Project Completion Report

The Project "Production of Biofuels Using Algal Biomass" in the Republic of South Africa

March 2022

Japan International Cooperation Agency (JICA)

Institute of Water and Wastewater Technology
Durban University of Technology

Nagoya University

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Abbreviations and Acronyms

ARC	Agriculture Research Council
DAC	Development. Assistance Committee
DME	Dimethyl ether
DUT	Durban University of Technology
EWS	eThekwini Municipality, Water Service
JCC	Joint Coordinating Committee
JICA	Japan International Cooperation Agency
JST	Japan Science and Technology Agency
M/M	Minutes of Meeting
MOU	Memorandum of Understanding
ODA	Official Development Assistance
PDM	Project Design Matrix
PO	Plan of Operation
R/D	Record of Discussions
SATREPS	Science and Technology Research Partnership for Sustainable Development
SDGs	Sustainable Development Goals
SOP	Standard Operating Procedure
TIA	Technology Innovation Agency

Contents of the Project Completion Report

I. Basic Information of the Project

1. Country: Republic of South Africa

2. Title of the Project: Production of Biofuels Using Algal Biomass

3. Duration of the Project: 30 March 2016 - 29 March 2022

4. Background:

Even with the rapid spread of solar and wind power generation, photosynthesis by plants is still an important way of fixing carbon dioxide from the atmosphere. The production of lipids from plants is also becoming increasingly important as an alternative to lipids for the sustainable production of a wide range of organic compounds needed for daily life in the face of fears of fossil resource depletion in the near future. In the case of maize, however, the area required to meet the world's oil demand is 14.3 times the size of the world's cultivated area, and 1.3 times that of jatropha, making it difficult to meet oil production from these crops. Considering that more water and agricultural land will be consumed in the future as the world's population grows and the demand for food production increases, it is not realistic to produce biofuels from higher plants. For this reason, the production of lipids from microalgae with excellent photosynthetic efficiency is expected. Microalgae can produce lipids tens times faster than other higher plants. Thus, the production of lipids from microalgae is inevitable for the production of sustainable alternatives to oil, especially for bioenergy production.

Microalgae are suitable for the treatment of sewage containing these nutrients because they produce lipids in their bodies which can be used as raw materials for biofuels when they are deficient in nutrients, and they also absorb valuable nutrient sources such as nitrogen and phosphorus during their growth stage. However, microalgae have a high-water content and need to be dried. Due to the presence of this drying process, the energy input for the production of biofuels from microalgae more than the total amount of heating value obtained by microalgae through photosynthesis (including not only lipids but also residues). This problem is still completely unresolved worldwide.

On 18 October 2019, the South African government published its Integrated Resource Plan, which sets out the country's energy policy up to 2030. diesel 8.1%, pumped storage 6.4%, nuclear 2.4% and others 0.5%. The current mainstream coal-fired power stations will be with a shift to renewable energy. However, the breakdown of renewable energy sources is 5.8% hydro, 10.5% solar, 22.5% wind and 0.8% solar thermal, not including biomass which competes with food production. For this reason, the Durban University of Technology has been developing a technology to grow microalgae using treated sewage water as biomass that does not compete with food production, but has been faced with the problem that there is no technology that can efficiently extract oil and fat from microalgae.

In this international joint research project, the Republic of South Africa, which possesses advanced microalgae cultivation technology, and Japan, which possesses lipid extraction technology that does not require drying treatment, will jointly solve the above technical problems, develop a greening support fertilizer (Agri-Mat) suitable for South Africa that makes effective use of the residue after extraction. Japanese side also support the development of a business model for the successful commercialization. These international collaborations will be promoted in collaboration with the Durban University of Technology (DUT), the Agriculture Research Council (ARC) and the Durban (eThekwini) municipality in South Africa.

5. Overall Goal and Project Purpose

<Overall Goal>

“Biofuel from microalgae is produced through the application of technology and determining its commercial viability.”

[Indicator]

Amount of biofuel production using the technology under the Project.

<Project Purpose>

“An energy effective process technology and preliminary business model for the production of biofuels from microalgae is developed.”.

[Indicator]

1. To supply field test equipment and status of the practical operation for biofuel and agricultural bi-products.
2. Patents/Intellectual property development of biofuel production and Agrimats production.
3. To supply handbooks for environment education.
4. Joint publication in ISI journals articles.

6. Implementing Agency: Nagoya University, Tokyo University of Agriculture and Technology, Aichi Shukutoku University, Durban University, Agriculture Research Agency, eThekwini municipality, Technology Innovation Agency. (Halfway through) Hitachi Ltd., Tokaigakuen University, Tsukuba University

II. Results of the Project

1. Results of the Project

1-1 Input by the Japanese side (Planned and Actual)

Planned at the time of R/D on 8th September 2015

a. Long term expert
   Project Coordinator
b. Short-term experts
   1) Hideki Kanda (Nagoya University/Japanese Project Team Leader)

2) Siaw Onwona Agyeman (Tokyo University of Agriculture and Technology)
3) Shoko Yamada (Nagoya University)
4) Makoto Nishimura (Nagoya University)
5) Akira Mochizuki (Hitachi)

c. List of Equipment

Equipment

1) Test equipment for harvesting technology 1
2) Test equipment for extraction technology 1
3) Agrimat fabrication machine 1
4) YSI multi-parameter system including chlorophyll sensor 1
5) Soxhlet extractor 1
6) Industrial Grinder 1
7) Jar test apparatus 1
8) Microwave digestion system 1
9) Rainfall simulator and pump set 1
10) Soil Moisture Thermometer 12
11) Soil Oxygen Meter 3
12) Portable moisture meter 1
13) Data logger 3

Training

JICA Experts will provide on-site training in the harvesting equipment, extraction equipment, and agrimat fabrication machine in South Africa through cooperative research works with South African researchers and engineers. JICA Experts also will receive the South African personnel connected with this Project for training in Japan.

Actual Inputs

The followings are the status of delivery of inputs as of 31st March 2022 by the Japanese side and as seen in Annex 1

(1) Total Inputs Amount: 300.0 million JPY

(2) Assignment of Specialists and Experts

11 Japanese and 8 South African specialists as seen in Annex 1 and 2 have been dispatched for the Project activities in South Africa (A total of dispatched period: 493 days) as short-term expert. In addition to this, we have carried out about 200 days of remote involvement from Japan.

In addition, two (2) long-term experts (Project Coordinator) were assigned to the Project in DUT, Durban, South Africa.

* In August 2021, the second Project Coordinator was sent to South Africa.

(3) Provision of Equipment

A total of 16 instruments amounting to 1.55 million ZAR and 163.8 million JPY were procured and provided to South African side under the Project as follows:

1) Test equipment for harvesting technology 1

2) Test equipment for extraction technology 1
3) Agrimat fabrication machine 2
4) YSI multi-parameter system including chlorophyll sensor 1
5) Soxhlet extractor 1
6) Industrial Grinder 1
7) Jar test apparatus 1
8) Double beam spectrophotometer 1
9) Sonicator 1
10) Microwave digestion system 1
11) Rainfall simulator and pump set 1
12) Soil Moisture Thermometer 12
13) Soil Oxygen Meter 3
14) Portable moisture meter 1
15) Data logger 3

(4) Local Cost Expense

As of the end of March 2022, the following amounts have been disbursed for the Project. The 2021 is the budgeted amount.

Table 1. Local Cost Expense from Japanese side

Year	Amount (ZAR)
2016	R4,692,491
2017	R2,754,158
2018	R20,070,216
2019	R2,306,908
2020	R1,499,321
2021	R5,971,055
Total	**R31,323,094**

(5) Training in Japan

8 trainees (5 in 2017, 7 in 2018, 7 in 2019 and 1 in 2020) participated in the short-term training program at Nagoya University and its surrounding area, extraction equipment training program at ToyoKoatsu, Japan and short-term Agrimat fabrication training program at Tokyo University of Agriculture and Technology, Japan. The participants list and the curriculums are shown in Annex 2.

Special note: From March 2020, traveling between South Africa and Japan was no longer possible due to the COVID-19 pandemic.

1-2 Input by the South African side (Planned and Actual)

Planned at the time of R/D(MoU) on 30th March 2016

a. Counterpart researchers
   1) Project Director, Prof. Faizal Bux, DUT
   2) Mr. Ismail Rawat, DUT
   3) Mr. Speedy Moodliar, EWS

4) Mr. Titus Kasie, EWS
5) Dr. Adornis Nciizah, ARC

b. Suitable office space with necessary equipment
c. Supply or replacement of machinery, equipment, instruments, vehicles, tools, spare parts and any other materials necessary for the implementation of the Project other than the equipment provided by JICA.
d. Information as well as support in obtaining medical services
e. Credentials or identification cards,
f. Available data (including maps and photographs) and information related to the Project.
g. Running expenses necessary for the implementation of the Project.
h. Expenses necessary for transportation within South Africa of the equipment referred to in 1-1 C above as well as for the installation, operation and maintenance thereof: and,
i. Necessary facilities for the JICA experts for remittance as well as utilization of the funds brought into South Africa from Japan in connection with implementation of the Project.

Actual Inputs

The followings are the status of delivery of inputs as at 31 March 2022 by the South African side and as seen in Annex-1.

Special note: From March 2020, traveling between South Africa and Japan was no longer possible due to the COVID-19 pandemic.

(1) Assignment of Counterpart Personnel

A total of 3 DUT researchers, 3 ARC researchers, 2 EWS engineers have been assigned as project's counterparts. They and their students have participated in the research activities of the Project. Since the commencement of the Project, the main counterparts have not been changed. The list of counterpart personnel shall be referred to in Annex 2.

(2) Facilities and Equipment

DUT procured the 300 tons open pond total for the Project and provided one room for the Japanese Project team.

In addition, DUT and EWS renovated and prepared the bottom of the culture pond and paddle for microalgal cultivation procured under the Project. and DUT have been maintaining the laboratory, providing reagents and supplies, and consumables under its own budget.

(3) Local Cost Expenditure

South Africa side have disbursed the following amounts for the Project activities.

Table 2. Local Cost Expense from South African side

DUT	
Year	Amount (ZAR)
2016	1,335,050
2017	1,650,353
2018	1,479,975
2019	2,708,086
2020	1,398,953
2021	0
Total	**8,572,416**
ARC	
Year	Amount
2016	12,000
2017	175,620
2018	249,888
2019	810,730
2020	140,000
2021	290,780
Total	**1,679,018**
EWS	
Year	Amount
2016	0
2017	418,600
2018	523,260
2019	545,400
2020	226,000
2021	344,250
Total	**2,057,510**

1-3 Activities (Planned and Actual)

The original procurement plan was changed, therefore, technology transfer on harvesting and extraction equipment started in the first half of 2019 onward. However, most of the activities had been conducted as planned.

Both planned and actual project activities shall be seen in the Plan of Operation as in Annex 5.

2. Achievements of the Project

2-1 1 Outputs and indicators

(Target values and actual values achieved at completion)

The status of achievement of the Project Outputs in terms of verification indicators as per PDM is as follows.

Output1: Develop of high biomass production system using open raceway pond.

Verification Indicators	Degree of Achievement and Status
1.1 Field test of algae culture using media 1.2 Field test of algae culture using wastewater 1.3 Evaluation of cheap nutrient substrates 1.4 Optimization of biomass and lipid yields	Achievement Degree: 100% ・Maximum biomass production: ~30gm-2d-1. Maximum lipid content: 28% Lipid g-1 day. ANFIS modelling of the system showed that maximum biomass productivity was achieved at depths between 20 and 22 cm at light intensities between 200 and 400 µmol/m2/s and pH in the range of 9 to 9.5. ・Requirement for supplementation in order to achieve maximum biomass. Maximum biomass production (supplemented): ~30gm-2d-1. Maximum lipid content: 36% Lipid g-1 DCW under ideal conditions. Biomass productivity is affected strongly be light intensity, pH and depth. Intermittent harvesting (weekly) is being optimised for higher productivity. Lipid content in week 3 of cultivation was higher than weeks 1 and 2 reaching above 25% lipid with intemittent harvesting. ・Urea has been identified as a viable chemical supplement to wastewater. Waste substrates currently under investigation. Urea found to be toxic to raceway configuration. Lower concentrations of NaNO3 found to be more suitable. ・Optimisation of biomass productivity is ongoing, Maximum productivity achieved at lower culture densities. Harvesting interval being optimised with water and nutrients being recycled.

Output 2: Development of effective biofuel extraction technology.

Verification Indicators	Degree of Achievement and Status
2.1 To make extraction mechanism clear for the selected endemic algae species in South Africa or similar algae species - Evaluation of extracted the lipid amounts.	Achievement Degree: 100% ・Mechanism of lipid extraction by liquefied DME was clarified. ・Water dissolved in liquefied DME is effective to extract polar glycolipid and phospholipids from WET microalgae. ・It was confirmed by bioassay that there was no biotoxicity of water in which DME was dissolved. ・CaSO4 and CaCO3 were found to act as catalysts to promote methyl esterification by supercritical methanol. ・Thermodynamic equation describing the extraction equilibrium was derived and its validity was confirmed by molecular dynamics.

Output 3: A cost effective technology and preliminary business model for the production of agricultural bi-products is developed from waste.

Verification Indicators	Degree of Achievement and Status
3.1 Results of component analysis of algae residual after extraction of lipid and sludge. 3.2 Survey on the availability of algae residue, sludge and unutilized woody biomass 3.3 Evaluation of the technology to produce the agri mats under suitable South African environment 3.4 Fabrication of different agri mats from different combinations of algae residue, sludge and unutilized woody biomass. 3.5 Field test are conducted to select the most suitable agri mat for South African agriculture 3.6 A preliminary Agri-business model based on agri mat concept is proposed for local companies	Achievement Degree: 80% ・ Complete results of component analysis of algal residues after lipid and sludge extraction. ・ A study on the potential use of algal residues, sludge and unused woody biomass was carried out. ・ Possibility of fabricating agri-mats without using any adhesives was explored. This means the development of agrimat production technology in appropriate South African settings. ・Agrimat fabricating machines were installed at ARC- Agricultural Engineering and successfully tested. By using the Agrimat fabricating machines, several prototypes of agri-mats were successfully fabricated. ・Field work was interrupted by COVID19. Therefore, plans were changed and a greenhouse experiment to assess the performance of AgriMat was carried out and completed. ・An agribusiness model based on the AgriMat concept was incorporated into the output5 handbook and proposed to the eThekwini municipality.

Output 4：Test equipment for harvesting and extraction technology is developed.

Verification Indicators	Degree of Achievement and Status
4.1 Selection of the test equipment for harvesting. 4.2 Evaluation of the test equipment for harvesting technology at site in South Africa complying with the EWS standards. 4.3 To develop a prototype for extraction of lipids from algal biomass. 4.4 Testing and operation at the site and the training on the test equipment for extraction technology complying with the EWS standards.	Achievement Degree: 80% ・Harvesting equipment made by Tomoe Eng. was installed in the Kingsburgh WWTW in May 2019. ・Energy consumption of harvesting equipment was estimated to be 33.8% of higher heating value of microalgae lipid. The separated effluent was colorless, clear and free of microalgae, which met the effluent standatds required by the EWS. ・ Design of test equipment of extraction was complete. ・Extraction equipment assembled by ToyoKoatsu was installed in the Kingsburgh WWTW in June 2019. During the research operation, revision of the extraction equipment was done to improve the practical usability of the system. ・Energy consumption by the extraction equipment was examined in more detail, and it was found to be 19.8% of higher heating value of microalgae lipid at present and 16.2% when the equipment is enlarged. For the new problem that the apparent filling volume is reduced to 1/3 due to the excluded volume of the mixed bagasse, we found that the apparent filling volume can be increased to 2/3 by using cellulose spheres. Although there was a period of interruption during the project due to COVID-19, the Japanese staff completed the preparation of the residue for the laboratory evaluation test of AgriMat. ・Training of harvesting equipment was done in May 2019 in Kingsburgh WWTW. The effluent is colourless, clear and free of microalgae, and the training complies with operating procedures that meet EWS standards. Training of extraction equipment was started in January 2019 in Hiroshima, Japan, and was done in June, August, September, and October 2019 in Kingsburgh. Until the end of SATREPS, driving proficiency training will be provided from the Japanese side to the South African side.

Output 5: Foundation of human capacity development and business model of the Project is established.

Verification Indicators	Degree of Achievement and Status
5.1 Survey of existing regulations regarding environmental protection and energy saving in South Africa. 5.2 Production of handbooks including example of Japanese success model for environment recovery and the training of the South African stakeholders 5.3 To formulate standard operating procedure (SOP) for harvesting and extraction and train personnel of eThekwini Municipality and DUT. 5.4 To establish sustainable project related capacity development system in eThekwini Municipality. 5.5 Exchange of students and researchers for short term training and workshops 5.6 Road map for the commercialization including PPP in eThekwini Municipality.	Achievement Degree: 80% ・Survey the previous studies and the public reports regarding to South Africa such as DST (2014) reports, and case studies of Japan in 1960s-70s regarding to the experiences of environmental pollution and their overcoming with foundation of the environmental business model. This means that a survey of existing regulations on environmental protection and energy conservation in South Africa has been completed. ・Creation the handbook for understanding the roles of our research activities and the importance of the environmental business model. Training for the South African side, in line with the content of the first edition of the handbook, in which best practices from Japan were presented, was conducted in February 2017. ・Operating manual for harvesting and extraction were completed. ・In accordance with the manuals, training of harvesting and extraction equipment were in progress in Kingsburgh WWTW. ・Through training according to the SOPs, researchers were developed on the South African side to a level where they could mentor other technicians and build the capacity development system necessary for sustainable project implementation. ・At least 10 South African young researchers (man-days are over 100days) have been trained in South Africa, and at least three of them have been able to operate the equipment without the help of the Japanese side. Japanese researchers, engineers and students visited South Africa for installation and training (man-days are over 300days). Until the end of SATREPS, driving proficiency training will be provided from the Japanese side to the South African side.

2-2 Project Purpose and indicators
(Target values and actual values achieved at completion)

The status of indicators that measure the achievement level of the Project Purpose is shown as follows.

Project Purpose Applicability of technologies developed by the Project is verified in the model site.	
Verification Indicators	Degree of Achievement and Status
1. To supply field test equipment and status of the practical operation for biofuel and agricultural bi-products. 2. Patents/Intellectual property development of Bio fuel production and agrimats production 3. To supply handbooks for environment education 4. Joint publication in ISI journals articles	Achievement Degree: 60% ・Field test equipment for harvesting, extraction, and Agrimat were installed in the Kingsburgh WWTW in 2019. Field test equipment for Agrimat harvesting and extraction were installed in the Kingsburgh WWTW in May 2019. However, due to project budget constraints, the extraction equipment and the Agrimat equipment have a smaller throughput than originally expected from the South African side. ・The patent for the production of biofuels was originally held by Nagoya University. Patents on agrimat is currently being considered by Tokyo University of Agriculture and Technology. The DME-based extraction method, which is part of biofuel production, and Agrimat, in which algae residues are embedded in wood board, are new developments in the project. ・The final handbook was provided to the South African side in mid-March. ・Although 22 ISI papers have been published by individual teams, delays in field testing due to COVID-19 have caused delays in joint publication, but data acquisition is progressing well and we will continue to work together to prepare for joint publication after completion. The co-authored paper has already been submitted and is under review and be published soon with revisions. However, JICA's evaluation criteria do not include the period of peer review, so the achievement level at the beginning is lower.

3. History of PDM Modification

3-1 At the 1st JCC meeting in November 2017, the following change was made to the PDM:

1) Objectively Verifiable Indicators

(original) 2.1 To make extraction mechanism clear for the selected endemic algae species in South Africa

(revised) 2.1 To make extraction mechanism clear for the selected endemic algae species in South Africa or similar algae species

(original) 4.1 To conduct design and production of a test equipment for harvesting technology based on Japanese technology and to make manuals to operate the plant.

(revised) deleted

(original) 4.2 Preliminary test of the equipment for harvesting technology in Japan.

(revised) 4.1 Selection of the test equipment for harvesting.

2) Activity

(original) 2.1 To make extraction mechanism clear for the selected endemic algae species in South Africa

(revised) 2.1 To make extraction mechanism clear for the selected endemic algae species in South Africa or similar algae species

(original) 4.1To design and produce a high speed and efficiency test equipment for harvest technology based on Japanese technology with manuals, and complete the basic design specification and the operation manual.

(revised) deleted

(original) 4-2 To complete the test equipment for harvesting technology.

(revised) deleted

(original) 4-3 To complete a preliminary test operation of the equipment for harvesting technology in Japan.

(revised) deleted

3-2 At the 3ed JCC meeting in October 2019, the following changes were made to the PDM:

1) Outputs

(original) Output 5：Foundation of the human resource development of the Project is established.

(revised) Output 5: Foundation of human capacity development and business model of the Project is established.

2) Activities

(original) 5.3 To formulate a training program and the implementation for stakeholders of eThekwini Municipality.
(revised) 5.3 To formulate standard operating procedure (SOP) for harvesting and extraction and train personnel of eThekwini Municipality and DUT.

(original) 5.4 To establish sustainable human resource development system in eThekwini Municipality.
(revised) 5.4 To formulate standard operating procedure (SOP) for harvesting and extraction and train personnel of eThekwini Municipality and DUT.

III. Results of Joint Review

1. Results of Review based on DAC Evaluation Criteria

The Project is evaluated based on the five criteria according to the following five levels: high, relatively high, moderate, relatively low, and low.

1-1. Relevance

The relevance of the Project is assessed as high.
As described below, the contents of the Project are in line with the needs of South African society, South African development policies and plans as well as the Japanese ODA policies.

(1) Relevance to South African development plan, and policy

Even with the rapid spread of solar and wind power generation, photosynthesis by plants is still an important way of fixing carbon dioxide in the atmosphere. The production of fats and oils from plants is also becoming increasingly important as an alternative to oil for the sustainable production of a wide range of organic compounds needed for daily life in the face of fears of fossil resource depletion in the near future. In the case of maize, however, the area required to meet the world's oil demand is 14.3 times the size of the world's cultivated area in the case of corn, and 1.3 times that in the case of jatropha, making it difficult to meet oil production from these crops. Considering that more water and agricultural land will be consumed in the future as the world's population grows and the demand for food production increases, it is not realistic to produce biofuels from higher plants. For this reason, the production of lipids from microalgae with excellent photosynthetic capacity is expected. Microalgae can produce oil tens to hundreds of times faster than other plants. Thus, the production of lipids from microalgae is inevitable for the production of sustainable alternatives to oil, especially for bioenergy production.

On 18 October 2019, the South African government published its Integrated Resource Plan (IRP), which sets out the country's energy policy up to 2030. diesel 8.1%, pumped storage 6.4%, nuclear 2.4% and others 0.5%. The current mainstream coal-fired power stations will be the last, with a shift to renewable energy.

(2) Relevance to the needs of target group

Durban University of Technology has been developing a technology to grow microalgae using treated sewage water as biomass that does not compete with food production, but has been faced with the problem that there is no technology that can efficiently extract lipids from microalgae.

Microalgae are suitable for the treatment of sewage containing these nutrients because they produce lipids in their bodies which can be used as raw materials for biofuels when they are deficient in nutrients, and they also absorb valuable nutrient sources such as nitrogen and phosphorus during their growth stage. However, microalgae have a high-water content and need to be dried. Due to the presence of this drying process, the energy input for the production of biofuels from microalgae ranges from two times (ideal) to more than seven times (actual) the total amount of heat obtained by microalgae through photosynthesis (including not only lipids but also residues). This problem has not yet been solved worldwide.

In this international joint research project, the Republic of South Africa, which possesses advanced microalgae cultivation technology, and Japan, which possesses oil and fat extraction technology that does not require drying treatment, will jointly solve the above technical problems, develop a greening support fertilizer (Agrimat) suitable for Africa that makes effective use of the residue after extraction, and conduct business model.

(3) Relevance to the Japanese ODA policies

The Japanese government set forth the ODA policy towards South Africa in October 2017. In the ODA policy, the Government of Japan notes that South Africa is a leading country in the development of the Southern African region and gives priority to cooperation with a view to contributing to the achievement of the SDGs. Tackling climate change is a key target of the SDGs. In this program, the Japanese government is interested in supporting South Africa to reduce the negative impact of climate change and to development of microalgal fuel to reduce the emission of greenhouse gases. Thus, the contents of the Project are consistent with ODA policy.

1-2. Effectiveness

The effectiveness of the Project is assessed as relatively high, as most of the research has been conducted as planned to achieve the Project purpose.

1-2-1. Relation between the Project Purpose and Outputs

The PDM of this project is to develop a technology for cultivating South African microalgae in treated sewage water in "Output 1", to develop a technology for extracting lipids from microalgae in "Output 2", to develop a technology for making wood board-like fertilizer from the residue after extracting lipids from microalgae and other plants in "Output 3", and to develop test equipment in South Africa to harvest microalgae from the culture medium and equipment to extract lipids in "Output 4", and to build a business model to support these in "Output 5". Therefore, the logic that the objectives of the Project will be achieved through the achievement of "Output 1" to "Output 5" is quite sound.

1-2-2. Prospect of Project Purpose achievement

- The practicality of the technology to be developed in this project will be confirmed by "Indicator 1" and "Indicator 3" of the Project Purpose, and the applicability of the technology to be developed in this project will be confirmed by the acceptance of the research results in "Indicator 2" and "Indicator 4". The achievement of these two indicators will lead to the achievement of the objectives of the Project. Therefore, the indicators set are appropriate.
- Regarding "Indicator 1", field test equipment for harvesting, extraction, and Agrimat were installed in the Kingsburgh WWTW in 2019. Due to project budget constraints, the extraction equipment and the Agrimat equipment have a smaller throughput than originally expected from the South African side. However, a detailed blueprint of the device has been disclosed to the South African side, and it is possible to build a larger device in the future.
- Regarding "Indicator 2", the patent for the production of biofuels was originally held by Nagoya University. Patents on agrimat is currently being considered by Tokyo University of Agriculture and Technology. The DME-based extraction method, which is part of biofuel production, and Agrimat, in which algae residues are embedded in wood board, are new developments in the project.
- Regarding "Indicator 3", final handbook is currently being prepared and is expected to be made available to South Africans side in due course.
- Regarding "Indicator 4", 22 peer-reviewed research papers have been accepted in international journals and reputable proceedings including internationally renowned journals with high impact factor. Considering the additional joint papers are currently being prepared and will be accepted by internationally renowned journals, at the time of project completion, this indicator is expected to be achieved.

1-2-2. Fulfilment of the Important Assumption to achieve the Project Purpose

[Important Assumption]

<u>The direction on the "A fair transition to a low carbon economy" policies is continuously retained</u>.

- The South African government's response to climate change to date has been the National Climate Change Response Policy (NCCRP), which in 2011 set out the government's targets for responding to climate change by 2050. The following year, the National Development Plan (NDP) was formulated in 2012, with a chapter on the environment and sustainability, and the slogan "A fair transition to a low carbon economy". It sets out targets for reducing emissions and moving away from fossil fuels and towards renewable energy. Based on the above trends, the aforementioned action plan to combat climate change up to 2050, was formulated as a concrete response to the Paris Agreement.

- The first concrete measure introduced by the government was the Carbon Tax Act 2019. The first phase of the tax, covering the period 2019 to the end of 2022, is currently underway and sets out tax-free emission allowances for each industry and economic activity. In addition, the Climate Change Bill is currently under discussion. The bill is in the final adjustment stage. If passed, it is expected to impose quantitative targets for emission reductions by industrial sector and allocate the national budget required to achieve them.

1-3. Efficiency

The efficiency of the Project is assessed as relatively high.

Although the input of some equipment was delayed due to the change of the plan for the recovery and extraction equipment, the project was switched to procurement and development by Nagoya University, and the necessary inputs (dispatch of Japanese experts, procurement of equipment, etc.) were implemented. In addition, although the dispatch of Japanese experts under COVID-19 was not possible during the course of the project, we attempted to improve the quantity and quality of inputs, for example by using remote technology to direct the adjustment of equipment in the field from Japan, and this was judged to have been carried out appropriately under various constraints. Despite these changes and the impact of budget constraints, outputs 1 to 4 described in the PDM are expected to be largely achieved by the end of the project.

1-3-1. Efficiency of Inputs from the Japanese Side

- The number, expertise, timing and duration of the dispatches of the Japanese experts were very appropriate, except for the interruption of travel due to COVID-19, which was minimized by remote implementation.
- The specifications, types and quantities of equipment installed were generally adequate. However, due to budgetary constraints, the throughput of the extraction equipment is inadequate, but all the detailed design drawings of the equipment have been provided to the South African side and there are no technical constraints on the future enlargement of the equipment. Most of the activities are being carried out as planned, although the installation of the equipment has been delayed due to the change for procurement and development from Hitachi to Nagoya University.
- The contents of the Training in Japan under the Project were effective for improving the skills and techniques of the DUT, ARC, and EWS researchers and engineers.

1-3-2. Efficiency of Inputs from the South African Side

- A sufficient number of DUT, ARC, and EWS researchers and engineers was assigned as counterparts for the Project. Since no counterparts were changed, the joint research and technology transfer under the Project have been conducted smoothly and effectively.
- The facilities and equipment provided by the South African side were more than appropriate in terms of the quality and quantity and entailed a better

prospect for sustained research activities after the project completion.

1-3-3. Achievement of Outputs

- Most activities described in the PDM have been implemented as planned.
- In addition, most indicators from Outputs 1 to 5 are expected to be achieved by the time of completion of the Project.
- However, the capacities of the extraction and agrimat production units are smaller than originally envisaged due to budgetary constraints.

1-3-4. Fulfilment of the Important Assumption to achieve the Output

[Important Assumption]
<u>The government policy for development of bio fuel from algae does not change</u>.
The important assumption is fulfilled.

- On 18 October 2019, the South African government published its Integrated Resource Plan, which sets out the country's energy policy up to 2030. diesel 8.1%, pumped storage 6.4%, nuclear 2.4% and others 0.5%. The current mainstream coal-fired power stations will be with a shift to renewable energy.

1-4. Impact

It is too early to assess the prospect of Overall Goal achievement.

1-4-1. Prospect of Overall Goal achievement

- At the end of the project, a drastic improvement in the energy balance to make algal fuel and the production of agri-mats was achieved through the cultivation of microalgae in secondary treated sewage water and the extraction of lipids without drying.
- This technology overcomes some of the technical challenges of the past, but the throughput of the whole system is still small. However, as the energy balance, which was the main problem, has been improved, it is certain that the project will have a direct impact if the throughput of all systems is increased.

1-4-2. Other impact of the Project

- The technology of Output 1 has potential for use in the field of cultivation of microalgae using treated sewage water as a raw material.
- Technology of Output 2 include the development of thermodynamic models to describe extraction phenomena and the evaluation of DME toxicity, and have the potential to be used in extraction technologies for objects other than microalgae using DME.
- The technology of Output 3 could be developed from other biogenic solids than bagasse, such as wood or sewage sludge.
- For Output 4, the detailed design of the extraction equipment has been provided to the South African side, and there is potential for the South African side to develop their own larger extraction equipment.
- Output 5 provides the South African side with a business model using

microalgae, and there is a possibility that the South African side will be able to establish its own environmental business.

1-5. Sustainability

The sustainability of the Project is assessed as relatively high in terms of policy, finance, organization and technique as follows:

1-5-1. Policy Aspects

- The South African government's response to climate change to date has been the National Climate Change Response Policy (NCCRP), which in 2011 set out the government's targets for responding to climate change by 2050. The following year, the National Development Plan (NDP) was formulated in 2012, with a chapter on the environment and sustainability, and the slogan "A fair transition to a low carbon economy". It sets out targets for reducing emissions and moving away from fossil fuels and towards renewable energy. Based on the above trends, the the aforementioned action plan to combat climate change up to 2050, was formulated as a concrete response to the Paris Agreement.
- The first concrete measure introduced by the government was the Carbon Tax Act 2019. The first phase of the tax, covering the period 2019 to the end of 2022, is currently underway and sets out tax-free emission allowances for each industry and economic activity. In addition, the Climate Change Bill is currently under discussion. The bill is in the final adjustment stage. If passed, it is expected to impose quantitative targets for emission reductions by industrial sector and allocate the national budget required to achieve them.

1-5-2. Financial Aspects

- To date, the DUT has been very active, publishing many papers, and has many employed researchers, which funds the operation of the laboratory.
- The DUT will continue to budget appropriately for the instruments and analytical equipment acquired through this project, including the operation and maintenance of the laboratory and equipment.

1-5-3. Organizational Aspects

- TUAT, which is involved in this project, has shown a strong interest in collaborating with ARC. Therefore, the production of agri-mats for the project can be continued in collaboration with these institutions.
- Nagoya University is in discussions with Japanese companies to collaborate on the development of an even larger extraction device after the end of the project, and is willing to return the results to South Africa if financial and human constraints can be overcome.

1-5-4. Technical Aspects

The major technical problem so far has been the negative energy balance due to the drying pre-treatment involved. The technology of this project, which solves this problem, is essential for the sustainability of the technology, and the fact that it is the first in the world to achieve this is a great strength, as it means that future funding and partnerships can be found more robustly.

1-6. Conclusions

- The summary of the review results 5 criteria is as follows.

	Evaluation result	Remarks
Relevance	High	● The Project is consistent with the relevant policies of South Africa and Japan, and with the needs of the society and target group.
Effectiveness	Relatively high	● Most of the researches have been conducted as planned to achieve the Project purpose, and the benchmark indicator of the Project Purpose was met.
Efficiency	Relatively high	● The inputs from the South African and Japanese sides are appropriate. ● Most activities are being carried out according to plan, although there are delays in the installation of some equipment and shortfalls in processing capacity due to budget constraints.
Impact	Too early to assess	● At the completion of the project, the biggest problem - the energy balance - has been overcome, but the scale of the system is still small compared to the size of the energy industry. ● However, the basic methodology has been clarified in the project and detailed design drawings of the equipment have been provided to the South African side, and it is expected that the system can be scaled up to produce biofuels successfully. ● The competitiveness of the biofuels may affect the impact of the project.
Sustainability	High	● In terms of policy, financial, organizational and technical aspects, sustainability is high.

2. Key Factors Affecting Implementation and Outcomes

- With the convergence of COVID-19, it is hoped that additional data will be available once agricultural trials with ARC are in full swing.
- DUT can secure funds to enable the operation of the laboratory in

terms of supplies, consumables, maintenance and repair.

3. Evaluation on the results of the Project Risk Management

- Due to the COVID-19pandemic, reciprocal travel between Japan and South Africa is no longer possible. As a result, the operation of the equipment by Nagoya University, which was to be carried out in South Africa, is no longer possible. Therefore, the operation of the device was continued by remote instructions from Japan using remote technology.
- The installation and commissioning of the laboratory with the donated equipment required a strong leadership of Nagoya University naturally. And the running of the equipment is now in the hands of the DUT and ARC.

4. Lessons Learnt

- As this project is a combination of different technologies, from cultivation to lipid extraction to fertilizer board (Agrimat) production, both the Japanese and South African teams have learnt the importance of bringing their different expertise to work together, which has resulted in synergies that have enabled the research to progress and produce excellent results.
- Through the implementation of this project, the two teams have been able to develop their research and technical capabilities, and deepen their knowledge of algae cultivation, post-treatment and agricultural applications.

IV. For the Achievement of Overall Goals after the Project Completion

1. Prospects to achieve Overall Goal

Overall Goal

Biofuel from microalgae is produced through the application of technology and determining its commercial viability.

Verification Indicators	Degree of Achievement and Status

Amount of biofuel production using the technology under the Project.	・Regarding “Indicator 1”, field test equipment for harvesting, extraction, and Agrimat were installed in the Kingsburgh WWTW in 2019. Due to project budget constraints, the extraction equipment and the Agrimat equipment have a smaller throughput than originally expected from the South African side. However, a detailed blueprint of the device has been disclosed to the South African side, and it is possible to build a larger device in the future. ・This indicator will be evaluated several years after the completion of this Project.

The Project team tried to meet the indicators.

- On the Japanese side, further major projects are currently being discussed with a number of Japanese companies.
- The negative impact of COVID-19 on the project, which was extremely critical for the project because of the lack of reciprocal travel between Japan and South Africa due to COVID-19, was minimized by the use of remote technology for the operation of the extraction equipment and the alternative implementation of some field tests on AgriMat in Japan.
- If a further major project is adopted based on the technology developed in this project, this verification indicator will be met and the project will achieve the set objectives.

2. Plan of Operation and Implementation Structure of the South African side to achieve Overall Goal

The SATREPS team at DUT will be working closely with educational, research and development institutions within and outside DUT on operational and organisational plans. Currently, research in the field of energy, especially renewable energy, is one of the focal points of the research agenda at DUT and in South Africa. Future research on microalgae-based energy sources at DUT will be supported by the excellent laboratory facilities, their detailed design drawings and excellent human resources provided by JICA as a result of the JICA/JST SATREPS project. In addition, DUT has the potential to become one of the centres of excellence at national and continental level. This mission will certainly be successful if DUT continues to develop its collaboration with the Government, the eThekwini Autonomous Community and other institutions.

3. Recommendations for the South African side

1. The current 300ton pond at Kingsburgh is one of large for research purposes and can produce about 10kg of lipids per day. However, typical thermal power

station in Japan consumes 8,000 tonnes of coal per day to produce 1,000,000 kW (= enough electricity for 800,000 people). Assuming that the calorific value of coal and lipids are equivalent, 10kg of lipids is only enough energy for one person. In other words, the pond, the recovery unit and the extraction unit are still small. However, now that we have achieved the biggest challenge of all - a positive energy balance - we need to move on to larger equipment.

2. To continue the research collaboration with Japanese side using different research schemes and funding.

3. To promote the results to South African government departments for use in the development of a larger plan.

4. To promote use of the research facilities developed under this Project for other research projects.

4. Monitoring Plan from the end of the Project to Ex-post Evaluation

Not applicable.

(If the Project will be continuously monitored by JICA after the completion of the Project, mention the plan of post-monitoring here.)

ANNEX 1: List of Japanese Experts Dispatched to the Project

ANNEX 2: List of Counterpart Training Implemented in Japan

ANNEX 3: List of Equipment Provided by JICA

ANNEX 4: List of Products (Journal articles, Handbooks, etc.) Produced by the Project

ANNEX 5: PDM (All versions of PDM)

ANNEX 6: R/D, M/M, Minutes of JCC (copy) (*)

ANNEX 7: Monitoring Sheet (copy) (*)

(Remarks: ANNEX 6 and 7 are internal references only.)

Annex1

List of Japanese Experts Dispatched to the Project

1. Short-term Expert

As of November, 2021

	Name	Research Subject / Title	Institution / Organization	Tenure		
				From	To	Days
1	Assist. Prof. Hideki Kanda	Chief Adviser, Extraction and Development of equipment / Leader	Nagoya University	31-Aug-16	9-Sep-16	10
				3-Oct-17	8-Oct-17	6
				7-Nov-17	12-Nov-17	6
				2-Oct-18	7-Oct-18	6
				27-Oct-18	4-Nov-18	9
				16-Feb-19	22-Feb-19	7
				15-Apr-19	21-Apr-19	7
				7-May-19	19-May-19	13
				8-Jun-19	23-Jun-19	16
				10-Aug-19	25-Aug-19	16
				7-Sep-19	22-Sep-19	16
				19-Oct-19	3-Nov-19	16
				16-Nov-19	1-Dec-20	16
				8-Dec-20	15-Dec-20	8
				3-Feb-20	9-Feb-20	7
				15-Feb-20	23-Feb-20	9
2	Prof. Shoko Yamada	Human Capacity Development	Nagoya University	31-Aug-16	9-Sep-16	10
				12-Dec-16	18-Dec-16	7
3	Assoc. Prof. Satoshi Watanabe	Environment business model	Aichi Shukutoku University	31-Aug-16	9-Sep-16	10
				3-Oct-17	8-Oct-17	6
				7-Nov-17	12-Nov-17	6
				27-Oct-18	4-Nov-18	9
				16-Sep-19	22-Sep-19	7
				26-Oct-19	1-Nov-19	7
4	Assoc. Prof. Siaw Onwona Agyeman	Agrimat	Tokyo University of Agriculture and Technology	31-Aug-16	09-Sep-16	10
				06-Nov-17	12-Nov-17	7
				27-Oct-18	4-Nov-18	9
				16-Feb-19	21-Feb-19	6
				30-Apr-19	8-May-19	9
				22-Sep-19	27-Sep-19	6
				27-Oct-19	01-Nov-19	6
5	Dr.Hideo Watanabe	Cultivation/ Research Fellow	University of Tsukuba	31-Aug-16	09-Sep-16	10
6	Prof. Makoto Nishimura	Environment business model	Tokaigakuen University	31-Aug-16	09-Sep-16	10
7	Dr. Akira Mochizuki	Development of equipment	Hitachi	31-Aug-16	09-Sep-16	10
8	Dr. Mutsvangwa Simba	Human Capacity Development/ Research Fellow	Nagoya University	11-Mar-17	26-Mar-17	16

9	Dr. Zheng Qingxin	Extraction and Development of equipment	Nagoya University	4-Mar-18	9-Mar-18	6
				2-Oct-18	7-Oct-18	6
				27-Oct-18	4-Nov-18	9
				16-Feb-19	22-Feb-19	7
				7-May-19	26-May-19	20
10	Ms. Mai Takikawa	Extraction and Development of equipment	Nagoya University	10-Aug-19	25-Aug-19	16
				7-Sep-19	22-Sep-19	16
				19-Oct-19	1-Dec-19	44
11	Mr. Masashi Yoshizumi	Extraction and Development of equipment	Nagoya University	3-Feb-20	13-Mar-20	40
						493

2. Long-term Expert

Name		Research Subject / Title	Institution / Organization	Tenure		
				From	To	Days
1	Mr. Ryosuke Iwasa	Project Coordinator		01-Nov-16	31-Mar-20	1247
2	Mr. Masaru Iizuka	Project Coordinator		17-Aug-21	29-Mar-22	225

Annex2

List of Counterpart Training Implemented in Japan

As of November, 2021

<Achievement>

1. Coordination Meeting for 10 days from February 17 to February 26, 2017

	Name	Title	Institution / Organization
1	Prof. Faizal Bux	Project Manager/Leader	IWWT, DUT
2	Mr. Ismail Rawat	Researcher	IWWT, DUT
3	Mr. Speedy Moodliar	Senior Manager (Planning)	EWS, eThekwini Municipality
4	Mr. Titus Kasie	Mechanical Engineer	EWS, eThekwini Municipality
5	Dr. Adornis Nciizah	Researcher	ARC-ISCW

2. Coordination Meeting for 9 days from May 6 to May 14, 2018

	Name of Candidate	Title	Institution / Organization
1	Prof. Faizal Bux	Project Manager/Leader	IWWT, DUT
2	Mr. Ismail Rawat	Researcher	IWWT, DUT
3	Mr. Speedy Moodliar	Senior Manager (Planning)	EWS, eThekwini Municipality
4	Mr. Titus Kasie	Mechanical Engineer	EWS, eThekwini Municipality
5	Dr. Adornis Nciizah	Researcher	ARC-ISCW

3. Training in operation of Agri-mat press machine for 8 days from November 10 to November 17, 2018

	Name of Candidate	Title	Institution / Organization
5	Dr. Adornis Nciizah	Researcher	ARC-ISCW
6	Dr. Khumbulani Dhavu	Senior Researcher	ARC-IAE

4. Training in operation of Extraction Equipment for 9 days from January 19 to January 27, 2019

	Name of Candidate	Title	Institution / Organization
2	Mr. Ismail Rawat	Researcher	IWWT, DUT
7	Mr. Kriveshan Pillay	Technician	IWWT, DUT

5. Coordination Meeting for 9 days from October 5 to October 13, 2019 (Extended up to 18 October due to Typhoon)

	Name of Candidate	Title	Institution / Organization
1	Prof. Faizal Bux	Project Manager/Leader	IWWT, DUT
2	Mr. Ismail Rawat	Researcher	IWWT, DUT
3	Mr. Speedy Moodliar	Senior Manager (Planning)	EWS, eThekwini Municipality
4	Mr. Titus Kasie	Mechanical Engineer	EWS, eThekwini Municipality
5	Dr. Adornis Nciizah	Researcher	ARC-ISCW

6. Training in Agrimat Production including Study on Agrimait Use for 14 days from February 10 to February 23, 2020

	Name of Candidate	Title	Institution / Organization
8	Mr. Sibongiseni Mgolozeli	Researcher	ARC-ISCW

Annex3

List of Equipment Provided by JICA

As of Febrauary, 2021

1. Equipment Procured in South Africa by Nagoya University (with financial support of JICA)

A. Provided for DUT **-Achievement-**

Installation Date		Name of Equipment	Maker / Model	Quantity	Location
1	Mar. 2017	YSI multi-parameter system including chlorophyll sensor	YSI Incorporated/ EXO-1 599501-00, 599810, 599870-01, 599701, 599103-01, 599100-01	1	Laboratory, IWWT- DUT
2	Jun. 2017	Soxhlet extractor	Labotech ltd/ Extraction unit E-816 Soxhlet	1	Laboratory, IWWT- DUT
3	Mar. 2017	Industrial Grinder	Waring / Blender 2.0Litre HGB55E	1	Laboratory, IWWT- DUT
4	Mar. 2017	Jar test apparatus	Lovibond Water Testing/ ET750 LABORATORY FLOC TESTER WITH 6 STIRRING UNITS	1	Laboratory, IWWT- DUT
5	Mar. 2017	Double beam spectrophotometer	Huck/ DR 6000 UV VIS SPECTROPHOTOMETER W RFID	1	Laboratory, IWWT- DUT
6	Mar. 2017	Sonicator	Cole-Parmer/ ULTRASONIC BATH B8510E-DTH DIG TIMER, HEATER,DEGAS, 20L WIRE MESH BASKET S; STEEL FOR ULTRASONIC BATH MDL 8510/8800	1	Laboratory, IWWT- DUT
7	Jun. 2017	Industrial microwave digester	Milestone S.r.l. / ETHOS EASY Advanced Microwave Digestion System	1	Laboratory, IWWT- DUT
			Total Value: R. 1,553,948/-		

2. Equipment Procured in Japan or Third Country by Nagoya University (with financial support of JICA)

A. Provided for DUT**- Achievement -**

Installation Date		Name of Equipment	Maker / Model	Quantity	Location
1	May. 2019	Test Equipment for harvesting technology	Tomoe Engineering/ decanter BDN 034	1	Kingsburg WWTW
2	Jun. 2019	Test Equipment for extraction technology	TOYO KOATSU Co.,Ltd/ Custom-made equipment Includes incidental consumables	1	Kingsburg WWTW
3	May. 2019	Agrimat fabrication machine	Imoto Machinery Co., Ltd./ Customized IMC-1A46-A	1	Laboratory, IWWT- DUT
			Total Value: JPY 152,866,341/-		

B. Provided for ARC **- Achievement -**

Installation Date		Name of Equipment	Maker / Model	Quantity	Location
1	Jun. 2017	Rainfall simulator and pump set	Techonocore/ TCC-1X5-SGS-YS; TCC-SPY-FK-V100	1	ARC
2	Jun. 2017	Soil moisture thermometer	Environmental Measurement Japan, CO., LTD./ Soil Moisture Sensors 5TE	12	ARC
3	Jun. 2017	Soil oxygen meter	Environmental Measurement Japan, CO., LTD./ Soil O2 Sensor MIJ-03	3	ARC
4	Jun. 2017	Handy moisture meter	Environmental Measurement Japan, CO., LTD./ HydroSense II Water Content Sensor with 20cm Rods	1	ARC
5	Jun. 2017	Data logger	Environmental Measurement Japan, CO., LTD./ Digital data logger Em50	3	ARC
			Total Value: 1,791,072 yen		

C. Provided for DUT **- Plan -**

Installation Date		Name of Equipment	Maker / Model	Quantity	Location
1	Feb. 2022	Agrimat fabrication machine	Techono Core Co., Ltd./ TCC-PSS-0	1	Laboratory, IWWT- DUT
			Total Value: 9,179,500 yen		

Annex4

List of Products (Report, Manuals, Handbooks, etc.) Produced by the Project

Original paper

Japanese fiscal year	Name of author, title of article, name of journal, year of publication, volume number, issue number, beginning and end pages	DOI	Domestic / International Journal	Remarks
2016	R. A. Omari, H. P. Aung, M. Hou, T. Yokoyama, S. Onwona-Agyeman, Y. Oikawa, Y. Fujii, and S. D. Bellingrath-Kimura "Influence of Different Plant Materials in Combination with Chicken Manure on Soil Carbon and Nitrogen"Pedosphere, 26, 4, pp.510-521	10.1016/S1002-0160(15)60061-3	International	
2017	T. Tokumaru, H. Okazaki, S. Onwona-Agyeman, J. Ofosu-Anim, and I. Watanabe "Determination of Trace Metals in Soils, Sediments, and Human Hair at e-Waste Recycling Site in Ghana" Arch Environ Contam Toxicol. 73,3, pp.377-390	10.1007/s00244-017-0434-5	International	
2017	Guldhe, A., Kumari, S., Ramanna, L., Ramsundar, P., Singh, P., Rawat, I. and Bux, F., Prospects recent advancements and challenges different wastewater streams for microalgal cultivation. Journal of Environmental Management. 203, 299-315 (2017)	10.1016/j.jenvman.2017.08.012	International	Scimago Journal & Country Rank Q1
2018	S. Machmudah, Wahyudiono, H. Kanda, M. Goto, Supercritical Fluids Extraction of Valuable Compounds from Algae, Engineering Journal, 22(5) 13-30, (2018)	10.4186/ej.2018.22.5.13	International	
2018	Ansari, F. A., Gupta, S. K., Nasr, M., Rawat, I. & Bux, F. Evaluation of various cell drying and disruption techniques for sustainable metabolic extractions from microalgae grown in wastewater: A multivariate approach. Journal of Cleaner Production, 182, 634-643.(2018)	10.1016/j.jclepro.2018.02.098	International	Scimago Journal & Country Rank Q1
2018	Gupta, S. K., Kumar, N. M., Guldhe, A., Ansari, F. A., Rawat, I., Nasr, M. & Bux, F. Wastewater to biofuels: Comprehensive evaluation of various flocculants on biochemical composition and yield of microalgae, Ecological Engineering 117, 62-68. (2018).	10.1016/j.ecoleng.2018.04.005	International	Scimago Journal & Country Rank Q1
2019	H. Kanda, R. Hoshino, K. Murakami, Wahyudiono, Q. Zheng, M. Goto, Lipid extraction from microalgae covered with biomineralized cell walls using liquefied dimethyl ether, Fuel 262, 116590 (p8) (2020).	0.1016/j.fuel.2019.116590	International	Scopus percentile above 90
2019	C. JIRARATCHWARO, Y. Suzuki, N. Saho, Siaw Onwona-Agyeman, Hirozumi Watanabe "Development of Mini Portable Pressure Head Type Rainfall Simulator for Investigating Runoff, Infiltration and Sediment Discharge"The Japanese Society of Irrigation, Drainage and Rural Engineering. 87, 2, pp.297-302	10.11408/jsidre.87.I_297	Domestiic	
2019	Sota Oshima, Siaw Onwona-Agyeman, Norihide Saho, Kwame Sarpong Appiah, Yoshiharu Fujii,"Development and Evaluation of Mulching Boards Fabricated from Bagasse",The Materials Research Society of Japan,2020.02,451,pp.9-13	10.14723/tmrsj.45.9	Domestiic	
2020	Ansari, FA., Nasr, M., Rawat, I. and Bux, F. Artificial neural network and techno-economic estimation with algae-based tertiary wastewater treatment. Journal of Water Process Engineering, 40, 101761, 2020	10.1016/j.jwpe.2020.101761	International	Scimago Journal & Country Rank Q1
2020	Siti Machmudah, Dimas Tiar Wicaksono, Mary Happy, Sugeng Winardi, Wahyudiono, Hideki Kanda, Motonobu Goto, Water Removal from Wood Biomass by Liquefied Dimethyl Ether for Enhancing Heating Value, Energy Reports, 6, 824-831, 2020	10.1016/j.egyr.2020.04.006	International	Scimago Journal & Country Rank Q1. Wood was found to be inert to DME. Based on this knowledge, a method of mixing algae and bagasse was devised.
2020	Hideki Kanda, Tsubasa Katsube, Rintaro Hoshino, Mitsuhiro Kishino, Wahyudiono, Motonobu Goto, Ethanol-free antisolvent crystallization of glycine by liquefied dimethyl ether, Heliyon, 6, e05258	10.1016/j.heliyon.2020.e05258	International	Scimago Journal & Country Rank Q1. The content reinforces the fact that the amino acids that make up the microalgae are insoluble in DME and remain in the residue.
2020	Hideki Kanda, Wahyudiono, Siti Machmudah, Motonobu Goto, Direct extraction of lutein from wet algae by liquefied dimethyl ether without any pretreatment, ACS Omega, 5, 24005-24010	10.1021/acsomega.0c03358	International	Scimago Journal & Country Rank Q1. Extraction of the carotenoid contained in algae.
2020	Akwasi Dwira Mensah et al., S. Onwona-Agyeman, Influence of Soil Characteristics and Land Use Type on Existing Fractions of Radioactive 137Cs in Fukushima Soils, Environments, 2020, 7, no.16	10.3390/environments7020016	International	
2020	Sibongiseni Mgolozeli, Adornis D. N. et al., Innovative Pro-Smallholder Farmers' Permanent Mulch for Better Soil Quality and Food Security Under Conservation Agriculture, Agronomy 2020, 10(4), no. 605	10.3390/agronomy10040605	International	Scimago Journal & Country Rank Q1
2020	Adam Yakubu et al., S. Onwona-Agyeman、Impact of Sugarcane Bagasse Mulching Boards on Soil Erosion and Carrot Productivity, Catena, in press, 2021		International	Scimago Journal & Country Rank Q1
2021	Hideki Kanda et al., Surfactant-free decellularisation of porcine aortic tissue by subcritical dimethyl ether, ACS Omega, 6, 13417 – 13425, 2021	10.1021/acsomega.1c01549	International	Scimago Journal & Country Rank Q1. The section on the biotoxicity of DME in the supplementary information of this paper is relevant.
2021	Hideki Kanda et al., Molecular dynamics simulation and thermodynamic model of triple point of Lennard-Jones fluid in cylindrical nanopores, Chemical Engineering Science, 244, 116829, 2021	10.1016/j.ces.2021.116829	International	Scopus percentile above 90. The results correspond to the single-component results obtained during the program development phase of the extraction simulation in research output 2.
2021	Hideki Kanda et al., Molecular Dynamics Simulation of Tolman Length and Interfacial Tension of Symmetric Binary Lennard-Jones Liquid, Symmetry, 13, 1376, 2021	10.3390/sym13081376	International	Scopus percentile above 90. This corresponds to the results of the verification of the bulk properties of the two-component fluid carried out in the extraction simulation in output 2.
2021	S. Takahashi, J. Che, N. Horiuchi, H. Y. Cho, S. Onwona-Agyeman, K. Kojima, M. Yamada, and I. Ogiwara "Production of Low-potassium Fruit of Potted and Fertigated Southern Highbush Blueberry (Vaccinium corymbosum L. interspecific hybrid)" 90,2,pp.161-171	10.2503/hortj.UTD-238	Domestiic	
2021	A. Yakubu, E. B. Sabi, S. Onwona-Agyeman, H.Takada, and H. Watanabe "Impact of sugarcane bagasse mulching boards on soil erosion and carrot productivity" CATENA 26, pp.1-9	10.1016/j.catena.2021.105575	International	Scimago Journal & Country Rank Q1

2021	T. Ohgaki et al and S. Onwona-Agyeman "International pellet watch: Global monitoring of polybrominated diphenyl ethers (PBDEs) in plastic resin pellets" Environmental Monitoring and Contaminants Research 1, pp.75-90	10.5985/emcr.20210002	International	
2021	Hideki Kanda et al., Molecular dynamics simulation and thermodynamic model of solid-vapor equilibrium of Lennard-Jones fluid in cylindrical nanopores, in press, 117116, 2021	10.1016/j.ces.2021.117116	International	Scopus percentile above 90. The results correspond to the single-component results obtained during the program development phase of the extraction simulation in research output 2.
2021	Hideki Kanda et al., Thermodynamic model of extraction equilibrium in cylindrical nanopores validated with molecular dynamics simulation, in press, 117115, 2021	10.1016/j.ces.2021.117115	International	Scopus percentile above 90. This corresponds to the results of the verification of the bulk properties of the two-component fluid carried out in the extraction simulation in output 2.
		Total	22	

Other publications (co-authored with the other country's research team) (e.g. review articles, books)

Japanese fiscal year	Name of author, title of article, name of journal, year of publication, volume number, issue number, beginning and end pages			Remarks
2017	M.Nishimura,S.Watanabe,H.Kanda,M.Yoshida,S.O.Agyeman、S.Yamada"Handbook 1 of SATREPS Project(Original Ver.)"、44pages、pages、2017年2月			
2017	M.Nishimura,S.Watanabe,H.Kanda,M.Yoshida,S.O.Agyeman、S.Yamada、I.Rawat、A.D.Nciizah、T.C.Kasie、"Handbook 1 of SATREPS Project(Revised Ver.)"、64pages、2017年9月			
		Total	2	

Project Monitoring Sheet I （Revision of Project Design Matrix）

Project Title: Production of biofuels using algal biomass

Implementing Agency: Durban University of Technology (DUT), Agriculture Research Council (ARC), eThekwini Municipality, Technology Innovation Agency (TIA)

Version 6

Date 18 November 2021

Target Group: Durban University of Technology

Period of Project: Six (6) years until the 29th of March 2022.

Project Site: Waste water treatment site operated by eThekwini municipality in Durban

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Important Assumption	Achievement	Remarks
Overall Goal					
Biofuel from microalgae is produced through the application of technology and determining its commercial viability.	Amount of biofuel production using the technology under the Project	Annual reports on field tests on biofuel production			
Project Purpose					
A cost effective process technology and preliminary business model for the production of biofuels from microalgae is developed.	1. To supply field test equipment and status of the practical operation for biofuel and agricultural bi-products. 2. Patents/Intellectual property development of Bio fuel production and agrimats production 3. To supply handbooks for environment education 4. Joint publication in ISI journals articles	- Operation status of the test equipment - Project report - -Handbooks developed during the project - To publish in International journals	The government policy for development of bio fuel from algae does not change.		
Outputs					
Output 1: Development of high biomass production system using open raceway pond	1.1 Field test of algae culture using media 1.2 Field test of algae culture using wastewater 1.3 Evaluation of cheap nutrient substrates 1.4 Optimization of biomass and lipid yields	Joint publications Project Reports		Biomass productivity decreases during prolonged cultivation and is affected strongly be light intensity, pH and depth. Biomass productivity was higher for the first 7 to 10 days of cultivation. Intermittent harvesting (weekly) is being optimised for higher productivity. Lipid content in week 3 of cultivation was higher than weeks 1 and 2 reaching above 25% lipid with intemittent harvesting. Adaptive Neuro-Fuzzy Inference System (ANFIS) modelling of the system showed that maximum biomass productivity was achieved at depths between 20 and 22 cm at light intensities between 200 and 400 µmol/m2/s and pH in the range of 9 to 9.5.	
Output 2： Development of effective biofuel extraction technology	2.1 To make extraction mechanism clear for the selected endemic algae species in South Africa or similar algae species - Evaluation of extracted the lipid amounts. - Evaluation of CHNO amounts in the lipids, residues and microalgae. - Evaluation of HHV of the lipids, residues and microalgae. - Evaluation of fatty acid components in the lipids. - Evaluation of molecular weight distributions of the lipids	Project reports - Researchers present at international conferences	The field test site is managed appropriately.	Some mechanism of lipid extraction by liquefied DME was clarified. Water dissolved in liquefied DME is effective to extract polar glycolipid and phospholipids from WET microalgae. It was confirmed by bioassay that there was no biotoxicity of water in which DME was dissolved. $CaSO_4$ and $CaCO_3$ were found to act as catalysts to promote methyl esterification by supercritical methanol. Thermodynamic equation describing the extraction equilibrium was derived and its validity was confirmed by molecular dynamics.	

Output 3：A cost effective technology and preliminary business model for the production of agricultural bi-products is developed from waste.	3.1 Results of component analysis of algae residual after extraction of lipid and sludge. 3.2 Survey on the availability of algae residue, sludge and unutilized woody biomass 3.3 Evaluation of the technology to produce the agri mats under suitable South African environment 3.4 Fabrication of different agri mats from different combinations of algae residue, sludge and unutilized woody biomass. 3.5 Field test are conducted to select the most suitable agri mat for South African agriculture 3.6 A preliminary Agri-business model based on agri mat concept is proposed for local companies	Project reports - Researchers present at international conferences	Regulation and law related to the test field site do not change.	Possibility of fabricating agri-mats without using any adhesives was explored. The Hot-press and MgO based types of test equipment were developed to fabricate agri-mats of various densities. These two machines are ready for shippment to South Africa. The two agrimat fabricating machines (hot and cold press) were installed at the ARC- Agricultural Engineering in May 2019. Several types of agrimats with various compositions have since been fabricated. The agrimats are currently undergoing various physical laboratory tests. Preliminary findings suggest that heatpressing 100% bagasse/MgO produces agrimats with superior physical properties than other biomass and binding agents. The first batch of algal residue was delivered to the ARC in August 2019. The most suitable mixing ratios of algal residue and bagasse are being explored. Studies on surface water flow, permeability characteristics, and the nutrient release patterns of agri-mats were done. The team in Japan has succeeded in significantly shortening the drying of agri-mats produced at room temperature from about 6 days to 40 minutes. This was made possible by the incorporation of a newly produced fertilizer (by a Japanese company) which accelerates the binding process of the mats. Laboratory experiments to determine the physical properties (tensile strength, water absorption, thickness swelling) of agrimats were successfully carried out. We also carried out laboratory studies to determine the composition of agrimat leachate to ascertain any potential toxicities to crop. Currently, a glasshouse experiment to evaluate the performance of agrimats with various compositions (bagasse, bagasse/alage mixure, bagasse/cattle manure/, bagasse/grass) is in progress. Field work is in progress in Japan.	Fabrication of agrimats was interrupted by COVID19 restriction. We will carry out a one season field experiment in a smallholder farming area in Limpopo to study the performance of the agrimats under field conditions in addition to the glasshouse experiment.
Output 4：・ Development of test equipment of extraction technology	4.1 To conduct a survey to use solar energy in South Africa and conduct design of test equipment for extraction technology based on regulations in South Africa. 4.2 To produce the test equipment for extraction technology. 4.3 Testing and operation at the site and the training on the test equipment for extraction technology complying with the EWS standards.	Project reports - Survey reports - Training modules Handbooks Report on quality of effluent to be submitted to EWS engineer frequency to be determined by the stakeholders.	To conduct the Training of staff and students from DUT and eThekwini municipality.	4.1 Harvesting equipment made by Tomoe Eng. was installed in the Kingsburgh WWTW in May 2019. 4.2 Energy consumption of harvesting equipment was estimated to be 33.8% of higher heating value of microalgae lipid. 4.3 Design was complete. 4.4 Extraction equipment assembled by ToyoKoatsu was installed in the Kingsburgh WWTW in June 2019. During the research operation, revision of the exteraction equipment was done to improve the practical usability of the system. 4.5 Energy consumption by the extraction equipment was examined in more detail, and it was found to be 19.8% of higher heating value of microalgae lipid at present and 16.2% when the equipment is enlarged. Mixing of algae and cellulose biomass is effective to decrease extraction resistance due to algae viscosity. For the new problem that the apparent filling volume is reduced to 1/3 due to the excluded volume of the mixed bagasse, we found that the apparent filling volume can be increased to 2/3 by using cellulose spheres. Although there was a period of interruption during the project due to COVID-19, the Japanese staff completed the preparation of the residue for the laboratory evaluation test of AgriMat. 4.6 Training of harvesting equipment was done in May 2019 in Kingsburgh WWTW. Training of extraction equipment was started in January 2019 in Hiroshima, Japan, and was done in June, August, September, and October 2019 in Kingsburgh. Until the end of SATREPS, driving proficiency training will be provided from the Japanese side to the South African side.	Because of COVID-19, we will be remotely instructing local Nagoya University staff to respond from Japan.

Output 5: Foundation of human capacity development and business model of the Project is established.	5.1 Survey of existing regulations regarding environmental protection and energy saving in South Africa. 5.2 Production of handbooks including example of Japanese success model for environment recovery and the training of the South African stakeholders 5.3 To formulate standard oparating procedure(SOP) for harvesting and extraction and train personnel of eThekwini Municipality and DUT. 5.4 To establish sustainable project related capacity development system in eThekwini Municipality. 5.5 Exchange of students and researchers for short term training and workshops 5.6 Road map for the commercialization including PPP in eThekwini Municipality.	Survey report Conference presentations Project reports		5.1 Survey the previous studies and the public reports regarding to South Africa such as DST (2014) reports, and case studies of Japan in 1960s-70s regarding to the experiences of environmental pollution and their overcoming with foundation of the environmental business model. We conducted to study previous survey and case of business model regarding biofuel production. 5.2 Creation the handbook for understanding the roles of our research activities and the importance of the environmental business. Until the end of SATREPS,revised handbook which is summarized the research output will be provided from the Japanese side to the South African side. 5.3 Oparating manual for harvesting and extraction were completed. 5.4 In accordance with the manuals, training of harvesting and extraction equipment were in progress in Kingsburgh WWTW. 5.5 At least 10 South African young researchers (man-days are over 100days) have been trained in South Africa, and at least three of them have been able to operate the equipment without the help of the Japanese side. Japanese researchers, engineers and students visited South Africa for installation and training (man-days are over 300days). Until the end of SATREPS, driving proficiency training will be provided from the Japanese side to the South African side. 5.6 Survey the previous literatures about PPP and the economic researches	

Activities	Inputs		Pre-Conditions
	The Japanese Side	The South African Side	
1-1 To conduct field test of algae culture using media 1-2 To conduct field test of algae culture using wastewater 1-3 To evaluate cheap nutrient substrates for algae cultivation 1-4 To optimize biomass and lipid production yields	【Dispatch of experts】 ◆ Chief Advisor ◆ Project Coordinator ◆ Other experts (Biofuel Extraction Technology, Biomass mat using algae residue, sludge and wood tips production technology, Water treatment technology, Solar energy utilization technology, Environment business and human resources development and related fields) 【Supply equipment】 ◆ Test equipment for harvesting technology for use of researchers and students of DUT ◆ Test equipment for extraction technology for use of researchers and students of DUT 【Other expenditure】 ◆ Costs of business trip pf the experts from Japan ◆ Operation cost of the Project ◆ Cost of business trip of the experts in Japan ◆ Training cost of invitation of researchers, officials and students in Japan	【Human resources】 ◆ Researchers and Students to conduct a field test using harvesting and extraction technology Project Manager (DUT) 4 Senior Researchers (DUT) Post Graduate Students (DUT) 3 Senior Researchers(ARC) Technical assistants Senior researchers and officers of EWS 【Facility and Equipment】 ◆ A field test site ◆ Laboratory space ◆ Water supply, electricity, air conditioner ◆ Supply of consumables for the field test (DUT) 【Other expenditure】 ◆ Operation cost for the South African stakeholders, facility including water quality tests, etc. ◆ Internet and print facilities	
2-1 To make extraction mechanism clear for Selected endemic micro algal strain in South Africa - To evaluate extracted the lipid amounts. - To evaluate CHNO amounts in the lipids, residues and microalgae. - To evaluate HHV of the lipids, residues and microalgae. - To evaluate fatty acid components in the lipids. - To evaluate molecular weight distributions of the lipids			
3-1 To analyze chemical constituents of algae residue and sludge. 3-2 To conduct survey on the availability of algae residue, sludge and unutilized woody biomass. 3-3 To evaluate technology t oproduce the agrimats under suitable South African environment. 3-4 To fabricate different agri mats from different combinations of algae residue, sludge, and woody biomass waste 3-5 To conduct field tests to select the most suitable agri mat for South African agriculture. 3-6 To develop preliminary Agri-business model based on agri-mat 4-1 To install the test equipment for harvesting technology in South Africa. 4-2 To complete a field test for the equipment for harvesting technology and report on results of on site tests in South Africa. 4-3 To complete to design the test equipment for extraction technology. 4-4 To conduct a preliminary test of equipment for extraction technology in Japan and to install the test equipment for extraction technology at the Project site in South Africa. 4-5 To complete a field test for test equipment for extraction technology and a report of the test. 4-6 To transfer the technology to South Africa and to submit the project report.			・Full support from eThekwini Municipality and the good relation are kept. ・The government of South Africa keeps their policy to develop bio fuel production business. <Problems and countermeasures＞

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