WASTE-TO-WEALTH THROUGH BIOTECHNOLOGY:

For Profit, People and Planet

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

PROFESSOR DR. MOHD ALI HASSAN
PhD (Okayama), M.Phil (Birmingham), M.Sc., B.Sc. (Leeds)

28 March 2008

Dewan Taklimat
Bangunan Pentadbiran
Universiti Putra Malaysia

Penerbit Universiti Putra Malaysia
Serdang • 2008
http://www.penerbit.upm.edu.my

First Print 2008

UPM Press is a member of the Malaysian Book Publishers Association (MABOPA)
Membership No.: 9802

Perpustakaan Negara Malaysia Cataloguing-in-Publication Data

Mohd. Ali Hassan
Waste-to-wealth through biotechnology for profit, people and
planet / Mohd. Ali Hassan.
(Inaugural lecture series)
ISBN 978-967-5026-57-7
1. Salvage (Waste, etc.). 2. Biotechnology industries. I. Title.
II. Series.
338.476606

Design, layout and printed by

Penerbit Universiti Putra Malaysia
43400 UPM Serdang
Selangor Darul Ehsan
Tel: 03-8946 8855 / 8854
Fax: 03-8941 6172
http://www.penerbit.upm.edu.my

Contents

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.

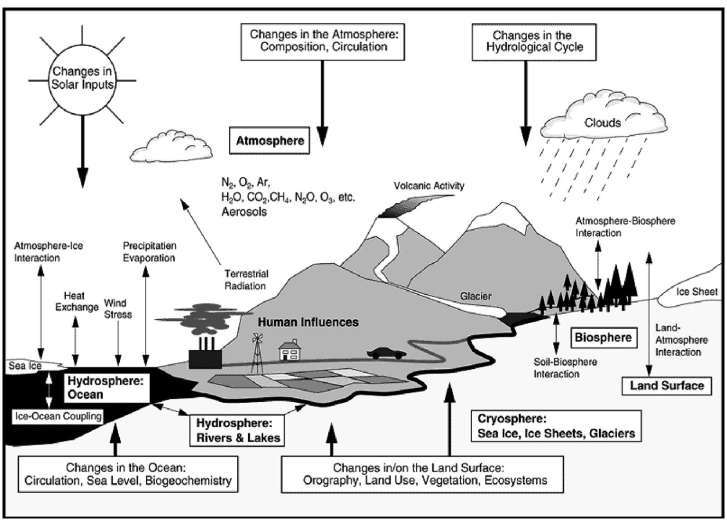


Figure 1 Effects of global warming
Source: CETDEM

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

Source: Abdullah Ahmad Badawi, Islam Hadhari – A Model Approach for Development and Progress, MPH (2003)

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

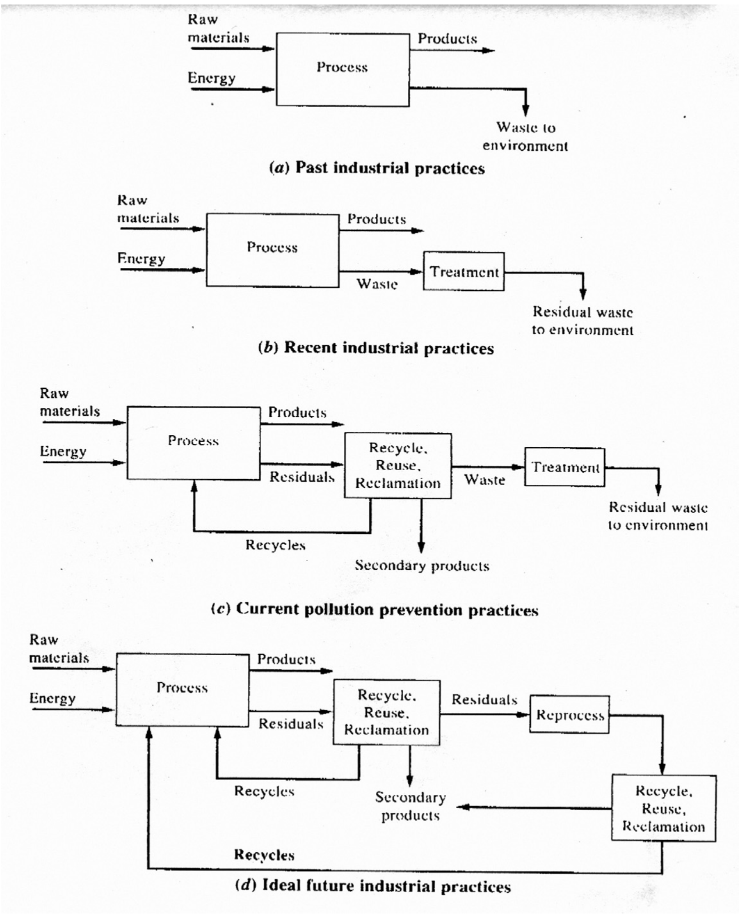


Figure 2 The four stages of waste management

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

Environmental Quality Act, 1974
Environmental Quality (Sewage and Industrial Effluents) Regulations, 1979 [Regulation 8(1), 8(2), 8(3)]
Parameter Limits of Effluent of Standards A and B

Parameter	**Unit**	**Standard A**	**Standard B**
Temperature	^oC	40	40
pH value	-	6.0 – 9.0	5.5 – 9.0
BOD_5 at 20^oC	mg/L	20	50
COD	mg/L	50	100
Suspended solids	mg/L	50	100
Oil and grease	mg/L	Not detectable	10.0
Iron (Fe)	mg/L	1.0	5.0
Lead (Pb)	mg/L	0.1	0.5
Cadmium (Cd)	mg/L	0.01	0.02

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.

Table 4 The nine thrusts of National Biotechnology Policy

The National Biotechnology Policy is underpinned by nine policy thrusts:

Thrust 1: **Agriculture Biotechnology Development**
Transform and enhance the value creation of the agricultural sector through biotechnology

Thrust 2: **Healthcare Biotechnology Development**
Capitalise on the strengths of biodiversity to commercialise discoveries in natural products as well as position Malaysia in the bio-generics market

Thrust 3: **Industrial Biotechnology Development**
Ensure growth opportunities in the application of advanced bio-processing and bio-manufacturing technologies

Thrust 4: **R&D and Technology Acquisition**
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

Thrust 5: **Human Capital Development**
Build the nation's biotech human resource capability in line with market needs through special schemes, programmes and training

Thrust 6: **Financial Infrastructure Development**
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

Thrust 7: **Legislative and Regulatory Framework Development**
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&D and commercialisation efforts

Thrust 8: **Strategic Positioning**
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

Thrust 9: **Government Commitment**
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

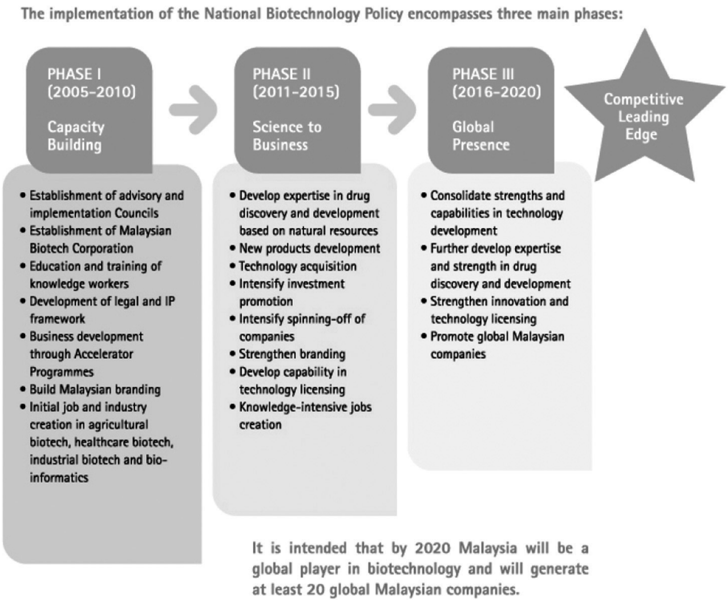
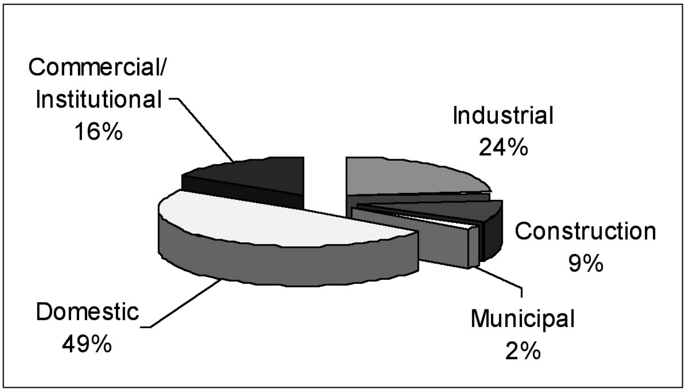


Figure 3 The three phases in National Biotechnology Policy

Table 5 Biomass resources in Malaysia

Sector	Quantity kton / yr	Potential Annual Generation (GWh)	Potential Capacity (MW)
Rice Mills	424	263	30
Wood Industries	2177	598	68
Palm Oil Mills	17980	3197	365
Bagasse	300	218	25
POME	31500	1587	177
Total	72962	5863	665

Table 6 Composition of solid MSW in Malaysia



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).

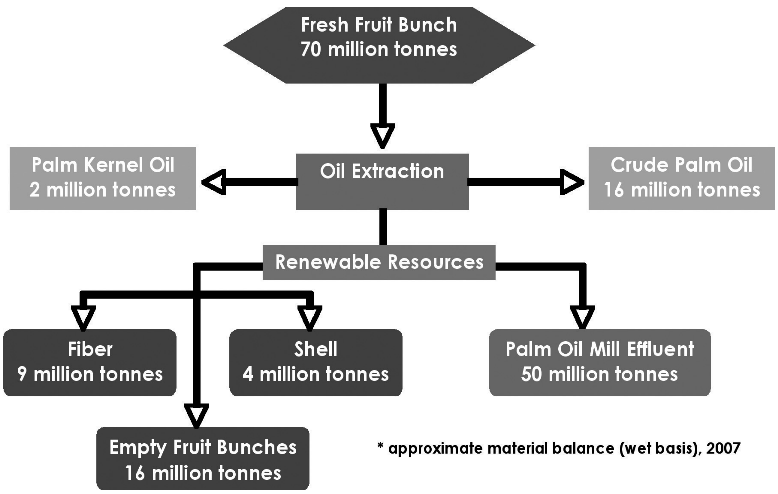


Figure 4 Mass balance in palm oil industry in Malaysia

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 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^{o}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.

Table 7 Characterisitics of palm oil mill effluent (POME)

Chemical property (mg/l)	Average	Range
pH	4.2	3.4 – 5.2
BOD	25,000	10,250 – 43,750
COD	50,000	15,000 – 100,000
Total solid	40,000	11,500 – 78,000
Suspended solid	18,000	5,000 – 54,000
Oil and grease	6,000	150 – 18,000
Ammoniacal nitrogen	35	4 – 80
Total nitrogen	750	180 – 1,400

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 occurrs 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/m^3/day of organic loading. In between the different 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.

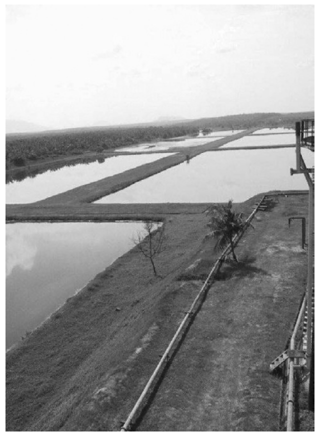


Figure 5 Tanks and ponds in FELDA Serting Hilir

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

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 0.09g 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!

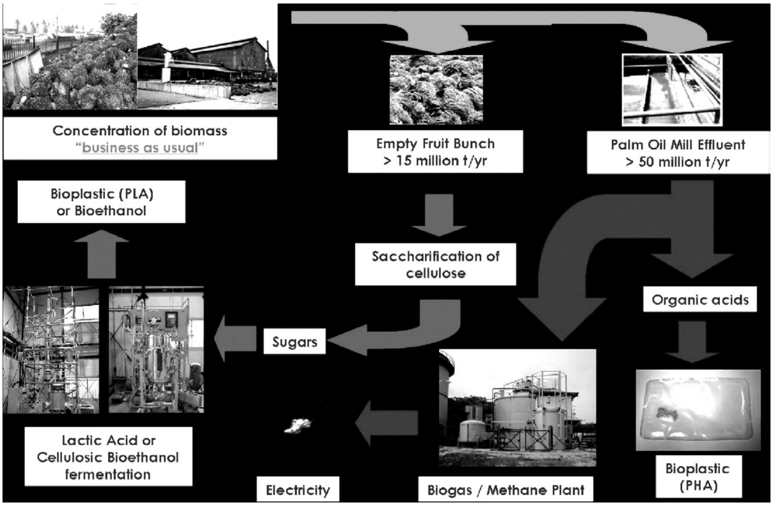


Figure 6 Utilisation of palm biomass through biotechnology

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_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

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

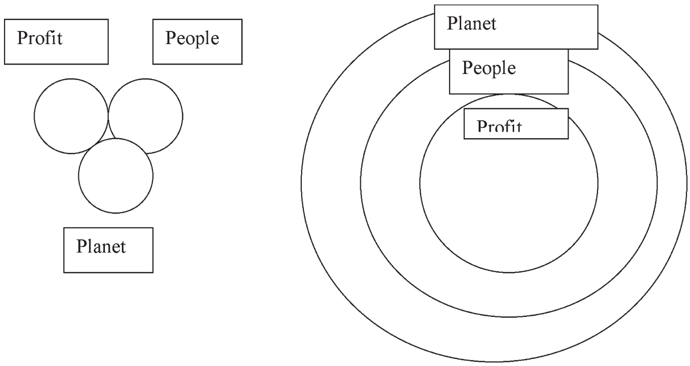


Figure 7 The three P's of sustainable development

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.

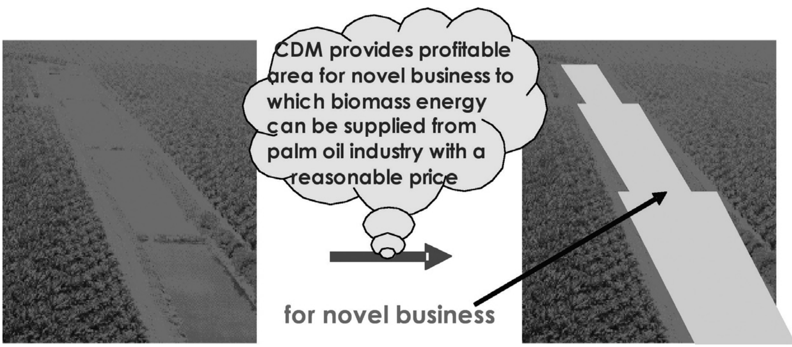


Figure 8 Towards a sustainable palm oil industry

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!

REFERENCES

Abdul Rahman, A.R., Baharum, Z., Hassan, M.A. and Idris, A. 2001. Bioreactor composting of selected organic sludges. *Proceedings 13th National Biotechnology* Seminar, Penang.

Agamuthu, P. 1995. Palm oil mill effluent – treatment and utilisation, In *Waste Treatment Plant.* Eds. Sastry, C. A., Hashim, M. A., Agamuthu, P., Narosa Publishing House, New Delhi, 338-360.

Basiron, Y. and Darus, A. 1995. *The oil palm industry – From pollution to zero waste*. The Planter **72(840)**: 141-165.

Hashim, M and N.A. Ludin, 2005. Biomass Energy Utilization in Malaysia: Present Status and Problems. Proceedings 2nd Asia Biomass Workshop, Tokyo, Japan.

Hassan, M.A., Yacob, S., Shirai, Y. and Y.T. Hung, 2006. Treatment of Palm Oil Mill Wastewaters. In *Waste Treatment in the Food Processing Industry.* Eds. Wang, L.K., *et al.*, CRC Press, Boca Raton, Florida, USA 101-117.

Hassan, M. A., Shirai, Y., Umeki, H., Yamazumi, H., Jin, S., Yamamoto, S., Abdul Karim, M. I., Nakanishi, K. and K. Hashimoto. 1997a. *Acetic acid separation from anaerobically treated palm oil mill effluent by ion exchange resin for the production of polyhydroxyalkanoate by Alcaligenes eutrophus*. Biosci. Biotech. Biochem. **61(9)**: 1465-1468.

Hassan, M. A., Shirai, Y., Kusubayashi, N., Abdul Karim, M. I., Nakanishi, K. and K. Hashimoto. 1997b. *The production of polyhydroxyalkanoate from anaerobically treated palm oil mill effluent by Rhodobacter sphaeroides.* J. Ferment. Bioeng. **83(3)**: 485-488.

Hassan, M.A., Nawata, O., Shirai, Y., Noraini, A.R., Yee, P.L. and Karim, M.I.A. (2002) *A proposal for zero emission from palm oil industry incorporating the production of polyhydroxyalkanoates from palm oil mill effluent.* J. Chem. Eng Japan, **35(1)**: 9-14.

Ma, A. N. 1999a. Environment management for the palm oil industry. *Palm Oil Developments* **30**: 1-10

Ma, A. N. 1999b. Treatment of palm oil mill effluent, In *Oil Palm and the Environment - A Malaysian Perspective.* Eds. Singh, G., Lim, K. H., Leng, T. and David, L. K., Malaysian Oil Palm Growers Council p.113-126.

Ma, A. N., Toh, T. S. and N. S. Chua. 1999. Renewable Energy from Oil Palm Industry. In *Oil Palm and the Environment - A Malaysian Perspective.* Eds. Singh, G., Lim, K. H., Leng, T. and David, L. K., Malaysian Oil Palm Growers Council p. 253-260.

Md. Noor, M. 1999. Environmental legislation: Environmental quality act, 1974. In *Oil Palm and the Environment - A Malaysian Perspective* Eds. Singh, G., Lim, K. H., Leng, T. and David, L. K., Malaysian Oil Palm Growers Council, p. 261-264.

MOSTI. 2005. National Biotechnology Policy.

Noraini, A.R., Hassan, M.A., Shirai, Y. and M.I.A. Karim. 1999. Production of organic acids from palm oil mill effluent during continuous anaerobic treatment. *Asia Pacific J. Mol. Biol Biotechnol.* **7(2)**: 179-184.

Yacob, S., Hassan, M.A., Shirai, Y., Wakisaka, M. and S. Sunderaj. 2005.

Baseline study of methane emission from open digesting tanks of palm oil mill effluent treatment. *Chemosphere* **59**: 1575-1581.

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.

Professor Mohd Ali enjoys teaching, research and professional services. Todate, 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.

ACKNOWLEDGEMENTS

Alhamdulillah, thank you ALLAH for all Your blessings and guidance. Thank you to Universiti Putra Malaysia for granting me the professorship and giving me the opportunity to enhance my career in teaching, research and professional services. Thank you to my parents Aminah and Hassan, my wife Hamidah and children who have supported me all the way. I would like to acknowledge the contributions of Professor Dr. Shigeaki Takagi and Professor Dr. Kazuhiro Nakanishi from Okayama University, Professor Dr. Yoshihito Shirai from Kyushu Institute of Technology and Professor Dr. Mohamed Abdul Ismail. These four personalities have been my mentors during the course of my career and I greatly appreciate their sincere help, guidance and advice. I would like to thank MOSTI (Ministry of Science, Technology and Innovation, Malaysia), JICA (Japan International Cooperation Agency), JSPS (Japan Society for the Promotion of Science), NEDO (New Energy Development Organisation), KIT (Kyushu Institute of Technology) and FELDA Palm Industries Sdn. Bhd. for the R&D and travel grants. Last, but not least, thank you to all my colleagues, staff and students who have worked with me through thick-and-thin. I feel honoured to have friends and colleagues who are better than me and to supervise good students who will do more than I have done in the future.

LIST OF INAUGURAL LECTURES

1. Prof. Dr. Sulaiman M. Yassin
   The Challenge to Communication Research in Extension
   22 July 1989

2. Prof. Ir. Abang Abdullah Abang Ali
   Indigenous Materials and Technology for Low Cost Housing
   30 August 1990

3. Prof. Dr. Abdul Rahman Abdul Razak
   Plant Parasitic Nematodes, Lesser Known Pests of Agricultural Crops
   30 January 1993

4. Prof. Dr. Mohamed Suleiman
   Numerical Solution of Ordinary Differential Equations: A Historical Perspective
   11 December 1993

5. Prof. Dr. Mohd. Ariff Hussein
   Changing Roles of Agricultural Economics
   5 March 1994

6. Prof. Dr. Mohd. Ismail Ahmad
   Marketing Management: Prospects and Challenges for Agriculture
   6 April 1994

7. Prof. Dr. Mohamed Mahyuddin Mohd. Dahan
   The Changing Demand for Livestock Products
   20 April 1994

8. Prof. Dr. Ruth Kiew
   Plant Taxonomy, Biodiversity and Conservation
   11 May 1994

9. Prof. Ir. Dr. Mohd. Zohadie Bardaie
   Engineering Technological Developments Propelling Agriculture into the 21st Century
   28 May 1994

10. Prof. Dr. Shamsuddin Jusop
    Rock, Mineral and Soil
    18 June 1994

11. Prof. Dr. Abdul Salam Abdullah
    Natural Toxicants Affecting Animal Health and Production
    29 June 1994

12. Prof. Dr. Mohd. Yusof Hussein
    Pest Control: A Challenge in Applied Ecology
    9 July 1994

13. Prof. Dr. Kapt. Mohd. Ibrahim Haji Mohamed
    Managing Challenges in Fisheries Development through Science and Technology
    23 July 1994

14. Prof. Dr. Hj. Amat Juhari Moain
    Sejarah Keagungan Bahasa Melayu
    6 Ogos 1994

15. Prof. Dr. Law Ah Theem
    Oil Pollution in the Malaysian Seas
    24 September 1994

16. Prof. Dr. Md. Nordin Hj. Lajis
    Fine Chemicals from Biological Resources: The Wealth from Nature
    21 January 1995

17. Prof. Dr. Sheikh Omar Abdul Rahman
Health, Disease and Death in Creatures Great and Small
25 February 1995

18. Prof. Dr. Mohamed Shariff Mohamed Din
Fish Health: An Odyssey through the Asia - Pacific Region
25 March 1995

19. Prof. Dr. Tengku Azmi Tengku Ibrahim
Chromosome Distribution and Production Performance of Water Buffaloes
6 May 1995

20. Prof. Dr. Abdul Hamid Mahmood
Bahasa Melayu sebagai Bahasa Ilmu- Cabaran dan Harapan
10 Jun 1995

21. Prof. Dr. Rahim Md. Sail
Extension Education for Industrialising Malaysia: Trends, Priorities and Emerging Issues
22 July 1995

22. Prof. Dr. Nik Muhammad Nik Abd. Majid
The Diminishing Tropical Rain Forest: Causes, Symptoms and Cure
19 August 1995

23. Prof. Dr. Ang Kok Jee
The Evolution of an Environmentally Friendly Hatchery Technology for Udang Galah, the King of Freshwater Prawns and a Glimpse into the Future of Aquaculture in the 21st Century
14 October 1995

24. Prof. Dr. Sharifuddin Haji Abdul Hamid
Management of Highly Weathered Acid Soils for Sustainable Crop Production
28 October 1995

25. Prof. Dr. Yu Swee Yean
Fish Processing and Preservation: Recent Advances and Future Directions
9 December 1995

26. Prof. Dr. Rosli Mohamad
Pesticide Usage: Concern and Options
10 February 1996

27. Prof. Dr. Mohamed Ismail Abdul Karim
Microbial Fermentation and Utilization of Agricultural Bioresources and Wastes in Malaysia
2 March 1996

28. Prof. Dr. Wan Sulaiman Wan Harun
Soil Physics: From Glass Beads to Precision Agriculture
16 March 1996

29. Prof. Dr. Abdul Aziz Abdul Rahman
Sustained Growth and Sustainable Development: Is there a Trade-Off 1 or Malaysia
13 April 1996

30. Prof. Dr. Chew Tek Ann
Sharecropping in Perfectly Competitive Markets: A Contradiction in Terms
27 April 1996

31. Prof. Dr. Mohd. Yusuf Sulaiman
Back to the Future with the Sun
18 May 1996

32. Prof. Dr. Abu Bakar Salleh
Enzyme Technology: The Basis for Biotechnological Development
8 June 1996

33. Prof. Dr. Kamel Ariffin Mohd. Atan
The Fascinating Numbers
29 June 1996

34. Prof. Dr. Ho Yin Wan
Fungi: Friends or Foes
27 July 1996

35. Prof. Dr. Tan Soon Guan
Genetic Diversity of Some Southeast Asian Animals: Of Buffaloes and Goats and Fishes Too
10 August 1996

36. Prof. Dr. Nazaruddin Mohd. Jali
Will Rural Sociology Remain Relevant in the 21st Century?
21 September 1996

37. Prof. Dr. Abdul Rani Bahaman
Leptospirosis-A Model for Epidemiology, Diagnosis and Control of Infectious Diseases
16 November 1996

38. Prof. Dr. Marziah Mahmood
Plant Biotechnology - Strategies for Commercialization
21 December 1996

39. Prof. Dr. Ishak Hj. Omar
Market Relationships in the Malaysian Fish Trade: Theory and Application
22 March 1997

40. Prof. Dr. Suhaila Mohamad
Food and Its Healing Power
12 April 1997

41. Prof. Dr. Malay Raj Mukerjee
A Distributed Collaborative Environment for Distance Learning Applications
17 June 1998

42. Prof. Dr. Wong Kai Choo
Advancing the Fruit Industry in Malaysia: A Need to Shift Research Emphasis
15 May 1999

43. Prof. Dr. Aini Ideris
Avian Respiratory and Immunosuppressive Diseases- A Fatal Attraction
10 July 1999

44. Prof. Dr. Sariah Meon
Biological Control of Plant Pathogens: Harnessing the Richness of Microbial Diversity
14 August 1999

45. Prof. Dr. Azizah Hashim
The Endomycorrhiza: A Futile Investment?
23 Oktober 1999

46. Prof. Dr. Noraini Abdul Samad
Molecular Plant Virology: The Way Forward
2 February 2000

47. Prof. Dr. Muhamad Awang
Do We Have Enough Clean Air to Breathe?
7 April 2000

48. Prof. Dr. Lee Chnoong Kheng
Green Environment, Clean Power
24 June 2000

49. Prof. Dr. Mohd. Ghazali Mohayidin
Managing Change in the Agriculture Sector: The Need for Innovative Educational Initiatives
12 January 2002

50. Prof. Dr. Fatimah Mohd. Arshad
Analisis Pemasaran Pertanian di Malaysia: Keperluan Agenda Pembaharuan
26 Januari 2002

51. Prof. Dr. Nik Mustapha R. Abdullah
Fisheries Co-Management: An Institutional Innovation Towards Sustainable Fisheries Industry
28 February 2002

52. Prof. Dr. Gulam Rusul Rahmat Ali
Food Safety: Perspectives and Challenges
23 March 2002

53. Prof. Dr. Zaharah A. Rahman
Nutrient Management Strategies for Sustainable Crop Production in Acid Soils: The Role of Research Using Isotopes
13 April 2002

54. Prof. Dr. Maisom Abdullah
Productivity Driven Growth: Problems & Possibilities
27 April 2002

55. Prof. Dr. Wan Omar Abdullah
Immunodiagnosis and Vaccination for Brugian Filariasis: Direct Rewards from Research Investments
6 June 2002

56. Prof. Dr. Syed Tajuddin Syed Hassan
Agro-ento Bioinformation: Towards the Edge of Reality
22 June 2002

57. Prof. Dr. Dahlan Ismail
Sustainability of Tropical Animal-Agricultural Production Systems: Integration of Dynamic Complex Systems
27 June 2002

58. Prof. Dr. Ahmad Zubaidi Baharumshah
The Economics of Exchange Rates in the East Asian Countries
26 October 2002

59. Prof. Dr. Shaik Md. Noor Alam S.M. Hussain
Contractual Justice in Asean: A Comparative View of Coercion
31 October 2002

60. Prof. Dr. Wan Md. Zin Wan Yunus
Chemical Modification of Polymers: Current and Future Routes for Synthesizing New Polymeric Compounds
9 November 2002

61. Prof. Dr. Annuar Md. Nassir
Is the KLSE Efficient? Efficient Market Hypothesis vs Behavioural Finance
23 November 2002

62. Prof. Ir. Dr. Radin Umar Radin Sohadi
Road Safety Interventions in Malaysia: How Effective Are They?
21 February 2003

63. Prof. Dr. Shamsher Mohamad
The New Shares Market: Regulatory Intervention, Forecast Errors and Challenges
26 April 2003

64. Prof. Dr. Han Chun Kwong
Blueprint for Transformation or Business as Usual? A Structurational Perspective of the Knowledge-Based Economy in Malaysia
31 May 2003

65. Prof. Dr. Mawardi Rahmani
Chemical Diversity of Malaysian Flora: Potential Source of Rich Therapeutic Chemicals
26 July 2003

66. Prof. Dr. Fatimah Md. Yusoff
An Ecological Approach: A Viable Option for Aquaculture Industry in Malaysia
9 August 2003

67. Prof. Dr. Mohamed Ali Rajion
The Essential Fatty Acids-Revisited
23 August 2003

68. Prof. Dr. Azhar Md. Zain
Psychotheraphy for Rural Malays - Does it Work?
13 September 2003

69. Prof. Dr. Mohd. Zamri Saad
Respiratory Tract Infection: Establishment and Control
27 September 2003

70. Prof. Dr. Jinap Selamat
Cocoa-Wonders for Chocolate Lovers
14 February 2004

71. Prof. Dr. Abdul Halim Shaari
High Temperature Superconductivity: Puzzle & Promises
13 March 2004

72. Prof. Dr. Yaakob Che Man
Oils and Fats Analysis - Recent Advances and Future Prospects
27 March 2004

73. Prof. Dr. Kaida Khalid
Microwave Aquametry: A Growing Technology
24 April 2004

74. Prof. Dr. Hasanah Mohd. Ghazali
Tapping the Power of Enzymes- Greening the Food Industry
11 May 2004

75. Prof. Dr. Yusof Ibrahim
The Spider Mite Saga: Quest for Biorational Management Strategies
22 May 2004

76. Prof. Datin Dr. Sharifah Md. Nor
The Education of At-Risk Children: The Challenges Ahead
26 June 2004

77. Prof. Dr. Ir. Wan Ishak Wan Ismail
Agricultural Robot: A New Technology Development for Agro-Based Industry
14 August 2004

78. Prof. Dr. Ahmad Said Sajap
Insect Diseases: Resources for Biopesticide Development
28 August 2004

79. Prof. Dr. Aminah Ahmad
The Interface of Work and Family Roles: A Quest for Balanced Lives
11 March 2005

80. Prof. Dr. Abdul Razak Alimon
Challenges in Feeding Livestock: From Wastes to Feed
23 April 2005

81. Prof. Dr. Haji Azimi Hj. Hamzah
Helping Malaysian Youth Move Forward: Unleashing the Prime Enablers
29 April 2005

82. Prof. Dr. Rasedee Abdullah
In Search of An Early Indicator of Kidney Disease
27 May 2005

83. Prof. Dr. Zulkifli Hj. Shamsuddin
Smart Partnership: Plant-Rhizobacteria Associations
17 June 2005

84. Prof. Dr. Mohd Khanif Yusop
From the Soil to the Table
1 July 2005

85. Prof. Dr. Annuar Kassim
Materials Science and Technology: Past, Present and the Future
8 July 2005

86. Prof. Dr. Othman Mohamed
Enhancing Career Development Counselling and the Beauty of Career Games
12 August 2005

87. Prof. Ir. Dr. Mohd Amin Mohd Soom
Engineering Agricultural Water Management Towards Precision Farming
26 August 2005

88. Prof. Dr. Mohd Arif Syed
Bioremediation-A Hope Yet for the Environment?
9 September 2005

89. Prof. Dr. Abdul Hamid Abdul Rashid
The Wonder of Our Neuromotor System and the Technological Challenges They Pose
23 December 2005

90. Prof. Dr. Norhani Abdullah
Rumen Microbes and Some of Their Biotechnological Applications
27 January 2006

91. Prof. Dr. Abdul Aziz Saharee
Haemorrhagic Septicaemia in Cattle and Buffaloes: Are We Ready for Freedom?
24 February 2006

92. Prof. Dr. Kamariah Abu Bakar
Activating Teachers' Knowledge and Lifelong Journey in Their Professional Development
3 March 2006

93. Prof. Dr. Borhanuddin Mohd. Ali
Internet Unwired
24 March 2006

94. Prof. Dr. Sundararajan Thilagar
Development and Innovation in the Fracture Management of Animals
31 March 2006

95. Prof. Dr. Zainal Aznam Md. Jelan
Strategic Feeding for a Sustainable Ruminant Farming
19 May 2006

96. Prof. Dr. Mahiran Basri
Green Organic Chemistry: Enzyme at Work
14 July 2006

97. Prof. Dr. Malik Hj. Abu Hassan
Towards Large Scale Unconstrained Optimization
20 April 2007

98. Prof. Dr. Khalid Abdul Rahim
Trade and Sustainable Development: Lessons from Malaysia's Experience
22 Jun 2007

99. Prof. Dr. Mad Nasir Shamsudin
Econometric Modelling for Agricultural Policy Analysis and Forecasting: Between Theory and Reality
13 July 2007

100. Prof. Dr. Zainal Abidin Mohamed
Managing Change - The Fads and The Realities: A Look at Process Reengineering, Knowledge Management and Blue Ocean Strategy
9 November 2007

101. Prof. Ir. Dr. Mohamed Daud
Expert Systems for Environmental Impacts and Ecotourism Assessments
23 November 2007

102. Prof. Dr. Saleha Abdul Aziz
Pathogens and Residues; How Safe is Our Meat?
30 November 2007

103. Prof. Dr. Jayum A. Jawan
Hubungan Sesama Manusia
7 Disember 2007

104. Prof. Dr. Zakariah Abdul Rashid
Planning for Equal Income Distribution in Malaysia: A General Equilibrium Approach
28 December 2007

105. Prof. Datin Paduka Dr. Khatijah Yusoff
Newcastle Disease virus: A Journey from Poultry to Cancer
11 January 2008

106. Prof. Dr. Dzulkefly Kuang Abdullah
Palm Oil: Still the Best Choice
1 February 2008

107. Prof. Dr. Elias Saion
Probing the Microscopic Worlds by Lonizing Radiation
22 February 2008