SUSTAINABLE PRACTICES OF AN EDIBLE OILS REFINING COMPLEX
Shyam Lakshmanan; Yen Li Yung*; Boon San Chan; Zhe Haw Chong

Abstract
Refineries play a vital role in the supply chain for processing crude palm oil and palm kernel into refined products which are ready for consumption. They need to continuously improve operational efficiencies and strive to reduce carbon footprint. These improvements in our referenced refinery were achieved through installation of new equipment, process changes, heat recovery and water recycling. Installation of inverters and LED lights yielded electrical energy savings of 2.5%. Process change implemented in the effluent treatment plant and heat recovery resulted in electrical energy savings and fuel reduction of 40% and 30%, respectively. Condensate recovery and capture of steam vapor emissions resulted in the reduction of steam usage by 50% in the palm kernel dry fractionation plant and 20% in the dry fractionation plant. The refinery has stopped relying on fuel oil and started using liquified natural gas, resulting in lower carbon footprint. In addition, it reduces resource exploitation by implementing water recovery within the complex and has achieved 85% recovery of its treated effluent water. Some of the additional benefit of implementing these changes are better product quality, less chemicals consumption, and cleaner working environment.

1. Introduction
The refinery reference in this article is IOI Edible Oils Sdn. Bhd. (Sandakan Refinery), which operates over a 62 acre site in Batu Sapi, Sandakan, Sabah (Fig. 1). The company is certified with ISO 9001, 14001, 45001, HACCP, MSPO, RSPO and ISCC. The integrated complex houses a whole range of processes, ranging from water and effluent treatment to crude and refined palm oil processing as well as storage tanks. It is also connected to an export jetty. The site encompasses 15 different plants, including refineries, fractionation plants, kernel crushing plants, palm kernel fractionation plants, biomass fired steam boiler and power plant. There are over 60 storage tanks for various products. The complex is one of the largest exporters of oil palm products of Sabah, as well as in Malaysia. Table 1 is a list of some of the production facilities.

Keywords
palm oil refinery; palm dry fractionation; palm kernel fractionation; vent economizer; heat recovery

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Published: 9 November 2020
Received: 24 August 2020
Accepted: 20 October 2020
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When the plant first commenced its operations in 1997, there was no water and electricity supply. The plant had to set-up its own power generators and water treatment plants to support its operation. It had some fuel oil-fired boilers. After having stable power supply, the complex continued growing and has become the largest power consumer in the district of Sandakan. As a part of its sustainability initiatives, the company has pursued projects to generate steam and power from biomass and has improved its raw water and wastewater treatment systems. It continued expanding its physical refinery, fractionation and kernel crushing plants’ capacity over the two decades. Currently, the workforce is entirely Malaysian, with more than 99% of employees from Sabah.

The products from this complex are mainly refined palm and lauric oils, which can be readily used for food applications. This is one of the few complexes in the country that processes both palm and lauric oils.

Figure 1: Aerial view of IOI site in Sandakan, Sabah

<table>
<thead>
<tr>
<th>No.</th>
<th>Plants</th>
<th>Quantity</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Refinery</td>
<td>3 plants</td>
<td>1,000,000 t/y</td>
</tr>
<tr>
<td>2</td>
<td>Fractionation</td>
<td>4 plants</td>
<td>1,000,000 t/y</td>
</tr>
<tr>
<td>3</td>
<td>Kernel Crushing</td>
<td>3 plants</td>
<td>300,000 t/y</td>
</tr>
<tr>
<td>4</td>
<td>Palm Kernel Fractionation</td>
<td>2 plants</td>
<td>120,000 t/y</td>
</tr>
<tr>
<td>5</td>
<td>Biomass Boiler</td>
<td>2 plants</td>
<td>400,000 t/y</td>
</tr>
<tr>
<td>6</td>
<td>Tank Farm/ Bulking Installation</td>
<td>64 tanks</td>
<td>175,000 t</td>
</tr>
<tr>
<td>7</td>
<td>Power plant</td>
<td>1 train</td>
<td>50,000 MWh</td>
</tr>
<tr>
<td>8</td>
<td>Effluent Treatment</td>
<td>1 plant</td>
<td>365,000 t/y</td>
</tr>
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</table>
As both palm and lauric oils consist of valuable components, they are often extracted. Palm oil refers to the oil that is obtained from the mesocarp of the palm fruit (CPO), while lauric oils are obtained from the palm kernel. The products processed at this site are used in a wide variety of applications, ranging from infant formula, cooking oils, soaps, detergents, biodiesel, lubricants, skin lotions, cosmetics, toothpaste, anti-bacterial, anti-viral, anti-fungal and many food related applications.

The refineries supply refined products to oleochemicals plants where various components of the oil are extracted. The following are the main processes in the IOIEO complex:

a. Physical refinery
The process flow diagram for palm oil physical refining is shown in Fig. 2. The physical refinery is where CPO, that is received from the mills, is processed. The CPO first goes through a degumming step, where it is filtered and heated before phosphoric acid is added to hydrolyse the gum (phospholipids) content in the CPO (see Fig 3a). The amount of phosphoric acid added would depend on the gum content of the incoming CPO. The higher the gum content, the more phosphoric acid is dosed.

After thorough mixing of the acid with the CPO, the mixture is allowed to react for a contact time of around 20 minutes. CPO is then channelled to the bleaching step, where bleaching earth is added. This adsorbent is allowed to contact with the CPO for around 40 minutes. After sufficient contact time, the bleaching earth is removed from the CPO via filtration in vertical leaf filters (Fig. 2a). Apart from impurities, hydrolysed gums contained in the CPO are also removed as they adhere to the bleaching earth. The filtered oil has a lighter colour than CPO, and is called degummed and bleached palm oil (i.e. BPO in short). BPO goes through a de-aerating (drying) step before it is channelled to the deodorization stage.

During deodorization, BPO first goes through a series of heating steps to raise its temperature to 260°C (Fig 2b). The heated BPO then goes to the pre-stripper which operates under high vacuum for the removal of its volatile impurities. From the pre-stripper, BPO is fed to the deodorization step which operates at close to total vacuum. Here, more volatiles and low boiling materials in the BPO are distilled off. The deodorizer facilitates the required retention time to break down colour-causing components in the oil into smaller molecules. BPO enters at the top of the deodorizer and exits from its bottom (Fig. 2b). Each tray of the deodorizer is equipped with steam injection to agitate and mix the BPO in the tray. This thorough mixing helps to lift volatiles to the surface, so that they are removed by the vacuum system. Steam bubbles rising from the bottom of the deodoriser help to strip impurities contained in the BPO. The volatiles leaving from the deodoriser are scrubbed in a fatty acid scrubber where the vapours are collected; this top product stream is called palm fatty acid distillate (PFAD).

The oil that leaves the deodorizer is now impurity-free and is a bland oil with no odour or taste. This oil is referred as refined, bleached, and deodorized palm oil (or RBDPO). As the oil leaving the deodorizer is still very hot, an intricate heat recovery system is employed, where the incoming BPO is heated using the outgoing RBDPO. This helps to reduce fuel consumption of the plant. The vacuum in the deodorizer is generated using steam, which is generated from palm biomass that is collected from nearby mills. Note that this is one of the company’s sustainability initiatives.

The complex has three independent refineries (with slightly different configurations) that serve the same purpose. The smallest refinery is used for refining lauric oils, while the larger capacity units are used for refining palm oils. The processing of lauric oils in the refinery is similar to that of refining CPO, but the dosage of phosphoric acid, bleaching earth and deodorization temperatures differ.
Figure 2: Physical refinery: (a) degumming and bleaching processes; (b) deodorization process
b. Dry fractionation

Upon cooling to 25°C, palm oil forms liquid and solid fat fractions. RBDPO often undergoes fractionation. The two main types of fractionations employed are with and without solvent. The method without solvent is referred as the dry fractionation process, and is the method employed at IOIEO as part of its sustainability initiatives (Fig. 3).

Fractionation involves two-stage operations where the oil is first cooled in a large vessel, i.e. crystallizer. The oil is cooled to its desired temperature following a fixed cooling profile. The solid fats then crystallize and are allowed to consolidate and harden (Fig. 3).

At the second step, the slurry containing the solid fat is pumped into a filter press where the solids are filtered while the liquid flows through the filter cloth. The collected liquid fraction is called olein (or RBDPOL). Next, the solid that is trapped in the filter press is squeezed to extract more of the liquid fraction. All RBDPOL is pumped to storage and is ready for export, or to be used as cooking oil in the domestic market. Next, the solids are discharged into a heated trough. This solid fraction is called stearin (or RBDPS). It is melted using steam and then pumped into the storage tanks. This fraction will tend to solidify in storage and is normally heated using steam prior to shipment. For the dry fractionation process, the yield is calculated based on the amount of RBDPOL obtained from the RBDPO feed.

c. Kernel crushing plant (KCP)

This complex processes palm kernel that originated from the palm oil mills. The palm kernel is fed to custom-designed presses where the kernels are cracked under pressure and the oil is extracted from the kernel. The oil content in palm kernel is around 50%, and the KCP strives to extract as much oil from the kernel as possible through a two-stage screw pressing system. Solvent-less screw press does not generate any waste at KCP plant and leaves a low carbon footprint. The oil extracted in these presses is called crude palm kernel oil (CPKO) and does not contain any solvent. The solid remains is called palm kernel expeller (PKE) and is sold as animal feed.

d. Palm kernel fractionation

The palm kernel fractionation plant (PKF) processes CPKO that is extracted in the KCP. The method is similar to that employed for dry fractionation but uses a different plant that is dedicated for CPKO. Fig. 4 shows the CPKO.
dry fractionation process. The process involves dry fractionation as it avoids the use of solvents for fractionation. It is more environment friendly without effluent. No solvent is released to the environment and no solvent is found in the processed oil. There are three main steps in the PKF, i.e. crystallization, statolisation and membrane filtration.

The capacity of the plant is much smaller than the dry fractionation plant as the volume of CPKO is much lower than that of CPO. The settings and yields of solid and liquid fractions are entirely different from fractionation of RBDPO. As shown in Fig. 4, crystallization is followed by statolisation (Fig. 4) and both processes are under strict temperature control. This is followed by filtration to separate the kernel olein and kernel stearin fractions using high pressure membrane press filter. For the palm kernel fractionation, the yield is calculated for palm kernel stearin (the more valuable product) and not the palm kernel olein. The stearin fraction is the more valuable product due to its excellent properties for confectionery application.

2. Conservation of Energy

The company formed an Energy Management Committee (EMC) comprising of key plant executives. This committee looks into areas for reducing electricity, steam, fuel and water usage. The EMC has implemented many energy saving projects.

Inverters have been installed on many of the large motors for fans and pumps to control the equipment operation within optimum conditions. Previously valves were used to regulate the fluid flow to its desired flowrate. The presence of valves on the discharge side of the pumps and fans in a throttled position increases the pressure drop of the system. This results in more energy being consumed by the device to overcome the pressure loss. After installing the inverters, valves are placed in the fully open position. The inverters operate the motor at the desired speed (motor revolution) to cater to the desired flow-rate; thus, resulting in lower energy consumption. Evaluation is carried out at each plant on whether high efficiency pumps, motors and inverters may be used to reduce electricity consumption. Energy saving analysis is presented bimonthly to the EMC for further improvement, and to evaluate other areas with potential for savings.

Figure 4: Palm Kernel Oil Dry Fractionation process from Desmet Ballestra
Additionally, selected cooling tower fans were fitted with inverters which control their speeds in tandem with the cooling tower water temperature. The complex utilises energy saving alternatives such as LED and spotlights to replace conventional lighting and spotlights.

The savings in electricity consumption achieved over the past few years is shown in Fig. 5. The monthly saving is presented and discussed in the bimonthly EMC meetings, with the aim for knowledge sharing, and to allow duplication of such initiatives in other processes for greater energy conservation. As a policy, all new motors purchased must be of Premium Efficiency (IE3) or better efficiency rating. Generally, for an 80 kW motor, the efficiency of an IE3 motor would be 95%. In comparison, the IE2 rated motor would have 94% efficiency while an IE1 rated motor would have 93% efficiency. The higher the efficiency of the motor, the lower is the power consumed to do the same work. Despite higher costs, more environmental friendly or green purchasing concepts are also taken into consideration by the EMC.

Figure 5: Energy savings achieved in IOIEO between 2017 – 2019
3. Heat recovery and utilization - Vent Economizers

Some of these initiatives helped IOIEO to secure the Energy Award (Fig. 6a) organised by Ministry of Energy and Natural Resources (KeTSA) in year 2018. IOIEO was then selected to represent Malaysia at the ASEAN level, where it emerged as the 2nd Runner up in the large industry category (Fig. 6b).

IOIEO has implemented a steam condensate recovery scheme in its complex. The recovered condensate is collected in strategically located condensate tanks and hot water is used for heating purposes at different production lines, as shown in Fig. 7. Another project was implemented to supplement this by recovering heat from the vapour leaving the condensate tanks.
Heat is recovered from the vapour stream through an economizer. The heat is captured in a water stream. This hot water is used to melt stearin and supplied as process hot water for the fractionation plant. The vent economizer is a heat exchanger that captures heat from the escaping vapour stream and condenses it (to recover pure water) and reclaims some heat from the vapour as it condenses as shown in Fig. 8. Stearin is the solid fraction of palm oil, which sometimes can be seen at the bottom of cooking oil bottles when the cooking oil is stored lower than 30°C for a long period. Some molecules crystalize out from solution and the bottom oil appears cloudy. At lower temperatures, it becomes solid and this is only a physical transformation; the oil clears up when temperatures rise above its cloud point. The solidified oil is perfectly safe for consumption.

Vent economizers have been installed above the condensate recovery tanks. The success of this system has been proven, replicated and implemented in the other plants in the complex. Efforts to utilize hot water for heating stearin cake by replacing the low-pressure steam heating has also resulted in improved product quality in terms of colour and stability. Steam condensate is collected in the condensate tanks for this purpose. In utilising the condensate, water temperature is maintained below 90°C and is re-circulated. On the other hand, when steam is used, its temperature could be as high as 110°C because it depends on its pressure. Higher temperature steam degrades the product quality faster due to overheating. The dry fractionation plant results in savings in low-pressure steam consumption. After installing a vent economizer in 2016, there was a 13.9% reduction in steam consumption. Another vent economizer was installed in 2019 and it reduced steam consumption by 19.9%, as compared to the base year (Table 2).

Similar efforts were undertaken in the PKF plant, where low pressure steam consumption was reduced by 50%, improving it from 100 kg/t to 50 kg/t, as shown in Fig. 9. Efforts are currently underway to reduce this further by utilizing condensate streams that are available within the complex.

Figure 8: Vent economizers project - view of the vent economizer
Table 2: Reduction in steam consumed in dry fractionation plant

<table>
<thead>
<tr>
<th>Year</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
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<tbody>
<tr>
<td>Steam used (kg)/(t) CPO</td>
<td>25.5</td>
<td>24.9</td>
<td>22.0</td>
<td>20.5</td>
<td>21.1</td>
<td>20.5</td>
</tr>
<tr>
<td>Steam Saving (%)</td>
<td>Base year</td>
<td>2.5%</td>
<td>13.9%</td>
<td>19.7%</td>
<td>17.6%</td>
<td>19.9%</td>
</tr>
</tbody>
</table>

Figure 9: Reduction in steam consumption in PKF plant

4. Heat recovery for Physical Refinery
In 2014, the fuel consumption of Refinery 3 (the largest among three physical refineries in the complex) was reported as 5.73 L/t RBDPO, which was much higher than other refineries in the complex. The high fuel consumption was due to the inefficiency in heat exchange in the falling film heat exchanger (Fig. 10(a)). Efforts to clean the heat exchanger to improve its heat exchange only showed improved performance for a short duration before it deteriorated again. In 2016, two spiral heat exchangers were installed to replace the falling film heat exchanger (Fig. 10(b)). This helped to significantly reduce fuel consumption to 3.38 L/t RBDPO (see Table 3). In 2019, the existing falling film heat exchanger (after thorough cleaning) was reintroduced in series with the spiral heat exchanger, as shown in Fig. 10(c). This resulted in further fuel reduction to 2.89 L/t RBDPO (Table 3). This was achieved through improved heat recovery and without major investment. This refinery now has the lowest fuel consumption compared to the other refineries in the complex.

Table 3: Diesel consumption for refinery high pressure boiler operation

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</thead>
<tbody>
<tr>
<td>Refinery 3 (Diesel + LNG) L/t or Sm^3/t RBDPO</td>
<td>5.73</td>
<td>5.17</td>
<td>3.93</td>
<td>3.38</td>
<td>3.65</td>
<td>3.65</td>
<td>2.89</td>
</tr>
<tr>
<td>Reduction (%)</td>
<td>Base year</td>
<td>10%</td>
<td>31%</td>
<td>41%</td>
<td>36%</td>
<td>36%</td>
<td>50%</td>
</tr>
<tr>
<td>Configuration</td>
<td>Falling film (FF)</td>
<td>Change to Spiral Heat Exchanger (SHE)</td>
<td>SHE + FF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. Resource Utilization and Zero Waste
The IOIEO complex generates effluent water and some solid wastes. The effluent water comes from its physical refinery, where water is used for vacuum generation into which some fatty acid vapour condenses. The water contains fatty matter and is treated in the effluent treatment plant (ETP) before it is released to the environment. On the other hand, solid waste is generated from spent bleaching earth during the refining of CPO, CPKO and other lauric products. The spent bleaching earth contains approximately 20% oil. IOIEO works with the spent bleaching earth processing companies to extract the remaining oil from the spent bleaching earth for non-edible applications, such as synthetic oils and biodiesel production. No waste is generated from other plants in the complex.

The ETP of the IOIEO complex has been installed with aerobic digesters that treat the wastewater. Further studies were conducted to boost the ETP performance to handle the additional effluent load from the CPO washing process. A new effluent reactor has been installed to cater for additional wastewater from CPO washing at refinery, giving 15% additional processing capacity. Mini pilot plant studies were commenced in December 2019 to further improve aerobic activity of the effluent process. Improved operating conditions such as proper aeration (and monitoring of the dissolved oxygen content) and addition of sufficient amounts of nutrients for the bacteria have helped to maintain healthy bacterial performance for digesting the organic content of the wastewater. The reactors are always kept operating to avoid decay and loss in bacterial mass in the reactors. These changes have been implemented in the ETP resulting in substantial energy savings. The treatment cycle time has been reduced by 70%, which reduced the electricity consumption significantly. Monthly electricity consumption of ETP was reduced by 10,000 kWh, which equates to an electricity saving of 40%. This reduced operating time also extended the life span of the associated blowers and motors, as well as their parts.
This eventually leads to reduced maintenance downtime and costs. Since the refinery effluent water is organic in nature, the ETP process has been modified to channel all effluent streams to the digesters to be processed by bacteria. The use of poly aluminium chloride (PAC) for flocculation of solids was discontinued after the process had been improved. Minimization of chemical usage and shorter cycle times at the ETP also contribute to the reduction of greenhouse gas emissions from the complex. In addition, the sludge generated is used as fertilizer for plants and greenery maintained around the complex. The amount of sludge generated by the process has been reduced by 50%. Close to 85% of the treated water is reused as industrial water in the complex. Throughout the process, the quality of the treated water has been improved as well.

The complex processes its own raw water. Two new water catchment ponds were constructed in 2016 after severe drought was experienced in the area. Water catchment volume was increased to 100,000 m³ to cater for both refinery complex and the power plant's turbine operation. To increase water collection, rainwater harvesting was implemented for several large roof areas. By utilising natural resources together with industrial innovations, the entire plant is operated with its own processed water for production and for potable use.

Reverse Osmosis (RO) and Ultrafiltration (UF) system-rejected wastewater are reused for fire-fighting, general washing and cooling tower; it further minimises water usage and wastage. The summary for water recycling shown in Fig. 11. In year 2019, total RO reject generated was 75,000 m³ and the volume recycled was 89%, which was almost double of the volume achieved in the previous year (46%).

6. Reduction in atmospheric emissions
The company was the main driver among the refineries in Sabah for the switching from diesel to liquefied natural gas (LNG) as fuel for their high-pressure boilers. The plant has converted to LNG in July 2019, with most of the Sabah refineries following suit thereafter. This has resulted in reduced CO₂ emission of 10% from the high-pressure boiler.

In its efforts to reduce fuel consumption, heat transfer surfaces of selected heat exchangers were cleaned using third-party service providers who utilised high pressure water jets (Fig. 12). After service, the average LNG consumption for the period March to May 2020 was reduced to 3.348 Sm³/t RBDPO, it was equivalent to a reduction of 16.6%. For the annual throughput of 245,000 t (Refinery 2), this results in the savings of 160,000 Sm³ LNG, which is equivalent to a saving of RM240,000. Total CO₂ emission reduction ⁸ was determined as 460,000 kg/y.

**Figure 11:** Summary of reuse and recycle of reverse osmosis reject water in years 2017-2019
The company installed an electrostatic precipitator for one of its boilers, and a wet scrubber for the second boiler as part of its commitment to operate in a sustainable manner. Dust particulate was reduced to below 150 mg/Nm$^3$ (from 330 mg/Nm$^3$) with the wet scrubbing method, and below 50 mg/Nm$^3$ after the installation of the electrostatic precipitator.

The company had also installed dust plants for all kernel crushing plants to reduce its dust emission. The dust emission were reduced by 80% after the installation of these dust collectors. The company maintained the greenery around its facility as can be seen in Fig. 13.

Adjacent to the main office, there is a resting area in combination with a herbal garden with more than 20 types of natural herbs with illustration of their uses and medicinal benefits. The company hopes to create a healthy and sustainable environment within an industrial setting (Fig. 14).

Figure 12: High pressure jet cleaning of spiral heat exchangers

Figure 13: Birds eye view of the plant showing greenery within and around it
7. Conclusion
This paper shows that there are many opportunities to perform sustainable practices in a palm refinery. Since some of the refineries have been installed more than 20 years, plant operators must keep abreast of recent developments and implement ideas for process improvement and for reducing utility consumption. At IOIEO, a multi-pronged approach is pursued to reduce consumption. The efforts consist of the replacement of equipment (LEDs, inverters and high efficiency motors) to reduce electricity consumption as well as investing in heat exchange and heat recovery equipment (spiral heat exchangers, vent economizers) to reduce fuel and steam consumption. The heat exchange equipment installed in refinery has resulted in significant reduction in fuel consumption. The switch from diesel to LNG has resulted in lower GHG emissions. IOIEO has also done process improvement at its effluent treatment plant to significantly reduce its electricity consumption, as well as to eliminate chemical flocculant dosage. The new CPO washing process resulted in reduction in bleaching earth dosage for the physical refinery.

Abbreviations used
1. ASEAN – Association of South East Asian Nations
2. BPO – Bleached Palm Oil
3. CO₂ – Carbon dioxide
4. CPO – Crude Palm Oil
5. CPKO - Crude Palm Kernel Oil
6. DF – Dry fractionation
7. EMC - Energy Management Committee
8. ESP - Electrostatic precipitator
9. ETP- Effluent Treatment Plant
10. HACCP - Hazard Analysis and Critical Control Points (Food Safety Management System)
11. IChemE – Institution of Chemical Engineers
12. IE3 – International Efficiency (Premium Efficiency)
13. IOIEO – IOI Edible Oils Sdn Bhd, Sandakan
14. ISCC - International Sustainability and Carbon Certification
15. ISO 9001- Quality Management System
16. ISO 14001- Environmental Management System
17. ISO 45001- Safety Management System
18. KCP – Kernel Crushing Plant
19. KeTSA -- Ministry of Energy and Natural Resources
20. LED – Light Emitting Diode
21. LNG – Liquefied Natural Gas
22. MSPO - Malaysian Sustainable Palm Oil Certification
23. PFAD – Palm Fatty Acid Distillate
24. PKF – Palm Kernel Fractionation
25. RBDPO- Refined Bleached & Deodorised Palm Oil
26. RBDPOL- Refined Bleached & Deodorised Palm Olein
27. RBDPS- Refined Bleached & Deodorised Palm Stearin
28. RO – Reverse Osmosis
29. RSPO - Roundtable on Sustainable Palm Oil Certification
30. UF- Ultra Filtration
Acknowledgement
The authors acknowledge the strong encouragement and support given by the Group Managing Director of IOI, Dato’ Lee Yeow Chor, in the company’s pursuit of various sustainability initiatives.

References