

Country Name	Technical Cooperation for Development of Clean and Efficient Utilization of Low Rank Coals and Biomass by Solvent Treatment Project		
Kingdom of Thailand			

I. Project Outline

Background	<p>In Thailand, 17.8 million tons of domestic coal (lignite) and 16.3 million tons of thermal coal were used in 2009, accounting for 15% of primary energy consumption and 19.7% of total power generation, but by 2030 they were expected to account for 23.4% of total power generation and 9,200 MW in installed capacity. It was assumed that these increases in coal consumption would be met by low-grade domestic and imported coal, but the Government of Thailand planned to reduce greenhouse gas (GHG) emissions per unit of electricity generated in the National Power Development Plan 2010 and needed to overcome the disadvantages of low-grade coal in order to reduce GHG emissions. Meanwhile, Thailand, produced 140 million tons of biomass waste annually as a result of agricultural production, and mixed coal/biomass combustion was considered as a means to reduce GHG emissions from coal-fired power generation. However, due to the low calorific value of biomass and its high content of alkali metals and chlorine content, it not only reduces the efficiency of power generation, but also it has a negative impact on the operation of combustion boilers due to agglomeration in the boiler and adhesion to the boiler walls.</p> <p>In order to solve these problems, the energy development and energy efficiency policies of the government of Thailand promoted developments of human resources and technologies at universities and research institutions and the associated research systems, with the promotion of sustainable clean coal technology and biofuel development as a priority issue.</p>										
Objectives of the Project	<p>The project aimed to solve the problems of low-grade coal and biomass utilization by developing a novel technology to convert low-grade coal, rice straw and biomass wastes into biofuels, solid fuels and carbon fiber with high efficiency using the solvent treatment methods, thereby contributing to solving global energy and environmental problems.</p> <ol style="list-style-type: none"> Expected Overall Goal: None Project Purpose: To develop a novel technology to utilize low rank coals and biomass by overcoming the drawbacks as well as the utilization of extracts. 										
Activities of the Project	<ol style="list-style-type: none"> Project site: Bangkok and Ayuthaya Main activities: a) Research and experiment on upgrading of low rank coals and biomass by solvent treatment using a small semi-continuous process, b) Research and experiment on production of new biofuel from biomass wastes using the solvent treatment and effective upgrading and desulfurization, c) Research and experiment on production of high-grade carbon materials from the Solubles, and d) Research and experiment on combustion/gasification of upgraded fuels/residues. <p>Inputs (to carry out above activities)</p> <table border="0"> <tr> <td>Japanese Side</td> <td>Thai Side</td> </tr> <tr> <td>1) Experts: 19 persons</td> <td>1) Staff allocated: 17 persons</td> </tr> <tr> <td>2) Trainees received: 756 persons</td> <td>2) Land and Facilities: Two offices and four laboratories in KMUTT. One laboratory and two experimental lots in Innovation Institute of PTT Public Company Limited (PTT-InI).</td> </tr> <tr> <td>3) Equipment: CHN analyzer, Micro balance, Rotary evaporator, TMA analyzer, Autoclave (0.5L), Carbone fiber spinning machine, SEM with EDS analyzer, Thermobalance, Drop tube furnace, etc.</td> <td></td> </tr> </table>			Japanese Side	Thai Side	1) Experts: 19 persons	1) Staff allocated: 17 persons	2) Trainees received: 756 persons	2) Land and Facilities: Two offices and four laboratories in KMUTT. One laboratory and two experimental lots in Innovation Institute of PTT Public Company Limited (PTT-InI).	3) Equipment: CHN analyzer, Micro balance, Rotary evaporator, TMA analyzer, Autoclave (0.5L), Carbone fiber spinning machine, SEM with EDS analyzer, Thermobalance, Drop tube furnace, etc.	
Japanese Side	Thai Side										
1) Experts: 19 persons	1) Staff allocated: 17 persons										
2) Trainees received: 756 persons	2) Land and Facilities: Two offices and four laboratories in KMUTT. One laboratory and two experimental lots in Innovation Institute of PTT Public Company Limited (PTT-InI).										
3) Equipment: CHN analyzer, Micro balance, Rotary evaporator, TMA analyzer, Autoclave (0.5L), Carbone fiber spinning machine, SEM with EDS analyzer, Thermobalance, Drop tube furnace, etc.											
Project Period	(ex-ante) December 2013 – December 2018 (60 months) (actual) January 8, 2014 – January 7, 2019 (60 months)	Project only Cost (Japanese side)	(ex-ante) 370 million yen (actual) 363 million yen								
Implementing Agency	Joint Graduate School of Energy and Environment of King Mongkut's University of Technology Thonburi (JGSEE/KMUTT), Innovation Institute of PTT Public Company Limited (PTT-InI)										
Cooperation Agency in Japan	Kyoto University (Research Representative), Akita University, Kobe Steel Ltd., Central Research Institute of Electric Power Industry										

II. Result of the Evaluation

<Special Perspectives Considered in the Ex-Post Evaluation >

- The Expected Overall Goal was not set for the project, yet “Commercialization of carbon fiber production using solvent treatment methods” was indicated in the terminal evaluation report as utilization of research outcomes in the future. Therefore, in this ex-post evaluation, it was verified “Any initiatives for commercialization of carbon fiber production using solvent treatment methods” have been taken by the implementing agencies or not after the project completion. If it is confirmed, it was deemed as an overall goal of this project at the time of the ex-post evaluation.

1 Relevance/Coherence

[Relevance]

<Consistency with the Development Policy of Thailand at the Time of Ex-Ante Evaluation>

¹ SATREPS: Science and Technology Research Partnership for Sustainable Development.

The project was consistent with the development policy of Thailand such as the “Eleventh National Economic and Social Development Plan (NESDP)” (2012-2016) which focused on a low-carbon, environmentally friendly society and economy at the time of ex-ante evaluation.

<Consistency with the Development Needs of Thailand at the Time of Ex-Ante Evaluation>

The project was consistent with the development needs of developing a technology to convert low-grade coal and biomass materials into biofuels to be used as efficient energy sources or resources at the time of ex-ante evaluation.

<Appropriateness of Project Design/Approach>

The project design/approach was appropriate. No problem attributed to the project design/approach was confirmed.

<Evaluation Result>

In light of the above, the relevance of the project is ③².

[Coherence]

<Consistency with Japan’s ODA Policy at the Time of Ex-Ante Evaluation>

The project was consistent with the Japan’s Country Assistance Policy for the Kingdom of Thailand (December 2012) addressing “Advancement of research capabilities and networking through Thailand-Japan collaboration” in the Priority Areas “Sustainable development of economy and coping with maturing society”.

<Collaboration/Coordination with JICA’s other interventions>

Any collaboration/coordination between the project and JICA’s other intervention was not clearly planned at the time of ex-ante evaluation or during the project period.

<Cooperation with other institutions/ Coordination with international framework>

Any cooperation/coordination with other donors or international frameworks was not clearly planned at the time of ex-ante evaluation or during the project period.

<Evaluation Result>

In light of the above, the coherence of the project is ②.

[Evaluation Result of Relevance/Coherence]

In the light above, the relevance/coherence of the project is ③.

2 Effectiveness/Impact

<Status of Achievement of the Project Purpose at the Time of Project Completion>

At the time of project completion, the Project Purpose was mostly achieved as planned. The low rank coal/biomass were converted into high quality solid fuels under mild conditions without loss of heating values by using the solvent treatment method introduced by the SATREPS project. It was found that the new solid fuels produced by the converting method were free from water and their elemental composition is close to that of bituminous coal. As a result, it was confirmed that the converting method was superior to the current torrefaction technology for biomass, and better than the hydrothermal technology for low rank coal (Indicator 1). Also, liquid fuel (biofuel) was produced by the solvent treatment method using the small semi-continuous solvent treatment plant and hydro-treating unit, and it was confirmed that the biofuel had good physical properties and was successfully burned well. However, it contained high aromatic compounds that caused soot formation compared to kerosene. The fact indicated that hydrotreating would be necessary to upgrade the biofuel. On the other hand, because the new biofuel was evaluated by the petroleum-based testing method at this stage, it would be scored lower from the viewpoints of both combustion efficiency and cost competitiveness. However, if petroleum would be replaced by biofuel in the future, different evaluation method should be established. In such a situation, the newly developed technology for biofuel production was expected to come into spotlight (Indicator 2). It was confirmed that Soluble, which had properties suitable to carbon fiber production, was produced from low rank coal/biomass in high yield under mild condition by the solvent treatment method, and the optimal conditions to produce carbon fiber from Soluble. Basic examination successfully showed that the new coke binder converted from Soluble had better characteristic than existing binder. However, its application to produce electrical double layer capacitor (EDLC) from Soluble was not confirmed by the project completion (Indicator 3).

<Continuation Status of Project Effects at the Time of Ex-Post Evaluation>

The project effects have been partially continued by the time of the ex-post evaluation. After the project completion, JGSEE/KMUTT has started research project on producing EDLC from Soluble with the financial support from Thailand Science Research and Innovation (TSRI). However, the research on production solid and liquid fuels by using the solvent treatment method has not been continued because they have been still inferior from the viewpoints of both combustion efficiency and cost competitiveness to alternate petroleum. In addition, upgrading low-rank coals to reduce GHG emissions is not a priority of the government of Thailand at the time of ex-post evaluation. However, these research could be given renewed attention in the future if there are technological innovations in the related fields and if policies and other conditions are reviewed aftertime. The equipment procured by the SATREPS project has been utilized continuously. For example, the drop tube furnace is the only test facility in Thailand that can evaluate combustion characteristics using only a small amount of fuel sample, and has received requests from biomass fuel manufacturers, and so on, for evaluation of biomass fuels, and opportunities to conduct tests are increasing. The other test and measurement equipment procured by the SATREPS project has been fully utilized for research and teaching activities at the university.

<Status of Achievement for the Expected Overall Goal at the Time of Ex-Post Evaluation>

At the time of ex-post evaluation, the Expected Overall Goal has been mostly achieved as planned.

Based on the results of the SATREPS project, a new research project “Formation of research teams based in Thailand and other ASEAN countries for the development of biomass high-level utilization technology” has been started since 2021 under the scheme of Supporting Program for Interaction-based Initiative Team Studies (SPIRITS Programme³) established by Kyoto University. This research project aims

² ④ : very high, ③ : high, ② : moderately low, ① : low

³ The SPIRITS Program is a research programme of Kyoto University that aims to promote research that crosses interdisciplinary, international and interpersonal boundaries in order to challenge research frontiers, explore uncharted areas of science and promote innovation. The SPIRITS Program is funded by grants from the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan, and Kyoto University’s own resources.

to develop new technologies for the effective use of biomass, including the development of carbon materials in the ASEAN countries. In this research project, researchers from Myanmar and Lao PDR have joined SPIRITS, including those from Lao National University and Thanlyin Technological University, Myanmar, in addition to the JGSEE/KMUTT researchers involved in the SATREPS project. The industry-academia collaborative network established by SPIRITS Program will continue to expand, and research centers will be established in ASEAN countries to develop advanced biomass utilization technologies.

<Other Impacts at the Time of Ex-Post Evaluation>

The project has a positive impact on the capacity development of JGSEE/KMUTT and PTT-InI. Two PhD and three master course students received their degrees in JGSEE/KMUTT under the project. The JGSEE/KMUTT and PTT-InI researchers have improved their research capacity and multi-skills, which can be applied not only to the related research topics, but also to any other work as a whole. In particular, the researchers were able to gain valuable expertise in research using pilot-scale equipment.

<Evaluation Result>

In the light of above, the effectiveness/impact of the project is ③.

Achievement of Project Purpose and Overall Goal

Aim	Indicators	Results	Source
(Project Purpose) To develop a novel technology to utilize low rank coals and biomass by overcoming the drawbacks as well as the utilization of extracts.	Indicator 1 Low rank coal/biomass are efficiently converted to solid fuel to generate electricity and its comparative advantage over existing converting technology is confirmed.	Status of the Achievement (Status of the Continuation): Achieved as planned (Not continued) (Project Completion) <ul style="list-style-type: none"> • Low rank coal/biomass were converted into high quality solid fuels under mild conditions without loss of heating values by using the solvent treatment method introduced by this SATREPS project. • The new solid fuels produced by this converting method were free from water and their elemental composition was close to that of bituminous coal. • The converting method was superior to the current torrefaction technology for biomass. It was also better than the hydrothermal technology for low rank coal. (Ex-post Evaluation) <ul style="list-style-type: none"> • The research on production of solid and liquid fuels by using the solvent treatment method has not been continued because they are still inferior from the viewpoints of both combustion efficiency and cost competitiveness to alternate petroleum. 	Terminal evaluation report JGSEE/ KMUTT PTT-InI
	Indicator 2 Low rank coal/biomass are efficiently converted to liquid fuel by solvent treatment method and possibility to replace partially with conventional liquid fuel is confirmed.	Status of the Achievement (Status of the Continuation): Achieved as planned (Not continued) (Project Completion) <ul style="list-style-type: none"> • New liquid fuel was produced by the solvent treatment method using the small semi-continuous solvent treatment plant and hydro-treating unit. • The bio-fuel combustion was successfully tested in Japan, and the test results showed that the biofuel had good physical properties and was successfully burned well. • However, it contained high aromatic compounds that caused soot formation compared to kerosene. This suggested that hydrotreating would be necessary to upgrade the biofuel. • On the other hand, because the new biofuel was evaluated by the petroleum-based testing method at this stage, it would be scored lower from the viewpoints of both combustion efficiency and cost competitiveness. However, if petroleum would be replaced by biofuel in the future, different evaluation method should be established. In such a situation, the newly developed technology for biofuel production was expected to come into spotlight. (Ex-post Evaluation) <ul style="list-style-type: none"> • The research on production of solid and liquid fuels by using the solvent treatment method has not been continued because they are still inferior from the viewpoints of both combustion efficiency and cost competitiveness to alternate petroleum. 	Terminal evaluation report JGSEE/ KMUTT PTT-InI
	Indicator 3 Low rank coal/biomass are efficiently converted to carbon materials and their applications are confirmed.	Status of the Achievement (Status of the Continuation): Achieved as planned (continued) (Project completion) <ul style="list-style-type: none"> • Soluble, which had properties suitable to carbon fiber production, was produced from low rank coal/biomass in high yield under mild condition by the solvent treatment method. • The optimal conditions to produce carbon fiber from Soluble were successfully confirmed, but its application to produce electrical double layer capacitor (EDLC) from Soluble was not confirmed by the project completion. However, from the properties of Soluble, it was suggested that it had high potential as raw materials for producing EDLC. • Basic examination successfully showed that the new coke binder converted 	Terminal evaluation report JGSEE/ KMUTT PTT-InI

from Soluble had better characteristic than existing binder.
(Ex-post Evaluation)

- After the project completion, JGSEE/KMUTT has started research project on producing EDLC from Soluble with the financial support from Thailand Science Research and Innovation (TSRI).

3 Efficiency

Both the project cost and the project period within the plan (the ratio against the plan: 98% and 100%, respectively).

	Project Cost (Japanese side only, yen)	Project Period (months)
Plan (ex-ante)	370 million yen	60 months
Actual	363 million yen	60 months
Ratio (%)	98%	100%

Outputs were produced as planned. In the light above, the efficiency of the project is ④.

4 Sustainability

<Policy Aspect>

Based on the “Power Development Plan 2018-2037 (PDP2018)” at the time of the ex-post evaluation, the use of coal in power generation is less emphasized compared to the previous PDP2010 at the time of the ex-ante evaluation. Therefore, upgrading low-rank coals to reduce GHG emissions is not a priority at present. However, the government of Thailand attaches great importance to “the Bio-Circular-Green (BCG) Economy Policy” which places emphasis on applying science, technology and innovation to turn Thailand’s comparative advantage in biological and cultural diversity into competitive advantage. In addition, the market for bio-based products is expanding worldwide due to growing environmental concerns. For this reason, the research outcomes of the SATREPS project have been still relevant and have potential for future initiatives such as biomass to carbon conversion technology.

<Institutional/Organizational Aspect>

As mentioned above, JGSEE/KMUTT has started a new research project “Formation of research teams based in Thailand and other ASEAN countries for the development of biomass high-level utilization technology” since 2021 under the scheme of SPIRITS Programme with the researchers from Lao National University and Thanlyin Technological University, Myanmar. JGSEE/KMUTT researchers involved in the SATREPS project participated to the above new research project, and the results of the SATREPS project is utilized for this research project. As for PTT-InI, due to its reorganization in 2018, the current policy and organizational direction of PTT-InI does not include research topics related to the SATREPS project and/or biofuel. However, there are still prospects to resume biomass utilization research following the Thai government policy on BCG Economy as well as global trend such as circular economy and sustainable biofuel for aviation.

<Technical Aspect>

The JGSEE/KMUTT researchers have sufficient knowledge and skills to properly operate and maintain the facilities/equipment installed by the SATREPS project, as they have been involved from the installation of the equipment and have been well trained by the Japanese researchers/operators during the project implementation. By continuing the research activities and maintaining the communication/network established in the SATREPS project, the JGSEE/KMUTT researchers have maintained and improved their skills and knowledge. The laboratories and equipment procured by the SATREPS project are still being fully utilized by the researchers and students in both research and teaching activities. While the researchers at PTT-InI have improved their research capacity during their participation in the SATREPS project, due to reorganization, their current research activities focus on biotechnology and electric vehicle (EV) technology, rather than directly on biomass and coal. In addition, PTT-InI has not operated the semi-continuous solvent extraction unit because there is currently no related research and a limited number of well-trained operators for the large-scale equipment. PTT-InI plans to discuss with other researchers in Thailand and the network the possibility of utilizing/restarting the plant, including the possibility of relocation if necessary.

<Financial Aspect>

In addition to the regular university budget to conduct research and teaching activities, JGSEE/KMUTT received external financial support from TSRI to start a new research project on the production of EDLC from soluble, as well as the fund from Kyoto University for SPIRITS Program. In addition, JGSEE/KMUTT provides sufficient annual budget for the operation and maintenance of the equipment installed by the SATREPS project. While, due to reorganization, PTT-InI does not currently have any research activities related to the research results of SATREPS project. The budget for operation and maintenance of the pilot plant is not allocated on a regular basis as the pilot plant has not been operated since the reorganization.

<Environmental and Social Aspect>

No issue on environmental and social aspects has been observed, and it has not been necessary to take any countermeasures.

<Evaluation Result>

In light of the above, some problems have been observed in terms of the institutional/organizational and financial aspects of the implementing agency. Therefore, the sustainability of the project effects is ②.

5 Summary of the Evaluation

The project mostly achieved as planned the Project Purpose to develop a novel technology to utilize low rank coals and biomass by overcoming the drawbacks as well as the utilization of extracts, and the Expected Overall Goal to continue the initiatives of the project towards the realization of social implementation of the project outcomes. After the project completion, a new research project has been started since 2021 under the scheme of SPIRITS Programme by Kyoto University, and the research activities to develop new technologies for the effective use of biomass, including the development of carbon materials in the ASEAN countries have been undertaken by JGSEE/KMUTT with universities of Myanmar and Lao PDR.

Considering all of the above points, this project is evaluated to be satisfactory.

III. Recommendations & Lessons Learned

Recommendations for Implementing Agency:

- Since the social implementation of the conversion technology by solvent treatment developed in the SATREPS project might be difficult in the short-term due to changes in the situation surrounding coal utilization and changes in Thailand's policy for coal utilization; therefore, JGSEE/KMUTT and PTT-InI are advised to preserve this technology appropriately for using further expansion of research areas based on the research network and basic research capabilities fostered by the SATREPS project.
- Although no research activities related to the research topics of SATREPS project and/or biofuel has been carried out in PTT-InI after the project completion, PTT-InI is suggested to share their knowledge of the pilot plant operation constructed by the project with other researchers in Thailand as well as to seek a possibility of relocation of the plant to other Thai research institutes/universities for effective utilization of the plant.

Lessons Learned for JICA:

- In order to promote social implementation of the developed carbon materials, additional activities should have been included to evaluate the superiority of this technology from multiple perspectives by conducting life cycle assessments that considers the entire value chain and/or by conducting comparative analysis with competing technologies, since it would be difficult for bio-based products to gain a comparative price advantage over existing technologies in the absence of a market system that takes into account environmental externalities such as a carbon pricing,
- The involvement of both Japanese and Thai private companies, including PTT and Kobe Steel, from the beginning of the project was effective in efficiently conducting pilot-scale experimental research, which is important for social implementation. However, it should be fully recognized that economic conditions and other factors may result in significant changes in company and industry policies that could affect the sustainability of the project, and that an accurate understanding of the development status of competing technologies and market trends should be maintained, and active publicity should be considered to attract the interest of more companies and industries, while paying attention to intellectual property protection.



Experimental equipment procured in the project at JGSEE/KMUTT



Semi Continuous Extraction Unit at PTT-InI