Research & Development on Renewable Energy
Used Native Algae Biomass for Fukushima
Reconstruction and Revitalization

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ALGAE BIOMASS SUMMIT
October 23–26, 2016
Phoenix Arizona
Background on Fukushima Project

- Fukushima area was damaged by the Tohoku Earthquake occurred at March 11, 2011.
- Vast abandoned lands of over 25,000 hectares were not able to harvest any rice and crops by the Tsunami after this Earthquake.
- Japanese Administration is continuous promoting for reconstruction and revitalization toward production-base of biofuel made from algae biomass as a newly application of these abandoned lands in Fukushima area.
- Algae Industry Incubation Consortium Japan (AIICJ) applied to a renewable energy development project for Fukushima area in 2013.
- AIICJ obtained a competitive research fund from Reconstruction Agency from 2013 to 2015FY.
- Fukushima area colored by green is a cold temperature and a lack of sunlight intensity during winter (Latitude:37.63N)
- The task to be solved was how to cultivate and harvest algae biomass by using of ORP, especially during winter.
Outline of R&D on Fukushima Project

Purpose
Cultivate native algae biomass in Fukushima area

Goal
Harvest dry-based 8.5 g/m²/d yields of algae biomass, above

Methods
Harvest steady algae biomass throughout the year by using ORP
Use HTL to convert to more biocrude from poor lipid content with cultivated algae

Results
Establish systemized technologies to reduce biocrude cost to 2 $/oil-L, below
Build up some business models to expand sales territory of using biofuel after 2020
Organization of AIICJ for Fukushima Project

Algae Industry Incubation Consortium, Japan (AIICJ)
Established in June 2010

Promotion committee for the Fukushima Project
chief director,
administrative director
Committee

Secretariat of AIICJ

TF of Road map to reduce production cost of biofuel

TF of Facility design, operation & maintenance
TF of Microalga resources & incubation technologies
TF of Downstream technologies to produce biocrude
Experimental Facilities with AllCJ (ca.3ha)

ORP of 1,000m$^2$ (50m×20m)

ORP of 20m$^2$ (8m×2.5m)

ORP of 100m$^2$ (20m×5m)

Dehydrator, Centrifuge, HTL reactor, Spray dryer

Wastewater treatment equipment

Lagoon

Dehydrator

HTL Reactor
Process Flowchart & Tasks for Producing Biocrude

- Use groundwater and low temperature waste heat as heating sources & waste CO₂ gas
- Use sewage as nutritive resources
- Optimize reaction conditions by HTL
- Inspect mass & energy balance on HTL
- Promote operation efficiency of paddle & improve CO₂ absorption efficiency
- Reduce filtration-loss

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Evaluation Criteria for Suitability on Unit Operations

Unit Operations on the Process for Producing Biocrude

Evaluation Criteria (Minimize Environmental Loads)

- Energy consumption rate (kW/kg-dry) on each process
- Environmental loading & fire risk on the whole process
- Additive materials & flocculants on each process
- Wastes & residues on the whole process
Results on Yield of Harvested Algae Biomass

- **Relation between dry-based yield of harvested algae biomass and hydraulic retention time at depth of ORP of 0.2m**

- **Effect on adding sodium acetate (minimum 50mg/L) as heterotroph**

- **Achieve 30 g/m²/d yields, above**

- **Apply to a deep cultivation**

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Demura, et.al Univ. of Tsukuba, in preparation
Lipid Content with Cultivated Native Algae

Lipid content with cultivated native algae without heterotroph: from 7wt% to 8wt%

Lipid content with cultivated native algae fed sodium acetate as heterotroph: from 5wt% to 6wt%

Reason for using HTL reactor to convert to more biocrude from poor lipid content with the cultivated native algae

Lipid content in cultivated native algae

Demura, et.al Univ. of Tsukuba, in preparation
Influence of Outdoor Temp. for Algae Biomass Yields

- Outdoor temperature from October 2014 to September 2015 at Minami-Soma City
- Existence of temperature dependence on monthly harvested algae biomass yields
- Monthly harvested algae biomass yields
- Keep the water temperature in ORP within G.H. steady

Demura, et.al Univ. of Tsukuba, in preparation

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Temperature dependence on Algae Biomass Yields

Arrhenius plots to make the threshold of outdoor temperature clear for cultivating algae biomass in Fukushima area.

Achieve steady harvested algae biomass yield in all season.

Relation among daily mean outdoor temperature (dry-bulb), daily mean water temperature of ORP (wet-bulb) and these temperature difference.

Keep the water temperature in ORP within G.H. at 15°C above.
Practical Use of Sensitive Heat with Groundwater

- Keep the water temperature of 15°C in ORP constant by using groundwater during winter.
- Develop a new trial plate type HEX, holds advantage functions of cheaper, more light & easy cleaning and so on.

Schematic diagram of piping for using of sensitive heat in groundwater.
Configuration diagram of heat exchanger by using bubble wrap packaging material.
Flow pattern of groundwater in this heat exchanger from inlet toward outlet.

Groundwater

Installed heat exchanger into ORP

Metal panel
Bubble wrap packaging material

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Effects on Heated Water in ORP by Groundwater

Test & control system for heating water in ORP

Daily mean outdoor temperature: 10°C, blow in Fukushima area
Cultivated period: 12 days
Overall heat transfer coefficient of HEX: 0.35kW/(m²·K) above

<table>
<thead>
<tr>
<th>Items</th>
<th>With heating</th>
<th>Without heating</th>
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<tbody>
<tr>
<td>Depth of ORP</td>
<td>0.12m</td>
<td>0.12m</td>
</tr>
<tr>
<td>Groundwater Temperature</td>
<td>17°C</td>
<td>–</td>
</tr>
<tr>
<td>Supplied Flow Rate of GW</td>
<td>0.48m³/h·m²</td>
<td>–</td>
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<tr>
<td>Circulating Water Flow Speed</td>
<td>0.28m/s</td>
<td>0.28m/s</td>
</tr>
<tr>
<td>Change of Daily Air Temp. in GH</td>
<td>0~17°C</td>
<td>0~17°C</td>
</tr>
<tr>
<td>Change of Daily Water Temp. in ORP</td>
<td>10°C~15°C</td>
<td>0°C~15°C</td>
</tr>
<tr>
<td>Estimated Annual Yield of Biomass</td>
<td>6.6 g/m²/d</td>
<td>3.7 g/m²/d</td>
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</tbody>
</table>

Harvesting

Ca. 1.8 times
### Preliminary experimental results on converting to biocrude

<table>
<thead>
<tr>
<th>HTL Reactor Type</th>
<th>Algae Biomass Sample</th>
<th>Ash Content [wt%]</th>
<th>Reaction Condition [℃×MPa]</th>
<th>Retention Time [sec]</th>
<th>Biocrude Content Dry &amp; Ash free [wt%]</th>
<th>Lower Heating Value [MJ/kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>Dehydrated</td>
<td>4.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>21.6</td>
</tr>
<tr>
<td>-</td>
<td>Dehydrated</td>
<td>6.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>18.8</td>
</tr>
<tr>
<td>Batch (0.3L)</td>
<td>Dehydrated</td>
<td>-</td>
<td>350×22</td>
<td>0</td>
<td>21.8</td>
<td>-</td>
</tr>
<tr>
<td>Batch (0.3L)</td>
<td>Wetted</td>
<td>-</td>
<td>350×22</td>
<td>1,800</td>
<td>37.2</td>
<td>33.4</td>
</tr>
<tr>
<td>Batch (0.3L)</td>
<td>Wetted</td>
<td>-</td>
<td>350×22</td>
<td>1,800</td>
<td>44.8</td>
<td>-</td>
</tr>
<tr>
<td>Continuous Flow</td>
<td>Wetted</td>
<td>-</td>
<td>350×22</td>
<td>600</td>
<td>43.7</td>
<td>31.0</td>
</tr>
</tbody>
</table>

**Dehydrated:** Sample on dehydrating algae biomass for 80% free water content  
**Wetted:** Sample on adding water to algae biomass dried up by spray dryer for 80% water content

Continuous flow type HTL designed by AIICJ as a small scale testing apparatus with feed speed of 1.5L/h
Recycling Residues after Converting to Biocrude

Rich organic acid contents with the liquid after converting to biocrude by HTL

<table>
<thead>
<tr>
<th>Organic Acids</th>
<th>Formic Acid</th>
<th>Acetic Acid</th>
<th>Propionic Acid</th>
<th>Succinic Acid</th>
<th>Lactic Acid</th>
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<tbody>
<tr>
<td>Structure Formula</td>
<td>HCOOH</td>
<td>CH₃COOH</td>
<td>C₂H₅COOH</td>
<td>(CH₂)₂(COOH)₂</td>
<td>CH₃CH(OH)COOH</td>
</tr>
<tr>
<td>Before (g/L)</td>
<td>0</td>
<td>9.9</td>
<td>2.7</td>
<td>0.96</td>
<td>0.84</td>
</tr>
<tr>
<td>After (g/L)</td>
<td>0.17</td>
<td>15.8</td>
<td>4.1</td>
<td>1.76</td>
<td>1.23</td>
</tr>
<tr>
<td>After/Before</td>
<td>-</td>
<td>1.6</td>
<td>1.5</td>
<td>1.8</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Pelletizing residues for solid fuel after converting to biocrude

Before

Pelletizing

Flake → Cylinder → Granule

Flowchart of recycling residues after converting to biocrude

Nutritive resources as a heterotroph
## Scenarios for Cost Reduction of Biofuel

### Scenario (a)
- **Scenario for Reducing Cost**: ① + ② + ④ + ⑥
- **Total Reduction Cost**: 40.42 $/Oil-L
- **Biofuel Cost**: 0.95 $/Oil-L

### Scenario (b)
- **Scenario for Reducing Cost**: ① + ③ + ④ + ⑥
- **Total Reduction Cost**: 39.55 $/Oil-L
- **Biofuel Cost**: 1.82 $/Oil-L

### Scenario (c)
- **Scenario for Reducing Cost**: ① + ② + ④ + ⑦
- **Total Reduction Cost**: 34.90 $/Oil-L
- **Biofuel Cost**: 6.47 $/Oil-L

### Scenario (d)
- **Scenario for Reducing Cost**: ① + ③ + ④ + ⑦
- **Total Reduction Cost**: 34.03 $/Oil-L
- **Biofuel Cost**: 7.34 $/Oil-L

### Scenario (e)
- **Scenario for Reducing Cost**: ① + ② + ⑤ + ⑦
- **Total Reduction Cost**: 39.71 $/Oil-L
- **Biofuel Cost**: 1.66 $/Oil-L

### Scenario (f)
- **Scenario for Reducing Cost**: ① + ③ + ⑤ + ⑦
- **Total Reduction Cost**: 38.84 $/Oil-L
- **Biofuel Cost**: 2.53 $/Oil-L

### Notes:
- ① Improve conversion yield of biocrude by HTL from 37.2% ash-free to 44.8% ash-free.
- Adjust circulating water speed in ORP from 0.40m/s to 0.15m/s.
- Change from ORP made by concrete to ORP made by polyethylene sheet.
- ▲ 13.94 $/Oil-L

### Scenario (a)
- **Scenario for Reducing Cost**: ① + ② + ③ + ⑤
- **Total Reduction Cost**: 41.37 $/oil-L

### Scenario (b)
- **Scenario for Reducing Cost**: ① + ③ + ⑤
- **Total Reduction Cost**: 2.46 $/Oil-L

### Scenario (c)
- **Scenario for Reducing Cost**: ① + ⑤
- **Total Reduction Cost**: 1.75 $/Oil-L

### Scenario (d)
- **Scenario for Reducing Cost**: ② + ③
- **Total Reduction Cost**: 6.47 $/Oil-L

### Scenario (e)
- **Scenario for Reducing Cost**: ② + ④
- **Total Reduction Cost**: 7.34 $/Oil-L

### Scenario (f)
- **Scenario for Reducing Cost**: ① + ④
- **Total Reduction Cost**: 11.04 $/Oil-L

### Scenario (g)
- **Scenario for Reducing Cost**: ① + ③ + ⑤ + ⑦
- **Total Reduction Cost**: 2.53 $/Oil-L

### Scenario (h)
- **Scenario for Reducing Cost**: ② + ④ + ⑦
- **Total Reduction Cost**: 12.11 $/Oil-L

### Scenario (i)
- **Scenario for Reducing Cost**: ① + ② + ④ + ⑥
- **Total Reduction Cost**: 40.42 $/Oil-L

### Scenario (j)
- **Scenario for Reducing Cost**: ① + ③ + ④ + ⑥
- **Total Reduction Cost**: 39.55 $/Oil-L

### Scenario (k)
- **Scenario for Reducing Cost**: ① + ② + ④ + ⑦
- **Total Reduction Cost**: 34.90 $/Oil-L

### Scenario (l)
- **Scenario for Reducing Cost**: ① + ③ + ④ + ⑦
- **Total Reduction Cost**: 34.03 $/Oil-L

### Scenario (m)
- **Scenario for Reducing Cost**: ① + ② + ⑤ + ⑦
- **Total Reduction Cost**: 39.71 $/Oil-L

### Scenario (n)
- **Scenario for Reducing Cost**: ① + ③ + ⑤ + ⑦
- **Total Reduction Cost**: 38.84 $/Oil-L

### Structure of cost reduction & biofuel cost on each scenario

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Structure of Cost Reduction</th>
<th>$/Oil-L</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>① + ② + ③ + ④ + ⑤</td>
<td>0.95</td>
</tr>
<tr>
<td>(b)</td>
<td>① + ③ + ④ + ⑥</td>
<td>1.82</td>
</tr>
<tr>
<td>(c)</td>
<td>① + ② + ④ + ⑦</td>
<td>6.47</td>
</tr>
<tr>
<td>(d)</td>
<td>① + ③ + ④ + ⑦</td>
<td>7.34</td>
</tr>
<tr>
<td>(e)</td>
<td>① + ② + ⑤ + ⑦</td>
<td>1.66</td>
</tr>
<tr>
<td>(f)</td>
<td>① + ③ + ⑤ + ⑦</td>
<td>2.53</td>
</tr>
</tbody>
</table>

**Exchange**: 100 YEN/$

- ▲ 13.94 $/Oil-L
- ▲ 12.98 $/Oil-L
- ▲ 12.11 $/Oil-L
- ▲ 11.04 $/Oil-L
- ▲ 5.52 $/Oil-L

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Strategies on the Second Fukushima Project

① Establish the practical use system of lower temperature waste heat and waste CO₂ gas to reduce utility costs from cultivating native algae to converting biocrude.

② Establish the practical use of sewage to reduce each nutrition, ammonia and acetate cost to exchange the treatment cost for the getting income, when cultivating native algae in sewage plant.

③ Estimate exactly each energy and CO₂ profit rate to build up some business models of biofuel and to make clear tasks to be solved.

④ Make clear tasks on current social and political systems to accelerate early build of biofuel markets.
Acknowledgement

These works were supported by the Fukushima Prefecture under a competitive research fund of the Reconstruction Agency.

These studies were summarized results of activities by members joined to Algae Industry Incubation Consortium, Japan.


Thank you for your kind attention
Procedure for Extracting Biocrude by HTL

By continuous flow type HTL reactor of 1.5L/h for small scale testing

Feeding:
Algae biomass dehydrated until free-water content of 80%

Converting:
Reaction time: 1,800s
Press. of 20~25MPa
Temp. of 350℃

Stirring:
Continuous operation to protect products from caking

Cooling:
Separate liquid phase from products

Extracting:
Add organic solvent to cake for separating biocrude

Heating & Drying:
Obtain cake from liquid Phase by heating until 65℃

Filtrating:
Obtain cake from liquid phase by vacuumed filtration

Trial test conditions will be changed for better to maximize yield of biocrude made from harvested algae biomass

Extracted biocrude

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Steel Dram Dehydrator for Harvested Algae Biomass

Algae Culture 2.680kg
0.586kg Biomass 0.0219% Solid 99.797% aq

Gravitational Sedimentation
0.0759kg Biomass 0.00301% Solid 99.99% aq

Supernatant 2.520kg

Concentration 156kg
0.510kg Biomass 0.327% Solid 97.3% aq

Stainless Steel Drum Dehydrator
0.420kg Biomass 20.0% Solid 80.0% aq

Drainage 154kg
0.090kg Biomass 0.0584% Solid 99.94% aq

Dehydration 2.1kg
61.0 times Concentrated
0.0219% Solid

Recovery Ratio 82.3%

Mass balance on the dehydration process
Ichikawa et.al, University of Tsukuba In preparation

Energy Consumption: 1.0kWh/kg–dry
Recovery Ratio: 82.3%

Stainless steel drum dehydrator
• Improve recovery ratio
• Reduce vacuum pressure
• Optimize filter medias vs. steel
Reasonable Grounds of Estimated Scenarios

<table>
<thead>
<tr>
<th>Items</th>
<th>Current-base</th>
<th>Challenge-base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total ORP Areas</td>
<td>10 ha</td>
<td>12 ha</td>
</tr>
<tr>
<td>ORP Depth</td>
<td>0.80 m</td>
<td>0.85 m</td>
</tr>
<tr>
<td>Algae Biomass Yield</td>
<td>30g/m²/d</td>
<td>35 g/m²/d</td>
</tr>
<tr>
<td>Recovery Ratio by Dehydrator</td>
<td>80 %</td>
<td>85 %</td>
</tr>
<tr>
<td>Ash Content within Algae</td>
<td>24.2 %</td>
<td>25 %</td>
</tr>
<tr>
<td>Electric Charge</td>
<td>0.255/kWh</td>
<td>0.26/kWh</td>
</tr>
<tr>
<td>Generating Efficiency</td>
<td>35 %</td>
<td>38 %</td>
</tr>
<tr>
<td>Bio-Fuel Target Cost</td>
<td>1.008/Oil-L</td>
<td>1.128/Oil-L</td>
</tr>
<tr>
<td>Culture Media Cost</td>
<td>0.78 $/m³</td>
<td>0.8 $/m³</td>
</tr>
<tr>
<td>Ammonium &amp; Acetic Acid Cost</td>
<td>0.43 $/m³</td>
<td>0.45 $/m³</td>
</tr>
<tr>
<td>Waste sewage Treatment Cost</td>
<td>0.35 $/m³</td>
<td>0.4 $/m³</td>
</tr>
<tr>
<td>Mechanical &amp; Electrical</td>
<td>165 $/m²</td>
<td>180 $/m²</td>
</tr>
<tr>
<td>Construction Cost</td>
<td>15 years</td>
<td>18 years</td>
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<tr>
<td>Employment Cost</td>
<td>400 $/day</td>
<td>450 $/day</td>
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<tr>
<td>Expenses Cost</td>
<td>400 $/day</td>
<td>450 $/day</td>
</tr>
<tr>
<td>Selling &amp; Administrative Cost</td>
<td>-</td>
<td>41.37 $/Oil-L</td>
</tr>
<tr>
<td>Improved Conversion Yield of</td>
<td>-</td>
<td>37.2% ash-free</td>
</tr>
<tr>
<td>Biocrude</td>
<td></td>
<td>44.8% ash-free</td>
</tr>
<tr>
<td>Improved Circulating Water</td>
<td>-</td>
<td>0.40 m/s</td>
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<tr>
<td>Speed</td>
<td></td>
<td>0.15 m/s</td>
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<tr>
<td>Improved ORP Type</td>
<td>-</td>
<td>600 S/m²</td>
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<tr>
<td>Depreciation Years</td>
<td>-</td>
<td>5 S/m²</td>
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<tr>
<td>Sum of above Improved</td>
<td>(1)</td>
<td>▲13.94 $/Oil-L</td>
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<tr>
<td>Technologies</td>
<td>(2)</td>
<td>▲12.98 $/Oil-L</td>
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<tr>
<td>Utilization Ratio of</td>
<td>(3)</td>
<td>▲12.11 $/Oil-L</td>
</tr>
<tr>
<td>Sewage: 75%</td>
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<tr>
<td>ditto: 70%</td>
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<tr>
<td>Utilization Ratio of</td>
<td>(4)</td>
<td>▲2.46 $/Oil-L</td>
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<tr>
<td>Recycled Organic Acids:</td>
<td></td>
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<tr>
<td>70%</td>
<td>(5)</td>
<td>▲1.75 $/Oil-L</td>
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<tr>
<td>ditto: 50%</td>
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<tr>
<td>Income of Sewage Treatment</td>
<td>(6)</td>
<td>▲11.04 $/Oil-L</td>
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<tr>
<td>0.50 $/m³</td>
<td></td>
<td></td>
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<tr>
<td>ditto: 0.25 $/m³</td>
<td>(7)</td>
<td>▲5.52 $/Oil-L</td>
</tr>
</tbody>
</table>

Exchange rate: 100 YEN/$

These scenarios were not considered the cost of CO₂ gas. When using waste CO₂ gas, add $0.3/oil-L to the previous biofuel cost.

When generating efficiency of 35%, EFR=1.1 on producing biocrude without using lower temperature waste heat and renewable energy.