Public Final Report
Vietnam Aquatic Biofuels Project

Context and reasons to start the project

Vietnam passed its first biofuel law in 2007, calling for significant production of fuel-blendable ethanol in the country by 2015. There are a variety of biomass types in Vietnam suitable for conversion to biofuels including tapioca, jatropha, cassava, sugarcane, and rice husks. One of the most sustainable is aquatic macro-algae (seaweed). This can be grown readily in the brackish water areas of South Vietnam, which total over 300,000 hectares out of approximately 4,000,000 hectares of total delta land area. The plants serve as a source of food for the shrimp and clarify the water by taking up excess nutrients. This has the benefit of improving the health and quality of the shrimp which are the farmer's primary crop. If farmers are paid to gather and dry the harvested seaweed, this represents a new source of rural income.

The seaweed appears naturally in the ponds and has a growth rate in excess of 15% daily during prime season. If left to spread naturally, it will eventually die and decompose creating a significant bacterial load in the pond that can be hypoxic to the shrimp. When managed as a formal crop using best cultivation practice, it can serve as a desirable part of the ecosystem.

Brackish water green macro-algae such as *Enteromorpha intestinalis, Chaetomorpha spp., and Cladophora spp* are cellulosic but have no lignin. Certain species varieties have a carbohydrate content >65% and protein content up to 15%. Residual material following fermentation has an amino acid profile that makes it a good protein source for shrimp, thus ensuring minimal waste and a closed-loop biomass chain.

At the time the project began in May 2010, there was little in-country knowledge of bio-energy technologies. Vietnam pumps crude oil, but has no in-country refining capacity for many motive fuels (eg., JP8 aviation fuel). It depends on hydro and coal for its electrical production with little or no exploitation of wind or geothermal. Renewable fuel alternatives were being sought by the government, but there was and still is little funding available to facilitate its development, and almost no academic base on which to build. Project funding such as that provided by AgencyNL is required both to build the base of applied research considered too risky for private investment capital, and to provide a pool of trained personnel critical to future commercialization.

A primary deliverable of the project was to be the establishment of an academic biofuel center of excellence in the Mekong Delta that could support future industry development with biochemists, process engineers, and botanists. This required extensive knowledge transfer from western companies and/or research institutions that could mentor the in-country staff and implement required infrastructure.

Renewable energy biomass supply chains had never been established in Vietnam. Little baseline data existed on total chain economics, greenhouse gas footprint, or fossil fuel offsets. This was the case as well for the aquatic biomass chain proposed herein, although it would be the first to be evaluated against certification criteria, and could serve as a template for other value chains in future.

As such, this project was designed to supply a feedstock that conforms to Agenda21 best practice including the following framework criteria of the Cramer Commission:

1. Greenhouse gas emissions – GHG balance is measured across the complete value chain. The decision to deploy regional conversion facilities at smaller scale substantially reduces the transportation footprint. Use of solar water heating offsets some electricity use. CO^2 is sequestered by the biomass, and if captured during fermentation can be utilized in place of hydrocarbon-based CO^2.
2. Competition – There is no land use implication in this project. Aquatic plants are grown in co-culture with other aquatic species and will not displace them.
3. Biodiversity – There is no biodiversity implication in this project. Even if every pond were to be utilized, there would still be no crowding out of any species.
4. Environment – Significant improvement of water quality. No incremental use of agricultural chemicals.
5. Prosperity – The greatest financial benefit to the farmer community of our co-culture approach is improvement in both quality and yield of his primary shrimp crop. Any cultivation model will probably also offer the farmer a price for the dried seaweed consistent with his labor value.
6. Well-being – Existing farmers and labourers enjoy a new revenue stream that does not require significant training or supplies. There are few skilled jobs in the Mekong Delta. A new biofuel economy would provide jobs with higher pay while augmenting education resources.

Objectives of the project

The immediate goal of the project was to prove the economic, logistical, and scientific viability of sustainable high-volume aquatic plant co-culture and conversion to biofuels. In the medium term, it was to have the biomass chain certified by an accreditation body if applicable.

Specific objectives included:

- Building research capacity to western standard
- Replicating western biomass supply and ethanol production best practice
- Optimizing all methods to best fit local conditions
- Find a mix of primary and co-products that provide an economic path to commercialization
- Demonstrate all best practices at pilot scale
- Establish an on-going aquatic biofuels educational and research capacity

The original benefits of the project were forseen as:

- Farmers are compensated for the cultivation effort, and contract carriers are paid to transport the feedstock. These are new sources of income for rural people.
- Intentional cultivation removes undesirable water-borne nutrients that pollute the country's water supplies.
- Cleaner pond water results in higher aquaculture yields.
- The country develops local academic expertise in renewable energy.

These benefits address sustainability goals of Agenda21 and the "Action Plan for Global Biomass".

Activities of the Project

The following were the major activities undertaken by the project.

1) Establish facilities and staff

The research program was conducted at both Can Tho University (CTU) in the Mekong Delta and the Institute of Tropical Biology (ITB) in Ho Chi Minh City (HCMC). Both institutions operate research facilities, and improvements to both were included in project capacity building scope. Additionally, the project designed, constructed, and deployed a mobile conversion facility for use in pilot scale ethanol production.

- Cultivation lab – evaluated various feedstocks for biochemical makeup, environmental parameters, lifecycle behavior, and nutrient requirements.
- Bio-chemistry lab – evaluated the best methods of converting feedstock to sugars and producing/purifying alcohols. Included identifying best onversion micro-organisms.
- Culture ponds – rented from farmers for scaling lab cultivation processes to pilot scale.
- Conversion facility – pilot facility for demonstrating alcohol production in the field.

The project was led by two PhD research professors, Hoang Kim Anh of ITB and Tran Ngoc Hai of CTU. Field analysis was augmented by Dr. Bui Lai of the Biology Association of HCMC. They recruited teams of masters and bachelors level staff and students who carried out experimental work.

Algen Sustainables coordinated foreign support, and also served as project intermediary to facilitate NL Agency contract compliance. Dr. Chris Langdon of Oregon State University, Dr. Bruce Dien of the United States Department of Agriculture (USDA) Agricultural Research Service (ARS), and Dr. Haibo Xie of the China Clean Energy Institute all provided on-going mentoring.

2) Optimize feedstock supply

Vietnam has an abundance of cultivation area suited to aquatic plants that do not compete with terrestrial agriculture.

Following a national botanical survey, it was decided to focus on the macro-algal species *Chaetomorpha* and *Cladophora*, both of which grow rapidly in the region's brackish water areas. Both are highly adaptable plants and can be maintained in culture year-round. The contain a high protein fraction and a polysaccharide structure that can be hydrolyzed and saccharified using traditional cellulosic deconstruction techniques.

The project did extensive work documenting plant morphology, environmental parameters, lifecycle behavior, and best methods of encouraging continuous vegetative growth. Testing was done both in open water tanks at CTU, and in commercially-farmed shrimp ponds. The lab facilities allowed testing of environmental factors including water and air temperature, pH, salinity, substrates, seasonal light impacts, need for various nutrients including CO_2, and other factors that are known generally to influence aquatic plant growth rates.

Lab results were verified in field trials by growing cultivars in mesh happas in shrimp ponds. This allowed the team to evaluate additional real-world variables including turbidity, farm-induced nutrient flow, presence of epiphytes and other predators, hydrologic flow patterns, periodic shellfish harvests, and so on.

3) Optimize conversion of biomass to alcohols

There are several processes used in the production of biofuels including pre-treatment, saccharification, hydrolysis, fermentation, and distillation/purification. The project team began by observing these practices at the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) laboratory in Peoria, Illinois. It then replicated these techniques in Vietnam using local biomass and a locally available strain of the yeast *Saccharomyces cerevisiae*.

After exceeding the alcohol yields achieved at USDA, the team began optimizing the processes and adapting them to local fermentation organisms. Special effort was put into mastering simultaneous saccharification and fermentation (SSF) which substantially aided conversion economics.

The project did not evaluate issues of ethanol storage and transportation.

The project evaluated the feasibility of producing bio-butanol using the bacteria *Clostridium Acetylbutylicum* which is used in the Acetone-Butanol-Ethanol method. This work was to be undertaken by the project with match funding from the Ho Chi Minh City (HCMC) Deparatment of Science and Technology (DOST) and mentored by Dr. Hans Blachek of the Center for Advanced BioEnergy Research (CABER). The funding was not forthcoming and this work was scoped out after completing a literature review.

Centrifugation is used to separate post-fermentation solids from the liquid media containing the ethanol. Distillation is then used to separate the ethanol from the rest of the liquid media. Both processes produce residuals that must be used or disposed. The project team experimented with using both as a substrate for microbial multiplication, producing dried concentrates containing *Azobacter* (nitrogen fixer), *Trichoderma* (anti-pathogen), and *Bacillus* (phosphate converter). These have a market restoring depleted soils.

The most valuable bio-active compound in macro-algae is its protein fraction. A sodium extraction process was developed to simultaneously deconstruct the biomass and separate the protein. Purity levels of 50%+ were achieved, which is appropriate for an aquaculture feed input. The residuals from this process still contain unfermented sugars, which improves substantially the value of seaweed as a microbial multiplication substrate. No fuel-blendable alcohols are produced from this pathway.

4) Conduct full biomass value chain pilot

Once the procedure for fermenting and distilling alcohol from macro-algae was optimized at lab bench and 5 litre scale, the team designed and built a mobile conversion facility scaled to a 200 litre fermenter. This was deployed to a pilot site in the village of Long Dien commune in Bac Lieu province.

A biomass field team worked with several farmers to cultivate seaweed in co-culture with shrimp, identifying best real-world methods of seeding, thinning, and drying. Extensive work was done observing interactions between the two crops, and optimizing conditions such as water level, circulation, plant pond coverage, and larval shrimp management.

The dried seaweed was stockpiled for several weeks preparatory to a series of research trials. The first ten exposed issues in scale-up that were optimized in the subsequent batches. Final results in the pilot validated predicted outcomes based on lab experience.

As in the lab, post-fermentation solids and post-distillation liquid media were combined with microbial cultures to create a fertilizer emendation product containing three micro-organisms important to agriculture.

Operating a pilot scale facility required the team to learn several new disciplines typical of process manufacturing plants. Each procedure required full documentation, and several checklists were created. Safety became a significant issue given the use of caustic acids and high pressure steam. A supervisor read each checklist item and verified that a worker completed it correctly. Records were kept of all inputs, intermediate readings, and outputs. All chemicals were stored securely and accounted for when withdrawn for a research trial. The project experienced only one mishap during the entire pilot phase, which was traced to a seal that failed under pressure.

The project agreed to benchmark its pilot results against a draft certification standard for aquatic biomass created by consultants to NL Agency. Results validated all sustainability criteria except economic.

5) Conduct extended demonstration

It became clear early in the project that traditional acid hydrolysis combined with enzymatic saccharification was not an economic way of releasing fermentable carbohydrate sugars in the plants. So the project investigated recent work being done in the UK, USA, and China based on use of ionic liquids. This proved successful in deconstruction, but the formulations were expensive to produce, and recovery for reuse proved uneconomic as well. The conversion team then used a sodium-based extraction method to isolate plant protein at the start rather than end of the process, and this proved an effective and low-cost deconstruction method. This last approach was scaled to5 litre fermentation and yielded ethanol consistently with the acid/enzyme method.

During this activity, plant protein was purified to between 50 and 60%, which is suitable for aquaculture feed. Feed conversion ratios and palatability were tested and the extract deemed market ready. To examine an economically sustainable pathway, ethanol production was dropped in favour of testing the residual plant sugars as a substrate for enhanced microbial multiplication.

6) Prepare final report

Project personnel documented all research trials in phased reports, and all sub-contractors were likewise required to submit documentation of their scopes of work. Although intended for peer review, it was left to NL Agency to validate quality of written deliverables.

An important objective of the project was creation of a Biofuel Center of Excellence that would continue to develop the concepts in the project during a commercial rollout, and provide a future stream of qualified local employees. Funding for the center was assumed to be derived from commercial revenues. As indicated in the Addendum to this Final Report, an ethanol market never developed, and the project new faces competition from 500 m l/y capacity, most of it idle. Research work will continue less formally at ITB on protein extraction and microbial multiplication, both of which are viable businesses based on the aquatic biomass.

Results of the Project

The project has fully documented its scientific and engineering findings in a large body of literature submitted to Agency NL. This includes the following:

Biomass	Conversion
Literature review	Literature review
Phase 1 report (part 1)	Capacity building
Phase 1 report (part 2)	
Phase 2 report	Phase 2 report
	Conversion facility design Conversion facility procedures/checklists
Phase 3 report	Phase 3 report
	Protein feed test results
Other Project	NL Periodic
Draft certification standard/benchmark	Project status reports (Quarterly)
Ionic liquid trials - Lam Ionic liquid trials - Xie	NL Agency status reports (Semi-Annual) NL Agency financial reports (semi-Annual)

The table below lists the goals and indicators proposed by the project, along with final achievements.

Goals	*Indicator*	*Achievements*
Prove the economic, logistical, and scientific viability of sustainable aquatic-based biofuels, while building the in-country expertise needed for future commercialization.	Scientifically self-sufficient, on-going operation of pilot conversion facility.	The project pilot was conducted successfully, demonstrating small-batch continuous production of ethanol from biomass at quality levels consistent with blending requirements. The local team has utilized very little international expertise during the final year of work, demonstrating scientific self-sufficiency. Unfortunately, biofuel production in Vietnam is uneconomic because no market exists in-country. Project efforts

		in the extended pilot focused on co-products that can be economic.
Results	*Indicator*	*Achievements*
Trained cultivation staff	Team led by at least 1 PhD in place at CTU	CTU cultivation team led by Dr. Tran Ngoc Hai.
Trained conversion staff	Team led by at least 2 PhD in place at ITB	ITB conversion team led by Dr. Hoang Kim Anh. ITB biomass team being mentored by Dr. Bui Lai.
Facility infrastructure	Lab facilities support research leading to operating 5,000 l/yr pilot.	Lab facilities augmented with equipment and chemicals satisfactory to on-going biofuels research. Pilot facility operating with 200 litre fermenter, substantially exceeding production goal.
Educational curriculum	At least 10 students enrolled in formal curriculum by 2012-Q3.	Center of educational excellence not created since there is no market for biofuels expertise in Vietnam. However, CTU included 10 bachelor and masters students in its lab and pond trials.
Final report	Report accepted by funding source.	Reports submitted.
Activities	*Indicator*	*Achievements*
Establish facilities and staff	Pilot facility implemented and operating based on specifications.	Cultivation and conversion labs have performed efficiently. Pilot conversion facility has met all operating expectations during the pilot.
Optimize feedstock supply	Positive biomass growth rates obtained year-around.	Cultivation methods have been optimized. Cultures were maintained during the difficult dry season. Project never expanded cultivation area past 2 hectares, which is 10% of the original objective.
Optimize conversion to alcohols	Biomass yields commercial quality alcohols with valuable residual.	Hydrolysis and SSF trials complete and the total value chain demonstrated. Co-products protein and bacterial soil inoculant successfully demonstrated. Work on alternative saccharification using ionic liquids abandoned at lab scale as not economic due to high solvent recovery costs.
Conduct value chain pilot	Blend-ready alcohols produced at commercial ratio of yield to inputs.	Project has successfully produced at pilot scale 95% dry ethanol not denatured and ready for transport and final drying and fuel blending. The project produced the first available metrics on seaweed to ethanol yields.
Prepare final report	Report peer-reviewed and accepted.	Reports submitted.

The project has maintained plant cultures during the very difficult end of dry season, demonstrating year-round cultivation is possible. Optimum seeding, cultivation, harvest, and biomass pre-processing methods have been formalized and documented.

Alcohol fermentation results using seaweed C5 and C6 sugars exceeded USDA-ARS lab standard. The overall conversion pathway was enhanced through the application of simultaneous saccharification and fermentation (SSF). Hydrolysis was varied to allow post-processing of protein without denaturing it. Several strains of yeast were benchmarked to find one that was highly productive under local conditions.

Pilot scale conversion of biomass to ethanol rendered yields below those achieved under optimal lab conditions, but not significantly so. Product quality at pilot scale was equivalent to that achieved in the lab. The pilot also demonstrated effective production in a distributed, small-batch facility that included key bio-economy sustainability characteristics including waste treatment, heat conservation, water recovery/reuse, CO_2 capture, and maximum use of renewable energy.

Extended work deconstructing biomass by doing sodium extraction of crude plant protein was successfully demonstrated. Creation of a microbial soil emendation product using deconstructed biomass residual was also demonstrated (using both acid hydrolysis and sodium extraction residuals). The two together provide a viable economic return in the absence of ethanol production.

The project collaborated with both Dr. Ho Lam of IAMS and Dr. Haibo Xie of the China Clean Energy Institute to test ionic liquid based biomass deconstruction as an alternative to acid hydrolysis and sodium extraction. Consistent with literature, the high solvent recovery cost was found not economic.

AgentschapNL consultants observed the biomass to ethanol pilot in operation and collected data for a draft biomass certification standard. This was reviewed during a workshop in May 2013 with the consensus being that no formal certification should be implemented until there is an established need for one.

An original objective of the project was support of the Cramer Commission criteria for biomass certification. The project helped develop and benchmark a draft certification scheme for aquatic biomass, and participated in discussion of the draft at a workshop hosted by NL Agency in May 2013.

Lessons learned

There were a variety of lessons learned as regards conducting a large research project in Vietnam, with associated implications for a commercial business.

The project faced opposition at startup from a competing research institute which challenged the credentials of the project participants and attempted to administratively transfer the SenterNovem contract to its own organization. It is common in academic circles in Vietnam to try and monopolize the flow of research and associated funding. If this cannot be achieved then the next best option is to impede the work of others building competing capacity.

The project also faced an intellectual challenge from a researcher collaborating with our project team in work predating the NL funded scope of work. This researcher took the benefit of that work and filed a comprehensive patent application that sought to secure all rights to macro-algae (onshore and offshore) cultivation in Vietnam. If accepted, this would have prohibited our project from proceeding without paying royalties.

The project attempted to secure matching funding from three separate government ministries / departments. All asked for detailed proposals, and all indicated tacit approval. However, the project found it was expected to redirect a percentage of any funds granted. No funding was forthcoming from these sources.

Foreign members of the project team travelled regularly to rural provinces to provide technical assistance in the cultivation of biomass. In each instance provincial authorities required 2 weeks prior notice of a visit, which the project always provided. In one case a provincial official was not available to sign his approval, but this was not communicated to the project team. When the foreign members arrived in the province as scheduled, the police were waiting to escort them back out indicating that no authority existed for their on-site work.

The project selected a vendor to implement its mobile conversion facility and attempted to finalize a contract. Approval was withheld by the ITB parent organization VAST, which an audit found had been violating procurement standards. VAST was not willing to approve any new procurements until the general issue was resolved. The project addressed this by having NL Agency review its procurement contract and provide a letter to VAST indicating its approval. This finally allowed the project to proceed.

The cumulative effect of these and other challenges was to set the project back nearly 8 months from its original timeline, and to deprive it of funding it had been led to expect. Fortunately there was sufficient flow time in the Global Sustainable Biomass Fund programme to accommodate the delay.

These vignettes illustrate the challenges faced by any organization doing business in Vietnam, with implications for any future commercialization of project technologies. It is crucial to have strong support from a government behind any initiative, especially commercial, because it gives substantial leverage to problem resolution.

Project Follow-Up

Since the start of the project in May 2010, there has been substantial biofuel production activity in Vietnam. Commercial capacity built rapidly in 2010-2011 to 550 million liters/year, and then crashed beginning in 2012 leaving nearly the entire capacity idle. (See addendum.) This is not fertile ground for continuing our NL-subsidized project as a biofuels venture. We have therefore determined to focus on the co-products, including plant protein extract and microbial fertilizer inoculant. This will allow us to still fulfill the overall project vision for cultivating sustainable aquatic biomass for conversion into marketable products, with associated sustainable impact on local farmers and their communities.

To facilitate commercial scale-up, the project intends to partner with an international corporation having interest in supplying biomass-based feed and fertilizer inputs. The challenging business environment, lack of local capital for investment in operating companies, and project demands for process engineering expertise all advocate for a well-funded partner committed to long-term market development.

One of the attractive aspects of our project to corporate partners is the progress made in understanding the potential of Mekong Delta co-culture across the various sustainability domains. The delta still represents the largest pond infrastructure resource in the world which can supply biomass that is easily controlled and harvested.

The project has begun the process of applying for a local patent on its seaweed protein extraction and microbial cultivation methods. Protecting this intellectual property further increases the value of the project to a potential partner.

Colophon

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Addendum
Status of Biofuels Industry in Vietnam

Vietnam is an Agenda 21 signatory nation actively seeking alternative means of producing sustainable energy. On November 20, 2007 the Prime minister approved Decision 177/2007/QD-TTs titled “Scheme on Development of Biofuels up to 2015 With a Vision to 2025”. This act commits the country by 2010 to an “annual output of 100,000 tons of E5 and 50,000 tons of B5 in order to satisfy 0.4% of the whole country’s gasoline and oil demand”. This target is raised to 5 million tons of E5 and B5 by 2015, and satisfaction of 5% of the country’s gasoline and oil demand by biofuels in 2025.

The national biofuel objectives and targets were further referenced in Decision 1855/2007/QD TTg titled “Vietnam’s national Energy Development Strategy up to 2020, with 2050 Vision” dated December 27, 2007. This Decision seeks to balance environmental protection and energy exploitation by calling on the government “To integrate the use of new and renewable energies into the energy conservation program and other national target programs such as those on rural electrification, aforestation, hunger eradication and poverty alleviation, clean water, integrated fish pond – livestock pen – home garden model, etc”.

In August 2010, Don Xanh JSC began operating Vietnam’s first ethanol plant in Quang Nam, with a design capacity of 100,000 tons of bio-alcohol per year. Its principal feedstock was cassava grown in Quang Nam and Binh Dinh provinces. Petrolimex formulated the ethanol into B5 petrol (5% ethanol with 95 % petrol) and began distributing it to petrol stations in HCM City, Hanoi, Vung Tau, Hai Phong, Hai Duong, Da Nang, Hue and Can Tho. The bio-petrol was offered at VND 200 / liter less than normal petrol.

PetroVietnam (PV) joined with Japanese partner Itochu to form Orient Biofuels, which built PV’s first ethanol plant in Binh Phuoc province near PV’s existing 145,000 b/d Dung Quat petroleum refinery. PV then formed two additional operating subsidiaries. Central Petroleum Bio-Ethanol JSC built a plant in Quang Ngai province. PetroVietnam BioChem JSC built a plant in Phu Tho province. Each PV plant has a design capacity of 100m litres/year (629,000 barrels/year = 1,700 b/day) ethanol production requiring 250,000 tons/year cassava (2.5 kg cassava/litre ethanol). Each of the three plants cost between $80-120m to build, and represents 300 direct jobs sourcing cassava from 20,000 farmers.

Under the 2007 “Plan on biofuel development to 2015 with a vision to 2025”, Vietnam was envisioned to produce 1.8 m tons of ethanol and vegetable oils for fuel blending annually, meeting 5% of domestic petrol and diesel demand for the next 15 years. However, the market never developed. Only 155 petrol stations out of 12,000 in Vietnam are selling B5. Barring a government mandate, this is unlikely to change quickly.

At the start of 2013, there are six operating and idle plants in Vietnam with a total capacity of 550 million liters a year. PV sold 20,000 cubic metres of ethanol for the year out of its 300,000 cubic metre capacity. The rest was exported at a financial loss to the Philippeans and China. The PV Phu Tho plant never entered production. The Don Xanh JSC plant stopped operations in June 2012 and the company declared bankruptcy. In April 2013 Itochu notified PV that it desired to exit the Orient Biofuels partnership and would not be a source of further financing. PV refused to buy Itochu’s shares and has determined to quit the biofuels business altogether.

As ethanol production collapses, substantial cassava cultivation has also been idled. This is despite China's importing over 500,000 metric tons from Vietnam each year. Cassava cash prices have fallen from VND 5,500 to 3,500/kg dried, with dealers making VND 1,000 and farmers receiving VND 2,500.