BIORENEWABLES TECHNOLOGY PRIMER: A SUMMARY

BACKGROUND

Biorenewables are biological materials derived from living or recently living organisms, such that the source materials are renewed at a rate that avails them for future use. e.g. grass strands cut from hay crops represent a biorenewable resource, whereas a patch of tropical rainforest cleared for 'slash and burn' agriculture is not. Sources of biorenewables can be grouped into five main categories, as listed in *Figure 1*.

Types of biorenewable source material	Description
Virgin Wood	This type of wood is untreated and clean. It occurs in a range of physical forms, such as bark, brash, logs, sawdust, wood chips and wood pellets.
Energy crops	These crops are grown specifically for use as biorenewables. The four main classes of energy crops are short rotation energy crops, grasses and non-woody energy crops, agricultural energy crops, and aquatics (hydroponics).
Agricultural residues	There is a wide variety of residues. Their most significant distinction is between those residues that are predominantly dry (e.g. straw, corn stover and poultry litter) and those that are wet (e.g. animal slurry, farmyard manure and grass silage).
Food waste and residues	These are found at all points of the food supply chain from initial production, through processing, handling and distribution to post-consumer waste from households, restaurants and hotels.
Industrial waste and co-products	Waste and co-products from industrial processes and manufacturing operations can be divided into woody (e.g. untreated wood, treated wood wastes and wood composites) and non-woody (e.g. paper pulp, textiles and sewage sludge) materials.

Figure 1: Types of biorenewable sources

BIORENEWABLES AS A SOURCE OF ENERGY

According to projections made by the International Energy Agency (IEA), global total primary energy demand is expected to increase by 40% between 2007 and 2030[1]. Within Southeast Asia (SEA), this figure is 76%[2]. In view

[1] IEA (2009) World Energy Outlook 2009, France.

[2] MEWR (2010). Key Environmental Statistics, Ministry of the Environment and Water Resources.

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of the rapid increase in energy demand, high oil prices, concerns about the environmental impacts of fossil fuel use and strong government incentives for increasing the use of renewable energy in many countries around the world, biorenewables are potentially an attractive resource for the production of energy due to their low cost and widespread availability.

Similar to burning fossil fuels, the burning of biorenewable resources for energy generation has its share of problems. However, from a lifecycle point-of-view, the environmental burden from the use of biorenewables is generally much less than if the equivalent amount of energy was produced from fossil fuels. Biorenewables take carbon out the atmosphere while they are growing and return the carbon when they are burnt; thus, there is no net increase in atmospheric CO_2 levels. In contrast, fossil fuels (also derived from biological materials) are materials that have adsorbed CO_2 from the atmosphere millions of years ago. Therefore, when they are burnt, they contribute to increased CO_2 concentrations in the atmosphere as carbon sequestered millions of years ago is released.

AVAILABILITY OF TYPES OF FEEDSTOCKS IN THE ASIA-PACIFIC REGION

Singapore occupies a strategic location within the Asia-Pacific region, which is rich in biorenewable feedstocks such virgin wood, energy crops, agricultural residues, municipal solid waste, and industrial waste and co-products. The availability of each of these groups of feedstocks in this region is described in the *Appendix*.

MUNICIPAL AND INDUSTRIAL WASTE AVAILABLE IN SINGAPORE

In 2009, the total amount of waste generated and domestic waste disposed in Singapore was 6.1 and 1.5 million tonnes, respectively.[2] *Figure 2* illustrates some selected types of municipal and industrial waste produced locally, and the potential amounts of biorenewable feedstocks that can be obtained from them. *If these resources can be properly managed, considerable quantities of clean energy can be derived from them.*

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Types of waste	Disposed weight[3]	
	Absolute (tonnes)	Percentage of total
Food waste	539, 400	20.5
Paper/Cardboard	626, 800	23.8
Wood/Timber	80, 200	3.1
Horticultural waste	144, 600	5.5
Plastics	628, 600	23.9
Sludge	88, 900	3.4
Others	520,552	19.8
Total	**2, 623,052**	**100**

Figure 2: Selected types of municipal and industrial waste in Singapore, and their corresponding disposed weight in absolute terms and as a percentage of the total disposed weight in 2009

MUNICIPAL SOLID WASTE (MSW) WASTE-TO-ENERGY PLANT

MSW is widely used as feedstock in waste-to-energy plants around the world. *In countries such as Singapore, a large part of our MSW is disposed of in MSW incineration plants.* ***The authors assess that unfortunately, the energy efficiency of these plants*** *remains uncompetitive compared to traditional power plants due to the highly heterogeneous properties of MSW.*

There are many alternative technologies that can be used to convert MSW to energy, e.g. gasification[4] and pyrolysis.

OTHER BIORENEWABLE CONVERSION TECHNOLOGIES

(A) Conversion of Biomass into bio-oil using pyrolysis

Pyrolysis is a controlled thermochemical conversion technology used to produce energy from biomass, by heating the organic materials at temperatures above 500 degrees Celsius and in the absence of oxygen. This process produces bio-oil, which is the cheapest liquid fuel produced from biomass. Although bio-oil has the potential to replace traditional fuels (e.g. diesel and petrol), its properties such as high water content (~ 25% of its total

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[3] NEA (2010). Singapore's Second National Communication - Under the United Nations Framework Convention on Climate Change, National Environment Agency.

[4] Gasification is a process by which carbon-based materials are reacted at high temperatures (> 700°C), in a controlled amount of oxygen and/or steam. Combustion does not occur under these conditions, and the resulting mixture of carbon monoxide, hydrogen, carbon dioxide and methane ("syngas"), can be used as a renewable fuel.

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composition), high acidity, low energy content (~ 17 GJ/tonne), chemical instability and incompatibility with traditional fuels make it unsuitable for use as a transportation fuel. In view of this, an upgrading process can be employed to convert bio-oil to a petroleum fuel alternative in the transportation sector.

The authors assess that there is good potential for feeding/co-processing upgraded bio-oil in existing petroleum refineries to save facility costs. In order to develop this potential, the economic and technical feasibility of bio-oil co-processing in standard refinery facilities must first be systematically assessed. The parameters of those refinery facilities most viable for bio-oil co-processing should then be defined and changed, depending on the bio-oil specifications. One of the biggest challenges to overcome here is determining a universally accepted specification or standard for raw bio-oil and upgraded bio-oil.

(B) Conversion of food waste into biogas using anaerobic digestion

Food industries produce large amounts of waste from their production, preparation and consumption stages. In Singapore, about 500, 000 tonnes of food waste were collected for disposal in 2009.

Food waste can be converted to final energy products (e.g. biogas) using anaerobic digestion, which involves a series of processes such that in the absence of oxygen, microorganisms break down the biodegradable materials in the food waste to release energy. Pre-treatment of food waste can be carried out to enhance the anaerobic digestion process for a more efficient conversion of biomass to energy.

(C) Conversion of urban sludge waste into biogas using anaerobic digestion

Sewage sludge can be converted to biofuels as it has a high calorific value which is almost equivalent to that of coal. In Singapore, 460 tonnes/day of sewage sludge were collected and disposed in 2009. This amount comprises of 60 tonnes/day of dried sludge and 400 tonnes/day of dewatered sludge. Utilising the stored energy in sludge and minimising environmental impacts are the principal goals of thermal processing of sewage sludge.

Depending on availability and technologies applied, municipal and industrial waste, such as food waste, paper/cardboard, wood/timber, horticultural waste, plastics, sludge, could be converted into heat, steam, electricity as an alternative energy supply for a municipality. *Energy produced by biorenewables from waste may be able to provide as much as three times the amount that incineration contributes to Singapore's overall energy supply currently,* due to increases in efficiency gained from the use of steam, heat, or biogas using pyrolysis, gasification, or anaerobic digestion technologies.

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BIOFUELS FOR TRANSPORT APPLICATIONS

Biofuels are made from biorenewable resources through biochemical or thermochemical processes. Examples of biofuels include ethanol, methanol, biodiesel, bio-crude and methane. The most widely used liquid biofuel in the world is ethanol.[5] It can be produced from any biorenewable resource containing large amounts of natural sugars or starch that can be readily converted to sugar (e.g. sugarcane, maize and sugar beets). The sugars are fermented to produce ethanol. With additional processing, low-cost crops and residues of biorenewables (e.g. wood waste and paper and pulp liquors) can be processed into fermentable sugars to yield significant quantities of fuel-quality ethanol. *The authors assess that developing technologies to produce and use biofuels will create transportation fuel options for establishing safe, clean and sustainable alternatives to petroleum.*

Biofuels can be divided into different 'generations' according to their level of development and the feedstocks used. These generations of biofuels are commonly defined as:

a. *1st-generation biofuels.* These are conventional biofuels manufactured at commercial scales primarily from food crops, such as sugar, starch and rapeseed, using standard technology. e.g. biodiesel, pure vegetable oil and bioethanol. In most cases, the production processes of 1st-generation biofuel are limited in the sense that there is a threshold above which the technologies employed cannot produce enough biofuels without threatening biodiversity, food and water supplies. In addition, 1st-generation biofuels provide only limited GHG emission reduction benefits and at relatively high costs in terms of $ per tonne of CO_2 avoided.

b. *2nd-generation biofuels.* These biofuels are produced from new feedstock, such as agricultural and forestry waste, and non-food crops using advanced technical processes. Many of the issues associated with the production of 1st-generation biofuels can be addressed by the production of 2nd-generation biofuels. e.g. the latter has a more favourable GHG balance and ability to use a wider range of biomass for feedstocks (hence negating or reducing competition with food production). However, technologies used to produce these biofuels are still not fully available on the commercial scale.

c. *3rd-generation biofuels.* These advanced biofuels generally include biofuel production routes which are at the earlier stages of R&D or are significantly further from commercialisation (e.g. biofuels from algae and hydrogen from biomass). 3rd-generation biofuels production is a new technology and laboratory experiments have claimed that algae (i.e. the feedstock for this technology) can produce up to 30 times more energy per acre than conventional land crops such as rapeseeds and soybeans[6]. However, these yields have yet to be produced commercially. The major obstacles to the success of this technology are primarily the uncertainty of its success and the high up-front investment cost of algae-to-biofuels facilities.

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[5] EIA (2007) Biofuels in the U.S. Transportation Sector.

[6] L Eviana Hartman (2008-01-06). "A Promising Oil Alternative: Algae Energy". Washington Post. www.washingtonpost.com/wp-dyn/content/article/2008/01/03AR2008010303907.html, Retrieved 2008-01-15.

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Figure 3 provides an illustration of the pathways of biofuels production for the different biofuel generations.

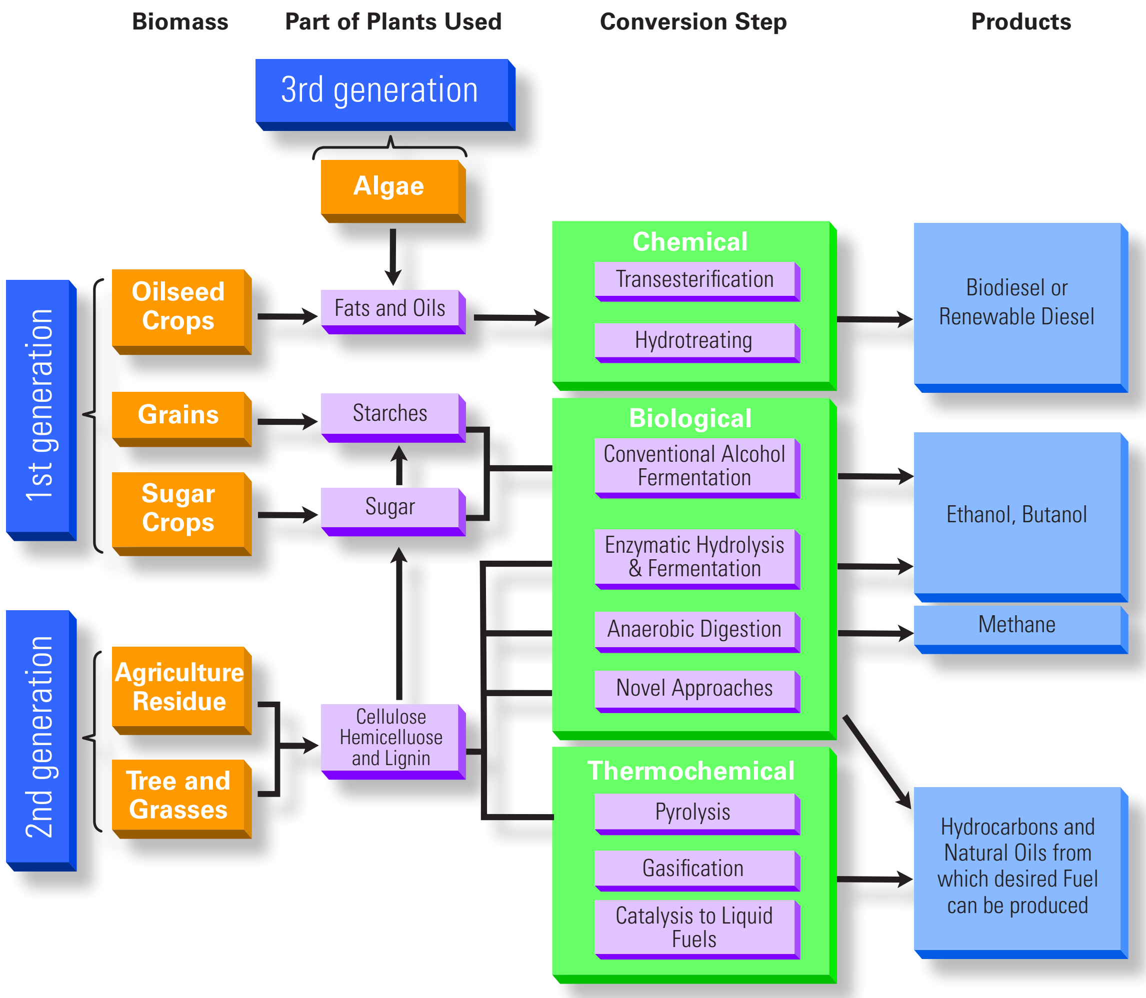

Figure 3: Current and emerging biofuel pathways.[7-8]

Considering the strong interest in green energy currently, biofuels production over the next few years is anticipated to involve more approaches and/or technologies for the purpose of making biofuels more cost-competitive with conventional fossil fuels. At present, the cost of producing gasoline (a conventional fossil fuel) is approximately S$2.0–4.0 per gasoline gallon equivalent (gge). In comparison, 1st-generation ethanol derived from corn in the US and sugarcane in Brazil costs about S$3.4/gge and S$1.0–1.7/gge, respectively.

In view of the increasing fossil fuel (petroleum) prices, interest in algaculture (i.e. farming microalgae) is growing. However, algae cultivation faces many challenges. e.g. microalgal cells must be mixed uniformly during the production process, otherwise biomass growth may be affected.[9] Other challenges faced include reducing capital and

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[7] Peña, N. and J. Sheehan. (2007). Biofuels for Transportation. CDM Investment Newsletter. 2007; 3.
[8] Peña, N., (2008). Biofuels for transportation: a climate perspective. Pew Center on Global Climate Change. Arlington, VA
[9] Energy Challenge Brochure (May 2010), NEA.

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operating costs, maintaining temperature and pH control of the areas used for microalgae growth, and determining CO_2 availability and delivery methods. If these challenges can be overcome, the production of biodiesel from algal biomass will be promising. Assuming an algal oil content of 30% (w/w) in biomass, the current cost of algal oil production is estimated at $2.8 per litre. Taking into account the energy density of algal oil being 80% of biodiesel, the algal oil production for biofuel would be viable at a cost of about $0.68 per litre, at the current crude oil price of $0.85 per litre (US$0.71/L). Looking from another perspective, the crude oil price has to rise above $3.36/L (US$443.56/barrel) for algal oil, i.e. 3rd-generation biofuel to be viable as a feedstock for biodiesel using the current production technology.

SEQUESTRATION OF CARBON

Microalgae utilizes carbon dioxide in the photosynthetic process, and has been proposed as a form of biological sequestration to lower carbon emissions.[10] Microalgae has the highest rate of biomass accumulation, and has the ability to store energy as lipids within its cells, which reduces processing requirements to obtain the bio-oils to use as biofuels.

BIOREFINERIES

A biorefinery is a chemical facility comprising of many processes that treat and convert biomass feedstocks into a spectrum of valuable products,[11] e.g. chemicals and fuels. The biorefinery concept has similarities to a conventional refinery, except that it uses biomass as feedstock instead of petroleum. Biorefineries are increasingly seen as facilities to produce not only a variety of chemicals, fuels, intermediates and consumer products, but that different feedstocks and processing methods can be used within a single biorefinery facility. *Nonetheless, while the technologies for developing such products in biorefineries already exist, none are currently cost-competitive with existing commercial fossil-based technologies.*

Biorefineries can be classified based on the types of feedstocks they use, namely, whole-crop, green-crop and lignocelluloses. Among these three feedstock types, *the authors assess that lignocellulosic feedstock (LCF) is the most promising because of its abundance, renewability, lack of competition with food crops, and its ability to contribute to reducing up to 70% or more CO_2 emissions compared to crude oil.* LCF includes biomass sources such as paper, MSW, forest waste, horticultural waste, corn stover and wheat straw.

[10] Intergovernmental Panel on Climate Change: Special report on Carbon Capture and Storage, (2005).

[11] U.S Department of Energy (1997) Energy, environmental, and economics (E3) handbook-a resource tool to aid the office of industrial technologies, 1st ed. http://www.p2pays.org/ref/36/35057.htm

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Approximately 1.8 million tonnes of lignocellulosic waste is generated every year in Singapore.[2] Singapore is also surrounded by biomass-rich countries (e.g. Malaysia and Indonesia), and this suggests that Singapore has access to sufficient feedstocks for commercial-scale biorefineries producing biofuels and value-added chemicals. *The authors assess that there is good potential to develop biorefineries in Singapore.* In addition, this development can potentially help to complement the pre-dominant petroleum-based complexes on Jurong Island.

With Singapore's excellent infrastructure, long-term investment in bio-based research and a pool of excellent research talent, the authors opine that Singapore has all the ingredients necessary to become a leader in implementing sustainable biorefinery and bio-based technologies. Neste Oil has taken a significant step in this direction by investing about S$995 million in building and operating the world's largest renewable diesel plant in Singapore. The plant came on stream in November 2010 and has a capacity of 800,000 tonnes. Over the product's entire life-cycle, the renewable biodiesel produced from this plant has been shown to reduce GHG emissions by at least 50% compared to diesel produced from fossil fuels.[12]

The production steps to obtain the basic building blocks of chemical production (e.g. ethylene, propylene and methanol) using a combination of developing biofuel and established chemical technologies are illustrated in *Figure 4*.

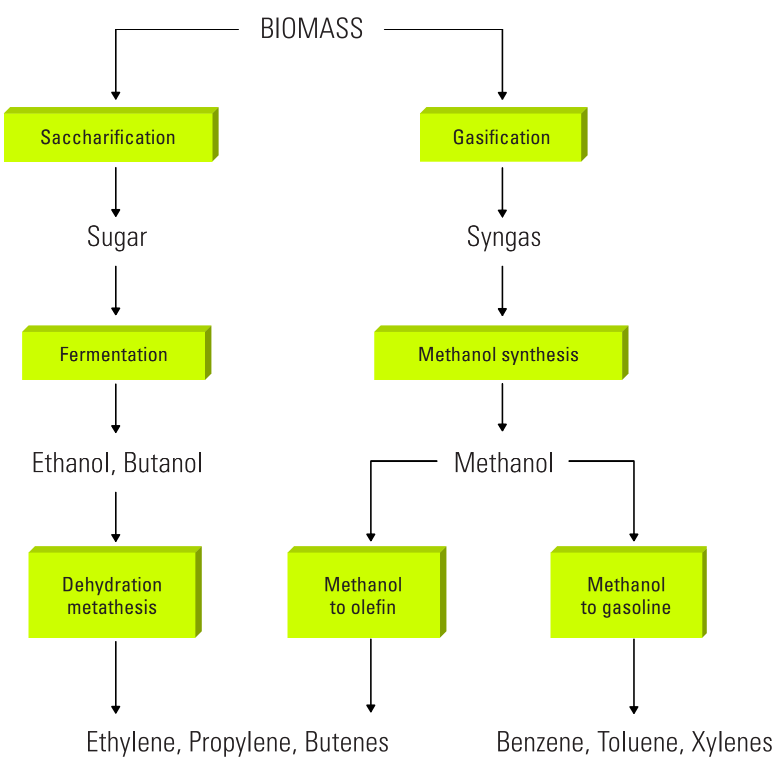

Figure 4: Steps for producing the basic building blocks of chemical production from biomass

[12] Neste Oil, (2011). http://www.nesteoil.com

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AREAS OF R&D FOR SINGAPORE

Photosynthetic microalgae is a means of converting CO_2 to biofuels. However, it has low energy density. In land scarce Singapore, it will not be a significant contributor to our energy demands. As such, *the authors recommend that one of the R&D focus for Singapore on biorenewables should be to increase the energy density of photosynthetic algae.*

Other areas of R&D that the authors recommend that Singapore should focus on for biorenewables include research in:

a. *Bio-oil upgrading technology* as it is still in its infancy stage and that the R&D efforts in Singapore are almost on par with its international competitors;
b. *Biomass pre-treatment*, e.g. by improving microbes through genome shuffling;
c. *Developing cost-effective and sustainable biorefineries.*

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Main contributors:

National University of Singapore (NUS)
Associate Professor Yuan Kuan LEE (Lead author)
Professor Iftekhar A. KARIMI

Nanyang Technological University (NTU)
Associate Professor Jing-Yuan WANG (Lead author)
Dr Dong Ho LEE
Dr Wei QI
Ms Yu MO
Dr Ke YIN
Dr Lei ZHAO

Institute of Chemical and Engineering Sciences (ICES), A*STAR
Dr Pui Kwan WONG
Dr Jie CHANG
Dr Luwei CHEN
Dr Kanaparthi RAMESH
Dr Ludger Paul STUBBS
Dr Jin Chuan WU

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APPENDIX

TYPES OF FEEDSTOCK IN THE REGION

(A) Virgin wood

Combustible renewables and waste supply about 35% and 15% of the energy demands in South Asia and Southeast Asia, respectively *(Figure A1)*. At present, wood fuel is the most commonly used combustible renewable worldwide for energy production. The uncontrolled combustion of wood fuel will lead to large-scale emissions of pollutants (e.g. carbon monoxide, hydrocarbons and particulates) into the atmosphere, which cause serious environmental and health problems. Technologies to convert virgin wood to clean energy are needed in view of its importance as a biorenewable feedstock.

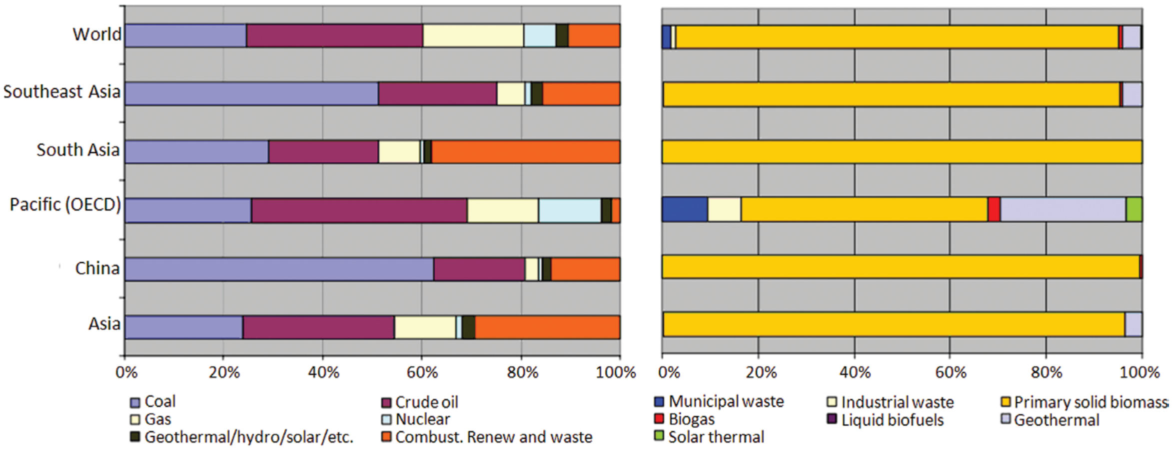

Figure A1: Breakdown of primary energy sources and feedstock types used for energy generation in 2004, according to world regions[13]

(B) Energy Crops and Agricultural Residues

Agriculture is a major industrial sector in all developing Asian economies.[14] As such, there is an abundant supply of biorenewables from energy crops and agricultural residues in this region. Some of the most important economic crops in Asia include rice, maize, wheat, oil seeds, fruits, vegetables, and industrial and beverage crops.[14] By 2017, China and India will have a combined total of 86 mega hectares (Mha) of land for energy crops. This will contribute to the total biomass potential from energy crops and agricultural residues for both countries reaching levels of 13.2 exajoule (EJ) and 3.7 EJ, respectively.[15]

[13] OECD/IEA (2007). Energy Balances of non-OECD Countries, Organisation for Economic Co-operation and Development / International Energy Agency.

[14] FAO (2006). The state of food and agriculture in Asia and the Pacific, Food and Agriculture Organization of the United Nations.

[15] IEA (2009). Bioenergy - a sustainable and reliable energy source, International Energy Agency.

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Agricultural residues from plantations such as straw, stalk and husk are well studied for their possibilities to be used as feedstocks for energy generation.[16-19]

(C) Municipal Solid Waste (MSW)

Urbanisation is occurring very rapidly in the Asia-Pacific region. In East Asia, the percentage of its population living in urban areas increased from 33% in 1994 to 42% in 2004.[14] The figures for Southeast Asia (SEA) were 34% in 1994 and 42% in 2004.[14] It is expected that a growing amount of MSW (e.g. food waste, sludge, plastic and horticultural waste) will be generated as a result of rapid urbanisation. The organic fraction of MSW can potentially be used as a biorenewable resource for energy generation.[20-23]

(D) Industrial waste and co-products

Technologies to convert the food industry's co-products to energy are currently being explored.[24–25] Co-products from the manufacturing process of palm oil (e.g. oil seed cakes and empty oil palm fruit bunches) are being used as feedstocks for bioenergy in Malaysia, Indonesia and Thailand.[26]

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[16] Velásquez-Arredondo, H. I., A. A. Ruiz-Colorado, et al. (2010). "Ethanol production process from banana fruit and its lignocellulosic residues: Energy analysis." Energy 35(7): 3081-3087.

[17] Wang, E. Q., S. Z. Li, et al. (2010). "Modeling of rotating drum bioreactor for anaerobic solid-state fermentation." Applied Energy 87(9): 2839-284.

[18] Theansuwan, W., M. Monteepila, et al. (2011). Bio-oil production from agricultural residues in Northeast of Thailand by fast pyrolysis technology. 189-193: 1584-1587.

[19] Zhong, W., Z. Zhang, et al. (2011). "Comparison of chemical and biological pretreatment of corn straw for biogas production by anaerobic digestion." Renewable Energy 36(6): 1875-1879.

[20] Fatih Demirbas, M., M. Balat, et al. (2011). "Biowastes-to-biofuels." Energy Conversion and Management 52(4): 1815-1828.

[21] Mata-Alvarez, J., J. Dosta, et al. (2011). "Codigestion of solid wastes: A review of its uses and perspectives including modeling." Critical Reviews in Biotechnology, 31(2): 99-111.

[22] Yangin Gomec, C., M. E. Ersahin, et al. (2011). "Biomethane production as an alternative bioenergy source from codigesters treating municipal sludge and organic fraction of municipal solid wastes." Journal of Biomedicine and Biotechnology

[23] Zhang, Q., L. Dor, et al. (2011). "Gasification of municipal solid waste in the Plasma Gasification Melting process." Applied Energy.

[24] Goh, C. S., K. T. Tan, et al. (2010). "Bio-ethanol from lignocellulose: Status, perspectives and challenges in Malaysia." Bioresource Technology 101(13): 4834-4841.

[25] Önal, E. P., B. B. Uzun, et al. (2011). "Steam pyrolysis of an industrial waste for bio-oil production." Fuel Processing Technology 92(5): 879-885.

[26] Razuan, R., K. N. Finney, et al. (2011). "Pelletised fuel production from palm kernel cake." Fuel Processing Technology 92(3): 609-615.

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