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Developing a Sustainable Business Model for Bio-Propylene Glycol Based on Crude Glycerol in Indonesia

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Abstract

Indonesia remains dependent on imported propylene glycol despite the availability of crude glycerol from the biodiesel industry, creating an opportunity for domestic low-carbon chemical production. This study aimed to develop and evaluate a sustainable business model for crude glycerol-based bio-propylene glycol production at PT Kilang Pertamina Internasional. The study developed a Business Model Canvas and an Operating Model Canvas, integrated them with the Triple Bottom Line framework, assessed financial feasibility using discounted cash flow analysis, conducted sensitivity analysis, and validated the model through site visits, stakeholder discussions, and focus group discussions. The 30,000-ton-per-year Balongan project demonstrated financial feasibility, generating a net present value of USD 49.8 million, an internal rate of return of 18.14%, a profitability index of 1.50, and a discounted payback period of 10.87 years. Product selling price, crude glycerol price, and capital expenditure were identified as the most influential variables affecting project feasibility. Integration with the existing Balongan refinery could improve utility utilization and operational efficiency, while the proposed model could create economic value through import substitution, social value through employment generation, and environmental value through waste valorization. The study concluded that the project was strategically promising, provided that PT KPI secured long-term feedstock supply, prospective offtakers, technology transfer, investment efficiency, and workforce readiness to support successful and sustainable commercial implementation.

INTRODUCTION

Pertamina, as the largest state-owned enterprise in the energy sector, manages the oil and gas value chain from upstream to downstream (Aprizal et al., 2022; Arifin et al., 2024; Bramasto & Daryanto, 2024; Lestari et al., 2025; Panjaitan et al., 2025). Pertamina's restructuring was continued by the Ministry of State-Owned Enterprises (SOEs) of the Republic of Indonesia, as the shareholder, on June 12, 2020, through the establishment of a new corporate structure that positioned Pertamina as a holding company with six subholdings: the Upstream Subholding (PT Pertamina Hulu Energi), Refining and Petrochemical Subholding (PT Pertamina Internasional Refinery), Commercial and Trading Subholding (PT Pertamina Patra Niaga [PT PPN]), Gas Subholding (PT Perusahaan Gas Negara Tbk), Power & New Renewable Energy (NRE) Subholding (PT Pertamina Power Indonesia), and Integrated Marine Logistics Subholding (PT Pertamina International Shipping). Among these six subholdings, PT Kilang Pertamina Internasional (PT KPI) plays a strategic role in managing the national energy and petrochemical supply chain, which is the focus of this research (Barus et al., 2025; Gumilar et al., 2024; Jamhari, 2025).

To realize Pertamina's vision of becoming an energy company that prioritizes energy security, availability, and sustainability, PT Kilang Pertamina Internasional (PT KPI), as the Refining and Petrochemical Subholding, established a vision of "Becoming a World-Class Oil and Petrochemical Refinery Company." PT KPI was mandated to strengthen national energy security through the development of high-value-added petrochemical products, including green bio-petrochemicals (oleochemicals) based on domestic resources. These initiatives support the government's objectives of achieving economic independence by strengthening domestic strategic sectors and contributing to the implementation of the Asta Cita of the President and Vice President of the Republic of Indonesia (eight national development aspirations).

This development aligns with the global transformation toward green petrochemicals and the circular bioeconomy, as highlighted by the European Commission (2023). A similar trend was also emphasized by the OECD (2023), which identified the transition toward a circular economy and bio-based chemicals as key drivers of heavy industry decarbonization in developing countries. However, the transformation toward bio-petrochemicals requires not only technological readiness but also the development of business models capable of integrating economic, social, and environmental dimensions.

As shown in Figure 1.1, PT KPI's business processes demonstrate integration between refinery and petrochemical value chains, providing a strategic foundation for developing new bio-based products such as Bio-Propylene Glycol (Bio-PG). This integration enables the utilization of existing refinery infrastructure to accelerate downstream development and improve the efficiency of national bio-petrochemical product development.

Currently, Indonesia remains highly dependent on imported propylene glycol (PG), an important chemical used in various industrial sectors, including pharmaceuticals, cosmetics, food and beverages, resins, and automotive applications. Indonesia continues to rely heavily on imports to meet domestic demand for PG products (Anggraini & Riani, 2025; Bustaman et al., 2022; Pane & Patunru, 2023; Susanto et al., 2024).

Based on data from the Central Statistics Agency (Badan Pusat Statistik [BPS], 2025), Indonesia's PG import volume has reached more than 35,000–40,000 tons per year over the past decade. This dependence not only increases pressure on the trade balance but also indicates that domestic capabilities in basic chemical downstream technology remain underdeveloped. This finding is consistent with Brobbey et al. (2024), who highlighted that developing countries face innovation gaps in the application of bio-based chemicals due to limited integration between academic research and industrial business models. This condition demonstrates the need for strategic innovation that is oriented not only toward import substitution but also toward sustainable value creation through the development of bio-based chemical supply chains.

Globally, the development of Bio-Propylene Glycol (Bio-PG) has become a major focus in developed countries as part of the chemical industry's transition from fossil-based feedstocks to renewable raw materials. Several companies, including ADM (United States), Oleon (Belgium), and Dow Chemical (United States), have commercially produced Bio-PG through the glycerol hydrogenolysis process since the mid-2010s. Bio-PG products have been marketed for cosmetics, pharmaceutical, and food applications as alternatives to petroleum-based propylene glycol, with reported carbon footprint reductions of up to 70%.

This trend indicates that the transition toward green petrochemicals has advanced significantly at the global level, while Indonesia remains in the early stages of development. Therefore, research on designing a sustainable business model for domestic Bio-PG projects is highly relevant for accelerating national industrial readiness toward a low-carbon economy. Similar developments have occurred in Europe and the United States, where Bio-PG has been commercialized as a renewable alternative to fossil-based propylene glycol within the transition toward green chemistry (Chum & Warner, 2016; Oleon, 2018). This demonstrates a readiness gap between developing countries, including Indonesia, and developed countries in commercializing bio-based chemical technologies.

In response to these conditions, PT Kilang Pertamina Internasional (PT KPI) has established a strategy for developing bio-petrochemical products as part of its downstream development, energy transition, and decarbonization agenda. This initiative is reflected in PT KPI's petrochemical development roadmap, as presented in Figure 1.2, where Bio-PG development is included in the Bio-Petrochemical Development Phase.

However, to date, no sustainable business model has comprehensively integrated economic, social, and environmental dimensions for developing crude glycerol-based Bio-Propylene Glycol (Bio-PG) in Indonesia. Such a model represents a strategic portfolio opportunity for PT Kilang Pertamina Internasional (PT KPI) to strengthen the national petrochemical industry while supporting Indonesia's decarbonization goals. From a strategic management perspective, successful commercialization of bio-based innovations depends not only on technical feasibility but also on the ability of an appropriate business model to capture sustainability value.

The trend of Indonesian propylene glycol imports shown in Figure 1.3 indicates relatively stable import volumes ranging from 35,000–40,000 tons per year, demonstrating market potential that could be addressed through domestic Bio-Propylene Glycol (Bio-PG) production. This condition confirms opportunities for developing competitive and sustainable domestic production capacity.

In addition to strong market demand, Indonesia has significant potential for crude glycerol feedstock as a by-product of the biodiesel industry (Fatty Acid Methyl Ester [FAME]). As shown in Figure 1.4, national biodiesel production capacity exceeds 9 million tons per year, generating approximately 1–1.5 million tons of potential crude glycerol annually that can be utilized as a raw material for Bio-PG production.

However, most of this glycerol is still exported to China, India, Malaysia, and the United States in raw form, resulting in limited domestic value creation. The increasing export trend shown in Figure 1.5 indicates substantial value-added potential that has not been optimally utilized domestically alongside the expansion of Indonesia's biodiesel industry.

This export of raw materials demonstrates the need for business model innovation to maximize domestic value creation. This condition creates strategic opportunities for developing Bio-Propylene Glycol (Bio-PG) through the hydrogenolysis process of crude glycerol. Bio-PG has similar properties and specifications to conventional PG while offering environmental advantages because it is derived from renewable resources and can achieve CO_2 emission reductions of up to 70–80% compared with petroleum-based PG. Therefore, the development of Bio-Propylene Glycol (Bio-PG) has the potential not only to reduce import

dependence but also to support the circular economy and Indonesia's Net Zero Emission 2060 target.

In line with the government's policy direction on downstream development of domestic resource-based industries and sustainable energy transition, PT KPI has established a program to develop a Bio-Propylene Glycol (Bio-PG) plant with a production capacity of 30,000 tons per year (30 KTA) in Balongan, West Java, as included in the Company's Long-Term Plan (Rencana Jangka Panjang Perusahaan [RJPP]) 2025–2029. This project represents part of PT KPI's efforts to strengthen its petrochemical (oleochemical) business and diversify its portfolio of high-value-added products. The Bio-PG project serves as a strategic initiative to bridge the value gap between domestic raw material potential and domestic market demand while strengthening the national bio-petrochemical value chain. As shown in Figure 1.6, the Bio-Propylene Glycol (Bio-PG) project site in Balongan was selected due to its direct integration with the RU VI refinery facility, providing logistical efficiency, competitive advantages through proximity to key markets in western Java, and infrastructure synergies.

The development of Bio-Propylene Glycol (Bio-PG) in this study can be understood from the perspective of the industrial value chain, covering upstream, midstream, and downstream activities. At the upstream level, Indonesia has abundant crude glycerol availability as a by-product of the national biodiesel industry, with production potential reaching 1–1.5 million tons per year. However, most crude glycerol is still exported as a raw material with relatively limited added value.

At the processing level (midstream), PT Kilang Pertamina Internasional has the opportunity to develop a crude glycerol-based Bio-PG facility integrated with existing infrastructure and utilities at RU VI Balongan. This integration provides benefits through investment efficiency, optimization of refinery assets, strengthening of domestic supply chains, and acceleration of national bio-petrochemical industry development.

At the downstream level, national propylene glycol demand, which is currently fulfilled through imports of approximately 35,000–40,000 tons per year, demonstrates a significant market opportunity for domestically produced Bio-PG. These products have potential applications in various industrial sectors, including pharmaceuticals, cosmetics, food and beverages, resins, and other chemical industries. Therefore, Bio-PG development has strong support from the perspectives of raw material availability, processing capabilities, and market opportunities, making it a strategic downstream alternative for supporting the development of a sustainable bio-petrochemical industry in Indonesia.

Based on the preliminary study results, the Bio-PG project demonstrated promising economic potential and strong synergy opportunities with PT KPI's petrochemical supply chain. However, long-term success is determined not only by financial performance but also by the development of a sustainable business model that integrates economic, social, and environmental dimensions. These findings align with the global trend reported by Sillanpää et al. (2023), which indicates that bio-propylene glycol is emerging as a potential substitute for petrochemical products with increasing market opportunities in the Asia-Pacific region.

From an academic perspective, the concept of business models has been widely discussed in strategic management literature as a foundation for organizations to create and sustain competitive advantages through effective resource management. Rossi, Tomatis, and Sassanelli (2023) stated that integrating circular economy principles with triple-layered

business models provides an important foundation for achieving long-term sustainability in bio-based industries. Meanwhile, Tomatis et al. (2024) emphasized the need to develop sustainable business model frameworks through holistic approaches that incorporate the entire bio-chemical value chain from upstream to downstream.

In this context, designing a sustainable business model is a key factor determining the successful commercialization of the project. Osterwalder and Pigneur (2010) explained that a business model represents the logic through which an organization creates, delivers, and captures value. Furthermore, Boons et al. (2020) emphasized that sustainable business models should expand value creation beyond economic aspects by incorporating social and environmental dimensions.

One of the most widely applied conceptual tools is the Business Model Canvas (BMC), which consists of nine key elements: customer segments, value propositions, channels, customer relationships, revenue streams, key resources, key activities, key partnerships, and cost structure. To ensure project sustainability, the BMC approach should be integrated with the Triple Bottom Line (TBL) framework, which includes people, planet, and profit (Elkington, 1998). This integration enables the development of a business model that is not only economically viable but also contributes to social and environmental sustainability.

Therefore, applying the BMC–TBL framework within the national bio-petrochemical industry provides a relevant approach for integrating sustainability dimensions into PT KPI's business strategy through simultaneous economic value creation (profit), social value creation (people), and environmental value creation (planet). Based on these considerations, research is needed to develop a sustainable business model for crude glycerol-based Bio-Propylene Glycol (Bio-PG) in Indonesia to support petrochemical downstream development, strengthen industrial competitiveness, and contribute to the transition toward a low-carbon economy.

In addition to providing economic benefits through increasing the added value of crude glycerol and reducing propylene glycol import dependence, the development of the Bio-Propylene Glycol (Bio-PG) industry also has the potential to generate social and environmental benefits. From the social perspective (people), the project is expected to create direct and indirect employment opportunities for approximately 800–1,000 workers during the construction phase (2027–2030) and approximately 50 operational positions when the facility begins operation in 2031. The project may also encourage the growth of supporting businesses, including transportation services, catering, accommodation, hotels, laundry services, and micro, small, and medium enterprises (MSMEs) around the project area, thereby generating a multiplier effect on the regional economy.

From the environmental perspective (planet), utilizing crude glycerol as a raw material for Bio-PG represents a form of waste valorization that supports circular economy principles by converting biodiesel industry by-products into high-value chemical products. Therefore, Bio-PG development is not only oriented toward economic benefits (profit) but also has the potential to generate sustainable social and environmental benefits.

METHOD

Methodology for Preparing *a Business Canvas Model* (BMC)

The preparation of the Business Model Canvas (BMC) in this study was conducted systematically based on the framework of Osterwalder and Pigneur (2010). The process began

with identifying customer segments to understand market needs, followed by formulating value propositions that addressed customer requirements and stakeholder interests.

Model Development Outputs and Plans

The results of the research are in the form *of a blueprint* of a sustainable business model *of Bio-Propylene Glycol (Bio-PG)* based on *the Business Model Canvas (BMC)* which is integrated with the principle *of Triple Bottom Line (TBL).* The TLBMC framework is used as a conceptual reference in ensuring integration between economic, social, and environmental dimensions, which will:

1. Supporting *PT KPI's* Bio-Petrochemical Development strategy.
2. It is the basis for *business feasibility analysis* for the implementation of the commercial stage (30 KTA Balongan).
3. It can be replicated for other *bio-based chemicals* projects such as Bio-Ethylene Glycol and Bio-Ethanolamine.
4. In addition to producing *a business model blueprint*, this study also provides initial *insights* into the financial feasibility of the Bio-PG project which can be used as a reference for *business decision making* and *investment appraisal* at PT KPI.

RESULTS AND DISCUSSION

Analysis Results

The economic calculations in Table 4.6 below show that the Bio-PG project has a good indication of financial viability. The *Net Present Value* (NPV) was recorded at US$ 49.8 million (positive/ *feasible*), which shows that the project is able to generate added value over the life of the project.

In addition, the Internal Rate of Return (IRR) is 18.14% so that the project is considered *feasible* in investment. A *Profitability Index* (PI) value of 1.5 indicates that the project is in the feasible category because it is above the minimum value of 1. Meanwhile, the results of the *Payback Period* (PBP) calculation show a return on investment period of around 10.87 years. Thus, the Bio-PG project is considered to have the potential to be developed commercially with a rate of return that is still within the investment range of the petrochemical industry.

Table 1. Results of the Financial Feasibility Analysis of the Bio-PG Project

Yes	Economic Indicators	Value
1	*CAPEX*	$76,863,987
2	*NPV*	$ 49.819.451
3	*IRR*	18,14 %
4	*Hurdle Rate*	12,04 %
5	*Profitability Index*	1,50
6	*Discounted Payback Pariod*	10,87 *years*

Sensitivity Analysis

The sensitivity analysis in Table 1 shows that there are three main variables that most affect the economics of the project, namely the selling price of Bio-PG, the *price of crude*

glycerol, and *the project cost (CAPEX).* The change in the selling price of Bio-PG has the most significant influence on the change *in the Internal Rate of Return* (IRR), which shows that the profitability of the project is greatly influenced by the dynamics of the *Propylene Glycol market*.

In addition, the price *of crude glycerol* is also a sensitive variable because feedstock is the dominant component in the operational cost structure of the project. Meanwhile, changes in *project cost (CAPEX)* also affect the rate of return on investment, especially in the early phase of project development. Therefore, controlling investment costs, stability of *feedstock supply*, and product marketing strategies are important factors in maintaining the economic sustainability of the Bio-PG project.

Table 2. Results of the Bio-PG Project Sensitivity Analysis

Sensitivity	-15%	-10%	-5%	0%	5%	10%	15%
Bio PG Price	14,9%	16,0%	17,1%	18,1%	19,1%	20,0%	20,9%
Project Cost (CAPEX)	20,3%	19,5%	18,8%	18,1%	17,5%	16,9%	16,4%
Crude Glycerol Price	20,35	19,6%	18,9%	18,1%	17,4%	16,6%	15,8%
Fixed Cost	18,4%	18,3%	18,2%	18,1%	18,0%	17,9%	17,8%
Variable Cost	18,6%	18,4%	18,3%	18,1%	18,0%	17,8%	17,7%

To clarify the sensitivity level of each variable to IRR changes, the results of the sensitivity analysis are visualized in the form of a tornado diagram as shown in Figure 1.

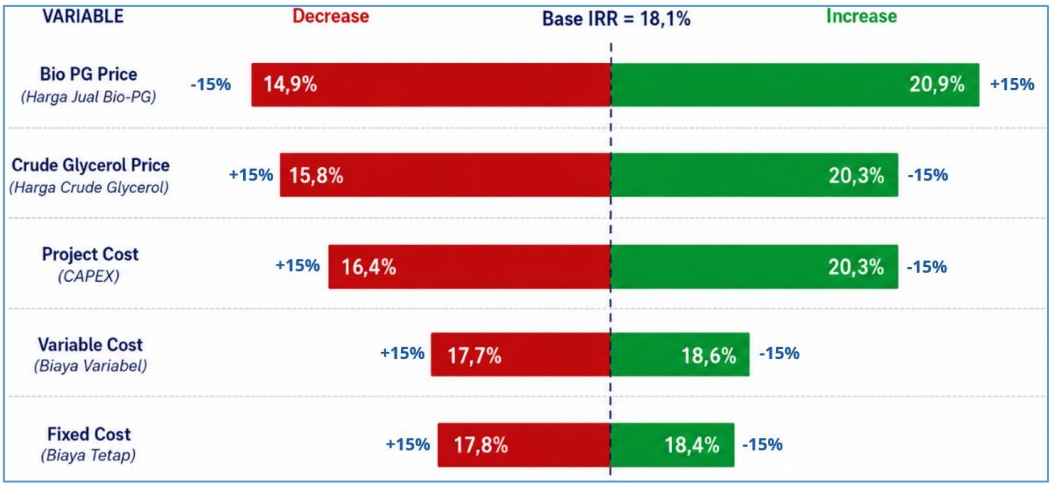


Figure 1. *Tornado Sensitivity Analysis Diagram* Bio-PG Project

Based on Figure 1, the selling price of Bio-PG is the most sensitive variable to changes in project IRR, followed by *crude glycerol price* and *project cost (CAPEX).* These conditions show that the profitability of the project is greatly influenced by the dynamics of the product market and the stability of *feedstock prices*.

The results of the sensitivity analysis indicate that the success of the project is greatly influenced by the company's ability to maintain *product premium value* and domestic market

stability. Therefore, the long-term offtaker security strategy, diversification of customer segments, and positioning of Bio-PG as *a low-carbon chemical* are important factors in maintaining the economics of the project and increasing the competitiveness of products against *fossil-based Propylene Glycol*. Meanwhile, changes in *fixed cost* and *variable cost* have a relatively smaller effect on changes in IRR. Thus, the project development strategy needs to be focused on securing the supply of *crude glycerol, optimizing* investment costs, and strengthening the product commercialization strategy to maintain the economic sustainability of the Bio-PG project.

Model Validation

Business model validation is carried out through discussions with industry practitioners, site visits, and *Focus Group Discussions* (FGD) to ensure that the developed model is not only conceptually relevant, but also in accordance with the real operational conditions and strategic direction of PT Kilang Pertamina Internasional (PT KPI). This validation process aims to evaluate the consistency of the model, feasibility of implementation, and integration of sustainability aspects in the development *of Bio-Propylene Glycol (Bio-PG).*

Table 2. Validation Results

Validation Aspects	Key Findings	Implications
Model Coherence	Value Chain, BMC, and OMC integrations are consistent	Conceptually viable models
Operational Feasibility	Integration with *refinery* is considered realistic	Support implementation
Commercial Readiness	The success of the project is influenced by market certainty and the commitment of potential customers	Perlu market sounding, LoI, MoU, dan *offtake agreement*
Feedstock Security	The availability and continuity of *crude glycerol* is a critical factor	Need long-term contracts and supplier diversification
Technology Readiness	Mastery of process technology and knowledge transfer still needs to be strengthened	Need to work with *technology providers*
Sustainability	Economic, social, and environmental dimensions have been accommodated	According to *the principle of Triple Bottom Line* (TBL)
Improvement Area	Human resource readiness and technology development need to be improved	Need for an advanced development program

Based on the validation results summarized in Table 4.8, some of the key findings can be identified as follows:

1. The business model that has been compiled is considered to have a clear relationship between *the value chain*, *the Business Model Canvas* (BMC), and *the Operating Model Canvas* (OMC) so that it forms a relatively consistent and integrated business flow.
2. The integration approach with the existing refinery at *the Balongan Refinery Unit* VI and the use of *crude glycerol* as *feedstock* are seen as realistic and in accordance with PT KPI's current operational conditions.

3. The business model is also considered to have reflected sustainability aspects through the integration of economic, social, and environmental dimensions, especially in the use of *biodiesel by-products* and reducing dependence on chemical imports.
4. However, there are several aspects that still need to be strengthened, especially related to mastery of process technology, human resource competency development, and operational readiness at the commercial implementation stage.
5. The validation results show that the success of the project implementation is not only determined by technical and financial aspects, but also by the ability to obtain market certainty through potential *offtakers* who can provide product absorption commitments in the initial phase of operations.
6. From the supply chain aspect, the availability and supply continuity of *crude glycerol* is seen as an important factor that needs to be maintained through long-term cooperation with national biodiesel producers and diversification of supply sources.
7. From the technological aspect, practitioners consider that mastery of *hydrogenolysis* technology, catalyst management, and knowledge transfer from *technology providers* are important factors to ensure the successful implementation of projects at the commercial stage.

Thus, the validation process strengthens that the Bio-PG business model developed is not only theoretically feasible, but also has a high level of applicability to be implemented in the context of the petrochemical and bio-based chemical industry in Indonesia.

Synthesis and Key Findings

Based on the overall analysis that has been carried out, *the Bio-Propylene Glycol* development project shows a strong potential to be developed, supported by a combination of internal and external factors that reinforce each other as follows:

1. In terms of strength, the availability *of abundant crude glycerol feedstock* and integration with the existing RU VI Balongan refinery infrastructure are the main advantages that are difficult for competitors to imitate.
2. On the opportunity side, the high dependence on *Propylene Glycol* imports and the increasing trend of eco-friendly based products open up significant market space for domestic Bio-PG.
3. Despite having promising prospects, the success of the project implementation is still influenced by several critical factors, including the readiness to master process technology, the development of human resource competencies, the ability to obtain market commitment through prospective *offtakers*, and the ability to maintain the stability of *crude glycerol* supply in the long term.
4. The project's main risks stem from the volatility of *crude glycerol* and Bio-PG prices, market uncertainty in the early phases of commercialization, as well as competitive pressures from global producers who have economies of scale advantage and longer operational experience.

Overall, the Bio-PG project has a strategic positioning as a link between the biodiesel industry and the downstream chemical industry, as well as being an instrument for downstream *crude glycerol* that is able to create economic, social, and environmental value simultaneously. Thus, Bio-PG has the potential to become one of the *bio-based petrochemical* development models that supports *the circular economy* agenda, import substitution, and transition to a low-

carbon industry in Indonesia.

Managerial and Strategic Implications

Implications for PT Kilang Pertamina Internasional

The results of the study show that the development of Bio-Propylene Glycol (Bio-PG) not only provides potential financial benefits, but also has strategic implications for the business transformation direction of PT Kilang Pertamina Internasional (PT KPI). From a business portfolio perspective, Bio-PG can be one of the *bio-based petrochemical* products that supports the company's business diversification towards high-value-added and low-carbon products. This development is in line with the company's efforts to reduce dependence on *the fuel business* and increase the contribution of the petrochemical sector to the company's revenue.

From a business development perspective, the results of the study show that market penetration strategy is one of the key factors for successful project implementation. Therefore, PT KPI needs to conduct *market sounding* and build strategic partnerships with key potential customers in the pharmaceutical, food and beverage, cosmetics, resin, and other chemical industries sectors from the project development stage. In addition, companies need to pursue *a Letter of Intent* (LoI), *Memorandum of Understanding* (MoU), and long-term *offtake agreements* to increase the certainty of product absorption and reduce market risk in the early phase of operations.

From the supply chain aspect, the success of the project implementation is greatly influenced by the stability of the supply *of crude glycerol* as the main raw material. Therefore, PT KPI needs to develop *a feedstock security strategy* through long-term contracts with national biodiesel producers, diversification of suppliers from various regions, and the preparation of a price mechanism that is able to maintain the competitiveness of the project against fluctuations in raw material prices. This strategy is important to ensure the long-term sustainability of plant operations.

From a technological and operational aspect, the development of Bio-PG requires organizational readiness to master *hydrogenolysis* technology, catalyst management, and a reliable operating system. Therefore, PT KPI needs to collaborate with *technology providers* from the advanced study stage, FEED, EPC, to *commissioning* to ensure knowledge *transfer* and improvement of human resource competence. In addition, the integration of Bio-PG facilities with existing infrastructure in RU VI Balongan has the potential to increase investment and operational efficiency through the use of utilities, logistics infrastructure, and supporting resources that have been available.

From a sustainability perspective, the development of Bio-PG can be one of the real implementations of the *circular economy* principle through the use *of crude glycerol* as a by-product of the biodiesel industry into high-value petrochemical products. In addition to supporting the company's sustainability agenda, this project also has the potential to strengthen the achievement of *Environmental, Social, and Governance* (ESG) targets, support the development of *bio-based petrochemicals*, and strengthen PT KPI's position as a pioneer in the low-carbon petrochemical industry in Indonesia.

Based on the results of the research, there are several key *success factors* that need to be considered by PT KPI in the implementation of the Bio-PG project, namely:

1. Success in obtaining market commitments through LoI, MoU, or *offtake agreements* with potential *offtakers*.
2. Success guarantees the availability and stability of *the supply of crude glycerol* through long-term contracts and supplier diversification.
3. Successful mastery of process technology through cooperation with *technology providers* and knowledge transfer programs.
4. The successful integration of Bio-PG facilities with existing utilities and infrastructure of RU VI Balongan.
5. Successful implementation of sustainability principles that include economic (*profit*), social (*people*), and environmental (*planetary*) aspects.

Implications for the Industrial and Government Ecosystem

In addition to providing benefits for PT KPI, the development of Bio-PG also has the potential to have a wider economic, social, and environmental impact on the national industry and the government. From the industrial side, this project can encourage the downstream *of crude glycerol* which has been mostly exported or has limited added value. The development of Bio-PG opens up opportunities for the formation of new value chains that connect the biodiesel industry, the basic chemical industry, and the domestic end-user industry.

From the social and economic aspects of the region, the construction of Bio-PG facilities is estimated to be able to absorb around 800–1,000 workers during the construction phase of the 2027–2030 period. Furthermore, in the commercial operation phase planned to start in 2031, this facility is estimated to require around 50 operational workers whose recruitment process can begin as early as 2030. In addition to direct employment, this project also has the potential to create indirect jobs through increasing activities in the logistics, transportation, catering, trade, boarding houses, hotels, laundry, local contractors, and various other supporting MSMEs around the project area.

Furthermore, the increase in economic activity has the potential to contribute to an increase in Gross Regional Domestic Product (GDP), a decrease in the Open Unemployment Rate (TPT), an increase in Gross Value Added (NTB), an increase in household income, and an increase in investment in the processing industry sector in Indramayu Regency, West Java Province, and at the national level. This impact shows that the Bio-PG project not only provides benefits for the company, but also produces a *broader economic* multiplier effect.

From a national policy perspective, the Bio-PG project supports the agenda of industrial downstreaming, import substitution, strengthening the resilience of the national petrochemical industry, developing a circular economy, and transitioning to a low-carbon economy. Therefore, this project has the potential to be an example of the implementation of the development of the bio-petrochemical industry in line with national industrialization policies, strengthening domestic added value, and Indonesia's sustainable development targets.

CONCLUSION

Research on the development of Bio-Propylene Glycol (Bio-PG) at PT Kilang Pertamina Internasional (PT KPI) was conducted to evaluate the potential development of a bio-based chemical industry through the utilization of crude glycerol, a by-product of the national biodiesel industry. Based on the overall analysis results, Bio-PG development demonstrated strong potential as part of Indonesia’s bio-based petrochemical industry from

operational, market, sustainability, and economic perspectives. Indonesia has significant crude glycerol potential in line with increasing national biodiesel production, creating opportunities for developing glycerol-based downstream industries with higher added value. The value chain analysis indicated that Bio-PG development was supported by domestic feedstock availability, integration opportunities with existing refinery facilities, and an open domestic market due to Indonesia's high dependence on imported propylene glycol.

Integration of the project with existing facilities at the Balongan Refinery Unit VI provided opportunities for utility optimization and operational efficiency, which could improve project competitiveness compared with the development of new greenfield facilities. The results of the Business Model Canvas (BMC) and Operating Model Canvas (OMC) analyses showed that the project combined cost efficiency through refinery integration and product differentiation through environmentally preferable bio-based product attributes. From a financial perspective, the Discounted Cash Flow (DCF) analysis indicated that the project was economically feasible, with a positive net present value (NPV) of USD 49.8 million, an internal rate of return (IRR) of 18.14%, a profitability index (PI) of 1.50, and a payback period of approximately 10.87 years. However, the sensitivity analysis showed that project economics were highly influenced by crude glycerol prices, Bio-PG selling prices, and capital expenditure (CAPEX). Therefore, feedstock supply stability and investment efficiency were identified as critical factors in maintaining project feasibility and long-term sustainability.

The validation process through site visits, discussions with industry practitioners, and focus group discussions (FGDs) confirmed that the Bio-PG business model had sufficient applicability for implementation in Indonesia's petrochemical and bio-based chemical industries. Furthermore, the integration of the Business Model Canvas (BMC), Operating Model Canvas (OMC), and Triple Bottom Line (TBL) frameworks demonstrated that Bio-PG development could generate economic benefits through value creation and import substitution, social benefits through employment generation and regional economic multiplier effects, and environmental benefits through crude glycerol utilization within a circular economy framework. Therefore, the development of crude glycerol-based Bio-Propylene Glycol represents a strategic opportunity to support biodiesel industry downstreaming and bio-based petrochemical development in Indonesia. This project has the potential to contribute to economic value creation, strengthen national chemical industry independence, and promote sustainability principles encompassing profit, people, and planet dimensions in the transition toward a low-carbon economy.

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