WASTE-TO-WEALTH THROUGH BIOTECHNOLOGY:
For Profit, People and Planet
WASTE-TO-WEALTH
THROUGH BIOTECHNOLOGY:
For Profit, People and Planet

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ABSTRACT

As part of business-as-usual, all industries and social communities create waste. Traditionally, wastes are considered as a problem and financial burden for the industry and community, since wastes have to be managed or treated for safe discharge or ultimate disposal. Currently, organic and agro-industrial wastes and biomass are increasingly regarded as additional income streams and potential raw materials for the generation of value-added products. In Malaysia, agro-industrial biomass has been widely used for heat and power generation for internal consumption, mainly in the palm oil and wood-based industries. This is attributed to the high demand of energy from these industries and the simplicity of the conversion technologies involved compared to that required for biological conversion. Moreover, this approach is another method of waste disposal for the industry. Power generation using boiler systems in all the palm oil mills in Malaysia is the best example, whereby electricity is generated through the simple combustion of palm kernel shell and mesocarp fiber. However, this thermal conversion of agro-industrial biomass represents low-end utilization of biomass. Moreover, oil palm empty fruit bunches which are produced in huge quantities are still very much underutilized. Our research group has embarked on comprehensive international and industrial research collaborations to enhance the technology and potential of agro-industrial biomass utilization in Malaysia, focusing mainly on palm oil -based residues, which are automatically collected as part of business-as-usual at the palm oil mills, for the production of new biotechnological products. Among the waste-to-wealth biotechnology products are biogas (methane) for renewable energy, organic acid feedstocks, biodegradable plastics, biocompost, biohydrogen and cellulosic bioethanol.

The main obstacles in the development of industries based on biotechnology are complexity of the technology and economic feasibility. As industrial and environmental biotechnologists in a developing country, we strive to develop appropriate technologies to raise the value chain of biomass from fuel to feed,
fiber, food and fine chemicals. We incorporate the use of the Clean Development Mechanism (CDM) under the Kyoto Protocol in realizing the sustainable biomass industry in Malaysia, encompassing economic, social and environmental benefits (the 3Ps - profit, people and planet). Apart from being a good strategy for the reduction of greenhouse gas (GHG) emissions, the CDM also provides a more attractive business plan to utilize biomass as renewable resources to generate new bioproducts and additional income streams for the palm oil industry.
INTRODUCTION

There is no known living system that does not generate wastes. On average, each one of us generates 1 kg of municipal solid waste and 200 liters of domestic sewage daily. Industrial processes are also inherently notorious pollutants due to the release of various waste streams. With increasing population, increasing per capita consumption and industrialisation in relation to increased economic activities, pollution due to the discharge of untreated wastes into the environment has attracted everyone’s attention and concern. Today, the issues of global warming and climate change due to the increasing discharge of greenhouse gases are so important that they are covered in mainstream newspapers almost daily and discussed by world leaders during their economic summit!

Figure 1 shows the effects of pollution on global warming and climate change. Table 1 lists issues related to environmental pollution due to two main root causes, i.e. over-population and in particular, over-consumption.
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Table 1  Issues on waste management and environmental pollution

- Global warming
- Greenhouse effect
- Changing weather patterns
- Melting of ice caps
- Depletion of ozone layer
- Pollution of water
- Leaching of toxic chemicals
- Deforestation
- Development versus environmental protection (3P – profit, people, planet)
- Sustainable development

The Holy Qur’an states in Surah Ar Rum (30), verse 41:

“Mischief has appeared on land and sea, due to the hands of men..”

and in Surah Al A’raf (7), verse 31:

“...eat and drink, but waste not by excess, for Allah loves not the wasters”.

It is in this spirit that Islam Hadhari includes the preservation of the environment among its 10 principles (Table 2; Badawi 2006).

Table 2  The 10 principles of Islam Hadhari

1. Faith and piety in ALLAH
2. Just and trustworthy government
3. Free and independent people
4. Vigorous pursuit and mastery of knowledge
5. Balanced and comprehensive economic development
6. Good quality of life for the people
7. Protection of the rights of minority groups and women
8. Cultural and moral integrity
9. Safeguarding of the natural resources and the environment
10. Strong defence capabilities

There are 4 stages of development in waste management and treatment as shown in Figure 2, i.e.:

1. no treatment (indiscriminate discharge)
2. treatment for safe discharge (to meet environmental standards)
3. incorporating several 3R approaches
4. zero-emission

Figure 2 The four stages of waste management
The Department of Environment, Malaysia sets several standards for the discharge of effluents; Standard A for water catchment areas, Standard B for other areas and specific standards for prescribed premises (Table 3; Md. Noor, 1999).

**Table 3** DOE discharge standards

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Standard A</th>
<th>Standard B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>pH value</td>
<td>-</td>
<td>6.0 – 9.0</td>
<td>5.5 – 9.0</td>
</tr>
<tr>
<td>BOD(_5) at 20°C</td>
<td>mg/L</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>COD</td>
<td>mg/L</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>mg/L</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Oil and grease</td>
<td>mg/L</td>
<td>Not detectable</td>
<td>10.0</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>mg/L</td>
<td>1.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>mg/L</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>mg/L</td>
<td>0.01</td>
<td>0.02</td>
</tr>
</tbody>
</table>

For solid wastes, there are three traditional approaches to waste treatment and ultimate disposal, i.e. landfilling, incineration and composting. Composting is the biotechnological solution to waste management, suitable for most organic and bio-based wastes.

Current waste management practices normally include the 3R strategies, i.e. reduce, re-use and recycle. The public can participate voluntarily by reducing consumption of resources such as water and electricity, performing source segregation of wastes and participating in community recycling campaigns.
The government introduced the National Biotechnology Policy in April 2005 with the motto “biotechnology for wealth creation and social well-being”. The Policy outlined 9 thrust areas (Table 4) and 3 stages of implementation (Figure 3) —incorporating the creation of new biotechnological industries through industrial and environmental biotechnology (MOSTI, 2005).

**WASTE AND BIOMASS RESOURCES**

Biomass can be defined as organic matter available on a renewable basis. Biomass includes forest and mill residues, agricultural crops and wastes, wood and wood wastes, animal wastes, livestock operation residues, aquatic plants, fast-growing trees and plants and municipal and industrial wastes. Thus biomass is any gaseous, liquid and solid product derived from biological or organic matters. These raw materials come mainly from plants, municipal wastes, forest residues and agricultural residues, as follows:

- **Agricultural crops** such as sugarcane, cassava, corn, etc.
- **Agricultural residues** such as oil palm fronds, rice straw from rice fields, cassava rhizome from tapioca fields, corncobs from cornfields, etc.
- **Wood and wood residues** such as fast-growing trees, wood waste from wood mills, waste from pulp and paper mills, etc.
- **Waste streams** such as oil palm fiber, empty fruit bunches and palm oil mill effluent, rice husk from rice mills, molasses and bagasse from sugar refineries, municipal solid wastes (MSW), etc.

In Malaysia, biomass resources are mainly from its palm oil, wood and agro-industries (Table 5). All of these residues come in many forms such as palm oil mill residues, bagasse, rice husks and wood/forest residues (Hashim and Ludin, 2005). Major sources of biomass are oil palm residues in the form of empty fruit bunches (EFB), fibers, shells, palm trunks, fronds and palm oil mill effluent (POME). The composition of MSW in Malaysia is given in Table 6.
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**Table 4** The nine thrusts of National Biotechnology Policy

<table>
<thead>
<tr>
<th>Thrust 1: Agriculture Biotechnology Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transform and enhance the value creation of the agricultural sector through biotechnology</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Thrust 2: Healthcare Biotechnology Development</th>
</tr>
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<tbody>
<tr>
<td>Capitalise on the strengths of biodiversity to commercialise discoveries in natural products as well as position Malaysia in the bio-generic market</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thrust 3: Industrial Biotechnology Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ensure growth opportunities in the application of advanced bio-processing and bio-manufacturing technologies</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thrust 4: R&amp;D and Technology Acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establish Centres of Excellence, in existing or new institutions, to bring together multidisciplinary research teams in co-ordinated research and commercialisation initiatives. Accelerate technology development via strategic acquisitions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thrust 5: Human Capital Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build the nation’s biotech human resource capability in line with market needs through special schemes, programmes and training</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thrust 6: Financial Infrastructure Development</th>
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</thead>
<tbody>
<tr>
<td>Apply competitive “lab to market” funding and incentives to promote committed participation by academia, the private sector as well as government-linked companies. Implement sufficient exit mechanisms for investments in biotech</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thrust 7: Legislative and Regulatory Framework Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create an enabling environment through continuous reviews of the country’s regulatory framework and procedures in line with global standards and best practices. Develop a strong intellectual property protection regime to support R&amp;D and commercialisation efforts</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thrust 8: Strategic Positioning</th>
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<tbody>
<tr>
<td>Establish a global marketing strategy to build brand recognition for Malaysian biotech and benchmark progress. Establish Malaysia as a centre for Contract Research Organisations and Contract Manufacturing Organisations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thrust 9: Government Commitment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establish a dedicated and professional implementation agency overseeing the development of Malaysia’s biotech industry, under the aegis of the Prime Minister and relevant government ministries</td>
</tr>
</tbody>
</table>
Mohd Ali Hassan

Figure 3  The three phases in National Biotechnology Policy

Table 5  Biomass resources in Malaysia

<table>
<thead>
<tr>
<th>Sector</th>
<th>Quantity kton / yr</th>
<th>Potential Annual Generation (GWh)</th>
<th>Potential Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice Mills</td>
<td>424</td>
<td>263</td>
<td>30</td>
</tr>
<tr>
<td>Wood Industries</td>
<td>2177</td>
<td>598</td>
<td>68</td>
</tr>
<tr>
<td>Palm Oil Mills</td>
<td>17980</td>
<td>3197</td>
<td>365</td>
</tr>
<tr>
<td>Bagasse</td>
<td>300</td>
<td>218</td>
<td>25</td>
</tr>
<tr>
<td>POME</td>
<td>31500</td>
<td>1587</td>
<td>177</td>
</tr>
<tr>
<td>Total</td>
<td>72962</td>
<td>5863</td>
<td>665</td>
</tr>
</tbody>
</table>
CURRENT PRACTICE IN PALM OIL INDUSTRY

Crude palm oil (CPO) is extracted from the mesocarp of the fruitlets while palm kernel oil is obtained from the kernel. The oil contents are 20% and 4% from mesocarp and kernel, respectively. Palm oil is semi-solid oil which is rich in vitamins. The major fatty acids present are oleic, palmitic and linoleic. In the process of producing the palm oil, a considerable amount of water is required. This results in large volumes of wastewater generated. There are 2 main sources of palm oil wastewaters - palm oil mills and palm oil refineries. However, the former is the larger source of effluent and the more polluting. It is known as palm oil mill effluent (POME). It was estimated that annually 50 million tonnes of POME were produced from about 400 palm oil mills in Malaysia. The average mass balance for the palm oil industry is given in Figure 4; Hassan et al, 2007).
Production of Crude Palm Oil

It is important to note that in the extraction of oil from the oil palm fruits no chemicals are added, thereby making all wastes generated from the palm oil mill, non-toxic to the environment. It involves, mainly, mechanical and heating processes. The extraction of crude palm oil involves several steps as illustrated below (Hassan et al, 2006).

Sterilization

To ensure the quality and productivity of palm oil mills, the fresh fruit bunches (FFB) must be processed within 24 hours of harvesting. That is the reason why most palm oil mills are located in close proximity to the oil palm plantation. In this process the FFB is subjected to 3 cycles of extreme heat and pressure for 90 minutes. There are 4 objectives for the FFB sterilization, i.e. to remove external impurities, to soften and loosen the fruitlets from the bunches, to detach the kernels from the shells and, most importantly, to deactivate the enzymes.
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responsible for the build-up of free fatty acids. The process is crucial as it will ensure that the fruitlets are dislodged from the bunch and reduce the production of undesirable free fatty acids. The sterilization process acts as the first contributor to the accumulation of POME in the form of sterilizer condensate.

**Bunch Stripping**

Upon completion of the sterilization, the “cooked” FFB will be subjected to mechanical threshing to detach the fruitlets from the bunch. At this stage the loose fruitlets are transferred to the next process while the empty fruit bunches (EFB) can be recycled within the plantation for mulching or as organic fertilizer.

**Digestion and Pressing**

The digester consists of a cylindrical vessel equipped with stirrer and expeller arms, mainly to digest and press the fruitlets. Steam is introduced to facilitate oil extraction from the digested mesocarp. At the end of the process, oil and pressed cake, comprising of nuts and fibre, are produced. The extracted oil will then be purified and clarified in the next stage. At the same time the fibre and nuts are separated in the depericarper column. The waste fibre is then burnt for energy generation inside the boiler.

**Oil Clarification and Purification**

As the name implies, the extracted oil is clarified and purified to produce CPO. Dirt and other impurities are removed from the oil by centrifugation. Before the CPO is transferred to the storage tank, it is subjected to high temperature to reduce the moisture content in the CPO. This is to control the rate of deterioration during storage prior to processing in the palm oil refinery. The sludge which is the by-product of the clarification and purification procedures is the main source of POME in terms of polluting strength and quantity.
Nut Cracking

At this point, the nuts from the digestion and pressing processes are polished (to remove remnants of fibre) before being sent to the nut cracking machine or ripple mill. The cracked mixture of kernels and shells are then separated in a winnowing column using upwards suction (hydrocyclone) and clay bath. The third source of POME is from the wash water of the hydrocyclone. The kernel produced is then stored before being transferred to the palm kernel mill for oil extraction. Shell wastes will join the fibre in the boiler for steam and power generation.

Palm Oil Mill Effluent (POME)

POME originates chiefly from 2 main processes i.e. the sterilisation and clarification stages, as condensate and clarification sludge, respectively. The clarification sludge shows higher levels of solid residues compared to the steriliser condensate. Both contain some levels of unrecovered oils and fats. The final POME would undergo hydrocyclone washing and cleaning up processes in the mill (Agamuthu, 1995). Approximately 1 tonne of water is required to process 1 tonne of FFB.

Based on the process of oil extraction and the properties of FFB, POME is made up of about 95% – 96 % water, 0.6% – 0.7% oil and 4% – 5% total solids including 2% - 4% suspended solids which are mainly debris from palm mesocarp (Ma, 1999a). No chemicals are added during the palm oil production process and thus it is non-toxic waste. Upon discharge from the mill, POME is in the form of highly concentrated dark brown colloidal slurry of water, oil and fine cellulosic materials. Due to the introduction of heat (during the sterilization stage) and vigorous mechanical processes, the discharge temperature of POME is approximately 80-90°C. The chemical properties of POME vary widely and depend on the operations and quality control of individual mills. The general properties of POME are as indicated in Table 7.
Apart from its organic composition, POME is also rich in mineral content particularly phosphorus (18mg/l), potassium (2,270 mg/l), magnesium (615 mg/l) and calcium (439 mg/l) (Basiron and Darus, 1995). Thus most of the dewatered POME dried sludge (solid end-product of the POME treatment system) can be recycled or returned to the plantation as fertilizer.

Owing to its chemical properties, POME can be easily treated using a biological approach. With its high organic and mineral content, POME provides a suitable environment for microorganisms to thrive. Hence it could harbour a consortium of microorganisms that will consume or break down the wastes or pollutants and turn them into harmless by-products. In some cases, these by-products have high economic value and can be used as potential renewable sources of energy. In order to achieve such a goal, a suitable mixed population of microorganisms must be introduced and the process should be optimised. There are 3 biological processes that are currently being employed by the industry as a series of anaerobic, facultative anaerobic and aerobic treatments. However, the major reduction of POME polluting strength i.e. up to 95% of its original BOD occurs in the first stage, i.e. during the anaerobic treatment process (Ma, 1999b).

The Anaerobic process involves 3 main stages; hydrolytic, acidogenic and methanogenic. In the first stage, hydrolytic microorganisms secrete extracellular
enzymes to hydrolyse the complex organic complexes into simpler compounds such as triglycerides, fatty acids, amino acids and sugars. These compounds will then be subjected to fermentative microorganisms that are responsible for their conversion into short-chain volatile fatty acids - mostly acetic, propionic, butyric acids and alcohols. At the final stage, there are 2 separate biological transformations. Firstly there is a conversion of acetic acid into methane and carbon dioxide by methanogens and secondly, the propionic and butyric acids will be converted to acetic acid and hydrogen gas before being consumed by the methanogens. The end-products of the anaerobic degradation are thus methane and carbon dioxide. Traces of hydrogen sulfide are also detected as a result of the activity of sulfate-reducing bacteria in the anaerobic treatment. The BOD during the first 2 stages is at the same level as when it entered the anaerobic treatment because only the breakdown of the complex compounds to a simpler mixture of organic materials had occurred. Only after the methanogenic stage, will the BOD be significantly reduced.

Wastewater Treatment Systems for POME

The choice of POME wastewater treatment systems is largely influenced by the cost of operation and maintenance, availability of land and the location of the mill. Nevertheless, the first factor plays a bigger role in the selection of the treatment systems. In Malaysia, the final discharge of the treated POME must follow the standard set by the Department of Environment (DOE) which is 100 mg/l of BOD or less (Table 2) regardless of which treatment system is utilized.

Prior to the primary treatment, the mixed raw effluent (MRE – mixture of wastewater from sterilization, clarification and other sources) will undergo a pre-treatment process which includes the removal of oil and grease, followed by a stabilization process. The excess oil and grease is extracted from the oil recovery pit using an oil skimmer. In this process, steam is continuously supplied to the MRE to aid the separation of the oil from the liquid sludge.
The recovered oil is then reintroduced to the purification stage. The process will prevent excessive scum formation during the primary treatment stage and increase oil production. The MRE is then pumped into the cooling and mixing ponds for stabilisation before primary treatment. No biological treatment occurs in these ponds, however, sedimentation of abrasive particles such as sand will ensure that all the pumping equipment are protected. The retention time of the MRE, in the cooling and mixing ponds, is between 1 to 2 days.

**Ponding System**

It comprises of a series of anaerobic, facultative and algae (aerobic) ponds. The ponding systems have less energy requirements with no mechanical mixing, operation control or monitoring required. Mixing is very limited and achieved through the bubbling of gases and this is generally confined to the anaerobic ponds and partly within the facultative ponds. On the other hand the ponding systems require a vast area to accommodate a series of ponds in order to achieve the desired characteristics for discharge. For example in the FELDA Serting Hilir Palm Oil Mill, the total length of the wastewater treatment system is about 2 kilometers with each pond about the size of a football field (Figure 5). Only clay lining of the ponds is needed and it is constructed by excavating the earth. Hence the ponding system is the most favourable system for the palm oil industry due to its low cost.

In constructing the ponds, the depth is most crucial as this would determine the type of biological process. The length and width differ based on the availability of land. For the anaerobic pond the normal depth is 5 meters while the facultative anaerobic ponds are 1.5 meters deep. The Effective hydraulic retention times (HRT) of anaerobic and facultative anaerobic processes are 45 and 20 days respectively. Shallower ponds of less than 1 meter depth are required for aerobic ponds with HRT of 14 days. POME is pumped at a very low rate of 0.2-0.35 kg BOD/m³/day of organic loading. In between the different
Mohd Ali Hassan

stages of the ponding system, no pumping is required as the treated POME will flow due to gravitational forces or sideways tee type subsurface draw-off systems. Under these optimum conditions the system is able to meet the requirements of DOE. The number of ponds will depend on the production capacity of each palm oil mill.

One of the problems faced by the operator is the formation of scum. It occurs as the bubbles rise, taking along fine suspended solids to the surface. This is as a result of the presence of oil and grease in the POME which are not effectively removed during the pre-treatment stage. Another disadvantage of the ponding system is the accumulation of solid sludge at the bottom of the ponds. Eventually the sludge and scum will combine and shape into islands inside the pond thus affecting the effectiveness of the pond by reducing its volumetric capacity and HRT. When this happens, the sludge is removed by either using submersible pumps or excavators. The sludge removed is dewatered and dried before being used as fertilizer. The clean up is normally carried out every 3 years or when the capacity of the pond has been significantly reduced.
Open Digester and Ponding Systems

The system encompasses a combination of open digester tank and a series of ponding systems. Anaerobic digestion is initially carried out in the digester followed by in the facultative anaerobic and algae ponds. It has been proven that by using an open digester, better reduction of BOD can be achieved in a shorter time. Digesters are constructed with mild steel at various volumetric capacities ranging from 600-3600 m$^3$. The treated POME from the digester will be fed to the facultative ponds and subsequently the algae ponds.

The HRT of the digester is only 20-25 days and it has a higher organic loading of 0.8-1.0 BOD kg/m$^3$/day compared to the anaerobic ponds. It requires minimal financial input from the operators as no mechanical mixing equipment is installed in the digesters. Using the same principle as the anaerobic ponds, the mixing of POME is achieved via bubbling of biogas. Occasionally, the mixing is also achieved when the digester is being recharged with fresh POME. The treated POME then overflows into the ponding system for further treatment.

Even though the digester system has proven to be superior to the anaerobic ponds, it faces similar problems of scum formation and solid sludge accumulation. Further, being made from mild steel, corrosion of the metal structures due to long exposure to hydrogen sulfide is a serious problem. Incidences such as burst and collapsed digesters have been recorded. Accumulated solids could be removed using the sludge pipe located at the bottom of the digester. The dewatered and dried sludge can then be disposed for land application.

Extended Aeration

To complement the previous systems, mechanical surface aerators can be introduced in the aerobic ponds. This is to effectively reduce the BOD through aerobic processes. The aerators are normally installed at the end of the ponding system before discharge. However, this happens only where land area is a
constraint and does not permit extensive wastewater treatment. Investment has to be made to ensure that the aerators comply with DOE regulations.

**Solid Palm Biomass**

The oil extraction ratio (OER) from the fresh fruit bunch is about 20%, thus 80% is waste or biomass. All the mesocarp fiber and most of the palm kernel shells are currently utilized for steam and electricity generation in the mills. The empty fruit bunches are mainly handled by mulching, incineration and as landfills. A limited number of mills are now beginning to shred the EFB for co-composting with POME and POME sludge.

**Future Trends**

Several potential and emerging technologies for POME wastewater treatment systems can be integrated into the palm oil mill operations. The strategy is to combine the existing wastewater treatment system with the production of appropriate bioproducts towards zero discharge for the palm oil industry (Hassan et al, 2002). During the anaerobic treatment, methanogenic activity will be suppressed or inhibited in order to extract the organic acids produced. This is turn will lower greenhouse gas (methane and carbon dioxide) emissions from the anaerobic digestion thus reducing the effects of global warming. Further separation and purification processes are needed before these organic acids can be utilised as a substrate for PHA-producing microorganisms. The solid wastes (sludges) generated from the wastewater treatment systems can be used as a mixture with EFB to form bio-compost.

Wastes generated from the palm oil mills contain a high percentage of degradable organic materials which can be converted into value-added products and chemicals. It is expected that changes in the technologies in POME treatment could lead to a substantial reduction in terms of the wastes discharged. On the other hand, the palm oil industry will experience sustainable growth by
addressing the excessive pollution issue through development of biowastes as alternatives sources of renewable energy and valuable chemicals which will generate additional revenues for the industry. Additionally, better integrated waste management is associated with other environmental benefits such as reduction of surface waterbody and groundwater contamination, preventing waste of land and resources, lower air pollution and reduction in the accelerating rate of climate changes.

WASTE-TO-WEALTH THROUGH BIOTECHNOLOGY

Ideally, wastes and biomass should be considered as resources or raw materials for value-added products going up the value chain from fuel to feed, fiber, furniture and fine chemicals. In reality, however, there are numerous obstacles and practical issues that have to be overcome, especially in terms of technical and economic feasibility (Table 8).

Table 8 Issues in biomass utilisation

1. Increasing demand for food leads to increased biomass/wastes
   a. problem with waste treatment and disposal

2. Open dumps/landfill and wastewater treatment facility
   a. uncontrolled release of greenhouse gases/global warming
   b. groundwater and river contamination from leachate

3. Burning of biomass
   a. emission of smoke (haze hazard), toxic chemicals such as dioxins

4. No special incentives or provisions to utilize these residues

5. Biomass business not economically feasible & long payback periods
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**Biogas (Renewable Energy)**

The biogas emitted from open digester tanks and the lagoon was lower than that reported for laboratory studies (Yacob et al., 2005). The biogas composition was 40% methane and 60% carbon dioxide for open digester tank and 55% methane and 45% carbon dioxide in anaerobic lagoons. In terms of energy value, it is comparable to commercially available gas fuels. The energy that could potentially be generated from 1 m$^3$ of biogas is 1.8kWh (Ma et al., 1999). A closed digester system was tested to improve the anaerobic digestion of POME leading to the production of biogas. Using the same design as an open digester, a fixed or floating cover was included, equipped with other facilities such as gas collector, safety valves and monitoring facilities.

**Biocompost**

Based on our research, dewatered POME sludge can be composted with solid wastes such as EFB and domestic wastes. A modified composter comprising a cement mixer with insulated drum was used as a reactor to run the composting process. Experimental parameters such as aeration, pH, temperature, C/N ratio and moisture content were controlled and monitored during the fermentation phase of the composting process. It took only 40 days to completely convert the POME sludge into a stable compost product via solid substrate fermentation process with mixed microbial inoculum. The carbon content decreased towards the end of the composting process, which resulted in a decrease in the C/N ratio from 30 to 20. The low C/N ratio of the final compost product was very important as an indicator of maturity. The characteristics of the final compost products of the POME sludge were similar to commercial composts and complied with USEPA standards especially in terms of heavy metal content and total coliforms. Planting out tests using leafy vegetables showed satisfactory performance (Abdul Rahman et al., 2001).
Bio-acids

Two-stage fermentation was carried out in a study where POME was used as substrate for volatile fatty acids (VFA) production by continuous anaerobic treatment using a locally fabricated 50 litre continuous stirred tank reactor (CSTR). The highest VFA obtained was at 15 g/L at pH 6.5, 30ºC, 100 rpm, sludge to POME ratio 1:1, HRT 4 days, without sludge recycle. The highest BOD removal corresponded with a high production of organic acids. The organic acids produced from POME were then recovered and purified using acidification and evaporation techniques. The clarified concentrated VFA comprised of 45 g/L acetic, 20 g/L propionic and 22 g/L butyric acids obtained with a recovery yield of 76% (Noraini et al., 1999).

Bioplastics (PHA, Polyhydroxyalkanoates)

The organic acids from treated POME can be used to biologically synthesize polyhydroxyalkanoates (PHA), a bacterial bioplastic. The concentrated organic acids obtained were used in the fed-batch culture of Alcaligenes eutrophus for the production of PHA. About 45% PHA content in the dry cells could be obtained, corresponding to a yield of 0.32 from acetic acid. The overall volumetric productivity of PHA is estimated at 0.09 g PHA per liter per hour. This indicates that the application of high density cell culture to produce bioplastics from POME can be achieved (Hassan et al., 1997a).

Biohydrogen

Another potential application of POME as a renewable resource of energy is the production of biological hydrogen via a fermentation process. The main purpose of producing biological hydrogen is as an alternative source of energy to fossil fuels. The major advantage of biological hydrogen is the lack of polluting emissions since the utilisation of hydrogen, either via combustion or fuel cells, results in pure water. Currently, there are 2 proposed systems to produce
biological hydrogen using photoheterotrophic and heterotrophic bacteria. The latter is most suitable for POME due to the limited light penetration caused by the sludge particles as experienced during the production of PHA by phototrophic Rhodobacter sphaeroides (Hassan et al., 1997b). Moreover, it would be costly to construct and maintain a photobioreactor for commercial scale operations. In the anaerobic degradation of POME, complex organic matter is converted into a mixture of methane and carbon dioxide by a network of syntrophic bacteria. Prior to this, fermentative and acetogenic bacteria will first convert organic matter into a mixture of VFA and hydrogen before it is consumed by methanogenic bacteria. Based on the metabolic activities of these microorganisms in POME degradation, a system combining the organic acids and biological hydrogen production is suggested. However, the utilisation of biological hydrogen from POME is still at the planning stage. Major developments in terms of selection of suitable microorganisms and optimisation of process conditions are required for cost-effective production of hydrogen. Nevertheless, this technology promises a way to conserve the environment by generating clean energy.

**Bioethanol**

Ethanol production from non-food raw materials, in particular cellulosic substrates, is one of the most intensively researched projects worldwide. There is now increased urgency in the race towards finding more sustainable alternatives to petroleum and other fossil fuels. Oil palm empty fruit bunch is an excellent resource for this, since it is automatically collected at the mills in huge amounts every day of the year, as part of “business-as-usual”. Basically there are 4 main stages; i.e. pretreatment of the lignocellulosic EFB for partial removal of lignin and to loosen its structure to make it more amenable to subsequent biological treatment; saccharification with cellulose enzymes or fungi to fermentable sugars; and finally fermentation of the sugars into ethanol followed by recovery and concentration of the ethanol by distillation. The other advantage of cellulosic
ethanol production from EFB is in the usage of the excess energy available in the mills, which makes the process more economically feasible.

**TOWARDS ZERO EMISSION**

Zero emission or zero-discharge is an ideal concept, which no known living system can truly achieve. However, this concept is a useful upper limit which we should strive to work towards. It also helps us to open our minds to the possibilities of developing smart strategies for better utilization of resources and less wastage or pollution. Figure 6 illustrates our strategy for zero emission (or zero discharge) for palm oil mills in Malaysia. The palm oil industry is well suited for biomass utilization, since the biomass is already available at the mills as part of its “business-as-usual”, without any extra cost incurred for collection as with most other biomass!

**Figure 6** Utilisation of palm biomass through biotechnology
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Achievements in research and development over the last decade have led to several appropriate technologies for utilization of palm biomass and POME to produce higher value-added products. In the proposed zero-emission system, the treated wastewater is clean enough to be recycled, hence tremendously reducing the pollution load to rivers. It is interesting to note that due to greater awareness of improved productivity and environmental preservation, some mills are beginning to install decanters and continuous sterilizers which have resulted in reduced usage of water and hence, less POME generated.

KYOTO PROTOCOL AND CLEAN DEVELOPMENT MECHANISM (CDM)

The Intergovernmental Panel on Climate Change (IPCC) declared in 2001 that human activity is the main factor contributing to global warming. In 2005, the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol were ratified by more than 150 countries. The Kyoto Protocol sets legally binding limits on greenhouse gas (GHG) emissions from industrialized countries (or Annex 1 countries) and promotes market-based mechanisms to implement measures to reduce emissions.

The three mechanisms that were developed under the Kyoto Protocol are:

1. Clean Development Mechanism (CDM)
2. Joint Implementation (JI)
3. Emissions Trading (with certified emission reduction, CER)

Malaysia is a non-Annex 1 country, and it is hence not legally required to reduce GHG emissions. However, the government has decided to voluntarily participate in the Kyoto Protocol and use CDM as a means of attracting foreign investment in GHG mitigation projects and to support the sustainable development objectives of Malaysia.
Malaysia has set five main criteria for CDM projects in the country:

1. the project must support the sustainable development policies of Malaysia
2. implementation of CDM projects must involve participation of a party/parties from an Annex 1 country
3. the project must provide technology transfer and/or improvement in technology
4. the project must fulfill all conditions underlined by the CDM Executive Board
5. the project proponent should justify its ability to implement the CDM project

Potential CDM projects in Malaysia include development of renewable energy (biomass power generation, biogas, solar, hydro, etc.), improvement in energy efficiency (heat and electricity, improved boilers, fuel switching, etc.) and waste management (power and heat from wastes, gas recovery from landfills, anaerobic wastewater treatment, biogas energy, etc.). Currently 26 CDM projects have been given host country approval and registered with the CDM Executive Board, with 4 CDM projects being issued with certified emission reduction (CER) credits amounting to more than 460,000 tons CO\textsubscript{2} equivalent.

**SUSTAINABILITY OF PALM OIL INDUSTRY – FOR PROFIT, PEOPLE AND PLANET**

In order to make the palm oil industry sustainable, the three sustainability domains must be addressed, i.e. economic, social and environmental (Figure 7). The strategy is to develop a win-win-win approach encompassing all these areas. Several key stakeholders in the palm oil industry including growers, processors, marketers, consumers and environmental groups have now established a non-profit organisation called the ‘Roundtable for Sustainable
Mohd Ali Hassan

Palm Oil' (RSPO). Recently, the concept of certified sustainable oil palm has been introduced by RSPO.

![Image of the three P's of sustainable development](image)

**Figure 7** The three P's of sustainable development

Our research group has been successful in developing joint projects with the palm oil industry which has led to commercialisation. Our approach has been to develop waste-to-wealth strategies by utilising oil palm biomass within the zero-emission framework, with the application of CDM. The big picture on sustainable palm oil using biomass for the palm oil mill is shown in Figure 8.

![Image of CDM and sustainable palm oil industry](image)

**Figure 8** Towards a sustainable palm oil industry
CONCLUSION

Palm oil has been and will continue to be one of the most important commodities for Malaysia, contributing to the agricultural sector which is the nation’s third engine of growth. In fact during the economic crisis in the late 1990s, palm oil was one of the saviours of the national economy. Even now, since the increase in palm oil prices correlates with the increase in crude oil prices, the contribution of palm oil to the economy is very significant. Nevertheless, in order to make palm oil competitive in the world market and in order to remain sustainable, the palm oil industry must peacefully co-exist with society and environment. Based on economic development in Malaysia, the growth of the palm oil sector will no longer be contributed to by increased plantation area which is now nearing the ceiling of 4 million hectares. Future growth and development in the sector will be driven by improved planting materials with higher oil yields, improved processing with higher oil extraction rates, adoption of zero-emission strategies and use of biomass for higher value-added products and services.

Our joint international and industrial research group is proud to have done our part to contribute towards the sustainability of our palm oil industry, by creating wealth from waste, promoting economic development in the rural areas and creating a cleaner environment – thus addressing all the three pillars of sustainable development - profit, people and planet!
Mohd Ali Hassan

REFERENCES


BIOGRAPHY

Professor Dr. Mohd Ali Hassan was born on 3rd April 1958 in Sungai Petani, Kedah. He is happily married to Hamidah Ibrahim, and the couple are blessed with 5 sons. Professor Mohd Ali is currently the Dean of the Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia (BioTech UPM). He is jointly appointed as a faculty member at the Department of Process and Food Engineering, Faculty of Engineering, UPM. In addition, he is also an active member of the Institute of Bioscience, UPM.

Professor Mohd Ali obtained his BS (Honours) Chemical Engineering and MS Food Engineering from University of Leeds, UK. He then obtained his MPhil in Chemical Engineering from University of Birmingham and PhD in Environmental Biotechnology from Okayama University, Japan. He also obtained a post-graduate Diploma in Islamic Studies from Universiti Kebangsaan Malaysia.

Professor Ali began his career in UPM as a lecturer in 1982 and has remained loyal to UPM since then. He obtained his professorship in 2002. He has more than 25 years of research and teaching experience in the areas of bioprocess engineering and environmental biotechnology. In addition he has held various administrative positions, as Head of Department, Deputy Dean (Research and Postgraduate) and Deputy Dean (Academic and Student Affairs), before being appointed as Dean of BioTech, UPM in March 2007.

His areas of specialization are Bioprocess Engineering and Environmental Biotechnology. He has taught courses in biochemical engineering, fermentation technology, bioremediation, waste management and utilization, recovery processes, bioreactor design and commercialization of biotechnology. He has worked on hydrolysis of sago starch, waste and wastewater treatment, bioconversion of solid wastes and agro-industrial effluents for improved production of biogas, organic acids and biodegradable plastics, development of a bioreactor system for rapid composting of sludge and municipal solid
waste and zero emission strategies and appropriate technologies for the palm oil industry. He has obtained industrial grants and support from Indah water Konsortium (IWK), Standards and Industrial Research Institute of Malaysia (SIRIM Berhad), Malaysian Technology Development Corporation (MTDC) and FELDA Palm Industries Sdn. Bhd.

Professor Mohd Ali has been actively involved in scientific and professional societies. He was the President of the Malaysian Society for Microbiology for three terms, from 1998-2001, and now serves as Treasurer for the Institution of Chemical Engineers, Malaysia. He is also a member of the IGS Technical Committee (Industrial Grant Scheme) on Waste Recycling and Utilization, Ministry of Science, Technology and Innovation. He also participated as a CRDF Expert Panel member (Commercialization of R&D Fund) under the Malaysian Technology Development Corporation. He is also a committee member advising the Ministry of Higher Education on the strategic areas of biotechnology for the country.

Over the years, from his involvement in biomass and bioplastic projects with JICA (Japan International Cooperation Agency), JSPS (Japan Society for the Promotion of Science), NEDO (New Energy Development Organisation, Japan) and AIST (Advanced Industrial Science and Technology Institute, Japan), Professor Mohd Ali has developed international linkages with researchers at Kyoto University, Osaka University, Tokyo University, Kyushu Institute of Technology and Kyushu University, Japan. He has also developed research linkages on polyhydroxyalkanoates (PHA, a group of degradable bioplastics) with Massachusetts Institute of Technology, USA. Currently, he is developing linkages with Manchester University, UK and the new prestigious King Abdullah University of Science and Technology (KAUST) on cellulosic bioethanol and metabolic engineering. Professor Mohd Ali now serves as the country representative in the Asia Biomass Association (ABA), based in Tokyo, Japan.
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Professor Mohd Ali enjoys teaching, research and professional services. To date, he has published his research work in more than 50 refereed journals. He has won several awards nationally and internationally, including at the International Invention Competition in Geneva, Switzerland. Even after obtaining his professorship in 2002, he continues to be active in research. Together with Professor Dr. Yoshihito Shirai, he initiated a CDM (Clean Development Mechanism) project aimed at reducing greenhouse gases and pollution from the palm oil mills as well as producing value-added bioproducts. His goal is to develop this into a viable joint CDM project between Malaysia and Japan with certified emission reduction and carbon credits in the near future.

Presently, Professor Ali is the project leader of a joint R&D project between UPM, Kyushu Institute of Technology and FELDA Palm Industries Sdn. Bhd. on the utilisation of biogas and biomass from the palm oil industry for the production of new value-added products. He is also actively working towards commercialisation of his patent on bioplastics. He is grateful to ALLAH SWT for His blessings and guidance in his life and career as Professor in UPM. His dream and desire is to achieve his true potential, with the ultimate goal of achieving success and happiness in this world and in the hereafter.
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106. Prof. Dr. Dzulkefly Kuang Abdullah
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