



Feasibility Study of an Active Dry Yeast Plant Based Sugarcane Molasses Fermentation in Indonesia



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Abstract

Indonesia's imports of dry baker's yeast rose from 4,610 t in 2020 to 9,488 t in 2024, while domestic sugar mills face a molasses surplus. This study assesses the preliminary techno-economic feasibility of a 6,000 t/year active dry yeast (ADY) plant that converts sugarcane molasses with *Saccharomyces cerevisiae*. It integrates a scenario-based market analysis, a fully reported Analytical Hierarchy Process (AHP) for selecting the fermentation mode, drying method and site, mass and energy balances, HACCP-based food-safety design, preliminary HAZOP screening, and a discounted cash-flow (DCF) analysis with sensitivity and scenario tests. The projected 2029 supply gap ranges from 11,042 to 47,953 t/year (base case 19,532 t/year). Multistage fermentation with batch seed propagation and intermittent fed-batch production stages, fluidized-bed drying, and a site in JIPE, Gresik, East Java, were selected; the site ranking was robust to $\pm 50\%$ changes in all criteria weights. At a biomass yield of 0.47 g/g sugar the plant requires about 23,980 t/year of molasses. After correcting the classification of the initial raw-material stock, the total capital investment is IDR 744.8 billion. Under the stated assumptions, the project IRR is 31.5%, the NPV at a weighted average cost of capital of 8.3% is IDR 1,534 billion, and the payback period is 3.3 years after start-up. Product price is the decisive variable: the NPV becomes negative below an ex-factory price of about IDR 97,300/kg. The plant is therefore feasible at a preliminary level, conditional on price, market and capital-cost assumptions that require verification.

Keywords: Active dry yeast; Analytical hierarchy process; Molasses; *Saccharomyces cerevisiae*; Techno-economic analysis

1. Introduction

Baker's yeast (*Saccharomyces cerevisiae*) is an indispensable ingredient of leavened bakery products. During proofing, the yeast ferments the sugars available in the dough into carbon dioxide and ethanol, which expand the gluten network and generate a large part of the aroma of bread [1]. Beyond baking, *S. cerevisiae* is one of the most widely used microorganisms in industrial biotechnology, with applications ranging from alcoholic beverages and bioethanol to food ingredients, nutraceuticals, and recombinant products [2], [3]. Commercial baker's yeast is marketed as cream, compressed, active dry, and instant dry yeast. The dry forms, with a moisture content below 8% and a shelf life of one to two years at ambient temperature, are preferred in tropical markets because they do not require a cold chain [4]. Industrially, baker's yeast is grown in large aerated fed-batch bioreactors ($>100\text{ m}^3$) on cane or beet molasses, in which the sugar feed is kept low to avoid aerobic ethanol formation and biomass yields of up to about 0.5 g/g sugar are obtained [5]; recent work has focused on model-based and data-driven feeding strategies for this operation [6], [7].

Bread and other bakery products have become an increasingly common alternative staple in Indonesia, supported by the expansion of both large industrial bakeries and small and medium-sized enterprises. Official trade data show that imports of dry yeast more than doubled from 4,609.76 t in 2020 to 9,488.11 t in 2024, whereas exports fell from 105.31 t to only 53.56 t [8]. Domestic supply has started to grow with the plant of PT Lesaffre Sari Nusa in Malang, inaugurated in 2024 [9], and further capacity is under construction [10]. Nevertheless, the persistent import volume

exposes bakeries to exchange-rate and supply risks and indicates room for additional domestic, import-substituting capacity.

Indonesia also has a strategic raw material for yeast manufacture. Sugarcane molasses, the final by-product of repeated sucrose crystallization, contains roughly 50–65% fermentable sugars together with minerals, vitamins, and nitrogenous compounds that support microbial growth [11], [12]. It is used mainly for ethanol, feed, and monosodium glutamate or exported with limited added value [13], and its market is volatile: in 2025, about 660,000 t of farmers' molasses were reported to be unsold and prices fell from IDR 2,500–3,000/kg to about IDR 1,000/kg when ethanol producers reduced purchases [14]. Molasses is the conventional carbon source of the global baker's yeast industry, and several studies have confirmed its suitability for producing yeast with good leavening performance [15]–[17]. Converting molasses into dry yeast therefore adds a more stable outlet for a sugar-industry by-product while substituting imports.

The contribution of this work is not a new fermentation technology, as the production route is well established, but an integrated and transparent decision framework for deploying it under Indonesian conditions. Compared with a conventional preliminary plant-design study, which usually derives capacity from a single extrapolation and reports a single-point economic verdict, the present study (i) sizes the plant against explicit low, base, and high demand scenarios; (ii) reports the AHP judgments, criteria weights, and ranking sensitivity so that the technology and site choices can be reproduced; (iii) integrates food safety with quantitative critical limits, halal assurance, and preliminary process-hazard screening into the design basis; and (iv) expresses economic feasibility as conditions, namely the break-even product price, capital cost, and capacity utilization, rather than as an unconditional conclusion. Techno-economic studies on yeast and fungal biomass have mostly addressed feed or protein applications in other countries [18], so such an integrated assessment for baker's yeast in Indonesia has not been reported. The objectives are to (i) determine the plant capacity from projected demand scenarios, (ii) select the fermentation mode, drying technology, and plant location, (iii) design the selected process, including mass and energy balances and food- and process-safety aspects, and (iv) evaluate the economic performance and its robustness.

2. Method

The study followed the sequence of a preliminary plant design: market analysis and capacity determination, selection of process technology and plant location, process design, food and process safety analysis, and economic evaluation. The same design basis was used throughout: a capacity of 6,000 t/year of active dry yeast, 330 operating days per year, 24 h of operation per day, and a plant life of 15 years.

2.1. Market analysis and plant capacity

Annual import and export quantities of dry yeast for 2020–2024 were obtained from Statistics Indonesia (BPS) [8]. National yeast demand in 2024 ($D_{2024} = 24,025$ t) was estimated from national bread consumption [19] and an average yeast dosage of 3% of bread mass. As a cross-check, the apparent consumption calculated from domestic production, imports, and exports in 2024 was 16,016 t, which is treated as a lower bound because small domestic producers are not captured in the statistics. Growth rates were expressed as compound annual growth rates (CAGR) and demand was projected to 2029, the planned start-up horizon:

$$\text{CAGR} = (X_{\text{end}} / X_{\text{start}})^{1/n} - 1 \quad (1)$$

$$D_{2029} = D_{2024} (1 + r)^5 \quad (2)$$

where X is the quantity at the start and end of a series of n years and r is the scenario growth rate. Three demand scenarios were defined: a low scenario using the CAGR of bread-based yeast consumption in 2020–2024 (−1.46%/year), a base scenario using the projected CAGR of the Indonesian yeast market (5.1%/year) [20], and a high scenario using the CAGR of imports in 2020–2024 (19.78%/year). The import growth rate of 21.10%/year used in the original design is the arithmetic mean of the year-on-year changes and is not used for projection. The import-substitution opportunity (G) was calculated as the projected demand plus exports minus domestic production, where P is the latest reported output of the operating domestic producer (11,330.53 t in 2025), held constant:

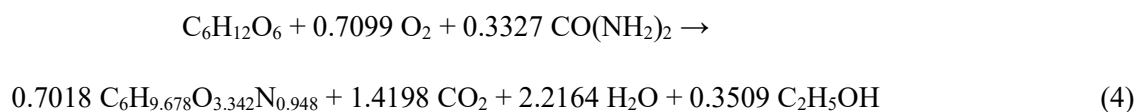
$$G = D_{2029} + E_{2029} - P_{2029} \quad (3)$$

2.2. Selection of process technology and plant location

Three decisions were made with the AHP in Expert Choice software [21]: the fermentation operating mode (simple batch, feedback-controlled fed-batch, or continuous) using ten criteria; the drying method (fluidized-bed or drum dryer) using nine criteria; and the plant site (Gresik, East Java; South Lampung, Lampung; Batang, Central Java) using seven criteria, two of which have sub-criteria. Pairwise comparisons on Saaty's 1–9 scale were made by the research team, consisting of two lecturers in chemical and food engineering with experience in bioprocess and plant design and three final-year undergraduate students who compiled the technical and site data. The judgments were made in moderated group sessions in which one consensus value was agreed for each pair, so a single matrix was obtained for each comparison and no aggregation of individual judgments was needed. The consistency ratio (CR) of each matrix was checked against the limit of 0.10 [21]. The criteria weights and local priorities are reported in full (Tables 3 and 5). Because the CR of the site decision was at the limit, the robustness of the ranking was tested by (i) varying each criterion weight from 0 to 1 while rescaling the others proportionally, and (ii) a Monte Carlo test in which all weights were perturbed simultaneously and independently by up to $\pm 50\%$ (10,000 draws).

2.3. Process design and safety analysis

Mass and energy balances were calculated for each unit on a per-batch basis. For the fermenters, which are not steady-state units, the balances were written in integral form over one complete batch cycle (initial charge plus all feeds equals final contents plus all gaseous outflows), so that the accumulation term refers to the change in content between the start and the end of the cycle; for the downstream units, which operate continuously from intermediate holding tanks, the steady-state form with zero accumulation was used. The molasses was assumed to contain 32% sucrose, 14% glucose, 16% fructose, 8% ash, 20% water, and 10% other impurities (w/w), i.e., 62% fermentable sugars. Aerobic growth of *S. cerevisiae* on sugar with urea as the nitrogen source was represented by the overall stoichiometry below, which also accounts for the ethanol formed through overflow metabolism:



The molasses requirement was calculated from the biomass formed per batch and the design yield of 0.47 g biomass/g sugar. The oxygen demand was obtained from an electron balance for substrate-limited respiratory growth at this yield, and the metabolic heat was estimated from the oxygen uptake with the empirical value of 460 kJ per mol O_2 consumed [22]. Equipment was specified according to standard design procedures [23], [24] and fermentation engineering practice [25]. Food safety was addressed with a Hazard Analysis and Critical Control Point (HACCP) plan following the Codex general principles of food hygiene [26] and ISO 22000:2018 [27], with quantitative critical limits derived from the product standard and current regulations on heavy-metal and microbial contamination [28]–[30]. Process safety was screened with a preliminary hazard and operability (HAZOP) study of the main fermenter following the IEC 61882 worksheet format [31]; each deviation was ranked on a 5×5 severity–likelihood matrix (low: 1–4, medium: 5–9, high: ≥ 10).

2.4. Economic evaluation

Purchased equipment costs were taken from the equipment cost list of the design (US\$5.90 million at the 2027 procurement basis), converted at IDR 17,826/US\$, and increased by 10% for delivery. Direct costs (installation, piping, electrical, buildings, yard, service facilities, and land) and indirect costs (engineering and supervision, contractor's fee, and contingency) were estimated as fractions of the delivered equipment cost [23], [24]. The initial stock of raw materials, which had been included in the direct capital cost in the original design, was removed from the fixed capital because inventories are part of the working capital; working capital was taken as 15% of the total capital investment (TCI). Annual production costs were calculated with the same factor structure as the design, with interest excluded from operating costs because financing is treated separately. Profitability was assessed with a nominal, unlevered DCF model (Table 15) using the net present value (NPV), internal rate of return (IRR), payback period, and break-even point (BEP):

$$\text{NPV} = \sum_{t=1}^N CF_t / (1 + \text{WACC})^t \quad (5)$$

$$0 = \sum_{t=1}^N CF_t / (1 + IRR)^t \quad (6)$$

$$WACC = w_E k_E + w_D k_D (1 - T) \quad (7)$$

$$BEP = FC / (S - VC) \times 100\% \quad (8)$$

where CF_t is the after-tax project cash flow in year t , w_E and w_D are the equity and debt fractions, k_E and k_D are the costs of equity and debt, T is the corporate income-tax rate, and FC , S , and VC are the annual fixed costs (including depreciation), sales, and variable costs at full capacity. The project IRR was compared with the WACC and with a hurdle rate of 12%; an equity IRR was also calculated with the loan drawdown, interest, and repayment schedule. Robustness was tested by one-at-a-time variation of product price, raw-material cost, fixed capital (which also represents the IDR/US\$ exchange rate, as equipment is priced in US dollars), utility cost, molasses price, biomass yield, capacity utilization, and loan interest rate, and by combined pessimistic and optimistic scenarios. Switching values were determined as the change in each variable at which the NPV becomes zero.

3. Results and Discussion

3.1. Market outlook and plant capacity

The trade data in Fig. 1 confirm Indonesia's structural reliance on imported dry yeast. Imports grew at a CAGR of 19.78% between 2020 and 2024 (arithmetic mean of year-on-year growth 21.10%), with the sharpest increase (50.3%) in 2023, whereas exports remained below 110 t/year. The cumulative import volume over the five years was 34,261.97 t, compared with only 264.31 t of exports.

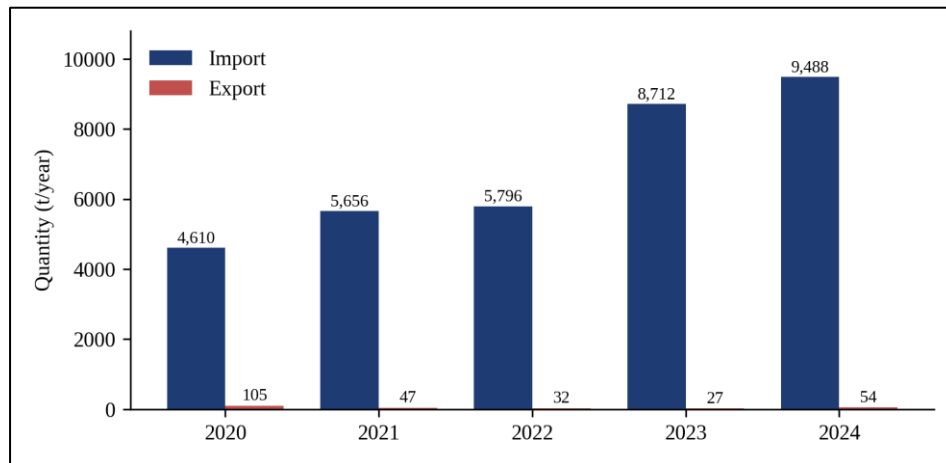


Figure 1. Import and export of dry yeast in Indonesia, 2020–2024 [8].

The demand scenarios are summarized in Table 1. In the base scenario, demand grows from 24,025 t in 2024 to 30,809 t in 2029, leaving an import-substitution opportunity of 19,532 t/year after the output of the existing domestic plant. The plant capacity of 6,000 t/year therefore corresponds to 30.7% of the base-case gap, 54.3% of the low-scenario gap, and 63% of the 2024 import volume. The capacity was set at about one-third of the base-case gap for three reasons: it leaves room for the expansion of existing producers and for imports of specialty products; it can be absorbed by import substitution alone even if demand does not grow, because the 2024 imports already exceed 6,000 t; and it is in the same order as the existing domestic plant, which allows a comparable fermentation train. The high scenario, based on import growth, gives a much larger gap but is regarded as an upper bound because import growth also reflects the substitution of products not covered by domestic plants. In comparison with the original design, which projected all variables with the arithmetic mean import growth rate and therefore overstated consumption and domestic production, the scenario approach gives a smaller but better-founded base-case gap that still supports the selected capacity.

Table 1. Projected 2029 demand and import-substitution opportunity for dry yeast in Indonesia.

Scenario	Demand growth (basis)	Demand 2029 (t/yr)	Domestic supply 2029 (t/yr)	Gap G (t/yr)	Share of G (6,000 t/yr)
Low	−1.46%/yr (CAGR of bread-based consumption, 2020–2024)	22,319	11,331	11,042	54.3%
Base	5.1%/yr (projected CAGR of the Indonesian yeast market)	30,809	11,331	19,532	30.7%
High	19.78%/yr (CAGR of imports, 2020–2024)	59,230	11,331	47,953	12.5%

$D_{2024} = 24,025$ t (bread-based estimate); $E_{2029} = 53.56$ t (2024 level); $P_{2029} = 11,330.53$ t (latest output of the operating domestic plant). Capacity additions under construction are not included and are discussed under limitations.

3.2. Selection of fermentation mode and drying method

The characteristics of the three fermentation modes are compared in Table 2, and the complete AHP weights and local priorities are given in Table 3. Feedback-controlled fed-batch operation reaches the highest biomass yields (0.48–0.54 g/g) because the feed rate is adjusted on-line to keep the sugar concentration low and to avoid the Crabtree effect, the aerobic formation of ethanol that occurs in *S. cerevisiae* when the glucose uptake rate exceeds its respiratory capacity [32]. Continuous culture offers the highest volumetric productivity but requires complex control of the dilution rate and carries the highest contamination risk over long operating periods [25]. The AHP ranked simple batch first (0.399), followed by feedback-controlled fed-batch (0.318) and continuous operation (0.283), with a CR of 0.08 (Fig. 2a). Simple batch scored best on operating condition, control system, process time, quality consistency, and initial investment, whereas fed-batch scored best on production scale and operating cost.

Table 2. Comparison of fermentation operating modes considered in the AHP.

Parameter	Simple batch	Feedback-controlled fed-batch	Continuous
Substrate flow	All substrate charged at start	Continuous feed, no outflow	Continuous inflow and outflow
Control system	Simple	On-line DO/RQ feedback	Complex (dilution rate)
Process time	16–24 h	60–80 h	Steady state
Productivity (g/L/h)	1.5–3.0	2.5–4.5	3.0–6.0
Biomass yield (g/g sugar)	0.40–0.50	0.48–0.54	0.16–0.48
Contamination risk	Low–medium	High	Very high
Initial investment	Lowest	Medium	Highest
AHP priority (CR = 0.08)	0.399	0.318	0.283

We recognize that the final design does not operate as a simple batch, because molasses and nutrients are added in portions during the production stages. The fermentation mode is therefore defined consistently throughout this paper as *multistage fermentation with batch seed propagation and intermittent fed-batch production stages*. In this mode, the feed is delivered from pre-sterilized tanks by dosing pumps following a pre-programmed profile, without the on-line DO- or RQ-based feedback loops that defined the fed-batch alternative in the AHP. The AHP result is retained as a screening result that favours low control complexity and low contamination risk, and the sensitivity analysis shows how close the decision was: the feedback-controlled fed-batch alternative overtakes simple batch only if the weight of

production scale increases from 0.171 to more than 0.43 or that of operating cost from 0.148 to more than 0.33. The intermittent fed-batch mode was adopted as an engineering refinement that keeps the simplicity favoured by the AHP while capturing the substrate-limited growth and yield advantage of fed-batch operation, and it can be upgraded to feedback control once operating experience has been gained [6], [7].

Table 3. AHP criteria weights and local priorities for (a) fermentation mode and (b) drying method.

Criterion	Weight	(a) Simple batch / (b) Fluidized bed	(a) Fed-batch / (b) Drum dryer	(a) Continuous
(a) Operating condition	0.116	0.589	0.253	0.158
Control system	0.069	0.478	0.304	0.217
Process time	0.076	0.446	0.169	0.386
Productivity	0.141	0.442	0.169	0.390
Quality consistency	0.109	0.414	0.328	0.258
Production scale	0.171	0.310	0.494	0.196
Initial investment	0.081	0.629	0.242	0.129
Operating cost	0.148	0.193	0.497	0.310
Labour requirement	0.042	0.400	0.200	0.400
Waste generation	0.048	0.255	0.255	0.489
Composite priority (Expert Choice)	1.000	0.399	0.318	0.283
(b) Operating condition	0.120	0.750	0.250	—
Main raw material	0.100	0.700	0.300	—
Auxiliary materials	0.060	0.667	0.333	—
Product characteristics	0.140	0.750	0.250	—
Main equipment	0.110	0.727	0.273	—
Energy demand	0.100	0.500	0.500	—
Product quality	0.220	0.818	0.182	—
Equipment cost	0.080	0.250	0.750	—
Product price	0.070	0.429	0.571	—
Composite priority (Expert Choice)	1.000	0.681	0.319	—

For drying, the fluidized-bed dryer obtained a priority of 0.681 against 0.319 for the drum dryer ($CR = 0.03$; Fig. 2b), with product quality carrying the largest weight (0.22). Drum dryers operate with surface temperatures of 120–170 °C, which reduce viability to below 50%, whereas fluidized-bed drying at 40–60 °C yields uniform granules with good rehydration and viabilities of 65–85% [4]. Most of the viability loss occurs when the moisture content falls below about 15%, so the air temperature must be reduced in the final stage of drying [33], and optimized fluidized-bed conditions of about 50 °C with protective agents can reproduce the viable cell counts of commercial products [34].

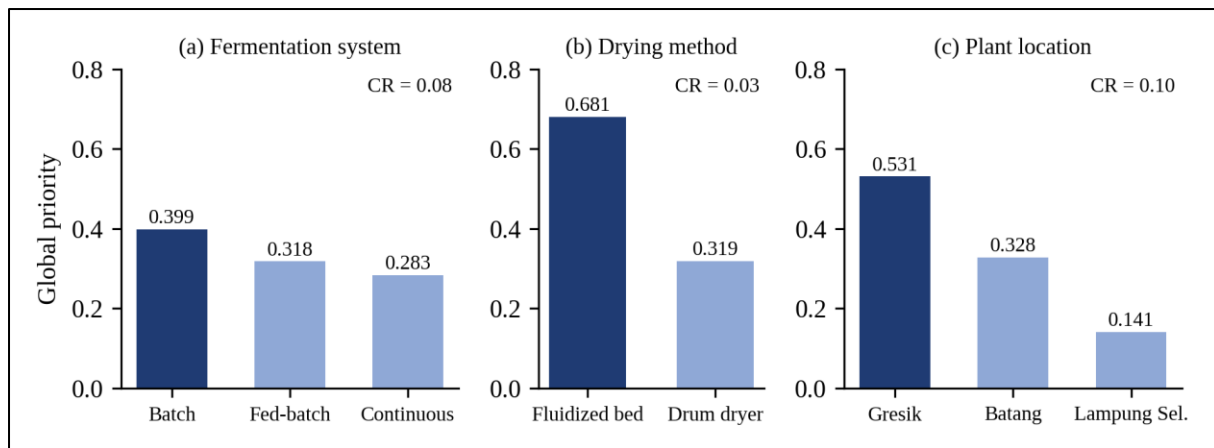


Figure 2. AHP priorities for (a) fermentation mode, (b) drying method, and (c) plant location.

3.3. Plant location

The site data are compared in Table 4, and the criteria weights and local priorities in Table 5. Raw-material availability received the largest weight (0.248), followed by utilities (0.196), market proximity (0.165), accessibility (0.128), and labour (0.126). Expert Choice ranked Gresik first (0.531), followed by Batang (0.328) and South Lampung (0.141) (Fig. 2c). Recomputing the composite scores from the rounded weights and local priorities in Table 5 gives 0.491, 0.323, and 0.186, respectively; the values differ slightly from the software output, which was synthesized from the unrounded matrices, but the ranking is identical. Gresik leads on raw materials, market, labour, accessibility, and climate, whereas Batang leads on utilities. In the one-at-a-time test, no change in the weight of any criterion other than utilities altered the first rank; Batang equals Gresik only when the utilities weight rises from 0.196 to 0.56, almost three times its elicited value. In the Monte Carlo test, Gresik remained first in all 10,000 draws. The ranking is therefore robust despite the CR of 0.10 being at the acceptance limit. The plant was located in the Java Integrated Industrial and Port Estate (JIPE), Gresik, which offers ready infrastructure and direct port access.

Table 4. Comparison of candidate plant locations.

Criterion	Gresik	South Lampung	Batang
Provincial sugarcane output (thousand t)	1,129.4	648.3	194.6
Labor force (persons)	739,013	542,691	503,157
Open unemployment rate (%)	6.82	4.95	5.67
Regional minimum wage (IDR/month)	4,874,133	3,076,990	2,379,702
Distance to toll gate (km)	16	27	8
Distance to seaport (km)	22	52	88
Distance to railway station (km)	2.4	33	2
Distance to airport (km)	43	78	84
Annual rainfall (mm)	1,565	1,563	2,421
AHP priority (Expert Choice, CR = 0.10)	0.531	0.141	0.328

Table 5. Site-selection criteria weights, local priorities, and ranking sensitivity.

Criterion	Weight	Gresik	South Lampung	Batang
Raw-material availability (sugarcane output and sugar mills)	0.248	0.520	0.274	0.206
Market proximity	0.165	0.558	0.122	0.320
Competitors	0.037	0.333	0.333	0.333
Utilities (power and water)	0.196	0.345	0.107	0.549
Labour	0.126	0.557	0.122	0.321
Accessibility (road, port, rail, airport)	0.128	0.517	0.153	0.330
Climate and topography	0.100	0.537	0.296	0.167
Composite score recomputed from this table	1.000	0.491	0.186	0.323
Weight of criterion needed to change the first rank	–	–	–	Utilities ≥ 0.56
First rank retained in Monte Carlo test ($\pm 50\%$ on all weights, $n = 10,000$)	–	100%	0%	0%

3.4. Raw material, product, and process description

The specifications of the main raw material and of the product are given in Table 6. The molasses specification combines the design composition with acceptance limits for total sugars, pH, density, and heavy metals; the heavy-metal limits are internal limits set at about half of the product limits so that contamination is controlled at receipt (CCP 1). The product specification follows SNI 01-2982-1992 [28], which is, to our knowledge, still the only Indonesian standard specific to dry baker's yeast. Because this standard dates from 1992, its contaminant limits were cross-checked against the current regulations on heavy metals [29] and microbial contamination in processed food [30], and the stricter value was adopted where they differ.

Table 6. Specifications of the main raw material and the product.

Parameter	Specification / design value	Basis
(a) Sugarcane molasses		
Sucrose / glucose / fructose	32 / 14 / 16% (w/w)	Design composition
Total fermentable sugars	62% (w/w); acceptance $\geq 52\%$	Design; cf. 39–67% sucrose (DM) [11]
Water / ash / other impurities	20 / 8 / 10% (w/w)	Design composition
pH	5.5–6.5	Acceptance range
Density	1.40–1.50 g/mL ($\approx 85^\circ$ Brix)	Acceptance range
Lead (Pb) / arsenic (As)	≤ 2.0 / ≤ 1.0 mg/kg	Internal limit (CCP 1)
Pesticide residues	$\leq$ Codex maximum residue limits	CCP 1
Supply and storage	Certificate of analysis per lot; ambient tank, 30°C	Design
(b) Active dry yeast		
Appearance / form	Yellowish- to brownish-white granules, 0.3–5 mm	SNI 01-2982-1992; design
Moisture	$\leq 8.0\%$ (w/w); dry matter 92–96%	SNI 01-2982-1992

Parameter	Specification / design value	Basis
Nitrogen content	6.0–7.5% (w/w)	SNI 01-2982-1992
Fermentation activity	Dough rise 2–3 times in 90 min	SNI 01-2982-1992
Pb / Cu / Zn / As	≤ 5.0 / ≤ 60 / ≤ 40 / ≤ 2.0 mg/kg	SNI 01-2982-1992; BPOM 9/2022
<i>E. coli</i> / <i>Salmonella</i>	< 3 MPN/g / negative in 25 g	SNI 01-2982-1992; BPOM 13/2019
Packaging and shelf life	Vacuum/N ₂ -flushed packs; 1–2 years at ambient temperature	Design

The block flow diagram is shown in Fig. 3 and the design basis in Table 7. Molasses is diluted with hot water, screened through a 1 mm strainer and a 500 μ m cartridge filter, clarified, sterilized in a heat exchanger at 120 °C for 60 s, and stored. Nutrient, acid, and base solutions (urea, H₃PO₄, H₂SO₄, Na₂CO₃, KCl, MgSO₄, ZnSO₄, and vitamins B1, B5, B6, and B7) are sterilized by 0.2 μ m filtration. A pure culture is propagated in two seed tanks in batch mode at 35 °C for 11 h, followed by first-stage and final fermenters operated in intermittent fed-batch mode at 30–34 °C, pH 4.5–5.5 (set point 5.5, adjusted with H₂SO₄ and Na₂CO₃), and dissolved oxygen above 2% of saturation. Each batch requires 32 h of fermentation plus 1 h each for filling and discharge; with staggered fermenters, a batch of 4,924 kg of product is released every 6.5 h, giving 1,218 batches per year. At the end of the final stage, the feed is stopped to consume residual sugar and ethanol (maturation). The broth is concentrated in a centrifugal separator (95% cell recovery), cooled, salted, and dewatered on a starch-precoated rotary drum vacuum filter to about 33% solids. The cake is mixed with about 1% sorbitan monostearate, extruded through 0.6 mm dies, and dried in a fluidized bed with dehumidified air at about 40 °C; the product temperature is kept below 50 °C until the dry matter exceeds 80% and then raised to 50–70 °C for 10–45 min. The product is screened (0.3–5 mm) and vacuum-packed under nitrogen.

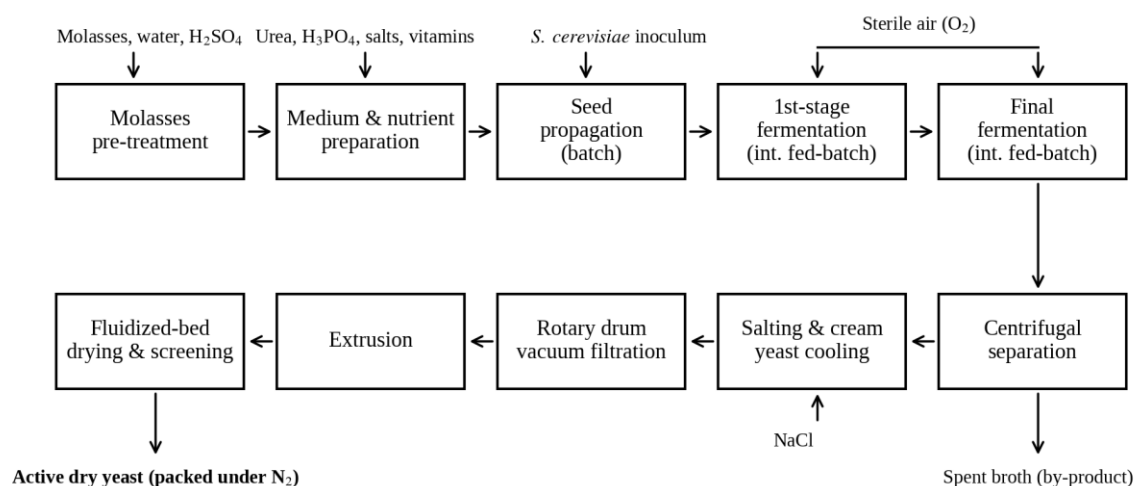


Figure 3. Block flow diagram of active dry yeast production from sugarcane molasses.

Table 7. Design basis and main operating conditions.

Parameter	Value
Production capacity	6,000 t/year (758 kg/h)
Operating time	330 days/year, 24 h/day
Molasses requirement	≈23,980 t/year (19,688 kg/batch)
Fermentation mode	Batch seed propagation; intermittent fed-batch production stages
Fermentation scheme	2 seed tanks, 4 first-stage and 4 final fermenters
Fermentation time per batch	32 h (plus 1 h filling and 1 h discharge)
Product per batch / batches per year	4,924 kg / 1,218
Temperature / pH / dissolved oxygen	30–34 °C (seed 35 °C) / 4.5–5.5 / > 2% saturation
Biomass yield on sugar	0.47 g/g
Medium sterilization	≥ 120 °C, ≥ 60 s
Centrifugal separation efficiency	95% cell recovery
Filter cake solids	≈33%
Drying	Fluidized bed; product < 50 °C until > 80% DM, then 50–70 °C

3.5. Mass and energy balances

The overall material balance per batch and per year is given in Table 8. The biomass formed in the fermenters is 5,737 kg per batch, of which 83% is recovered as product after separation, filtration, extrusion, drying, and screening losses. At the design yield of 0.47 g/g, this biomass requires 12,206 kg of fermentable sugar, i.e., 19,688 kg of molasses per batch or 23,980 t/year. This value corrects the figure of 14,708 t/year in the original manuscript, which implied an apparent yield above the theoretical maximum for respiratory growth (about 0.5–0.54 g/g); the additional molasses has been included in the raw-material cost. Process water and the nutrient, acid, and base solutions were obtained by difference so that the balance closes. The spent broth and the filter filtrate together amount to about 147,000 t/year (446 m³/day), which defines the hydraulic load of the wastewater treatment plant.

Table 8. Overall Material balance (per batch and per year).

Stream	kg/batch	t/year
Inputs		
Molasses	19,688	23,980
Process water, nutrient, acid, and base solutions (by difference)	107,584	131,038
Oxygen consumed (supplied as air)	5,560	6,772
NaCl (salting)	1,273	1,551
Wash water and starch precoat (RDVF)	3,172	3,864
Total inputs	137,277	167,203
Outputs		
Active dry yeast (product)	4,924	5,997
Screening fines and dryer dust	601	732
Extruder losses	89	109
Water evaporated in the dryer	3,316	4,038
CO ₂ from fermentation (RQ ≈ 1)	7,645	9,311
Spent broth (centrifuge supernatant)	99,720	121,459

Stream	kg/batch	t/year
RDVF filtrate	20,983	25,557
Total outputs	137,277	167,203
<i>Key intermediate quantities</i>		
Biomass formed (dry) / fermentable sugar consumed	5,737 / 12,206	6,988 / 14,867
Broth to centrifuge / cream yeast / filter cake	125,189 / 25,468 / 8,931	—

The utility requirements and heat duties are summarized in Table 9. The oxygen demand derived from the electron balance is 0.97 g O₂/g biomass, or 5,560 kg per batch, and the corresponding metabolic heat is about 80 GJ per batch. Averaged over the staggered operation, the fermenters release about 3.4 MW of heat, which dominates the cooling duty of the plant. Because cooling-tower water in Gresik is at 28–30 °C and the broth is controlled at 30–34 °C, the temperature approach is small and a chilled-water loop is recommended for the fermenter jackets and coils. The second largest load is aeration; with an oxygen-transfer efficiency of 25% and 0.1 kWh/Nm³ of compressed air, about 9.0 GWh/year of electricity is required. A bottom-up estimate of the main utility loads (aeration, chiller, process motors, steam, and dryer heat) gives about IDR 27 billion/year at an electricity price of IDR 1,500/kWh, which is below the factored utility allowance used in the economic analysis (Table 12); the factored value was therefore retained as a conservative estimate.

Table 9. Utility requirements and heat duties.

Item	Per batch	Per year	Average rate
Medium sterilization (steam, 7 bar)	5.99 GJ; 2.9 t steam	3,530 t steam	0.26 MW
Heat recovered in regenerative exchanger	3.36 GJ	4.1 TJ	—
Medium cooling after sterilization	4.06 GJ	4.9 TJ	0.17 MW
Fermentation heat removal (460 kJ/mol O ₂)	79.9 GJ	97.3 TJ	3.42 MW
Cream yeast cooling	1.02 GJ	1.2 TJ	0.04 MW
Total cooling duty (cooling/chilled water, ΔT = 5 K)	85.0 GJ; 4,067 t water	103.5 TJ	3.63 MW
Dryer evaporation duty (minimum)	8.06 GJ	9.8 TJ	0.34 MW
Aeration air (OTE 25%)	95.9 t (74,100 Nm ³)	116,800 t	—
Electricity for aeration (0.1 kWh/Nm ³)	7,410 kWh	9.0 GWh	1.14 MW
Electricity for process motors (design)	—	0.31 GWh	0.04 MW
Wastewater (spent broth + filtrate)	120.7 t	147,000 t	446 m ³ /day

3.6. Main equipment

The main equipment and its design capacities, materials, and operating specifications are listed in Table 10. All product-contact equipment downstream of molasses storage is made of austenitic stainless steel (AISI 316 for fermenters and mixing tanks), as required for CIP/SIP and food-grade operation. The purchased cost of the complete list of 78 items is US\$5.90 million.

Table 10. Main equipment list.

Code	Equipment	No.	Capacity / size	Material	Key operating specification
F-111	Molasses storage tank	1	37.2 m ³ (D 3.02 m × H 10.23 m)	CS SA-201 Gr. B	30 °C; 24 h holdup
M-110	Molasses dilution/medium tank	1	8.4 m ³ ; 3,956 kg/h	SS 316	Six-blade turbine agitator
E-118A–C	Medium regenerator, steam heater, cooler	3	Double-pipe; heater area 8.4 m ²	SS 316	Sterilization ≥ 120 °C, ≥ 60 s
M-120–150	Acid, nutrient, Na ₂ CO ₃ , KCl tanks	4	4.4 m ³ (M-120)	SS 316	With 0.2 µm sterile filters
R-160	Seed tank	2	25.6 m ³ (ID 2.72 m)	SS 316	Batch, 35 °C, 11 h
R-210	First-stage fermenter	4	23.1 m ³ (ID 2.57 m)	SS 316	Int. fed-batch, aerated, jacketed
R-220	Final fermenter	4	35.6 m ³ (ID 3.03 m)	SS 316	Int. fed-batch, 30–34 °C, DO > 2%
H-310	Centrifugal separator	1	Disc stack; 4.5 m ³ /h feed (10 m ³ /h hydraulic)	Super duplex 1.4501	95% cell recovery
F-320	Refrigerated cream yeast tank	1	20.2 m ³ (ID 2.59 m)	SS 316	Cooled storage and salting
H-330	Rotary drum vacuum filter	1	D 2.6 m × L 5.3 m; 33.0 m ²	SS 304	Vacuum 560 mmHg; starch precoat
C-331	Extruder	1	5 hp; 0.6 mm dies	SS	500–600 kPa
V-340	Fluidized-bed dryer-cooler	1	Bed area 161.5 m ² ; bed length 2 m	SS	Counter-current; u_{mf} 1.14 m/s; air ≈ 40 °C
H-341	Cyclone	1	13,440 kg/h air	SS	50 °C, 1 atm
H-345	Screener	1	4.9 t/h; 35 mesh; 3.0 m ²	SS	Linear vibrating screen
F-343	Dry yeast storage	1	5,471 kg/batch	SS 304	Before N ₂ packaging

3.7. Food safety and process safety

The hazard analysis identified four CCPs, for which quantitative critical limits, monitoring procedures, and corrective actions are given in Table 11. The receipt of molasses is a CCP for chemical hazards because heavy metals and pesticide residues cannot be removed downstream. Molasses sterilization, sterile filtration, and fermentation are CCPs for biological hazards, i.e., contamination by lactic acid bacteria, *Bacillus* spp., acetic acid bacteria, and wild yeasts. Other steps are controlled by prerequisite programs (GMP, sanitation procedures, CIP, and SIP). Because the product is intended mainly for the Indonesian market, the quality system also integrates the halal product assurance system, which is relevant for the selection of antifoams, emulsifiers, and culture-media components.

Table 11. Critical control points with quantitative critical limits.

CCP	Step / hazard	Critical limit	Monitoring	Corrective action
1	Molasses receipt: heavy metals and pesticide residues (chemical)	$Pb \leq 2.0$ mg/kg; $As \leq 1.0$ mg/kg; pesticide residues $\leq$ Codex MRL; valid certificate of analysis for each lot	CoA check per lot; ICP/AAS verification per new supplier and monthly	Reject lot; supplier corrective action
2	Molasses sterilization: surviving contaminants (biological)	Holding-tube outlet ≥ 120 °C; holding time ≥ 60 s (flow $\leq$ design flow)	Continuous temperature and flow recording	Automatic flow diversion; re-sterilize; hold product
3	Sterile filtration of nutrient, acid, base solutions (biological)	0.2 μ m rated membrane; integrity (bubble point) $\geq$ manufacturer minimum before and after use	Integrity test per batch; ΔP log	Replace filter; re-filter or discard solution
4	Fermentation: contaminating bacteria and wild yeasts (biological)	pH 4.5–5.5; 30–34 °C (seed 35 °C); cream yeast release: <i>E. coli</i> < 3 MPN/g, <i>Salmonella</i> negative in 25 g	On-line pH, temperature, DO; microscopy and plating per batch	Correct set points; divert contaminated batch to feed-grade by-product; CIP/SIP

The HAZOP worksheet for the main fermenter is presented in Table 12. It should be read as a preliminary hazard screening at the conceptual-design stage rather than as a complete HAZOP study. The two high-risk deviations are high vessel pressure, caused mainly by foam blocking the off-gas line, and high broth temperature, caused by an insufficient cooling capacity relative to the large metabolic heat release. Both are addressed by recommendations that will be carried into the detailed design: a relief system sized for the full aeration rate with off-gas pressure-drop alarms and a mechanical foam breaker, and redundant chilled-water supply with a high-temperature interlock that stops the substrate feed.

Table 12. Preliminary HAZOP worksheet for the final fermenter ($S \times L$ = risk score).

Parameter	Deviation	Causes	Consequences	Safeguards	$S \times L$	Recommendations
Air flow	Low / no	Compressor trip; air filter fouled; valve V-8 closed	DO < 2% sat.; ethanol formation; yield loss	FIC; DO probe	$3 \times 3 = 9$ (M)	DO-low alarm interlocked with feed pumps; standby compressor
Air flow	High	FIC failure; valve fully open	Foaming; antifoam overuse; carry-over to off-gas filter	FIC; foam probe	$2 \times 3 = 6$ (M)	Foam-controlled antifoam dosing; high-flow alarm
Pressure	High	Off-gas line or filter blocked by foam; PIC failure	Over-pressure, rupture risk; loss of sterility	PSV / rupture disc; PI	$5 \times 2 = 10$ (H)	Relief sized for full air flow; off-gas ΔP alarm; mechanical foam breaker

Parameter	Deviation	Causes	Consequences	Safeguards	S × L	Recommendations
Pressure	Low (vacuum)	Cooling after SIP with vents closed	Vessel collapse; non-sterile air ingress	Sterile vacuum breaker	4×2 = 8 (M)	Interlock SIP sequence; verify vacuum-breaker sizing
Temperature	High	Cooling-water failure; fouled jacket; feed overdosing	Heat stress, ethanol, cell death, batch loss	TIC; high-temperature alarm	4×3 = 12 (H)	Redundant chilled-water pumps; high-T interlock stops feed
Substrate feed	More	Dosing-pump or timer malfunction	Sugar accumulation; ethanol > 1%; yield loss	FIC; totalizer	3×3 = 9 (M)	Off-gas O ₂ /CO ₂ (RQ) monitoring; totalizer alarm
Level	High	Overfeeding; foam	Overflow to off-gas system; contamination	LIC; high-level alarm	3×2 = 6 (M)	High-level trip of feed pumps
Sterility	Leakage	Seal or valve leakage; incomplete SIP	Contaminated batch	SIP; sterile filters; CIP	3×3 = 9 (M)	SIP temperature mapping and records; double mechanical seals

3.8. Capital investment and production cost

The revised capital investment is presented in Table 13. The delivered equipment cost (E) is IDR 115.78 billion, the direct costs amount to IDR 452.48 billion, and the indirect costs to IDR 180.61 billion, giving a fixed capital investment (FCI) of IDR 633.09 billion. With working capital of IDR 111.72 billion, the TCI is IDR 744.81 billion (US\$41.8 million). The original estimate of IDR 800.17 billion contained one year of raw materials (IDR 243.21 billion) in the direct cost while also adding working capital as 15% of TCI, so the raw-material inventory was counted twice and at an excessive level; removing this item and aligning the equipment cost with the equipment list reduced the TCI by 7%.

Table 13. Revised capital investment.

Component	Basis	Value (IDR billion)
Purchased equipment (US\$5.90 million)	Equipment list	105.25
Delivered equipment (E)	+10% delivery	115.78
Installation and instrumentation	43% E	49.78
Piping (installed)	86% E	99.57
Electrical (installed)	15% E	17.37
Buildings and services	35% E	40.52
Yard improvement	10% E	11.58
Service facilities	50% E	57.89
Land	—	60.00
Total direct cost (DC)		452.48
Engineering and supervision	65% E	75.25
Contractor's fee	29% E	33.57
Contingency	62% E	71.78
Total indirect cost (IC)		180.61

Component	Basis	Value (IDR billion)
Fixed capital investment (FCI = DC + IC)		633.09
Working capital (incl. raw-material inventory)	15% TCI	111.72
Total capital investment (TCI)		744.81
<i>Original manuscript: TCI (incl. one-year raw-material stock in DC)</i>		<i>800.17</i>

The annual production cost at full capacity (2027 prices) is IDR 554.94 billion (Table 14), of which raw materials account for 48.0%, including IDR 59.95 billion for molasses at IDR 2,500/kg. The unit production cost is about IDR 92/kg, compared with the assumed ex-factory price of IDR 134,680/kg derived from the design sales revenue of IDR 808.08 billion/year. The dominance of raw-material cost is typical of fermentation-based commodity products [18].

Table 14. Annual total production cost at full capacity (2027 prices).

Component	Value (IDR billion/yr)	Share of TPC (%)
Raw materials (incl. molasses 59.95)	266.39	48.0
Operating labour	30.93	5.6
Supervision and laboratory	6.19	1.1
Utilities (10% TPC)	55.49	10.0
Maintenance and repair (5% FCI)	31.65	5.7
Operating supplies	3.17	0.6
Direct production cost	393.82	71.0
Depreciation (10 years, excl. land)	57.31	10.3
Local tax (2% FCI) and insurance (1% FCI)	18.99	3.4
Plant overhead	32.84	5.9
General expenses (administration, distribution, R&D)	51.98	9.4
Total production cost (TPC)	554.94	100.0

3.9. Discounted cash-flow analysis

The DCF assumptions are listed in Table 15, and the profitability indicators in Table 16. The corporate income-tax rate was updated to the prevailing 22% [35], and the cost of equity was set at 14%, which reflects a government bond yield of about 6.5% plus an equity risk premium for a new food-manufacturing venture. With 40% equity and 60% debt at 5.75%, the WACC is 8.3%. The project generates a positive after-tax cash flow from the first year of operation, and the NPV at the WACC is IDR 1,533.6 billion (IDR 987.9 billion at a 12% hurdle rate). The project IRR of 31.5% exceeds both the WACC and the hurdle rate, and the equity IRR is 50.6%. The payback period is 3.3 years after start-up (5.3 years from the start of construction), and the discounted payback period is 4.0 years after start-up. The BEP is 46.7% of design capacity. These values differ from the original manuscript (IRR 21.58%, BEP 36.5%) because of the corrected capital structure, the explicit nominal cash-flow model with ramp-up and working-capital recovery, the updated tax rate, the higher molasses requirement, and a BEP definition that includes all fixed costs.

Table 15. Assumptions of the discounted cash-flow analysis.

Item	Assumption
Price basis and discounting	2027 prices; end-of-year cash flows discounted to the beginning of 2028
Construction / operation	2028–2029 (40% / 60% of FCI); operation 2030–2044 (15 years)
Capacity utilization	70% (2030), 85% (2031), 100% from 2032

Item	Assumption
Escalation	3.08%/year on sales and costs from 2029 (nominal model)
Working capital / land	15% of TCI invested in 2030; working capital and land recovered in 2044
Depreciation	Straight line over 10 years on FCI excluding land
Corporate income tax	22% of taxable income
Financing	40% equity, 60% bank loan at 5.75%/year, 10 equal principal instalments from 2030
Cost of equity / WACC	14% / 8.3% (after tax)
Treatment of interest	Excluded from project cash flows (captured by WACC); included in the equity IRR
Product price / molasses price	IDR 134,680/kg / IDR 2,500/kg

Table 16. Profitability indicators (base case).

Indicator	Result	Criterion
Total capital investment	IDR 744.8 billion	–
Sales at full capacity (2027 prices)	IDR 808.08 billion/yr	–
Total production cost (2027 prices)	IDR 554.9 billion/yr	–
NPV at WACC (8.3%)	IDR 1,533.6 billion	> 0
NPV at hurdle rate (12%)	IDR 987.9 billion	> 0
Project IRR	31.5%	> WACC and > 12%
Equity IRR	50.6%	> cost of equity (14%)
Payback period after start-up (simple / discounted)	3.3 / 4.0 years	< plant life
Break-even point	46.7% of capacity	< 100%
Break-even ex-factory price (NPV = 0)	IDR 97,300/kg	< assumed price
Price for IRR = 12%	IDR 102,000/kg	–

3.10. Sensitivity and scenario analysis

The sensitivity of the project IRR is shown in Fig. 4, and the IRR, NPV, and switching values in Table 17. Product price is by far the most influential variable: a 20% lower price reduces the IRR to 16.1%, and the NPV becomes zero at about IDR 97,300/kg, i.e., 27.7% below the base price. The fixed capital (or, equivalently, the exchange rate applied to imported equipment) and the raw-material cost follow, with switching values of +132% and +70%, respectively. The project remains profitable down to a capacity utilization of about 50%. Biomass yield, molasses price, and utility cost have only a minor effect because molasses accounts for about one-fifth of the raw-material cost and utilities for one-tenth of the production cost. The loan interest rate affects only the WACC and therefore the NPV, not the project IRR.

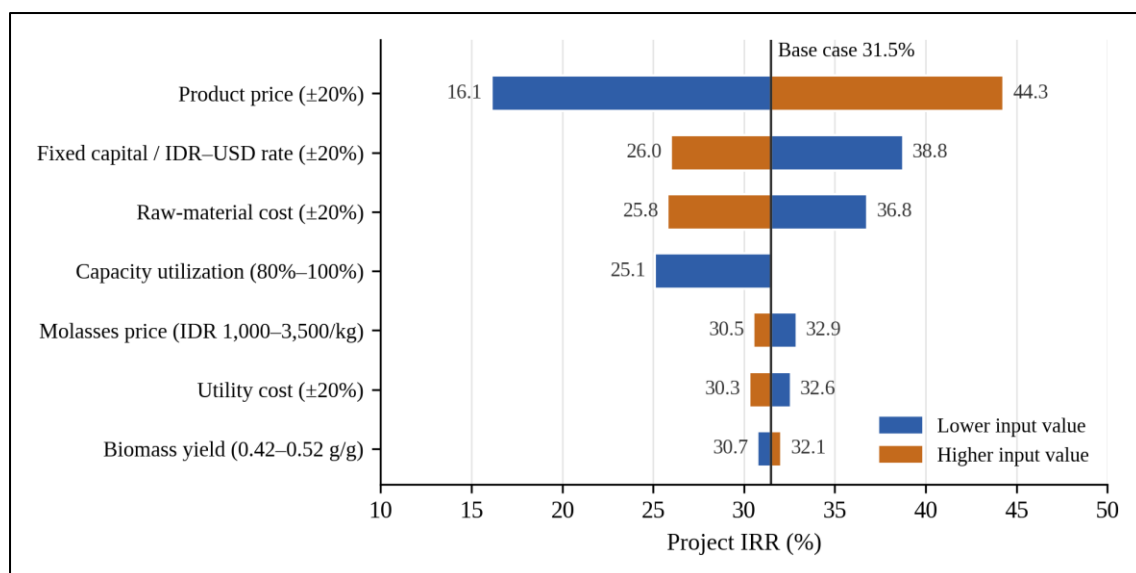


Figure 4. Sensitivity of the project IRR to the main input variables.

Table 17. Sensitivity of the project IRR and NPV (at WACC) and switching values.

Variable	Range tested	IRR (%)	NPV (IDR bn)	Switching value (NPV = 0)
Product price	–20% / +20%	16.1 / 44.3	434 / 2,633	–27.7% (IDR 97,300/kg)
Fixed capital / IDR–US\$ rate	–20% / +20%	38.8 / 26.0	1,764 / 1,303	+132%
Raw-material cost	–20% / +20%	36.8 / 25.8	1,971 / 1,096	+70%
Capacity utilization	80% / 90%	25.1 / 28.6	966 / 1,257	50% utilization
Utility cost	–20% / +20%	32.6 / 30.3	1,623 / 1,440	> +100%
Molasses price	IDR 1,000 / IDR 3,500	32.9 / 30.5	1,648 / 1,457	not reached
Biomass yield	0.42 / 0.52	30.7 / 32.1	1,475 / 1,581	not reached
Loan interest rate	8% / 10%	31.5 / 31.5	1,354 / 1,212	–

The combined scenarios in Table 18 show that the conclusion depends on the price assumption. At a conservative ex-factory price of IDR 95,000/kg the NPV is slightly negative (IDR -98.0 billion), and the pessimistic scenario, which combines a 20% lower price, 20% higher raw-material cost, 25% higher fixed capital, a lower yield, and 85% utilization, gives a negative NPV. Conversely, the optimistic scenario raises the IRR to 44.8%. The economic feasibility is therefore conditional: it requires an ex-factory price of at least about IDR 97,300/kg (IDR 102,000/kg for a 12% IRR), which should be verified through supply agreements with bakeries and distributors before investment.

Table 18. Scenario analysis.

Scenario	Project IRR (%)	NPV at WACC (IDR bn)
Base case	31.5	1,534
Conservative price (IDR 95,000/kg)	6.3	-98
Pessimistic (price -20%, raw materials +20%, FCI +25%, yield 0.42, utilization 85%)	-5.8	-643
Optimistic (price +10%, raw materials -10%, FCI -10%, yield 0.50)	44.8	2,444
Original tax rate (30%)	29.3	1,394
Constant prices (no inflation)	27.2	1,078

3.11. Social and environmental aspects

The plant is expected to create direct employment in production, quality control, maintenance, logistics, and administration, and to strengthen the linkage between sugarcane farmers, sugar mills, and the fermentation industry by providing an outlet for molasses in a period of surplus [14]. The main environmental concern is the spent broth and filtrate (about 446 m³/day), which has a high chemical oxygen demand and a dark color caused by recalcitrant melanoidins. Combined anaerobic and aerobic biological treatment followed by advanced oxidation or membrane processes can reduce these loads to discharge or reuse standards [36], and biogas from the anaerobic stage can partly offset the steam demand. Residual biomass and filter-press sludge can be used as compost or soil conditioner, and the CO₂ from fermentation (about 9,300 t/year) is a candidate for recovery.

3.12. Limitations

The results are subject to several limitations. First, the demand projection rests on short data series and a bread-based demand estimate, and the supply side includes only the operating domestic plant. Capacity additions under construction, notably a 20,000 t/year yeast line in Lampung scheduled for commissioning in 2027 [10] and the second-phase expansion in Malang, are not included; if they operate at full capacity they could absorb most of the base-case gap, so that the project would depend on demand growth above the base case, further import substitution, or export markets in Southeast Asia. Second, the equipment sizes and costs are taken from the preliminary design. The fermenter and separator capacities and the escalation of the historical equipment-cost data should be verified in the next design stage against the batch broth volume of about 120 m³; larger fermenters or a higher cost index would increase the fixed capital, and the NPV remains positive only up to about 2.3 times the present FCI estimate. Third, the ex-factory price is an assumption that has not yet been validated with buyers. Finally, the biomass yield, molasses composition, and drying conditions should be confirmed at pilot scale with the selected molasses and production strain.

4. Conclusions

This study indicates that an active dry yeast plant based on sugarcane molasses is technically and economically feasible in Indonesia at a preliminary level and under the stated assumptions. The import volume of about 9,500 t in 2024 and a base-case import-substitution opportunity of about 19,500 t/year in 2029 support a capacity of 6,000 t/year. A transparent AHP analysis supported fluidized-bed drying and a site in JIPE, Gresik, with a site ranking that is robust to large changes in criteria weights, and led to a multistage fermentation with batch seed propagation and intermittent fed-batch production stages. The plant converts about 23,980 t/year of molasses at a yield of 0.47 g/g, and its food safety is controlled by four CCPs with quantitative critical limits. After correcting the classification of the raw-material stock, the TCI is IDR 744.8 billion, the project IRR is 31.5%, and the NPV at a WACC of 8.3% is IDR 1,534 billion. However, feasibility is conditional on an ex-factory price above about IDR 97,300/kg, on fixed capital not exceeding about twice the present estimate, and on the plant securing its market share as new domestic capacity comes on stream. Market validation of the price, verification of equipment sizing and costs, and pilot-scale confirmation of yield are therefore required before an investment decision.

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