# Palm oil mill effluent treatment and utilization to ensure the sustainability of palm oil industries

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## ABSTRACT

The purpose of this study was to evaluate the current condition of palm oil mill effluent (POME) treatment and utilization and to propose alternative scenarios to improve the sustainability of palm oil industries. The research was conducted through field survey at some palm oil mills in Indonesia, in which different waste management systems were used. Laboratory experiment was also carried out using a 5 $m^3$ pilot-scale wet anaerobic digester. Currently, POME is treated through anaerobic digestion without or with methane capture followed by utilization of treated POME as liquid fertilizer or further treatment (aerobic process) to fulfill the wastewater quality standard. A methane capturing system was estimated to successfully produce renewable energy of about 25.4–40.7 kWh/ton of fresh fruit bunches (FFBs) and reduce greenhouse gas (GHG) emissions by about 109.41–175.35 $kgCO_2e$/tonFFB ($CO_2e$: carbon dioxide equivalent). Utilization of treated POME as liquid fertilizer increased FFB production by about 13%. A palm oil mill with 45 ton FFB/hour capacity has potential to generate about 0.95–1.52 MW of electricity. Coupling the POME-based biogas digester and anaerobic co-composting of empty fruit bunches (EFBs) is capable of adding another 0.93 MW. The utilization of POME and EFB not only increases the added value of POME and EFB by producing renewable energy, compost, and liquid fertilizer, but also lowers environmental burden.


**Key words** | compost, GHG emission, land application, palm oil mill effluent, renewable energy


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## INTRODUCTION

Indonesia is the biggest crude palm oil (CPO) producer with a share of about 46.6% of the world production (Widjaya *et al.* 2013). The growth of CPO production in Indonesia is 7.8% per year; it is higher than that of Malaysia, which is only 4.2% per year (MP3EI 2011). In 2013 the total oil palm area in Indonesia had reached 8.83 million ha with a total CPO production of 27.64 million ton. It is projected that by 2015 and 2020 the plantation area will be 10.7 million ha and 13.3 million ha, respectively. At the same time, CPO production will be 32.36 million ton in 2015 and 43.93 million ton in 2020 (GAPKI 2014). On the demand side, it was predicted that the total world demand of palm oil will be about 64.5 million ton in 2015 and will increase to 95.7 million ton in 2025 (Oil World Statistic 2013). This situation indicates that palm oil industries will continuously grow to fulfill the world demand.

In addition to CPO as the main product, palm oil mills produce shells, fibers, empty fruit bunches (EFBs), boiler ash, decanter cake, and palm oil mill effluent (POME), either as byproducts or waste. The yield of CPO as the main product is usually less than 25% of the fresh fruit bunches (FFBs). Therefore, biomass waste recycling from palm oil mills to the plantation is one of the important ways to develop sustainable oil palm industries (Hasanudin 2007). The major environmental burden of palm oil mills results from POME. Each ton of CPO production will produce about 2.5–3.0 $m^3$ of POME (Saidu *et al.* 2013). The POME is effluent from the final stage of palm oil processing in the mill. It is a colloidal suspension containing 95–96% water, 0.6–0.7% oil and 4–5% total solids (TS) including 2–4% suspended solids (Mohammad *et al.* 2008). A huge amount of POME with high concentration of organic content has a high potential to cause environmental pollutions if it is not properly treated. In contrast, the utilization of POME can produce some valuable materials or energy, which is important to support the sustainability of oil palm plantations and palm oil mills.

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Waste management in palm oil mills is greatly important in term of minimizing environmental impact and increasing revenue of the industry. This means that improving waste management systems will ensure the sustainability of palm oil industries, which is the final goal of palm oil industry development. Generally POME is treated biologically using a series of open ponds followed by land application or aerobic process (Hasanudin 2007). Development of POME treatment and utilization systems is very important to ensure the sustainability of palm oil industries. The appropriate technology of a POME treatment and utilization system for each palm oil mill depends on the condition of the palm oil mill and plantation, energy supply and utilization, and how much the management pays attention to greenhouse gas (GHG) emission reduction. Evaluation of current condition of POME treatment and utilization systems in some palm oil industries is required to clarify the environmental impact and advantages of each system. From the evaluation, a sustainable POME treatment and utilization system can be developed. The purposes of this study are to evaluate current condition of POME treatment and utilization systems and to propose alternative scenarios to improve the sustainability of palm oil industries. The scope of the research is to develop alternatives for handling POME and EFBs in order to improve sustainability of palm oil mills and plantations.

## MATERIALS AND METHODS

A field survey was conducted in palm oil industries located in Lampung, North Sumatra, and Riau provinces. The survey and interview were conducted to get secondary data and information about FFB production, material balance and energy supply system in palm oil industries. Waste management practices (especially for POME and EFB) were also observed during this survey.

The material balance for EFB composting was evaluated from composting plants at Bekri Palm Oil Mill (Lampung) and Sei Daun Palm Oil Mill (North Sumatra). An open windrow composting system was applied at those palm oil mills. Compressed EFB was used as main raw material for the composting process. POME was sprayed over the EFB pile keep the moisture of the EFB around 60% during the composting process as well as to add organic matter. The volume of the POME, leachate quantity produced during composting and the amount of compressed EFB were estimated based on the supplied data.

Anaerobic biogas production and GHG emission from POME was evaluated using a 5 $m^3$ wet anaerobic digester (Figure 1). The POME for this digester was supplied from Bekri Palm Oil Mill (capacity of 25 ton FFB/hour). Sludge collected from the Bekri palm oil mill wastewater treatment pond was used as inoculums source. After a stabilization period, the digester was operated with hydraulic retention time of 30 days (POME loading rate of 150 L/day). Chemical oxygen demand (COD) values of inlet and outlet of the reactor were analyzed using the closed reflux method (Hach DRB 200) followed by spectrophotometry (Hach DR/4000 U).

The experiment of anaerobic co-composing of EFB and POME was also conducted in a pilot-scale reactor. The process was described in our earlier work (Haryanto et al. 2014). The process was conducted using shredded EFB supplied by Bekri Palm Oil Mill with inoculum from effluent of a pilot-scale POME-based biogas reactor. A plastic drum of 220 L capacity was modified and used as a digester equipped with water shower and gas piping (Figure 1). The inside of the drum was equipped with a perforated floor to facilitate leaching. Shredded EFB (16 kg) was loaded in the drum, which was then tightly sealed. The substrate (EFB) was daily sprayed with 10 L of effluent from the POME-based biogas reactor. Volatile solids (VS) content of fresh and composted EFB was analyzed by burning the material in a furnace (Barnstead Thermolyne 1300) at temperature of 500 °C for 2 hours. The volume of biogas production was monitored daily using a simple water displacement method. Biogas composition was analyzed using a gas chromatogram (GC) (Shimadzu GC 2014) with a thermal conductivity detector at temperature of 200 °C, injection pressure 100 kPa, injection time 1 min and injection temperature of 100 °C. The GC was equipped with a Shincarbon column of 4.0 m length, 3 mm inner diameter. Helium gas was used as carrier gas with flow rate of 40 mL/min.

## RESULTS AND DISCUSSION

### Waste generated from palm oil mills

The mass balance analysis conducted in Bekri Palm Oil Mill revealed that oil extraction rate (OER) resulting from CPO processing was about 21.8% of FFBs. Based on a field survey in two palm oil mills in Lampung Province with a mill capacity of 25 and 40 ton FFBs per hour, the wastes generated from palm oil processing are described in Table 1 (Bekri Palm Oil Mill 2007).

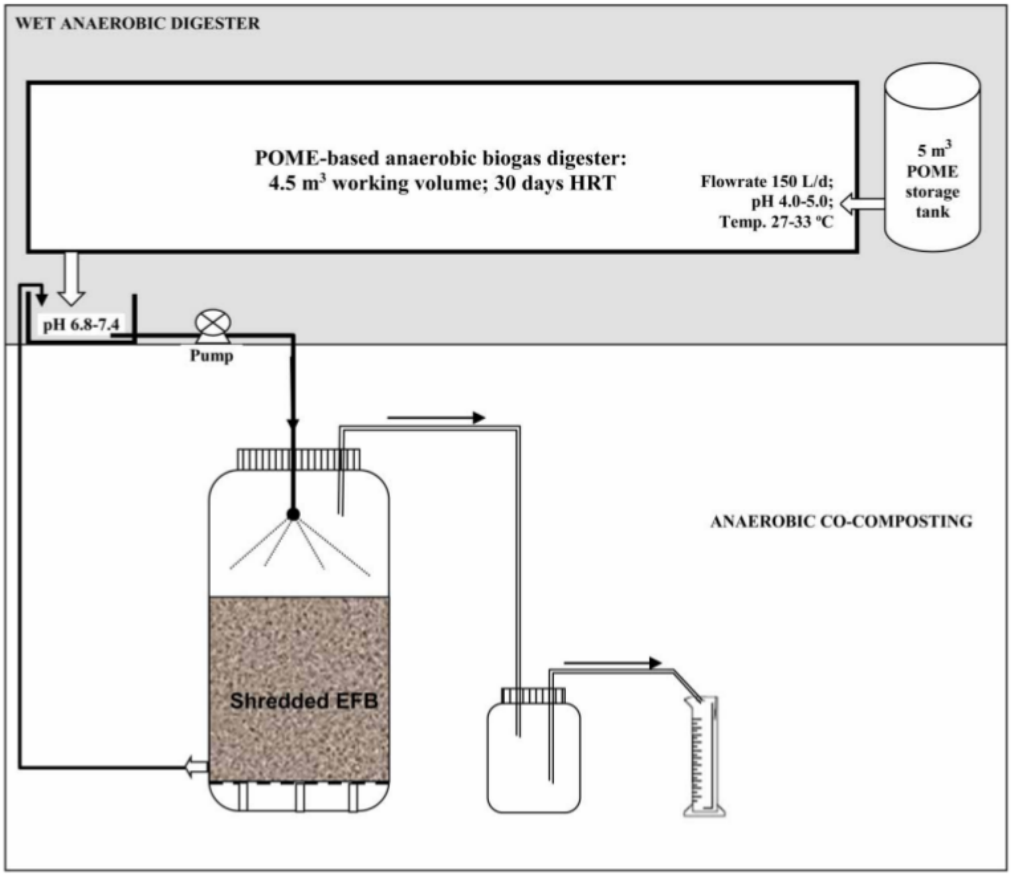


**Figure 1** | Schematic for integration of wet anaerobic digestion of POME and anaerobic co-composting of EFB-POME. HRT: hydraulic retention time.

**Table 1** | Wastes generated from palm oil processing

| Type | Unit | Amount |
|---|---|---|
| FFBs | ton/ton FFB | 0.20–0.23 |
| Mesocarp fiber | ton/ton FFB | 0.12–0.13 |
| Palm kernel shell | ton/ton FFB | 0.05–0.06 |
| Boiler ash | ton/ton FFB | 0.005–0.006 |
| POME | $m^3$/ton FFB | 0.77–0.84 |

Waste management practices affected the productivity of the oil palm plantation and the quality of fruit. Companies carrying out better waste management have achieved a higher productivity. For instance, our survey revealed a certain company was capable of getting a productivity of on average 23 tons of FFBs per hectare per annum with on average 24 percent OER. Another company, in contrast, gets only on average 13 tons of FFBs with 18 percent OER. Based on this information, it is obvious that about 80% of FFBs is biomass waste.

## POME treatment and utilization

POME is the biggest source of palm oil mill pollution with an oxygen-depleting potential 100 times that of domestic sewage (MPOB 2012). Table 1 shows that palm oil mill released 0.77–0.84 $m^3$ POME per ton of FFB being processed. This number was a little higher than the value reported by Saidu *et al.* (2013), which was 2.5–3.0 $m^3$ for each ton of CPO production (equivalent to 0.55–0.65 $m^3$ per ton FFB with 21.8% OER). The sources of POME are mainly from sterilization (36%), clarification and purification of CPO (60%), and hydro-cyclone (4%) processes. Setiadi *et al.* (1996) reported that POME had characteristics as presented in Table 2. Our laboratory measurements showed that untreated POME has COD values varying

**Table 2** | The characteristics of POME (Setiadi *et al.* 1996)

| Parameters | Unit | Value |
|---|---|---|
| BOD | mg/L | 8,200 to 35,400 |
| COD | mg/L | 15,103 to 65,100 |
| Oil and grease | mg/L | 2,200 to 4,300 |
| TS | mg/L | 16,580 to 94,106 |
| Total suspended solids (TSS) | mg/L | 1,330 to 50,700 |

from 43,375 to 60,400 mg/L, while COD values of treated POME varied from 5,500 to 9,000 mg/L.

POME reduction technologies are important to reduce the environmental burden. One way to reduce POME quantity is by implementing a programmable logic controller (PLC) in the boiler and sterilization units. Our observation in Rambutan Palm Oil Mill (Riau Province) revealed that the implementation of PLC has reduced water consumption from 1.73 to 1.54 $m^3$ per ton of FFBs. The reduction of water consumption in the mill resulted in the reduction of POME from about 0.6 to 0.55 $m^3$ per ton of FFBs (Rambutan Palm Oil Mill 2013).

A conventional biological treatment using a series of open ponds is usually applied for POME treatment. The treated POME is then discharged to a water body if the biochemical oxygen demand (BOD) value is less than 100 (Ministry of Environment 2014) or is used for land application. To reach this limit, the POME exiting from the anaerobic open ponds required further treatment, such as the aerobic activated sludge process, to comply with the national effluent standard. The process, however, needs a great deal of energy for aeration. In addition, a lot of nutrient and organic materials are lost from the POME.

POME, either in fresh or treated form, contains a high level of plant nutrient. A sound alternative for utilizing the treated POME is applying it as liquid fertilizer on the oil palm plantation. In Indonesia, land application of POME is regulated in the decree of Ministry of Environment number 28/(2003a) and 29/(2003b). Based on the regulation number 29/2003, land application of treated POME is permitted given that treated POME has BOD value less than 5000 mg/L. The regulation further states that land application is not allowed for oil palm plantations fulfilling these criteria: (1) peat land, (2) soil permeability lower than 1.5 cm/h or higher than 15 cm/h, and (3) depth of ground water less than 2 m.

Recently, biological treatment of POME using a series of open ponds followed by land application of treated POME has been a common practice for wastewater treatment in palm oil industries. Studies by various groups have demonstrated that such application has been beneficial to oil palm (MPOB 2012). In addition, the application extensively saves the fertilizer cost. The application of treated POME has also increased the productivity of the plantation. Table 3 describes the effect of treated POME application on FFB production. Utilization of treated POME for land application has increased FFB production by about 13% compared to the plantation without land application.

The most important problem is that POME treatment using open lagoons emits a huge amount of GHGs. Anaerobic digestion of POME in deep open lagoons produces methane (one of the GHGs) to the atmosphere. Table 4 gives an estimation of GHG emission potential from POME. Energy generated from POME was calculated using a methane low heating value of 191.76 kcal/mole (Perry & Chilton 1983) or 35.82 MJ/N $m^3$ and 35% conversion efficiency from biogas to electricity. Based on the methane production potential, the energy electricity production from POME was estimated to be about 25.4–40.7 kWh per ton of FFBs. Using this value, palm oil mill with a capacity of 45 ton FFBs per hour or 900 ton per day has a potential to generate electricity of about 0.95–1.53 MW.

POME utilization and recycling through methane capturing and land application of treated POME is

**Table 3** | The effect of treated POME application on FFB production (Rejosari Palm Oil Mill 2007)

| | Productivity (kg of FFB /ha) | |
|---|---|---|
| Production[a] | With treated POME | Without treated POME |
| January | 805.82 | 697.87 |
| February | 222.51 | 151.22 |
| March | 222.56 | 182.61 |
| April | 201.56 | 180.00 |
| May | 395.68 | 347.83 |
| June | 526.80 | 425.15 |
| July | 947.38 | 846.82 |
| August | 1159.17 | 1018.26 |
| September | 2161.10 | 2034.78 |
| October | 2835.50 | 2675.74 |
| November | 3679.87 | 3374.87 |
| December | 2202.27 | 1687.30 |
| Average | 15,360.21 | 13,622.45 |

[a]Age of oil palm trees are 21 years.

**Table 4** | Estimation of GHG emission potential from POME

| Parameter | Unit | Value Min | Value Max |
|---|---|---|---|
| COD of fresh POME | mg/L | 43,375 | 60,400 |
| COD of treated POME | mg/L | 5,500 | 9,000 |
| POME production | $m^3$/ton FFB | 0.55 | 0.65 |
| COD removal | kg/ton FFB | 20.83 | 33.41 |
| IPCC default value[a] | kg $CH_4$/kg COD removal | 0.25 | |
| $CH_4$ production | kg/ton FFB | 5.21 | 8.35 |
| IPCC default value[a] | $m^3$ $CH_4$/kg COD removal | 0.35 | |
| $CH_4$ production potential | $m^3$ $CH_4$/ton FFB | 7.29 | 11.69 |
| GWP potential of $CH_4^a$ | kg $CO_2$e/ kg $CH_4$ | 21 | |
| GWP potential | kg $CO_2$e/ton FFB | 109.41 | 175.35 |

[a]IPCC (2006). $CO_2$e: carbon dioxide equivalent.

becoming more and more practiced by palm oil industries. This practice not only reduces significantly the environmental impact of POME, but also produces some valuable products, increases energy efficiency, and maximizes renewable energy utilization. Implementation of a methane-capturing system also contributes GHG emission reduction, which is a very important issue in palm oil industries.

## Co-composting EFB and POME

EFB and boiler ashes (residue from boiler system) are directly used for mulching and fertilizer that is returned to the plantation to reduce chemical fertilizer consumption and to maintain microclimate condition in nearby oil palm trees. Even though EFB can provide energy by direct burning, it contains relatively high moisture, so there will be problems, and pre-treatment is required if it is used as fuel like fiber and shell. Co-composting of EFB and POME using an aerobic system currently has been promoted. POME was used to keep the moisture of EFB around 60%. The palm oil industries are currently using its EFB waste for mulching and its treated POME as a liquid fertilizer through implementation of a land application system. Some other industries are using the EFB and POME together to produce compost. Composting of EFB together with POME can minimize nutrient losses and concentrate all the nutrients from POME and EFB in the one product. Using co-composting of EFB and POME almost all (depending on how much POME is produced per ton FFB) of the POME is utilized to keep the moisture around 60% during the composting process. Application of EFB-POME compost will increase the productivity of land to produce FFBs of oil palm (Schuchardt et al. 2008). The diagram of compost production is given in Figure 2.

A case study of the EFB-POME aerobic co-composting plant in Sei Daun Palm Oil Mill (North Sumatra) and

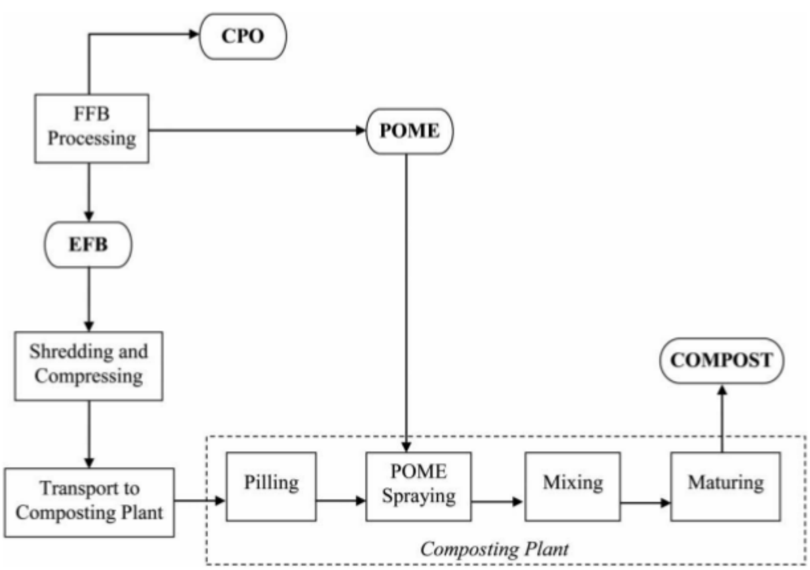


**Figure 2** | Diagram of EFB-POME co-composting process.

Bekri Palm Oil Mill (Lampung) showed that about 0.091 $m^3$ of wastewater or about 13.06% of POME still remains and needs to be treated or utilized for land application. Table 5 shows the material balance of aerobic POME-EFB co-composting.

Anaerobic co-composting of EFB-POME is another choice to be evaluated. The process produces compost and biogas as well. Figure 3 depicts daily and cumulative biogas production from anaerobic composting of EFB using effluent from conventional POME anaerobic digestion as bacteria source. During anaerobic fermentation that was going on for 6 weeks, TS decreased from 35.8 to 27.1%, while organic matter slightly decreased from 91.6 of TS to 88.9% of TS. Water content, conversely, increased from 64.2 to 72.9% (wet basis). For the duration of anaerobic digestion, the fiber of EFB was still physically strong. This implied that the biogas was produced mainly from the degradation of such organic materials as oil and debris attached in the EFB.

Biogas production reached 1,235 L (average 77.18 $m^3$/ton EFB or 17.75 $m^3$/ton FFB) with biogas yield of 1,120.6 L/kg $VS_{removed}$. The biogas had a composition of methane (40.1%), nitrogen (13.1%), and carbon dioxide (46.7%). The low methane and high nitrogen contents of biogas produced from small scale were also reported by Cahyani (2012). Using this value, integrating anaerobic co-composting of EFB-POME with a POME-based biogas digester at a palm oil mill with a capacity of 45 ton FFBs per hour is capable of adding 0.93 MW more electricity. Using this system, the palm oil industry produces higher energy, compost and liquid fertilizer, which is important to ensure the sustainability of FFB production.

**Table 5** | Material balance in POME-EFB co-composting process

| Parameter | Unit | Amount |
|---|---|---|
| FFB | ton | 1 |
| Volume of POME | $m^3$ | 0.7 |
| EFB | ton | 0.23 |
| Water in EFB (moisture 60%) | $m^3$ | 0.138 |
| Total POME utilized for composting (3 $m^3$ of POME/ton EFB) | $m^3$ | 0.690 |
| Total water evaporated (evaporation rate = 51 L/ton EFB/day[ab]) | $m^3$ | 0.657 |
| Total water remaining (un-evaporated water) | $m^3$ | 0.171 |
| Total weight of compost (65% of EFB) | ton | 0.150 |
| Total water in compost (moisture 60%) | $m^3$ | 0.090 |
| Total leachate released | $m^3$ | 0.081 |
| Total un-utilized POME | $m^3$ | 0.010 |
| Total wastewater released | $m^3$ | 0.091 |
| | % | 13.06 |

[a]Schuchardt et al. (2002).
[b]Assumption: effective evaporation conducted for 8 weeks (56 days).

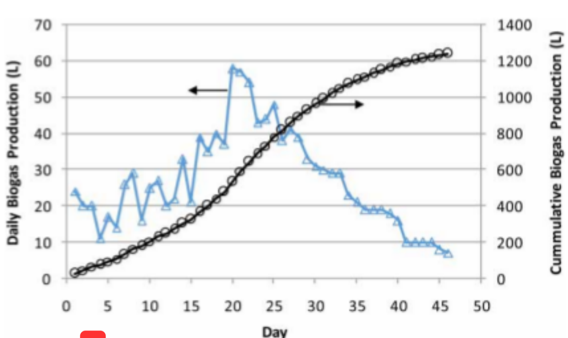


**Figure 3** | Daily and cumulative biogas production from dry anaerobic digestion of EFB.

## CONCLUSIONS

POME is the biggest waste generated from palm oil mills. Currently, POME is treated mainly through anaerobic digestion in a series of open anaerobic ponds followed by land application of treated POME. Treating POME by methane capture followed by utilization of treated wastewater as liquid fertilizer is important to ensure the sustainability of FFB production. A methane-capturing system was able to produce renewable energy of about 25.3–40.6 kWh per ton of FFBs and reduce GHG emission by about 109.41–175.35 kg $CO_2e$ (carbon dioxide equivalent) per ton of FFBs. Utilization of treated POME as liquid fertilizer through land application has increased FFB production by 13%. Palm oil mill with a capacity of 45 ton FFBs per hour has a potential to generate about 0.95–1.52 MW of electricity through implementation of methane capture from open ponds. Integration of anaerobic co-composting of EFB-POME with a POME-based biogas digester is capable to add 0.93 MW more electricity. This integration is beneficial to increase the added value of POME and EFB, to lower the environmental burden, and to ensure the sustainability of palm oil industries.

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