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Techno-Economic Analysis Of Establishing A Seaweed Processing Plant With A Flexible Manufacturing System

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ABSTRACT

Seaweed is a mainstay in the development of the blue economy in Indonesia, with production reaching 8.6 million tons in 2022. In Indonesia, the types of seaweed cultivated are Euchema sp. as a source of carrageenan and Gracilaria sp. which is a type of seaweed often cultivated in ponds as a source of agar. The two types of seaweed have different characteristics, so they have different extraction methods in the processing. Separate process designs for the two types of seaweed are inefficient due to different harvesting patterns. Several processing machines for the two types of seaweed function similarly, so they can be rotated in the processing. With some additional equipment, a Flexible Manufacturing System (FMS) is produced, in which the factory system can process agar-agar and kataginan alternately. This study was conducted to analyze the feasibility of a seaweed factory designed with the FMS model. The analysis was carried out using a financial feasibility method with the Weighted Average Cost of Capital (WACC) as a reference indicator. The Capex for the FMS factory with a combined product capacity of 1500 tons/year is estimated at Rp. 60.6 billion with Opex of Rp. 8.65 billion. The factory is projected to generate an average net profit of 9.77%. The investment itself will be recovered between the 7th and 8th year. The establishment and operation of the FNS seaweed factory is deemed feasible with a positive NPV of IDR 28.88 billion, an IRR of 17.81% higher than the WACC of 10.49%, and a PI of 1.42. The break-even point for the factory is reached at a production rate of 667.38 tons per year, or approximately 44.49% of installed capacity. This condition allows the factory to adjust to seaweed harvest patterns to overcome raw material shortages.

Keywords: Seaweed, Techno-economics, Flexible Manufacturing System, Feasibility Study, Weighted Average Cost of Capital

I. INTRODUCTION

Indonesia has a large share in the global seaweed market.According to FAO data from 2022, Indonesia is the world's second-largest seaweed producer, with a production volume of 9.6 million tons. Indonesian seaweed exports reached 180,600 tons, valued at USD 455.7 million. According to the Central Statistics Agency (BPS, 2023), seaweed production in Indonesia is spread across 23 provinces. The top five seaweed-producing provinces are South Sulawesi, East Nusa Tenggara, North Kalimantan, Central Sulawesi, and West Nusa Tenggara.

According to FAO data, global seaweed production in 2021 was 36.3 million tons. Seaweed production was dominated by Laminaria sp., contributing 36.7%, followed by Kappaphycus sp. (17.2%), Gracilaria sp. (16.5%), Undaria (7.6%), Euchema sp. (6.8%), and other species (15.2%). Carrageenan from the tropical algae Kappaphycus and Eucheuma accounted for 32.62% and is the most widely used for carrageenan extraction. Gracilaria, Porphyra, and Undaria contributed 10.32%, 8.33%, and 7.16%, respectively (Munaeni et al., 2023).

The types of seaweed that are found and spread widely in Indonesian marine waters according toKristiningsih et al. (2024) are the types of Eucheuma, Sargasum, Gracilaria, Tubrinaria, Gelidium, and Hypnea. Several types of seaweed that have been developed and traded are producers of carrageenophytes, agarophytes, and alginophytes. The types of Eucheuma Cottonii, Eucheuma Edule, Eucheuma Serra, Eucheuma Spinosium, and Eucheuma sp. are seaweeds that produce carrageenophytes. Meanwhile, seaweeds that produce agarophytes include Gracilaria sp., Gelidium sp., and Gelidiella sp. Seaweeds that produce alginophytes include Sargassum sp., Ascophyllum spp., Laminaria spp., and Macrocystis spp.

In Indonesia, the types of seaweed that are cultivated are: a) Euchema cottonii is the type of seaweed that is most often cultivated in the sea as a producer of carrageenan in a monoculture system; b) Euchema spinosum is a type of seaweed that is usually cultivated in the sea as a producer of carrageenan in a monoculture system; and c) Gracilaria sp is a type of seaweed that is often cultivated in ponds as a producer of agar in a polyculture system.

Eucheuma cottoni is a type of red seaweed known as Kappaphycus alvarezii because it produces the kappa-carrageenan fraction (Davi et al., 2020). Eucheuma cottonii generally grows in reef areas, typically areas with relatively stable seawater flow and daily temperatures. Eucheuma cottoni has a smooth, slippery, cylindrical, and cartilagenous surface.

Eucheuma cottonii and Eucheuma spinosum are widely traded seaweeds, both for domestic industrial raw materials and for export (Anila et al., 2023). Eucheuma cottonii is a type of red algae that can produce the polysaccharide carrageenan. Carrageenan is a galactose polysaccharide compound and a hydrocolloid compound consisting of potassium, sodium, magnesium, and potassium sulfate esters with a galactose copolymer of 3,6-anhydrogalactose (Naufal et al., 2022).

In the carrageenan production process, harvested seaweed undergoes initial processing to clean/remove sand, salt, and other impurities by washing with fresh water. The washed seaweed is dried until clean seaweed with a water content of 10–25%. Drying can be done in the sun or using a drying machine. The dried seaweed can be processed directly or can also be used for dried seaweed exports. The carrageenan extraction process from seaweed includes: washing, concentration (evaporation), separation (filtration with a centrifuge), precipitation, drying (roll dryer), grinding (mill), and packaging (Devi et al., 2020).

Agar is defined as the non-nitrogenous, amorphous, gelatin-like dry extract of Gelidium and other red algae, a linear sulfated galactan, insoluble in cold water but soluble in hot water, a 1 to 2 percent solution of which after cooking solidifies into a solid gel at 35° to 50° and melts at 90° to 100°(Kambey et al., 2022. Agar-agar as a dry hydrophilic colloidal substance extracted from Gelidium cartilagenium (Linne) Gaillon (Fam. Gelidiaceae), Gracilaria confervoides (Linne) Greville (Sphaerococcaceae spp.) and related red algae.

In the manufacture of agar-agar, according to Santos (2018), dried seaweed (Gracilaria sp.) goes through the stages of washing, concentration with 0.25% chlorine for 4–6 hours, soaking in 10% dilute sulfuric acid until soft. The seaweed soaked in sulfuric acid is cooked by adding water to an operating temperature of 90°–100°C, pH 5–6 (in an acidic environment), where the pH is adjusted by adding 0.5% acetic acid. In addition to maintaining the pH, acetic acid also functions as a stabilizer so that a consistent molecular texture is obtained. After all the seaweed is crushed, separation is carried out through filtration with a filter press. The filtrate is collected, then cooled for approximately 7 hours (until frozen). The frozen result is crushed and pressed using a cloth. The result of the pressing is agar in the form of sheets that are dried and then ground.

The different characteristics and availability of raw materials, processing routes, and chemical use between carrageenan and agar products have led to numerous studies separating the feasibility of the two plants. Tsabisah et al. (2023) conducted an economic study on the pre-design of a semi-carrageenan-only production plant.Ali and Kashem (2019) only reviewed agar-agar factory operations. Meanwhile, developments in production systems have enabled multi-product process designs. Therefore, techno-economic studies of seaweed processing should be conducted using a Flexible Manufacturing System, capable of processing at least two products from two different seaweed species, namely Eucheuma sp. and Grasilaria sp.

II. RESEARCH METHODOLOGY

Flexible Manufacturing System

Flexible manufacturing system(FMS) is a manufacturing system in which a certain amount of flexibility is prepared to respond to various cases of change, whether previously predicted or not. This flexibility can be divided into two categories:

1. Machine flexibility, including the system's ability to change when producing new product types, and the ability to change following the execution of operations on the part;
2. Line flexibility, includes the ability to use multiple machines to perform the same operation on a component, as well as the system's ability to absorb large-scale changes in volume, capacity, and reliability.

Each part or piece of work will require a different combination of manufacturing nodes (Shivhare and Bansal, 2014). The movement of components from one node to another is carried out using a material handling system. At the end of each component processing, the finished part will be passed to an automatic inspection node and then removed from the FMS. The FMS system really needs an accurate control system. The types of controls available in the FMS include: 1) Point-to-point tool movement; 2) Continuous tool path movement; 3) Tool movement control using a loop system; and 4) Backlash control.

Economic Feasibility Analysis

Economic data analysis is conducted to evaluate the financial and economic feasibility of a bioplastics project. Standard financial analysis methods include Net Present Value (NPV), Payback Periods, IRR, and Profitability Index. To determine a project's financial feasibility, a benchmark rate of return is required.

As a reference for the project, this study estimates the Weighted Average Cost of Capital (WACC) and its components. WACC is calculated using the following formula (Lobe., 2009):

$$WACC = (We \times Ke) + (Wd \times Kd) \times 1-T)$$

Where:

We = Equity ratio to total funding
To = Cost of equity
Wd = Debt ratio to total funding
Kd = Cost of Debt
T = Tax Rates

Break-Even Points (BEP) analysis is also carried out to measure the operational strength of the designed factory. Break-even point analysis uses the following equation,

$$Break\ Event\ Point\ (BEP) = \frac{Biaya\ Tetap}{Harga\ Jual\text{-}Biaya\ Variabel}$$

III. **RESULT AND DISCUSSION**

Flexible Manufacturing System Design and Production Planning

The design of the seaweed processing production process using FMS was carried out to utilize the similarities in machines and production lines between Carrageenan and Agar-agar. According to Vivekanand et al., (2016) point-to-point tool movement control, the tool moves from point to point on the component and completes an operation only at that point. The tool does not have continuous contact with the component while moving at the location it is working on. Production limitations are at the settling stage of the carrageenan production process and gel formation in agar-agar production. With the availability of a cooking tank, quantitatively production is estimated to be able to reach 5 tons per day with 16-hour operation (2 shifts) or 1500 tons in a year of mixed carrageenan and agar-agar. In general, the production process design is presented in Figure 1.

The factory is designed to process Grazilaria sp. seaweed to produce agar and Eucheuma cottonii to produce carrageenan. The production composition of agar and carrageenan is designed at a ratio of 2:1, where Grazilaria seaweed is the raw material for agar.

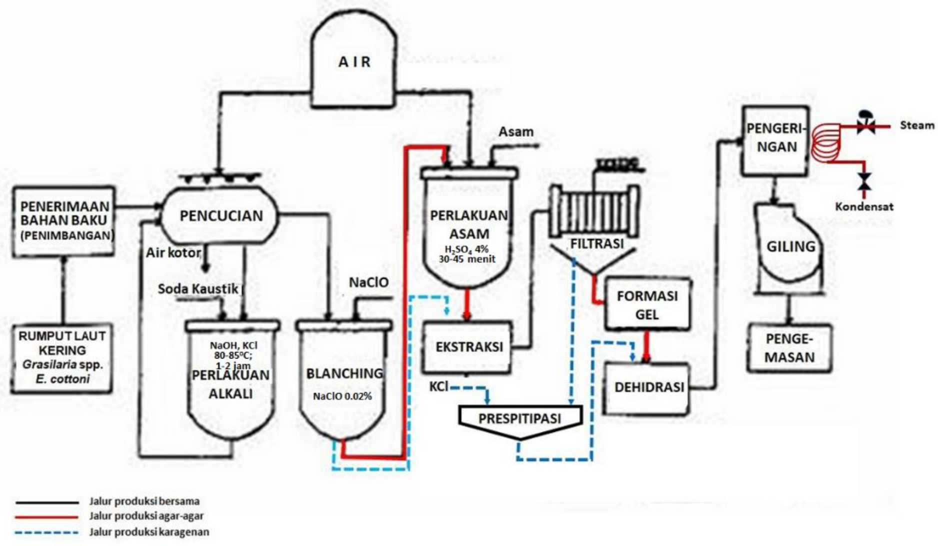


Figure 1. Design of Flexible Manufacturing System process for seaweed processing

For the technoeconomic analysis, a ten-year production plan was prepared, with the factory's utility level designed to increase gradually. The factory's utilization rate in the initial year was designed to be only 75% and then gradually increase. The production mix plan is presented in Figure 2.

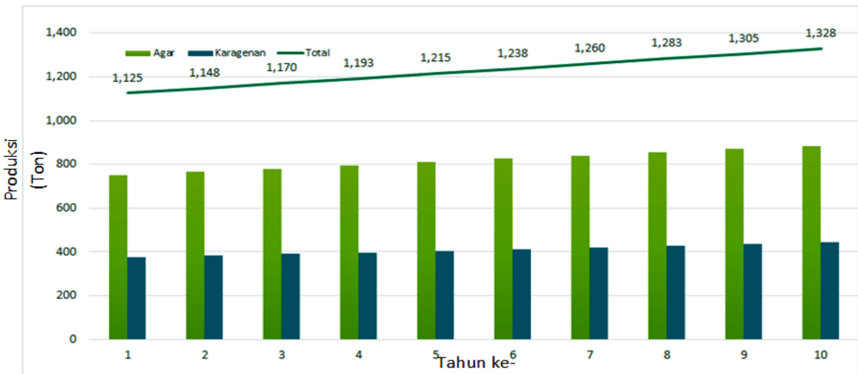


Figure 2. Production mixed planning of the Flexy Manufacturing System seaweed processing factory

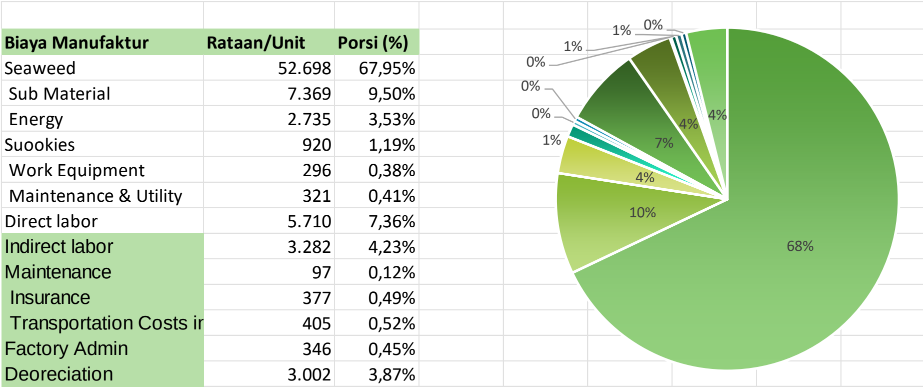
Capital and Operating Costs

In business development, investment costs are generally grouped into two, namely fixed asset investment costs, known as Capital Expenditure, and working capital investment costs or known as Operational Expenditure. Based on the investment data inventory, it is known that this factory has reached Rp 60,626,410,289. Meanwhile, the working capital (Operational Expenditure) required to operate this factory is Rp 8,650,593,590. Based on the assumption of investment needs for facilities and working capital, it is known that the total investment for the seaweed factory is Rp 69,277,003,878. The complete details of the seaweed factory investment needs are presented in Table 1.

Table 1. CAPEX and OPEX

I	CAPITAL EXPENDITURE	
No	**Description**	**Investment**
A	Machineries	
1	Mesin Utama dan Instalasi	Rp11,101,577,238
2	Peralatan Tambahan	Rp4,860,550,621
5	Safety, Health, Environment Equipment	Rp548,651,034
4	Laboratorium	Rp2,275,862,069
	Sub Total	Rp18,786,640,962
B	Building & Civil Works	
5	Prelimeneries	Rp1,100,000,000
6	Civil works	Rp30,726,050,000
	Sub Total	Rp31,826,050,000
C	Land for Project	
7	Land Acquasition	Rp2,164,098,200
8	Land Certification Process to BPN	Rp62,646,137
9	Licensing of Local Government	Rp93,969,205
10	Land Preparation	Rp3,564,468,055
	Sub Total	Rp5,885,181,597
D	**Additional Equipment**	
11	Office Furniture	Rp132,000,000
12	Perlengkapan Rumah Tangga Pabrik	Rp89,400,000
	Sub Total	Rp221,400,000
E	**Others**	
13	Pressure Vessel Lisence	Rp53,000,000
14	Other Licensing	Rp650,000,000
15	Commissioning	Rp140,000,000
16	Line Electric Installation	Rp68,696,740
17	Communication System	Rp274,000,000
18	Generator Licencing	Rp263,000,000
19	Legal and Administration	Rp265,000,000
20	Launching Product	Rp198,500,000
21	Jasa Arsitek	Rp1,393,980,990
22	Technical Consultant (including AMDAL)	Rp600,960,000
	Sub Total	Rp3,907,137,730
	CAPEX	Rp60,626,410,289
II	**OPERATIONAL EXPENDITURE**	
1	Persediaan	Rp2,500,000,000
2	Cadangan Operasional	Rp6,150,593,590
	OPEX	Rp8,650,593,590
	CAPEX + OPEX	Rp69,277,003,878

The ov is divided into two categories: manufacturing operational costs and administrative operational costs. Fixed production costs in the first year of Rp 7,404,309,000 include indirect labor costs, maintenance costs, insurance, in-plant transportation costs, and in-unit administration. Meanwhile, variable production costs are Rp 7,404,309,000.Rp. 67,583,434,000,-Costs include raw materials, direct labor, sub-materials, and energy. Sub-materials and energy consist of plastic supplies, work equipment, utilities, and direct labor costs. The largest component of manufacturing costs is raw material costs, at approximately 67.95%, followed by sub-material costs and depreciation at 9.50% each, and direct labor costs at 7.36%. The operational cost structure of the seaweed factory that will be operational is shown in Figure 3.



Biaya Manufaktur	Rataan/Unit	Porsi (%)
Seaweed	52.698	67,95%
Sub Material	7.369	9,50%
Energy	2.735	3,53%
Suookies	920	1,19%
Work Equipment	296	0,38%
Maintenance & Utility	321	0,41%
Direct labor	5.710	7,36%
Indirect labor	3.282	4,23%
Maintenance	97	0,12%
Insurance	377	0,49%
Transportation Costs ir	405	0,52%
Factory Admin	346	0,45%
Deoreciation	3.002	3,87%

Figure 3. Proportion of FMS Seaweed Processing Manufacturing Costs

Administrative operational costs include all operating costs for office activities, marketing, personnel, and general. Office operational costs can also be grouped as fixed company costs. General and administrative costs in the first year are Rp 40,123,981,000,- consisting of: General and administrative expenses include general fixed salary, BPJS employment, BPJS Health, stationaries, vehicle operation, office electricity, training, communication, office HSE, traveling and entertainment, funds & donations, holiday allowance, office car insurance, other expenses. From the description, there are still several things that have not been taken into account, including office electricity costs, domestic water usage, and consumables. The need for HR operational costs is allocated to direct labor costs (variable costs) and fixed costs and General Affairs.

Determination of Discount Factor

As a reference for the project, this study estimates the Weighted Average Cost of Capital (WACC) and its components. Based on calculations from research and analysis, the WACC value is estimated at 10.49%. The details of the calculations underlying the WACC estimate are as shown in the following table.

Table 2 WACC Components

WACC Description	*Benchmark*	Notes
Cost of Equity (Ke)	11.47%	
Pre-Tax Loan Cost (Kd)	8.46%%	Average investment loan costs from State-Owned Banks, National Private Banks, Foreign Banks, Joint Venture Banks, and Commercial Banks as of November 2021
Tax (t)	22%	Indonesian Corporate Tax Rates as of April 2022
After-Tax Borrowing Cost ((Kd x (1-t))	6.60%	(Kd) x (1-t)

WACC Description	*Benchmark*	Notes
Equity Proportion (e) – Long Term	79.87%	Long-term equity proportion based on market benchmark data
Loan Proportion (d) – Long Term	20.13%	Proportion of long-term loans based on market comparison data
Weighted Cost of Capital ("WACC")	10.49%	**[Ke xe%] + [(Kd x (1-t) xd%]**

Summary of General Assumptions of Seaweed Factory

A summary of the general assumptions for the Flexible Seaweed Factory to be built can be seen in the table below

Table 3. Summary of General Assumptions of the Flexible Planting System Seaweed Factory

No	Information	Amount	Unit	Information
1	Working Days a Year	350	Day	
2	Project Age	10	Year	
3	Land acquisition	20,882.0	m2	*Extended*
4	Production Water			*Deep well*
5	Electricity			PLN
6	Steam	4	Ton	Own production
7	Seaweed Transportation	4	Source	Using supplier transportation
8	Grasilaria sea urchin price	6000 – 7000	IDR per kg	
9	Price of E.cottoni seaweed	10,000 – 13,000	IDR per kg	
10	Exchange rate 1 USD	Rp. 16,500	Rupiah	

Break-Even Analysis

The average selling price of carrageenan and agar-agar products is Rp94,010.19 for the export market and Rp29,905.81 per kg. Overall, the average selling price isRp. 123,916/kg.The average fixed costs for factory operations are Rp35,950,045,000 per year. Fixed costs are calculated by subtracting the average fixed administrative costs and fixed manufacturing costs. Meanwhile, variable costs are Rp70,049 per kg.

$$Break\ Event\ Point\ (BEP = \frac{Biaya\ Tetap}{Harga\ Jual\text{-}Biaya\ Variabel} = \frac{Rp35.950.045.000}{Rp\,123.916\text{-}70.049}$$

` =667.38 Tons/Year

The break-even point value is thus at a production volume of 667.38 tons per year or around 44.49%.of installed capacity.

Profit and Loss Projection

The FMS seaweed factory's operational management has been profitable since its first year and has gradually increased. The seaweed factory generated an average profit of 11.93%, with a positive growth pattern. Table 4 presents the estimated profit and loss calculations for seaweed processing in the first five years after revitalization. Profit growth is presented in Figure 4.

Table 4. Projected Profit and Loss from the Operation of the FMS Seaweed Factory After Revitalization

No	Explanation	Per Unit (Rp.1000/Ton)	Tahun 1 (xRp. 1000)	Tahun 2 (xRp. 1000)	Tahun 3 (xRp. 1000)	Tahun 4 (xRp. 1000)	Tahun 5 (xRp. 1000)
	INCOME						
1	Sales Eksport	Rp94.010,19	Rp108.000.000	Rp116.400.000	Rp118.900.000	Rp116.400.000	Rp118.100.000
2	Sales Domestik	Rp29.905,81	Rp21.760.000	Rp25.600.000	Rp26.240.000	Rp30.080.000	Rp33.280.000
3	Others	Rp0,00	Rp0	Rp0	Rp0	Rp0	Rp0
	Sub Total Income	Rp123.916	Rp129.760.000	Rp142.000.000	Rp145.140.000	Rp146.480.000	Rp151.380.000
	EXPENSES						
4	Manufacturing Costs	Rp63.247,55	Rp74.987.743	Rp74.984.548	Rp75.181.854	Rp76.344.753	Rp77.029.844
5	Administration Costs	Rp35.440,31	Rp41.702.761	Rp42.345.554	Rp42.584.063	Rp42.844.169	Rp43.129.615
6	Others Costs	Rp9.868,79	Rp11.669.050	Rp11.733.010	Rp11.776.592	Rp11.918.892	Rp12.015.946
	Sub Total Expenses	Rp108.556,64	Rp128.359.555	Rp129.063.112	Rp129.542.508	Rp131.107.814	Rp132.175.404
	EARNING BEFORE INTEREST &	Rp15.359,36	**Rp1.400.445**	**Rp12.936.888**	**Rp15.597.492**	**Rp15.372.186**	**Rp19.204.596**
	Interest		Rp1.274.570	Rp1.274.570	Rp1.274.570	Rp1.274.570	Rp1.274.570
	EARNING BEFORE TAXES		**Rp125.875**	**Rp11.662.319**	**Rp14.322.922**	**Rp14.097.616**	**Rp17.930.026**
7	Taxes	0,22	Rp27.693	Rp2.565.710	Rp3.151.043	Rp3.101.476	Rp3.944.606
	EARNING AFTER TAXES	Rp12.105,03	Rp98.183	Rp10.371.178	Rp12.446.449	Rp12.270.710	Rp15.259.990

Financial Feasibility Analysis

The feasibility analysis is primarily measured by four key indicators: 1) Payback Period; 2) Internal Rate of Return (IRR); 3) Net Present Value (NPV); and 4) Profitability Index (PI). Based on the analysis of these four indicators, it is known that the seaweed factory revitalization investment is declared feasible, with details of each financial feasibility indicator. The results of the analysis are presented in Table 5.

Table 5. Summary of Operational Feasibility Analysis of FMS Seaweed Factory

No	Indicator	Mark	Information
1	*Currency rates*per 1 US$	Rp. 16,500.00	August 2025

No	Indicator	Mark	Information
2	WACC	**10.49%**	
3	Price of raw materials		
3.1.	Gracilaria spp. (per kg)	Rp. 6,000 - Rp. 7,000	Range
3.2.	Eucheuma cottoni (per kg)	Rp. 10,000 - Rp. 13,000	Range
4	Selling price		
4.1	Agar-agar Flour (per kg)	Rp. 125,000	Export Price
4.2	Carrageenan (per kg)	Rp. 210,000	Export Price
5	Analysis Knowledge	10 years	After revitalization
6	Tax	22%	
7	Capital Expenditures (Total CAPEX)	**Rp60,626,410,289**	New Calculation
8	Revitalization CAPEX	Rp19,604,253,646	
9	Average Earnings After Tax	9.77%,	
10	Net Present Value (NVP)	Rp28,882,376,000	Worthy
11	Net B/C Ratio / Profitability Index	1.42	Worthy
12	Internal Rates of Return (IRR)	17.91%	Worthy
13	Payback Periods		
	- Discounted Payback Period	7 years 7 months	Worthy
	- Non Discounted Pay-Back Period	3 years 11 months	Worthy
14	Return on Investment (ROI)	0.21	
15	Break Event Points (kg/year)	667,380	

*Pay-Back Period*calculated using two approaches, namely discounted and non-discounted cash flow basis. The discounted cash flow basis is applied to provide confidence to investors that the project's return has considered the time value for money objectively. Based on the analysis results, it is known that the Pay-Back Period with a non-discounted cash flow basis was achieved in the 11th month of the 4th year. Meanwhile, the Pay-Back Period with a discounted cash flow basis was achieved in the 7th month of the 8th year. Thus, in the perspective of investment returns (Pay-Back Period), it can be concluded that the seaweed revitalization investment is DECLARED FEASIBLE, because the capital can be returned before the economic life of the asset is exhausted. Overall, the financial feasibility indicators tested show that the seaweed factory with the FMS system is declared feasible to be established and operated.

IV. CONCLUSION

In Indonesia, the following types of seaweed are cultivated: Euchema cottonii sp. is the type of seaweed most often cultivated in the sea as a carrageenan producer, and Gracilaria sp. is a type of seaweed often cultivated in ponds as an agar-agar producer. Both types of seaweed have different characteristics, marked by different salt levels. Therefore, they require different extraction methods in their processing.

The separate process design for the two types of seaweed is inefficient due to the different harvesting patterns. Some processing machines for both types of seaweed function identically, allowing for alternating processing. With additional equipment, a Flexible Manufacturing System is created, allowing the factory to process both agar-agar and agar-agar in rotation.

The Capex amount for the FMS plant with a combined product capacity of 1500 tons/year is estimated at IDR 60.6 billion with Opex of IDR 8.65 billion. The plant is projected to generate an average net profit of 9.77%. The investment itself will be returned between the 7th and 8th years. The establishment and operation of the FNS seaweed plant is declared feasible with a positive NPV value of IDR 28.88 billion, an IRR value of 17.81% higher than the WACC of 10.49%, and a PI value of 1.42.

The factory break-even point analysis occurred at a production operation of 667.38 tons per year or around 44.49%.of installed capacity. This allows the factory to adapt its seaweed harvesting pattern to address raw material shortages. FMS seaweed factories are recommended for areas located along river estuaries but also with coastal areas.

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