



Process Innovation of Biogas Power Plant from Palm Oil Mill Effluent: A Case Study in Thailand

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Abstract

This study aims to (1) examine the use of process innovation in biogas power plants utilizing palm oil mill effluent (POME) in Surat Thani Province; (2) investigate the outcomes of implementing process innovation in these biogas power plants; and (3) explore the strategic plans for scaling up process innovation among biogas power plant operators using POME in Surat Thani. This qualitative research collected data from nine biogas power plants, where interviewees were supervisors or managers with an average of 9.3 years of work experience. The sampled power plants had an average electricity generation capacity of 4.2 megawatts, an average operating duration of 12.9 years, and an average of nine employees per plant, with the number ranging from 6 to 14. The findings reveal that four power plants applied process innovation by mixing decanter cake with POME to enhance biogas production. This approach increased the average chemical oxygen demand (COD) from 70,000 mg/l to 100,000 mg/l. Consequently, the biogas yield increased by approximately 43% with the same volume of wastewater. Other plants in the sample are currently assessing potential drawbacks, particularly concerns about sedimentation in anaerobic digesters. In addition, innovations were adopted to improve the performance of bio-scrubbers, effectively reducing hydrogen sulfide (H₂S) levels in the treated biogas to below 50 ppm. This enhancement extended the service life of engine lubricants by approximately 67%, thereby lowering operational costs and increasing productivity. Regarding future plans, the power plants intend to continue innovating their production processes to further improve the efficiency of biogas power generation.

Keywords: Biogas Power Plant, Process Innovation, Palm Oil Mill Effluent (POME)

Introduction

Electricity is a critical factor in driving national economic growth. Each country must ensure a sufficient and affordable power supply to alleviate the burden of electricity costs for both households and the industrial sector. At present, more than 51% of Thailand's electricity is generated from natural gas (Energy Policy and Planning Office, 2023) ^[5]. However, due to the declining volume of domestic natural gas production in the Gulf of Thailand, Thailand has increasingly relied on imported natural gas for power generation, which significantly impacts electricity costs and national energy security. As a response, the Energy Policy and Planning Office (EPPO) has sought to reduce the reliance on natural gas by promoting electricity generation from renewable energy sources. In alignment with this policy, the Thai government has endorsed regulations to purchase electricity from Very Small Power Producers (VSPPs) utilizing renewable energy. This initiative encourages domestic investment and resource utilization, thereby reducing the dependency on imported energy (Energy Policy and Planning Office, 2017) ^[4]. One example of such renewable energy initiatives is the development of biogas power plants that utilize palm oil mill effluent (POME) as a raw material for electricity generation.

Given the rapid advancements in production technology and innovation, it is essential for organizations to adapt by integrating new process innovations. This study, therefore, aims to investigate the use of process innovations within biogas power plants

utilizing wastewater from palm oil mills in Surat Thani Province. Specifically, it seeks to (1) examine the current adoption of process innovations; (2) evaluate the outcomes derived from these innovations; and (3) explore the future innovation development plans of biogas power plant operators in the province. The findings of this research are expected to provide practical insights for stakeholders aiming to enhance operational efficiency and align with national renewable energy strategies.

Literature Review

Definition of process innovation

Kahn (2018) ^[6] defines process innovation as the improvement of methods or workflows aimed at enhancing efficiency, such as accelerating operations, increasing production capacity, or reducing costs within production systems, service systems, or internal organizational processes. This definition aligns with the perspective of Ozturk and Ozen (2021) ^[14]. Aujirapongpan (2010) ^[1] identifies three essential components of innovation: (1)

Newness, referring to the creation of something novel or recently developed; (2) Economic Benefits, indicating that innovation must generate added value through the development of new solutions; and (3) Knowledge and Creative Ideas, suggesting that innovation must stem from a foundation of knowledge and creativity.

Importance of palm oil mills in Thailand

Thailand is one of the major palm oil producers in Southeast Asia. Palm oil mills, as upstream industries, play a vital role in processing fresh fruit bunches (FFB) into crude palm oil (CPO). As of 2021, there are over 147 registered palm oil mills across the country (Oil Palm and Palm Oil Research and Innovation Institute, Prince of Songkla University, 2021) ^[12], predominantly located in key palm-growing regions such as Krabi, Surat Thani, and Chumphon. The palm oil extraction process generates a specific type of wastewater known as Palm Oil Mill Effluent (POME), which is characterized by its high viscosity and elevated levels of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD).

Table 1: Characteristics of Palm Oil Mill Effluent (POME)

Data source	pH	Temp OC	COD (mg/l)	BOD (mg/l)	SS (g/l)	O&G (g/l)
Muneesri, P. (1996)	4.61	66.3	70,647	35,160	2.05	11.10
Ortayagul, J. (2006)	4.29	-	112,500	53,400	5.50	2.568
Mohd Amran Bin Mohd Yusof (2023)	4.50	81.3	73,437	35,270	2.90	3.364
Paveen Fatemeh Rupani (2010)	4.7	80-90	50,000	25,000	1.80	4.00
Average	4.53	73.80	76,646	37,208	3.06	5.260
Industrial Effluent Discharge Standards (Ministry of Industry, 2017) ^[8]	5.5-9.0	40	120	20	0.05	0.005

From Table 1, a comparison between the characteristics of wastewater from palm oil mills and Thailand's industrial effluent standards, as stipulated by the Ministry of Industry (2017) ^[8], reveals that the pollutant concentrations—particularly Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD)—in Palm Oil Mill Effluent (POME) exceed regulatory discharge limits by more than 600 times. In the past, many mills employed open lagoon systems for wastewater treatment, which caused significant environmental and social concerns, particularly regarding

offensive odors and methane gas emissions. These methane emissions contributed directly to atmospheric degradation and global warming.

In recent years, the emergence of biogas power plants utilizing wastewater from palm oil mills has played an increasingly important role in sustainable waste management. By converting high-COD wastewater into biogas, these facilities not only mitigate the environmental impact but also create economic value from previously discarded waste streams.

Table 2: Biogas Power Plants Utilizing Palm Oil Mill Effluent in Southern Thailand

Province	Number of Projects	Installed Capacity (MW)	Share of Total Capacity (%)
Surat Thani	24	51.5	44%
Krabi	13	24.0	21%
Chumphon	9	21.2	18%
Trang	4	6.0	5%
Nakhon Si Thammarat	3	3.8	3%
Pattani	2	4.8	4%
Phang Nga	1	2.8	2%
Ranong	2	1.5	1%
Satun	1	1.0	1%
Total	59	116.6	100%

Source: Adapted from Department of Alternative Energy Development and Efficiency (2022) ^[3].

According to Table 2, Surat Thani Province hosts a total of 24 biogas power plants utilizing wastewater from palm oil mills, accounting for approximately 44 percent of the total installed capacity in Southern Thailand (Department of Alternative Energy Development and Efficiency, 2022) ^[3]. The biogas power plant sector in Surat Thani plays a critical role in managing industrial wastewater from palm oil

extraction processes. It contributes not only to the promotion of renewable electricity generation but also to regional economic development through job creation and positive impacts on environmental quality and public health for surrounding communities.

Conceptual Framework

This study employs a three-part conceptual framework to examine the implementation, impact, and future development of process innovations within biogas power plants that use palm oil mill effluent as a primary feedstock.

The first component involves analyzing the implementation of process innovation. This is assessed by classifying modifications in biogas production processes to determine whether they qualify as innovations, based on three key characteristics: (1) Newness—the process must introduce novelty at the departmental, organizational, or industry level; (2) Economic Benefits—the process must yield measurable gains such as cost reduction, increased productivity, or enhanced operational efficiency; and (3) Knowledge and Creativity—the process must originate from internal organizational creativity or the adaptation of external technologies and innovations for production improvement.

The second component investigates the outcomes derived from the use of process innovations. This includes both direct impacts, such as measurable improvements in cost efficiency, production output, operational streamlining, and time savings, and indirect impacts, such as enhanced organizational image, employee and customer satisfaction, reduced environmental footprint, improved workplace safety, and elevated quality of life in nearby communities.

The third component of the framework explores future innovation development plans. This involves gathering insights through interviews with operators regarding their strategies for extending or enhancing current process innovations, identifying the targeted improvements in efficiency or effectiveness, and understanding the rationale and methods for achieving these enhancements.

Research Methodology

This study, titled Process Innovation in Biogas Power Plants Utilizing Palm Oil Mill Effluent in Surat Thani Province,

employed a qualitative research design. Data collection was conducted through semi-structured interviews with plant operators or supervisors directly responsible for innovation or research and development within their respective organizations.

Data Analysis

The study applied descriptive statistical methods to analyze the data obtained from interviews. The responses were categorized and analyzed using mean scores, frequencies, and percentages. The evaluation of process innovations was structured around three core components: (1) the novelty level of the innovation; (2) the economic impact in terms of cost reduction, productivity improvement, and organizational benefits; and (3) the origin of the innovation, distinguishing between internally developed knowledge and creativity versus externally sourced technologies adapted for internal use.

Research Findings

1. General information of the sample group: The study was conducted with permission from nine biogas power plants located in Surat Thani Province. Interviewees were plant supervisors or managers with an average of 9.3 years of experience in the industry. The average power generation capacity of the plants was 4.2 megawatts, with an average operational lifespan of 12.9 years. On average, each plant employed nine workers, with the number of employees ranging from a minimum of six to a maximum of fourteen.

2. Implementation of Process Innovation in Biogas Power Plants Using Palm Oil Mill Effluent. Data collected from interviews revealed several process innovations being adopted within the biogas production systems of the participating plants. Key innovations included:

Table 3: Specifications and Efficiency of Anaerobic Digestion Systems in Participating Biogas Plants

Plant	Reactor Type	No. of Reactors	Water Volume (m ³)	Influent Volume (m ³ /day)	Retention Time (Days)	COD In (mg/l)	COD Out (mg/l)	Treatment Efficiency (%)
A	Fix Film	3	15,000	600	25	90,000	17,500	81
B	CSTR + Cover Lagoon	2	36,000	720	50	110,000	10,000	91
C	Cover Lagoon	5	68,000	1,000	68	98,000	5,300	95
D	Cover Lagoon	4	66,000	700	94	95,000	20,000	79
E	CSTR	1	8,000	250	32	100,000	15,000	85
F	Cover Lagoon	3	26,149	1,500	17	70,000	9,000	87
G	Cover Lagoon	2	10,000	500	20	80,000	10,000	88
H	Cover Lagoon	2	20,000	1,000	20	85,000	7,500	91
I	Cover Lagoon	2	119,000	2,000	60	80,000	15,000	81
Average			40,905	919	43	89,778	12,144	86

2.1 Biogas production process

According to the data presented in Table 3, most anaerobic digestion systems used in biogas plants are of the covered lagoon type. The number and volume of these digesters vary by facility, depending on the quantity of palm oil mill effluent (POME) generated. Some plants have adopted process innovations by incorporating decanter cake into POME to enhance biogas production efficiency.

2.2 Hydrogen sulfide (H₂S) removal process

The H₂S removal system plays a critical role in biogas production, as hydrogen sulfide is highly corrosive and can significantly shorten the lifespan of gas engines and related equipment if not effectively removed. All plants in the study utilized vertical cylindrical bio-scrubbers for H₂S treatment.

Table 4: Specifications of Bio-Scrubber Systems for Hydrogen Sulfide Removal

Plant	pH Value of Water in Scrubber Tank	Total Volume of Scrubber Tank (m ³)	Gas Flow Rate through System (Nm ³ /h)	H ₂ S		Target/Control Value (ppm)
				Before Treatment (ppm)	After Treatment (ppm)	
A	2.0 - 3.0	72	600	3,000	<50	<100
B	2.0 - 3.0	462	1,900	2,500	<50	<50
C	6.5 - 7.5	233	1,200	3,000	<10	<200
D	2.0 - 3.0	155	1,400	2,000	<10	<100
E	2.0 - 3.0	360	1,800	3,000	<50	<200
F	6.5 - 8.0	212	900	2,000	<10	< 170
G	1.0 - 2.0	370	2,350	1,500	<40	<50
H	6.5 - 7.5	367	2,500	2,500	<10	< 50
I	7.0 - 8.0	552	2,300	2,500	<50	<50
Average	-	309	1,661	2,444	22	108

Analysis of these systems revealed that all plants aim to optimize the performance of their bio-scrubbers to reduce H₂S levels to a minimum. Data indicated an average reduction in hydrogen sulfide concentration exceeding 98%. Interviewees consistently emphasized the importance of the bio-scrubber's effectiveness, as it directly impacts engine performance and the longevity of lubricating oil.

3. Outcomes of process innovation in biogas plants two major

types of process innovation were identified across the surveyed biogas power plants:

3.1 Innovation in the use of decanter cake for biogas production Interviews with plants implementing decanter cake mixing revealed that COD levels increased from an average of 70,000 mg/L to 100,000 mg/L. This improvement significantly enhanced methane yield in anaerobic digestion systems.

Table 5: Comparative Analysis of Increased Methane Generation through Decanter Cake Addition

Item	Unit	Before Use (POME)	After Use (Decanter Cake + POME)
COD Concentration	mg/l	70,000	100,000
Wastewater Volume	m ³	1	1
COD Amount	kg COD	70	100
Digester Efficiency	%	80	80
Methane Gas Volume (CH ₄)	Nm ³	19.6	28
Biogas Volume (60% CH ₄)	Nm ³	33	47
Biogas Increase	%	-	43%

Note: Methane generation was estimated based on an average methane yield of 0.35 Nm³/kg COD removed, as referenced by Burton *et al.* (2009) and McCarty (1964).

From Table 5, it is evident that incorporating decanter cake led to a 43% increase in biogas output per unit of wastewater, demonstrating the process innovation's substantial benefit.

3.2 Innovation in hydrogen sulfide removal efficiency Hydrogen sulfide removal is critical due to its corrosive nature. Ineffective removal significantly degrades engine

components such as gas blowers, chillers, heat exchangers, intercoolers, and reduces the lifespan of lubricating oil. Plants that enhanced their bio-scrubber performance to maintain post-treatment H₂S levels below 50 ppm reported a significant increase in the interval between oil changes.

Table 6: Effects of Bio-Scrubber Optimization on Lubricant Longevity

Item	Unit	Before Improvement	After Improvement
Average H ₂ S Concentration Before Treatment	ppm	2,500	2,500
Average H ₂ S Concentration After Treatment	ppm	150	25
Bio Scrubber Efficiency	%	94%	99%
Lubricant Oil Change Interval	Hours	750	1,250
Increase in Lubricant Oil Service Life	Hours	-	500
Percentage Increase in Lubricant Oil Service Life	%	-	67%

As seen in Table 6, enhanced bio-scrubber efficiency directly increases lubricating oil lifespan, and indirectly reduces

engine wear.

Table 7: Estimated Lubricant Cost Savings from Biogas Engine Operation

Item	Unit	Before Improvement	After Improvement
Lubricant Oil Price	Baht/Liter	115	115
Oil Volume per Engine Change Cycle	Liters	900	1,000
Cost per Change Cycle	Baht	103,500	115,000
Engine Operating Hours per Change Cycle	Hours	750	1,250
Cost per Operating Hour per Change Cycle	Baht/Hour	138	92
Annual Engine Operating Hours	Hours/Year	6,000	6,000

Annual Lubricant Oil Cost	Baht/Year	828,000	552,000
Annual Cost Reduction	Baht	–	276,000
Annual Cost Reduction Percentage	%	–	33%

Table 7 shows that the cost savings on engine lubricants can be calculated to assess the payback period of investments made in optimizing bio-scrubber systems.

4. Future plans for process innovation among biogas operators: Interviews indicated that most biogas plant operators do not yet have clear, formalized plans for further process innovation. Respondents generally expressed broad intentions to improve operational efficiency but lacked defined annual improvement plans or innovation roadmaps. Decisions regarding innovation implementation were typically made at the executive level, suggesting a need for strategic planning frameworks to guide ongoing innovation.

Discussion and Conclusion

Based on the field study and data collection on process innovations implemented in biogas power plants utilizing palm oil mill effluent (POME) in Surat Thani Province, the research findings can be discussed in accordance with the study's three main objectives as follows:

1. Utilization of process innovation in biogas power plants: The findings revealed that the adoption of process innovations in biogas power plants in Surat Thani primarily stems from internal knowledge-sharing practices within corporate networks and the introduction of innovative solutions by business partners. These innovations are considered new at the organizational level. This aligns with the study by Najafi-Tavani *et al.* (2018) ^[11], which investigated the role of collaborative innovation networks in enhancing new product performance. The results of their study indicated that collaboration with competitors, research institutions, and partner companies significantly enhances an organization's capability to generate both product and process innovations.

2. Outcomes of process innovation in biogas power plants: The study further demonstrated that the implementation of process innovations in biogas power plants using POME led to measurable outcomes, including cost reduction, increased production output, and improved operational efficiency. These results are consistent with the definitions and characteristics of process innovation described by Kahn (2018) ^[6] and Ozturk & Ozen (2021) ^[14], which emphasize the importance of process improvements aimed at enhancing performance, reducing cost, and increasing productivity.

3. Innovation development plans among biogas power plant operators: Regarding future innovation development plans, the findings revealed that most operators currently lack clearly defined strategies, including methodologies, structured plans, or measurable indicators for scaling up process innovations. Notably, more than 80% of the sample group indicated the absence of a dedicated unit or personnel responsible for innovation development within their organizations. These findings are in line with the study by Pakdeelao (2011) ^[15], which argued that innovative organizations must establish a designated department to lead innovation initiatives. Such units are essential to systematically drive and manage innovation strategies, ensuring sustained innovation development.

Research Recommendations

1. Biogas power plants utilizing palm oil mill effluent (POME) represent a business sector well-suited for the development of an Open Innovation Network. As these power plants operate under non-competing power purchase agreements with the Provincial Electricity Authority and are not in competition for raw materials or markets, forming a collaborative learning network would be highly beneficial. Such cooperation could accelerate innovation diffusion and enhance technological advancements across the industry.
2. For operators seeking to retrofit existing anaerobic digesters—which were originally designed to process only POME—to accommodate additional waste by-products such as empty fruit bunches (EFB), EFB pressing liquor, or decanter cake, it is essential to undertake comprehensive studies. These should include evaluations of both technical feasibility and potential environmental or operational impacts, particularly regarding sedimentation risks and the possible decline in digestion efficiency due to improper feedstock blending.
3. Biogas power generation from palm oil mill effluent, as a form of renewable energy production, offers substantial environmental and social benefits. Therefore, it is recommended that future research and innovation development in this field be conducted through collaborative efforts between biogas plant operators and academic institutions or government research agencies. Such partnerships would not only strengthen the sector's capacity for process innovation but also facilitate faster technological progress and broader application of sustainable energy solutions.

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