This number is somewhat arbitrary and simply a choice made here. It is reasonable to assume for net importing economies, such as Chile, Japan, Korea, and Chinese Taipei that biofuels production from these crops will not be viable in the near future. However, with advancements in crop development and yield increase, the situation in these economies may change with time. The first generation resource availability in the APEC region is estimated at 252 Mt, equal to about 92 hm^3 of ethanol (44 Mt gasoline equivalent), enough to replace only 7% of APEC's current gasoline consumption and 3.5% of crude oil import (Table 35).

Resource Availability for Biodiesel and Potential Petro-Diesel Displacement. The assessment of biodiesel resource availability was conducted in a similar way to the ethanol assessment. However, data on second generation feedstock (non-edible crops, such as Jatropha and Pongam, or from algae) was insufficient to provide meaningful results. If 20% of economies' current vegetable oil production, as well as all waste oils and fats, are used for biofuels, it would yield about 21.8 Mt of biodiesel. This amount would replace 6.8% of their current diesel consumption and 1.7% of crude oil import (Table 37). Economies with the highest resource availability include China, Indonesia, Malaysia, and the United States. It is expected that the resource potential for biodiesel production in APEC economies will increase significantly over the next years with the development of second generation feedstock.

Table 35. First-generation Resource Availability for Ethanol Production in APEC Economies

Economy	Feedstock Type	20% of Current Production ('000 tonnes)*	Ethanol Potential (hm3)	Gasoline Equivalent ('000 tonnes)	Gasoline Consumption ('000 tonnes)**	Share of Gasoline Consumption (%)	Crude Oil Import ('000 tonnes)**	Share of Crude Oil Import (%)
Australia	barley, corn, oats, rice, sorghum, sugar cane, wheat	8,919	3.11	1,498	14,520	10.3	20,070	7.5
Brunei					196			
Canada	barley, corn, oats, sugar beet, wheat	6,765	2.18	1,050	29,751	3.5	45,336	2.3
Chile	corn, sugar beet, wheat	635	0.26	125	2,081	6.0	10,219	1.2
China	cassava, corn, rice, sorghum, sugar cane, sweet potato, wheat	96,590	32	15,416	46,097	33.4	126,817	12.2
Hong Kong					325		352	
Indonesia	cassava, rice, sugar	16,400	6.73	3,242	12,942	25.1	20,829	15.6
Japan	rice, sugar beet, sugar cane, wheat	2,000	0.75	361	44,391	0.8	207,266	0.2
Korea	rice	954	0.33	159	6,969	2.3	113,234	0.1
Malaysia	rice	288	0.10	48	7,756	1	7,885	0.6
Mexico	corn, sorghum, sugar cane, wheat	6,830	3.02	1,455	27,704	5.3		
New Zealand	whey	N/A	0.015	7	2,325	0.3	4,488	0.2
PNG	sugar cane	100	0.06	29	N/A	N/A	435	6.6
Peru	cassava, corn, rice, sugar cane, sweet potato	2,039	0.99	477	771	61.9	4,809	9.9
The Philippines	cassava, sugar cane	804	0.33	159	4,111	3.9	10,681	1.5
Russia	barley, corn, oats, rice, sugar beet, wheat	14,774	4.87	2,346	26,260	8.9		
Singapore					727		54,786	
Chinese Taipei	rice, sweet potato	247	0.08	39	7,845	0.5	54,035	0.1
Thailand	cassava, rice, sweet potato	8,677	2.70	1,301	5,280	24.6	39,815	3.3
United States	barley, corn, oats, rice, sorghum, sugar beet, sugar cane, wheat	74,000	30	14,452	373,930	3.9	538,651	2.7
Viet Nam	cassava, rice, sugar cane	11,600	4.57	2,202	2,546	86.5		
APEC Total		**251,622**	**92.1**	**44,365**	**616,527**	**7.2**	**1,259,708**	**3.5**

*Source: USDA (indexmundi.com), 2005; ** Source: IEA, 2005; hm^3 – cubic hectometer or 1,000,000 m^3 or 10^9 L, described in some sources as a GL (Gigaliter); N/A – information not available; Areas in gray - not applicable; to compute 1,000 tonne gasoline equivalent: ethanol volume (hm3)*21.1PJ/43.8 TJ.

Table 36. Second-generation Resource Availability for Ethanol Production in APEC Economies

Economy	Feedstock Type	Resource Availability ('000 tonnes)	Ethanol Potential (hm3)	Gasoline Equivalent ('000 tonnes)	Gasoline Consumption ('000 tonnes)*	Share of Gasoline Consumption (%)	Crude Oil Import ('000 tonnes)*	Share of Crude Oil Import (%)
Australia	crop, forest, and primary mill residues; urban wood waste	36,700	11.0	5,299	14,520	36.5	20,070	26.4
Brunei					196			
Canada	crop, forest, and primary mill residues; hog fuel piles	71,000	21.3	10,261	29,751	34.5	45,336	22.6
Chile	primary mill residues	3,254	0.9	434	2,081	20.8	10,219	4.2
China	crop, forest, and primary mill residues	788,000	236.0	113,689	46,097	246.6	126,817	89.6
Hong Kong					325		352	
Indonesia	crop residues; sugar cane bagasse; oil-palm, rubber, and coconut residues	74,000	22.2	10,695	12,942	82.6	20,829	51.3
Japan	crop and forest residues; urban wood waste	15,000	4.5	2,168	44,391	4.9	207,266	1.0
Korea	crop and forest residues	13,100	3.9	1,879	6,969	27.0	113,234	1.7
Malaysia	crop residues; sugar cane bagasse; oil-palm and wood-processing residues	32,392	9.7	4,673	7,756	60.2	7,885	59.3
Mexico	crop, logging, and primary mill residues	74,500	22.4	10,767	27,704	38.9		
New Zealand	crop, logging, and primary mill residues; horticultural and urban wood waste	5,500	1.7	795	2,325	34.2	4,488	17.7
PNG	logging, oil-palm, and coconut residues; sugar cane bagasse	N/A	N/A	N/A	N/A	N/A	435	N/A
Peru	crop, logging, and oil-palm residues; sugar cane bagasse	N/A	N/A	N/A	771	N/A	4,809	N/A
The Philippines	crop, logging, and coconut residues; sugar cane bagasse	18,000	5.4	2,601	4,111	63.3	10,681	24.4
Russia	crop and forest residues	100,000	30.0	14,452	26,260	55.0		
Singapore					727		54,786	
Chinese Taipei	crop residues	1,900	0.6	275	7,845	3.5	54,035	0.5
Thailand	crop residues; sugar cane bagasse; oil-palm and coconut residues	47,800	14.3	6,889	5,280	130.5	39,815	17.3
United States	crop, forest, primary mill, and secondary mill residues; urban wood waste	324,448	97.3	46,873	373,930	12.5	538,651	8.7
Viet Nam	crop, wood-processing, and coconut residues; sugar cane bagasse	93,000	27.9	13,440	2,546	527.9		
APEC Total		**1,698,594**	**509.0**	**245,189**	**616,527**	**39.8**	**1,259,708**	**19.5**

*Source: IEA, 2005; hm^3 – cubic hectometer or 1,000,000 m^3 or 10^9 L, described in some sources as a GL (Gigaliter); N/A – information not available; Areas in gray - not applicable; to compute 1,000 tonne gasoline equivalent: ethanol volume (hm3)*21.1PJ/43.8 TJ.

Table 37. Resource Availability for Biodiesel Production in APEC Economies

Economy	Vegetable Oils	20% of Current Production ('000 tonnes)*	Waste Oils and Fats ('000 tonnes)	Biodiesel Potential ('000 tonnes)	Diesel Consumption ('000 tonnes)**	Share of Diesel Consumption (%)	Crude Oil Import ('000 tonnes)**	Share of Crude Oil Import (%)
Australia	rapeseed, soybean	39	340	379	7,643	5.0	20,070	1.9
Brunei					107			
Canada	rapeseed, soybean	339	211	550	12,511	4.4	45,336	1.2
Chile	rapeseed, soybean	8	46	54	3,260	1.7	10,219	0.5
China	rapeseed, soybean,	2,226	3,000	5,226	46,934	11.1	126,817	4.1
Hong Kong			9	9	1,317	0.7	3,512	0.3
Indonesia	palm, coconut	3,376	N/A	3,376	9,974	33.8	20,829	16.2
Japan	rapeseed, soybean	285	500	785	27,896	2.8	207,266	0.4
Korea	soybean	31	230	261	14,841	1.8	113,234	0.2
Malaysia	palm	3,200	N/A	3,200	4,998	64.0	7,885	40.6
Mexico	rapeseed, soybean	230	N/A	230	12,487	1.8		
New Zealand			132	132	1,741	7.6	4,488	2.9
PNG	palm, coconut	82	N/A	82	170	48.2	435	18.9
Peru	palm	9	294	303	2,209	13.7	4,809	6.3
The Philippines	coconut	310	N/A	310	4,211	7.4	10,681	2.9
Russia	rapeseed, soybean,	506	N/A	506	13,527	3.7		
Singapore					1,323		54,786	
Chinese Taipei	soybean	77	189	266	3,657	7.3	54,035	0.5
Thailand	palm, coconut, soybean	217	N/A	217	12,625	1.7	39,815	0.5
United States	rapeseed, soybean,	1,975	3,741	5,716	135,346	4.2	538,651	1.1
Viet Nam	coconut	30	134	164	3,558	4.6		
APEC Total		**12,940**	**8,826**	**21,766**	**320,335**	**6.8**	**1,262,868**	**1.7**

*Source: USDA (indexmundi.com), 2005; ** Source: IEA, 2005; N/A – information not available; areas in gray - not applicable.

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