Scaling up Model for Developing Second-Generation (2G) Bioethanol by using Palm Empty Fruit Bunches Feedstock

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Abstract

As the country with the largest palm oil production in the world, the potential of lignocellulose waste like an empty fruit bunch produced by Indonesia is huge. Utilization of empty fruit bunch feedstock into second-generation (2G) bioethanol on a pilot scale is quite extensive. 2G bioethanol is also generally recognized as a promising market potential because of its less impact on the environment, however, the production cost is still rather high and the development of a commercially competitive process for 2G technology poses a challenge. This research attempts to investigate the model of scaling up of 2G bioethanol production to accelerate commercialization by integrating the well-established sucrose-to-bioethanol process from palm oil lignocellulose feedstock. The case of scaling up to be calculated for a chemical pathway of bioethanol production with productivity consideration. Scaling up shows some of the unit process shall complete the basic step in laboratories scale. The supporting process must develop in pretreatment step likes empty fruit bunch washing, drying, and mechanical tearing. The additional process in hydrolysis step is filtering and evaporation glucose liquor until appropriate concentration. The distillation step develops for industrial scale according to alternatives products such as ethanol for solvent, pharmaceutical grade ethanol, or biofuels. The industrial-scale model estimate to produce 18.6 KL/days of bioethanol (ethanol content of 99.6%) need to support at least three crude palm oil plant with capacities 30-45 ton empty fruit bunch feedstock/hour. The model calculated empty fruit bunch feedstock about 600 ton/day.

Keywords
Empty fruit bunch, palm oil, scale-up, 2G bioethanol

1. Introduction

Indonesia has many sources of agricultural products that can be developed as raw materials for the bioenergy industry. From a variety of agriculture products that became Indonesia's flagship, palm oil is the result of national flagship plantations. Palm plantations spread in 22 provinces in four islands namely Sumatra, Kalimantan, Sulawesi and Papua. Based on data from the Ministry of Agriculture of the Republic of Indonesia (2015), Riau Province ranks highest in palm plantations, followed by North Sumatra and Central Kalimantan.

Development of the bioenergy industry can not be separated from the national downstream program of the palm oil industry. Government Regulation No. 14 of 2015, this industry is categorized in palm oil derivative industry and become the mainstay of Indonesia's industry strengthening in the future.

The Government has issued a National Energy Policy (NEP) as stipulated in Government Regulation No. 79/2014. NEP mandated percentage of new and renewable energy (NRE) utilization in the national energy mix with minimum of 23% in 2025 and 31% in 2050 (Hasibuan & Nazir, 2017). With these targets, development of NRE can be optimized and at the same time it can take advantage of environmentally friendly energy and support regional development in remote and isolated area. The main intention of the regulation is to reduce the dependence of Indonesia on imported fossil fuel and cushion it from the erratic price fluctuations as well as ensure the availability of clean energy which can lead to reductions in Greenhouse Gas (GHG) emissions. Therefore, the development of biofuel is one of the main agenda of new and renewable energy development in Indonesia. Bioethanol has a great potential for substitution of oil fuel in Indonesia.

A number of studies have been conducted to produce bioethanol from empty palm oil bunches, but until now the industrialization process is still very limited, more ending in laboratory scale. A second generation ethanol production doubling of empty palm oil bunches continues to be needed to provide industrial scale development support.

2. Literatur Review

2.1 Bioethanol

Based on its raw materials, there are three generations of bioethanol namely first, second, and third generation bioethanol. The 1st generation bioethanol (G1) is bioethanol produced from starch-containing feedstock such as cassava, sweet potato, cane juice, corn, beet sugar, sorghum, potatoes, wheat and so on. Processing from starchy material through starch extraction process, starch hydrolysis process to dextrin using acid or enzyme, saccharification process to convert dextrin into glucose monomer by gluco-amylase which can be fermented into ethanol (Dammer *et al*., 2017).

The 2nd generation bioethanol (G2) is a bioethanol produced from biomass waste feedstock containing lignocellulose. The lignocellulosic material is a high-cellulose and hemicellulose (holocellulose) material contained in agro-industrial solid waste such as sugarcane bagasse, rice straw, palm stem, corncobs and stalks, brown skin, and empty palm oil bunches (EFB) (Sutikno et al., 2010). The process of making lignocellulosic based bioethanol consists of three main stages, namely pretreatment to remove lignin, hydrolysis and fermentation. Production from this 2nd generation also has constraints that is high in lignin content, requires expensive and uneconomical technology in large scale production (Brennan and Owende, 2010).

The 3rd generation bioethanol (G3) is a bioethanol that uses the raw materials of algae groups namely microalgae and macroalgae (seaweed) (Dragon *et al*., 2010). The groups of algae that can be used as bioethanol biomass are microalgae (*Anabena*, *Botryococcusi*, *Chlamydomonas*, *Dunaliella*, *Chlorella*, *Euglena*, *Porphyridium*, *Prymnesium*, *Scenedesmus*, *Spirogyra* sp, *Spirulina*, *Synechoccus*, *Tertaselmis*), and macroalgae (seaweed). Production of bieotanol from algae using fat and holoselulose. The algae group was selected because it proved to be able to grow and hold in various environments, sufficient and safe to supply, with little lignin or no lignin at all, rapid growth, and a role in reducing the greenhouse effect.

2.2 Potential of Palm Biomass

The palm oil industry produces huge amounts of biomass such as old palm fruit (OPF), old palm stems (OPT), and empty fruit bunches (EFB). OPF and OPT feedstocks are produced from palm plantations while EFB is produced from palm oil processing plants. EFB biomass is one of the by-products of crude palm oil industry. Palm empty bunches are the largest solid waste of fresh fruit bunches (FFBs) in the palm oil industry that are abundant and renewable in nature. According to Fauzi *et al*. (2005), from processing 1 ton of fresh fruit bunches (FFBs) will yield 23-25% EFB, 13-15% fiber, 6.5% shell, 5.5-6% seed and 16-20% crude palm oil CPO). With the production rate of Indonesia's palm oil around 33.50 million tons in 2016 (Ditjenbun, 2017), it is estimated that EFB biomass in Indonesia is 25.12 million tons.

In addition to empty fruit bunches, other potential lignisellulose biomass from palm oil waste are stem, trunk and fiber. When mapped in one year, the greatest potential is actually the stem. The distribution of potential biomass from palm oil for the production of second generation bioethanol is shown in Figure 1.

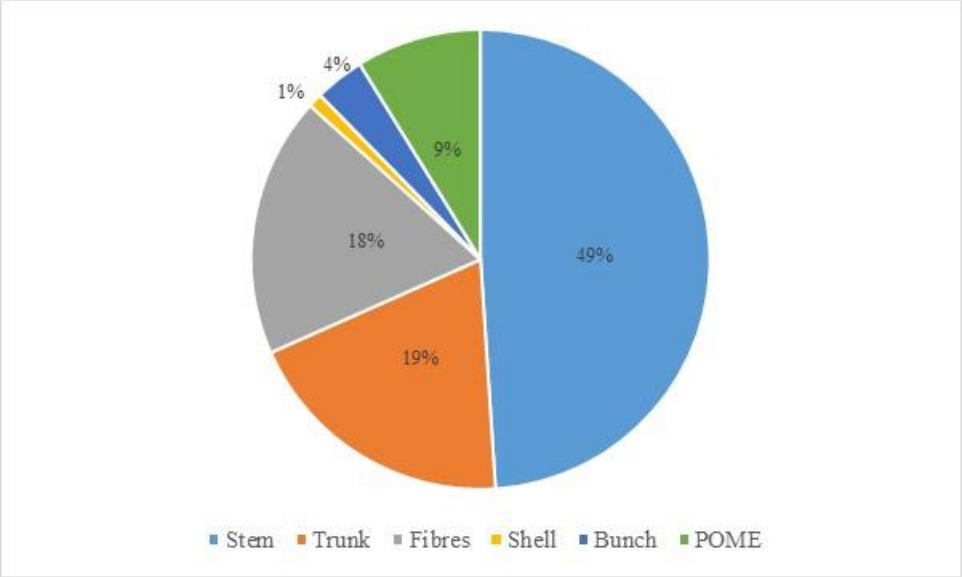

Figure 1. Potential distribution of second generation bioethanol feedstock from palm oil waste.

The largest potential of oil palm biomass is found in the provinces of Riau, North Sumatra, Central Kalimantan and South Sumatra. Therefore the development of G2 bioethanol industry can be considered in the four areas as pioneers. When considering the availability of road and port infrastructure, the island of Sumatra is much more prepared than Kalimantan. The empty fruit bunches (EFB) from oil palm include potentially lignocellulosic biomass processed into a variety of products, but the utilization is still limited. Currently, EFB only burned and partially spread in the field as mulch. The empty fruit bunches from oil palm are potentially processed into compost, animal feed, briquettes, boiler fuel, pulp, paper, fiber, and bioethanol.

The main content of EFB is lignocellulose (Lynd *et al*., 2005; Carvalho *et al*., 2016). Lignocellulose is a complex carbohydrate derived from plants and is composed of lignin, hemicellulose and cellulose. Components of cellulose, hemicellulose, and lignin EFB are detailed in Table 1. Because of the high EFB holocellulose content, The EFB has potential as a feedstock for bioethanol production.

Table 1. Lignocellulose content in EFB

Cellulose	Hemicellulose	Lignin
45,95%	22,84%	16,49%
42,28%	24,34%	28,99%
49,76%	28,92%	22,42%
50,13%	24,32%	24,15%

Sources: Lynd *et al*. (2005); Carvalho *et al.* (2016)

The OPF ingredients are one source of abundant by-products in oil palm plantations. The trunk can be obtained daily during the year when the palm is weeded during the fruit harvest. OPF ingredients contain carbohydrates as well as lignocellulose and amount to 24 million tons/year removed from palm mills. OPF material lags behind the palm tree, generally for soil conservation, erosion control and in the long run improves nutrient recycling.

2.3 Redesign the Production Process

2.3.1 Pretreatment of Eempty Palm Fruit Bunchs

Lignocellulosic based biomass requires pretreatment or pre-treatment before the biomass is hydrolyzed and fermented. The delignification process is required to break the long polymer chain into shorter polymer chains, increase the amorphous region (decrease the degree of crystallinity) and separate the lignin portions of the holocellulose. The proper pretreatment process will increase the efficiency of the hydrolysis process by expanding the contact surface of the substrate with the enzyme (Mergner *et al*., 2013). However, the selection of methods for pretreatment will affect the next process. Unwanted conditions during the pretreatment process will lead to the

formation of partial products of hemicellulose and lignin and toxic compounds or inhibitors that can reduce the performance of enzymes and microorganisms.

Pretreatment can be done physically, chemically, biologically or in combination of these methods. The use of pretreatment methods has been done on different biomass, and the results vary for each method and type of material used (Isroi *et al*., 2011). Each of these pretreatment methods has their respective advantages and disadvantages, so it is necessary to consider choosing the right pretreatment method in order for the conversion process to run optimally.

Types of pretreatment often used in EFB biomass are chemical pretreatment or pretreatment with chemical (acid or base) and steam (physical-chemical) combination. According to Ramli *et al*. (2014), pretreatment method using alkaline solution will increase the effectiveness of enzymatic hydrolysis process by increasing the accessibility of enzyme on cellulose surface. The basic compound that is often used for pretreatment EFB is NaOH. According to Sutikno *et al*. (2010), the use of NaOH in agro-industrial waste can degrade lignin more than 99% after immersion in 1 M NaOH solution at room temperature for 48 hours or at 121 °C for 15 minutes or more. NaOH works by attacking and destroying lignin structures, crystalline and amorphous parts, separating some lignin and hemicellulose and causing cellulosic structure bloat. When the higher base concentrations, the -OH groups will be easier to enter the water, so that between the cells of the cellulose molecules will contain water. It indicates that pretreatment is base more effectively used for bioconversion process of EFB.

2.3.2 Hydrolysis/Likuification

The hydrolysis process of the EFB bioconversion serves to break down long chain carbohydrate polymers ie holocellulose (hemicellulose and cellulose) into reducing sugar monomers. The perfect hydrolysis of cellulose produces glucose, whereas hemicellulose produces several monomers of pentose sugar (C5) and hexose (C6). This is based on the differences of cellulose and hemicellulose compounds (Mergner *et al*., 2013).

The hydrolysis process in the production of bioethanol can be carried out chemically (using acidic compounds) as can be seen in Figure 2. The hydrolysis mechanism of acid is breaking cellulose bonds randomly, so as to produce products other than glucose, ie furfural, 5-hydroxymethylfurfural (HMF), levulinic acid (levulinic acid), acetic acid (acetic acid), furan, phenolic and some other unexpected compounds.

Another disadvantage of using acid is that it can cause sugar degradation during hydrolysis reactions resulting in reduced glucose and ethanol yield (Howard *et al*., 2003), and inhibition of fermentation by these inhibitor compounds and acidic compounds may corrosive the environment (Taherzadeh and Karimi, 2008).

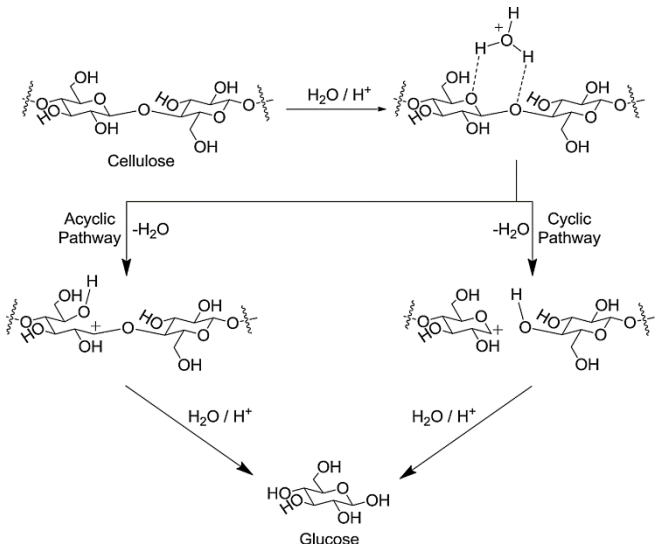

Figure 2. Hydrolysis process using acid (Howard *et al*., 2003).

Another disadvantage of using acid is that it can cause sugar degradation during hydrolysis reactions resulting in reduced glucose and ethanol yield (Howard *et al*., 2003), and inhibition of fermentation by these inhibitor compounds and acidic compounds may corrosive the environment (Taherzadeh and Karimi, 2008).

2.3.3 Holoselulose Fermentation

Fermentation process is the conversion process of reducing sugar from hydrolysis into ethanol which is biologically conducted by microorganism. The conversion process of hexose sugar such as glucose generally requires anaerobic conditions to maximize ethanol formation. While with aerobic conditions, the fermentation process will produce CO_2 gas, H_2O and energy. Equation of anaerobic fermentation reaction process can be seen in the following equation.

$$n\ (C_6H_{12}O_6) \longrightarrow 2n\ (CH_3CH_2OH) + 2n\ (CO_2)$$

Ethanol and CO_2 formed from the fermentation process can inhibit the fermentation process (end-product inhibition). It takes a fermentation technique that can minimize the role of the inhibitor because the microorganisms that convert glucose to ethanol are not resistant to alcohols at a certain concentration.

Various kinds of microorganisms such as yeasts can be used in fermentation with the product of ethanol. One of the well-known yeasts for ethanol production is *Saccharomyces cerevisiae*. In general, yeasts can grow and produce ethanol optimally at pH 3.5- 6.0 and temperature 30-37 ^oC. *S. cerevisiae* belonging to the eukaryotic group that is easily obtained and cultured with the characteristic traits generally have no hyphae and fruit body (Haetami *et al*., 2010). *S. cerevisiae* is an anaerobic facultative organism that can live either aerobic or anaerobic or semi anaerobic systems that contain little dissolved oxygen to digest glucose and produce CO_2 and energy (Buckle *et al*., 2007). *S. cerevisiae* has a high conversion power to ethanol and has a high tolerance to ethanol. The main metabolites are ethanol, CO_2 and water, also produce little metabolites. Every 1 mole of fermented glucose produces 2 moles of ethanol, CO_2 and ATP.

Theoretically every 1 g of fermented glucose yields 0.51 g of ethanol (Wahyudi *et al*., 2010). But in reality, ethanol does not exceed 90-95% of the theoretical results. This is because some nutrients are used for biomass synthesis and maintenance of reactions. Side reactions can also occur, namely the formation of glycerol and succinate that can consume 4-5% of the substrate (Ojokoh and Uzeh, 2005).

There are at least two types of fermentation methods to produce ethanol. The first method is a separate hydrolysis and fermentation known as Separated Hydrolysis and Fermentation (SHF) and the second method is simultaneous Saccharification and Fermentation (SSF) simultaneous saccharification and fermentation (SSF) (Rana et al., 2014). SHF is a method of bioethanol production where the process of substrate hydrolysis and fermentation process take place separately. The advantage of SHF is hydrolysis by cellulase enzyme and fermentation by microorganism can be done at each optimum condition (Taherzadeh and Karimi, 2008).

Ethanol and CO_2 formed from the fermentation process can inhibit the fermentation process (endproduct inhibition). Therefore, it is necessary fermentation method that can minimize the role of the inhibitor. The SSF method is a bioethanol production method that combines the enzymatic hydrolysis stage with the fermentation stage taking place in one bioreactor and at the same time (Olofsson *et al*., 2008).

2.3.4 Purification of ethanol

To achieve purity above 90 percent, the fermented bioethanol must go through a distillation process to separate the alcohol with water by taking into account the difference in the boiling points of the two materials which are then condensed. The process of separation of alcohol with water is usually called refinery. A simple distillation (distillation unit) consists of several components: reactor, coloum, condenser, distillate reservoir and control system. In the process of distillation, the control system has a very important role in obtaining distillate (distillate) with the expected quality. The control system in the distillation process serves to keep the process parameters (such as temperature, pressure, mixer velocity, etc.) in the desired value, so that the steady state can be maintained.

3. Method

Scaling up in principle according to Cooley and Ved (2012) centered on three stages of expansion, replication, and collaboration. Expansion refers to the measurement model for improving the scope of operation. Replication involves increasing use of common processes, technologies or models. Collaboration, is the third method in scaling, is between expansion and replication. The details of the three methods are presented in Table 2.

Table 2. Alternative approaches and methods of s*caling up*

Approach	Method
Ekspansion	- Growth - Restructuring - *Franchising* - *Spin-off*
Replikation	- Adoption of policy - Diffusion - Grafting - Commercialization
Collaboration	- Formal partnership and strategic alliances - Network and coalitation

Cooley dan Ved (2012)

In the development of chemical industry processes (pharmaceuticals, petroleum, food, chemical and biotechnology) are generally initiated in small glass reactors. From the laboratory small-scale reactor is observed the influence of kinetics constant and mixing effect. Bentolila (2015) demonstrates the difference that a glass reactor is not an ideal reactor. Excellent data for multiplication of scale measurement is explained from a combination of experimental data with a calculation facility. Figure 3 shows the scale multiplication process by Ka Ming and Wibono (2003), based on data collection from data collection equipment, data welding by designing a commercial-scale configuration process (not for construction but for detailed critical analysis) using math and knowledge calculations.

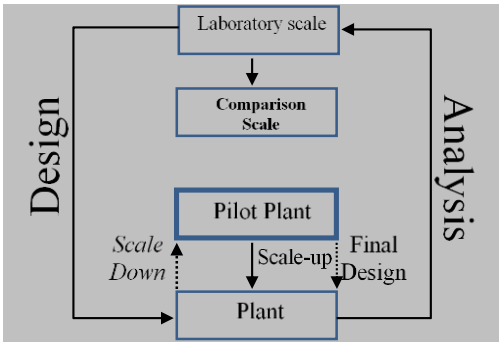

Figure 3. Feedback round of experimental-cycle-analysis design (Ka Ming and Wibono, 2003).

After several rounds of experiments on the scale range and design calculations it will be possible to raise the scale of the design to a larger factory scale and confirm experimental data of the hybrid model under the condition of the plant facility. After these critical stages it is possible to be refined into a commercial scale.

Based on Figure 3, it is concluded that the process stages for the multiplication of scales are as follows:

1) Mechanism of chemical or biological processes;
2) Upcoming feasibility plan following the company's business plan;
3) Calculate through different simulation devices how to get to commercial scale
4) Set the laoratorium equipment on a scale that allows it to provide the conditions closest to commercial production scale
5) The optimization process is based on the working range most likely in the commercial phase
6) Use medium scale to verify the model.

The method to simulate the multiplication of scale in the chemical production process is presented in Figure 4.

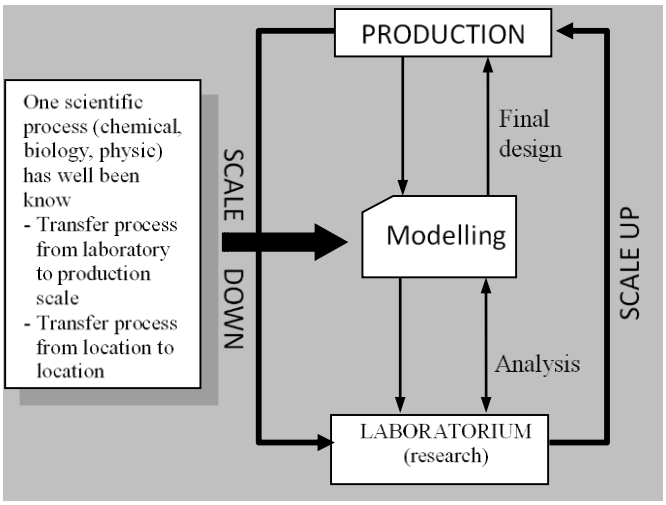

Figure 4. General schema modeling of scale duplication and scaling process (Bentolila, 2013 processed).

4. Result and Discussion

The choice of bioethanol production technology developed consists of four main stages: 1) delignification; 2) liquification or saccharification; 3) fermentation; and 4) distillation. The method chosen for the calculation is a chemical method with easier consideration and higher productivity per unit time. Stages of the process are washing of bunches to dispose of the remaining oil, mechanical empty bunch destruction, removal of lignin by soda method, liquification that is transforming cellulose into monosaccharides, fermentation, and distillation to produce alcohol with the desired concentration. Operational scenarios used are presented in Table 3.

Table 3. Scenario of bioethanol production from empty fruit bunches

Description	Benchmarks	Referens
Capacity of palm oil plant	30-45 ton EFB/hour	
Empty Fruit Bunches (EFB)	1.88/6.25 = 30% EFB	Pleanjai *et al* (2004)
	23% fresh fruit bunches	Najafpour *et al* (2006)
Sellulose	50% EFB	Najafpour *et al* (2006)
Gula Terlarut	24-32 %	Najafpour *et al* (2006)
Bioethanol plant	2-3 CPO plant	

Delignification is the step of separating the fibers from lignin, carried out by a combination of a mechanical milling method with a chemical treatment, which is cooked with NaOH. The resultant process is a cellulose pulp that can be separated from lignin.Saccharification is the process of cooking cellulose fibers into a simple sugar solution. The fiber, which is a long-chain cellulose, is cooked into simple sugars using sulfuric acid. The result is a sugar solution still mixed with the cellulose slurry. Gong and Tsao (2010) reported that hydrolysis yields a mixture of glucose and xylose.

The next process is washing with hot water and then carried out screening. Report of Samsudin *et al* (2012) that washing with hot water separates glucose. Glucose dissolved in the hydrolysis process is generally low, so it should be concentrated at least up to 14%. Evaporation process is required to produce sufficient concentration for yeast culture Saccharomyces cereviceae.After the sugar solution reaches a concentration of about 14%, then the fermentation stage is performed. Nutrient ingredients for yeast life such as urea are added. Fermentation is carried out for 40-50 hours depending on the sugar concentration.

The ethanol concentration resulting from the fermentation of S. cerevisae of an alkaline sugar solution resulted in 262 ml/kg of FFB, while acid hydrolysis produced only 179 ml/kg of ethanol (Richana *et al*., 2015). Ningsih *et al.* (2012) found that fermentation was done by using *Saccharomyses cerevisiae* result of hydrolysis of EFB yielding highest result of bioethanol content equal to 9,698%. To make bioethanol fuel, further distillation process. The calculation of scale material balance from production of bioethanol plant made from empty palm oil bunch feedstock is further presented in Figure 5.

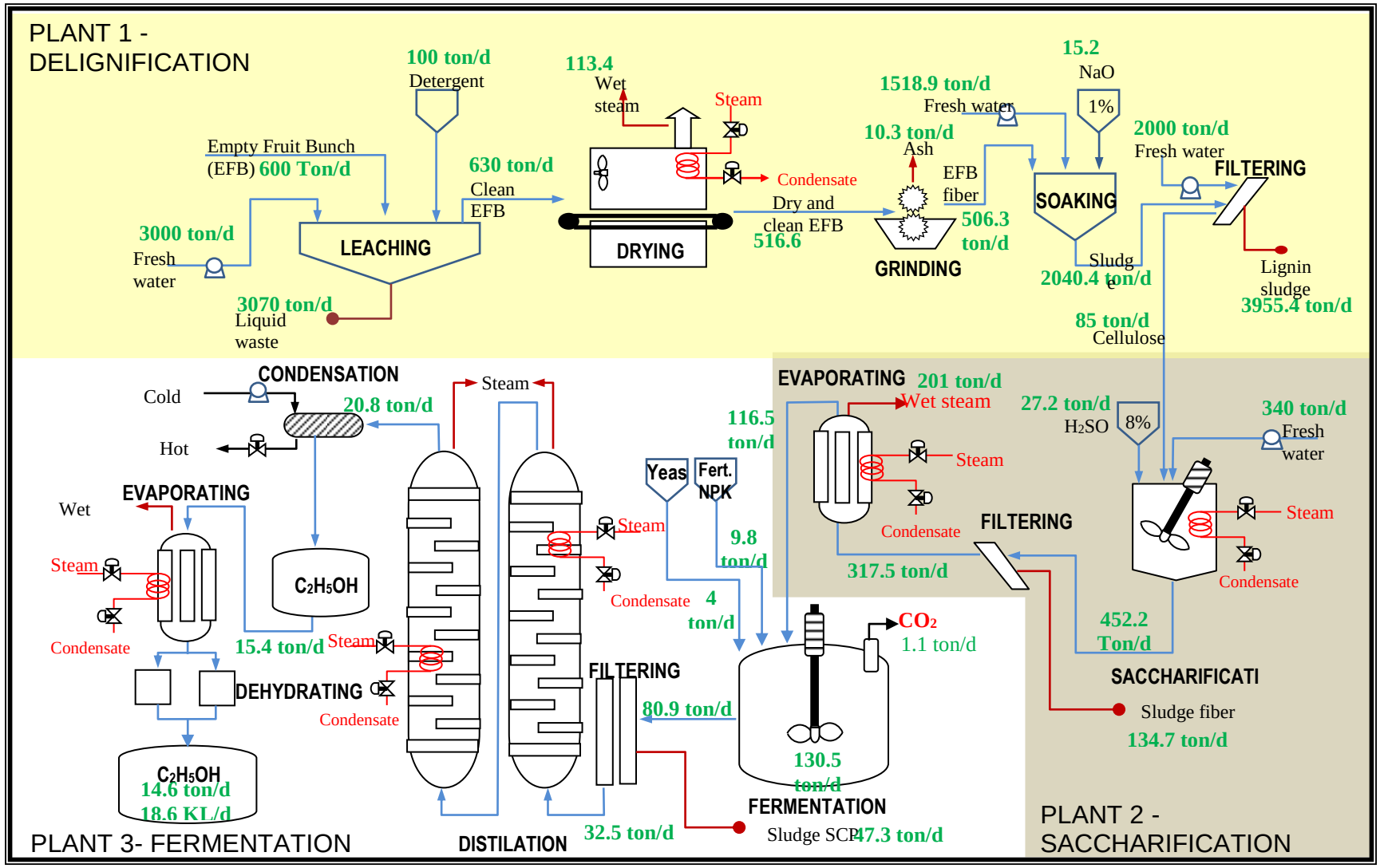

Figure 5. Scale multiplication model for the development of G2 bioethanol industry using acid hydrolysis method, made from palm oil empty bunch

5. Conclusion

A scale multiplication study is needed to support the success of second-generation bioethanol production (Gen2) on a commercial scale. These efforts provide support for the utilization of palm oil mill waste and produce renewable alternative fuels. Second-generation bioethanol production process using chemical hydrolysis pathways is an option, especially when considering industrial productivity. The use of chemical processes will shorten the processing time.

The multiplication of the scale shows that a number of processes found on the scale of laboratory experiments need to be developed more fully, especially in supporting processes such as leaching of empty bunches, empty bunch drying, mechanical fiber pretreatment separation. The addition of an industrial scale process is also required for the separation of the glucose solution and concentration of the solution before it becomes a fermentation substrate. In industrial scale also developed purification step by distillation to become main product either as solvent ethanol, pharmaceutical grade ethanol, and also fuel.

In the modeling process, it is calculated that for the production of ethanol 99.5% as much as 18.6 KL/day required the support of at least three palm oil industries with a capacity of 30-45 ton empty fruit bunches/hour.

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