Background:

The Nature Conservancy estimates that coral reefs are central to the survival of over 500 million of people worldwide (~8% of human population) who are directly dependent upon the reefs for food and income. In the Philippines, coral reefs provide about 60% of animal protein consumed at the national level (*Science*, February 15, 2002). For the rural poor Filipino who inhabits the coastal areas, coral reefs provide a staggering 90% of animal protein intake. Aside from nourishment, coral reefs also bring income and employment through tourism, marine recreation and fisheries. Furthermore, coral reefs offer countless benefits to humans by supplying new compounds for industrial applications and medicines that attack cancer cells and improve human life.

The highest marine biodiversity in the world is concentrated in the East-Indies or Coral Triangle (see Figure 1). This area encompasses the countries of Indonesia, Malaysia, Papua New Guinea, and the Philippines. This area is equivalent to half the size of the United States and is home to over 75% of all coral species known to science and more than 3,000 species of reef fish. The World Atlas of Coral Reefs (University of California Press, Berkeley, 2001) recently compiled the most detailed assessment of coral reefs to date and their data showed that reefs are under continuous assault worldwide. The Atlas indicated that the Philippine Islands hold the third largest coral reef network in the world, behind Indonesia and Australia. However, the country also has about 90% of coral reefs either badly damaged or highly threatened by human activities. These destructive practices include methods such as dynamite and cyanide fishing, over-fishing, and pollution from marine and land-based sources. The high threat of human devastation has earned the Philippines a number *one* rank in the world's top 10 hotspots for coral reefs (*Science*, February 15, 2002). The devastation of coral reefs in the Philippines, one of the world's centers for marine biodiversity, would be a catastrophic loss for this developing nation with a rapidly growing population, currently at over 80 million. Moreover, it would be a great loss to the world as a natural wonder and potential source of disease fighting compounds for next generation medical therapies.

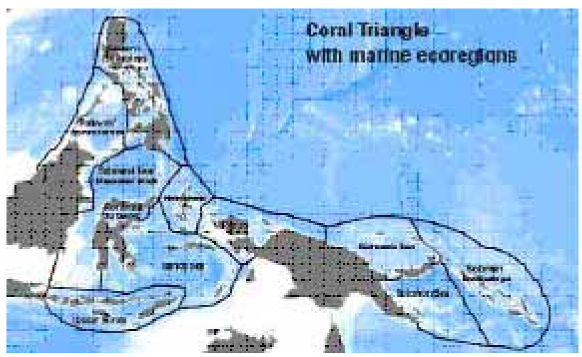

Figure 1. The Coral Triangle (Ref. The Nature Conservancy)

To address the rampant destruction of coral reefs in the Philippines, drastic measures of marine conservation and resource regeneration are required. Current methods of regenerating coral reefs primarily involve the use of large structures sunk into the devastated coral areas to increase coral larvae regeneration sites as well as protect these from the shifting sea-bottom. Another approach to coral regeneration has involved the use of intricately woven meshes of stone and netting grafted with small coral members and placed on the damaged reef site. The woven meshes act as coral "plantings" that serve to repopulate damaged reef area. Both of these methods although beneficial have been shown to have mixed results. Large scale structures (i.e., old boats, planes, and vehicles) are problematic in that they contain oil and paint residues that add to marine pollution. Moreover, painted surfaces often contain chemicals that do not support adhesion of coral larvae making these impervious to coral regeneration for a good period of time until these are broken down by the marine environment. Intricate mesh structures, on the other hand, with improved coral regeneration properties are still prone to uncontrollable climatic effects that cause coral bleaching.

Figure 2. 6-blade Gorlov turbine used in rural Amazon electrification project

Therefore, to improve coral rehabilitation and improve on this current practice, we propose the innovative First-Step Coral project. The First-Step Coral project will combine the newly developed Gorlov helical turbine (see Figure 2) (Invented by Prof. Alexander Gorlov, Dept. of Mechanical Engineering, Northeastern University) to harness previously unexploited tidal energy to grow Biorock™ assisted coral reefs. Corals grown with the assistance of the BioRock™ method have been shown to have enhanced coral growth rates, reduced soil erosion in low-lying coastal communities, increased fish populations and improved the lives of thousands of families who depend on the coral resource for daily survival.

The Biorock™ process (see Figure 3) employs low voltage DC currents to electrochemically deposit calcium and magnesium rich substrates on a metallic mesh (this serves as the cathode or negative electrode shown in Figure 3a) that then acts as a nutrient rich base for coral regeneration. Small coral members are then fastened to the BioRock™ structure where improved growing conditions are present due to the abundance of calcium based minerals on the substrate. These coral members are then monitored for growth. Biorock™ assisted coral reef clusters have not only been observed to grow (up to four times!) faster, but have been shown to be more resistant to environmental and climatic stresses that lead to coral bleaching (Asian Diver Publication, January 2001). To supply the electrical energy that will power the Biorock™ mineral deposition process, we will utilize the Gorlov helical turbine to convert highly abundant and previously untapped tidal energy into required electricity to power the Biorock™ structure. These two technologies *have never been brought together before* and its successful implementation in the First-Step Coral project will result in a revolutionary system for coral regeneration in the Philippines and the rest of the world.

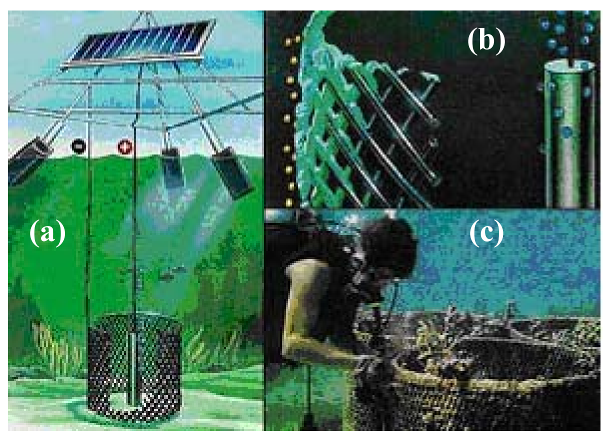

Figure 3. (a) BioRock™ cylinder structure powered by solar-cells, (b) electrode configuration of BioRock™ system with mineral deposit on mesh and (c) diver with BioRock™ structure (Ref. www.biorock.net)

The community we have targeted as the first testing site for this project is the coastal city of Sagay, in the Province of Negros Occidental, Philippines (see Figure 4). Sagay City with a population of about 70,000 is considered a major fishing area in the Province of Negros Occidental as it is bounded to the north by the rich Visayan Sea. For the past three decades, rampant dynamite and cyanide fishing has decimated the coral formations of Carbin and Molocaboc Reefs located just off the city's coastline. In 1995, a presidential decree declared approximately 32,000 hectares of Sagay's territorial waters into a protected area and in 2001 the Sagay Marine Law was passed that established a local government unit (Sagay Marine Reserve Authority) that oversees resource management and protection.

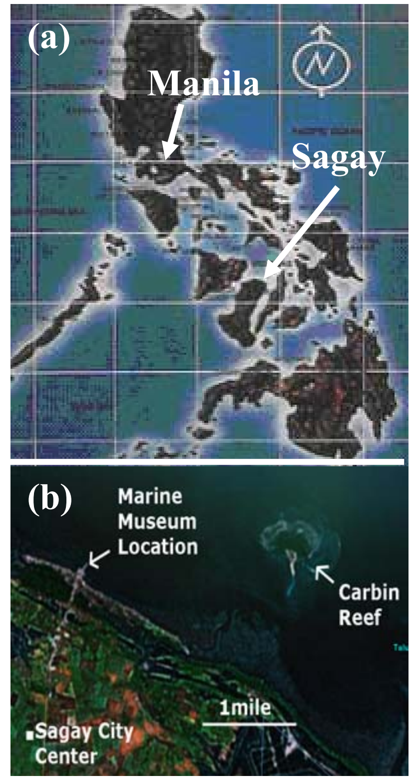

Figure 4. (a) Map of Philippines, (b) Aerial view of Sagay City with Marine Museum and Carbin Reef detailed. (Ref. Google Maps)

Innovation:

The high threat of coral reef devastation in the Philippines needs to be addressed with improved technology and more effective regeneration systems and this is where First-Step Coral project comes in. Current methods of reef restoration, as previously explained above, in combination with strong community involvement have made little impact on the overall declining health of coral reefs in the Philippines (*Status of Coral Reefs of the World: 2002*, Australian Institute of Marine Science). The standard methods of coral restoration, using sunken structures or intricate meshes, have shown limited effectiveness, only long-term feedback, and are critically influenced by climatic conditions. A coral restoration system with an intrinsically higher probability of success is urgently required to stem this declining trend.

The combination of a proven coral regeneration process, BioRock™, with a newly developed hydro/tidal turbine, Gorlov, has never been combined before. Previous BioRock™ projects have either used land-based electricity resulting in reef rehabilitation near electrified coastal areas or expensive solar (shown in Figure 3a) or battery power. Solar power is not only expensive but also requires a complex framework of structures and floatation devices to keep this steadily anchored. Batteries on the other hand require constant replenishment and are not cost-effective for the majority of rural coastal area projects. The electrical limitations these previous technologies placed on BioRock™ projects meant that it was difficult (and expensive) to implement and

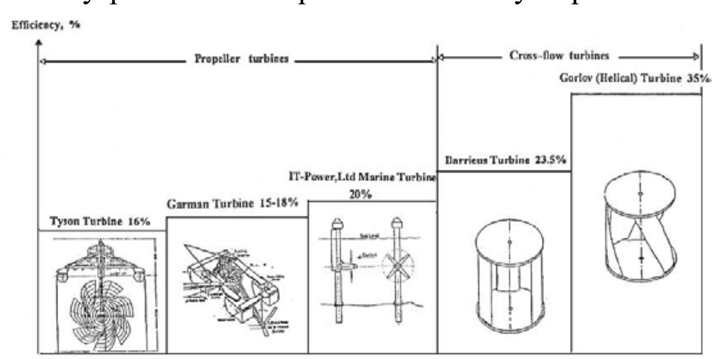

Figure 5. Hydro turbine efficiencies as a function of design.

site. The highly efficient Gorlov turbine (see Figure 5, previous page), on the other hand, will harnesses *in-situ* power from tidal currents making this a renewable and sustainable source of electricity creating zero pollution and allowing for the deployment of the First-Step Coral project to any remote location in the Philippines or the rest of the world where coral regeneration is required. In addition, the much lower cost of a Gorlov turbine will make this combined system accessible to thousands of coastal communities and empower them to regenerate their coral resources with greater probabilities of success.

Feasibility:

The successful implementation of the First-Step Coral project depends on two factors; (i) an ideal coral rehabilitation site with good water quality and tidal currents, about 2knots averaged during tidal shifts, to run the Gorlov turbine and (ii) strong local community involvement in execution, management and security of the coral rehabilitation site. The First-Step Coral team here at MIT has been hard at work putting together all the critical pieces of this project for the past 2 months. In addition, a support network of key persons has also been identified to greatly enhance project execution and success.

The Carbin reef area of the Sagay Marine Reserve provides the *first* key factor required for project feasibility- an ideal test site for the deployment of the First-Step Coral project. The Carbin area has had its coral reef communities significantly damaged by unabated dynamite fishing. Bleaching effects due to unusually warm summers in the past few years have also stunted coral growth. In addition, vast areas of the Carbin reef have not been rehabilitated as of the moment due to lack of technical expertise from the local community. The good water quality and tidal currents are in the Carbin area are ideal to host the First-Step Coral project where an innovative project combined with a good test bed will allow for greater chances of success.

Figure 6. Sagay City Marine Museum set to open in June 2006 (photo taken Feb. 2006). Note the museum is shaped like a fish!

The *second* factor, community involvement, will determine the long-term success of the coral resource rehabilitation. With the establishment of the Sagay City Marine Reserve, the Carbin reef is now a protected area and free of the past destructive fishing methods that had plagued this precious marine resource. A manned watchtower and constant community vigilance oversees the daily protection of the Carbin reef. The Sagay City government, in addition, has further promoted its marine resources and its heritage to the sea via the construction of a marine museum (see Figure 6). This museum will serve to highlight the abundance of the sea and the economic benefits it has given to the city and province. The Sagay City Marine Museum's mission is to serve as a showcase and working laboratory for students interested in the conservation of marine environments. In line with this mission are the livelihood and marine conservation workshops that will be hosted at the museum teach seaside communities in the area as well as the entire Negros Occidental province on topics such as reef preservation/conservation, mangrove reforestation, and waste management, to name a few. The addition of a First-Step Coral project to these set of programs would greatly enhance the technical know-how of seaside communities looking for straightforward techniques in regenerating their coral resources.

Support Network:

The BioRock™ expertise of Dr. Thomas Goreau who has implemented numerous BioRock™ projects (see Figure 7) in the past decade (Projects in Maldives, Indonesia, Jamaica, see http://www.biorock.net) has greatly increased the probability of success for this project. The technical assistance of Mr. Ed Kurth, President of GCK Technology and technology partner for the Gorlov turbine will be a great resource in the design and fabrication of low-cost Gorlov turbines for the implementation into the Carbin reef project site. Mr. Antonio Cueva from the Sagay Marine Reserve Authority and his local staff will assist in the actual construction of the BioRock™ structure, location of reef rehabilitation site as well as proper positioning of the Gorlov turbine to maximize the tidal energy captured and converted to electricity.

Figure 7. BioRock™ "dome" structure after assembly in Bali, Indonesia (Ref. Dr. Thomas Goreau)

Implementation and Prototype Design:

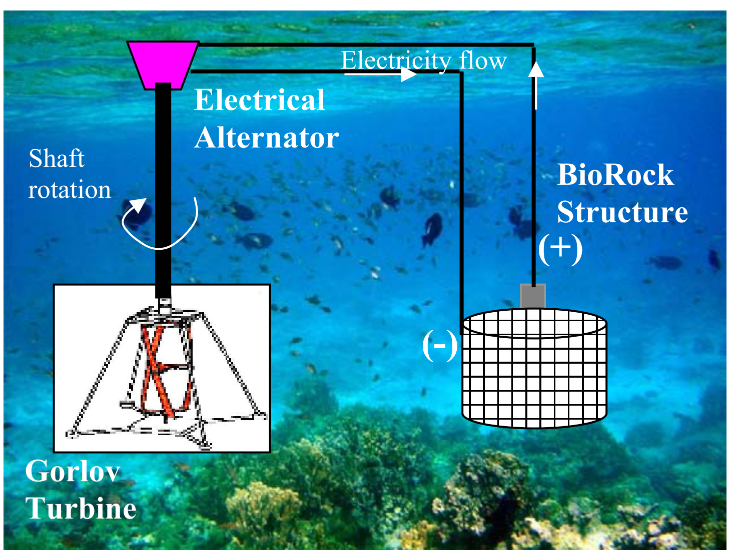

Figure 8. Prototype design will have Gorlov turbine anchored to sea bed with shaft leading to electrical alternator encased in waterproof housing. BioRock structure will be positioned on sandy bottom and anchored for coral rehabilitation.

The key technology and community partners for the First-Step Coral project are currently in place for its successful implementation. The tested and proven BioRock™ system now combined with the new Gorlov turbine can potentially open up new avenues for coral restoration in the Philippines. The Carbin reef area with its strong community support will be the first and ideal test bed for this system. The Sagay City Marine Reserve with its well-established protection and conservation plan for the Carbin reef area is the ideal community for the successful realization of this project. Mr. Illac Diaz, Mr. Rhoderick Samonte, and Dr. Thomas Goreau will be the lead persons from the First-Step Coral team who will oversee the construction and proper implementation of the project proposal during time period of July-August 2006. A schematic prototype for the First-Step Coral system is shown in Figure 8. In this schematic, both

BioRock™ and Gorlov turbine structures will be anchored to the seabed to prevent structural shifting during tidal changes. An electric alternator with waterproof housing will be connected via a shaft to the Gorlov turbine. The alternator converting tidal-mechanical energy into electricity can be positioned either above or below sea level. The power generated will finally be delivered to the BioRock™ structure via copper cables and allow for electrochemical deposition of calcium and magnesium rich layers on the mesh structure for coral rehabilitation.

Timeline:

<u>April-May 2006:</u>
MIT
- Determine Gorlov turbine size and power specifications for BioRock™ system
- Determine Alternator size and power output for BioRock system

Sagay
- Identify Carbin Reef site location for coral rehabilitation
- Locate area in Carbin Reef with ~2knots of sustained current tidal shifts adjacent to site

<u>June 2006:</u>
MIT
- Purchase Gorlov turbine components and send to Sagay City, Philippines
- Purchase anode material for BioRock™ structure and send to Sagay City, Philippines

Sagay
- Purchase steel rebars and fastening wires for constructing BioRock™ structure
- Purchase Alternator for electricity generation (i.e., vehicle alternator)
- Purchase lead-based anchoring weights to secure Gorlov turbine and BioRock structure
- Purchase copper cable wiring for electrical connection
- Purchase housing and shaft materials for Gorlov turbine

<u>July 2006:</u>
Sagay
- Assembly of 2-3 cylindrical BioRock™ structures (size of 2m diameter x 1.5m height)
- Construction of Gorlov turbine with housing and shaft
- Installation and anchoring of BioRock™ structure along Carbin reef seabed
- Installation and anchoring of Gorlov turbine adjacent to BioRock™ structure
- Connection of Gorlov turbine to BioRock structure
- Initial survey of marine population (at initiation of First-Step Coral project)

<u>August 2006:</u>
Sagay
- Assessment of BioRock™ structure mineral accretion
- Installation of first coral members on the BioRock™ structure to accelerate coral growth

<u>September 2006:</u>
Sagay
- Assessment of BioRock™ structure coral growth
- Survey of marine population impact from First-Step Coral project

October 2005 and onwards:
Sagay
- Perform seminars/workshops to other communities for replication of First-step project
- Integration of First-Step Coral into the Marine Museum as an off-shore marine exhibit
- Management of First-Step Coral turned over to the Sagay Marine Reserve Authority
- Monthly surveys of marine population impact

MIT
- Quarterly reporting of coral reef rehabilitation to be made to MIT First-Step Coral team and Ideas Competition organizers

Community Connection and Impact:

The Sagay City government and the Sagay Marine Reserve Authority will be the main community connection for the First-Step Coral team. Mr. Antonio Cueva and his staff of marine biologists at the Sagay Marine Reserve will be the initial contact point for determination of ideal Carbin reef sites and deployment of the BioRock™ structures and the Gorlov turbine. Sagay City is a coastal city heavily dependent on its fisheries to feed and sustain its economy and populace. The direct benefits of improved fish populations will be the local fishermen who are dependent on this resource for daily living.

As knowledge and experience is gained in this initial project, more efficient, lower cost designs and implementation kits will be developed such that other communities can then be educated in this project (see Figure 9). The impact of a successful First-Step Coral project in Sagay will create ripples that will reach numerous fishing communities in the Province of Negros and the rest of the Philippines. The ripples will occur via the dissemination of knowledge, experience and expertise from this initial project using the Sagay Marine Museum's educational programs that will be structured with the help of the First-Step Coral team. The success of the First-Step Coral system will translate into *active* coral reef rehabilitation rather than the former passive methods of sinking large scale structures that are not guaranteed for success. Once this project has been shown to work in many communities, the same model can be copied throughout the Coral Triangle region (see Figure 1) where over a quarter of the world reef resources are located and where anthropogenic pressures in exploiting these resources are very strong.

Figure 9. BioRock™ dome in Bali, Indonesia with rejuvenated fish population. (Ref. Dr. Thomas Goreau)

Footnote:

The city name Sagay was actually derived from the name of a small semi-spherical shell called "sigay" that was once found abundantly its beaches (see Figure 10). These shells were wantonly plucked from its shores and turned into jewelry and decorative pieces that can be found in many shops today. From the restoration of the marine resources we hope to bring back the splendor of what Sagay was named after.

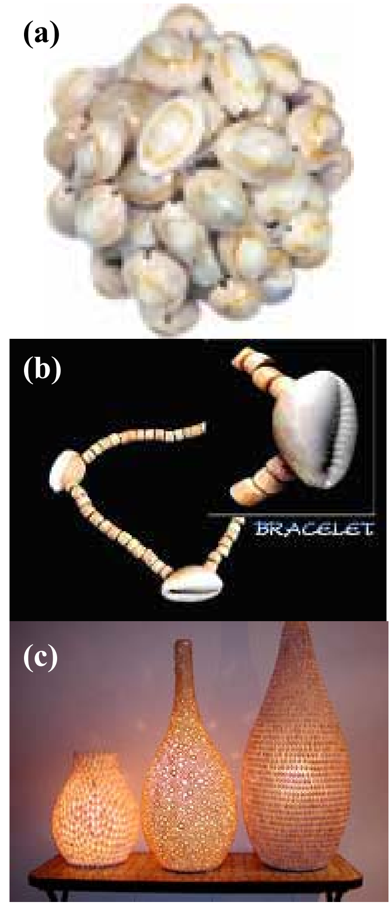

Figure 10. (a) Sigay shells, (b) Sigay bracelet, and (c) Sigay vase lamps

A letter from the Mayor of Sagay City, Negros Occidental, Philippines to First-Step Coral Team Leader:

Republic of the Philippines
Province of Negros Occidental
City of Sagay
OFFICE OF THE CITY MAYOR

April 18, 2006

Gerardo Jose la O'
Electrochemical Energy Laboratory
Ph.D. Candidate, Material Science and Engineering
Massachusetts Institute of Technology
77 Massachusetts Ave
Building 31-065
Cambridge, MA 02139 USA

Dear Mr. la O'

Greetings! I read with much interest the project you are proposing for our Sagay Marine Reserve. As you know, the local government of Sagay City has been working hard to try and preserve/conserve our precious marine resources. We have been undertaking different ways of restoring our destroyed and diminishing coral reefs.

After all, all our coastal communities are dependent on the sea for their food and their livelihood. So we must do everything to keep this precious marine resource sustainable now and for future generations.

Your idea is an innovative approach and we believe that it will work here in our area. Should you need any other information regarding our area, we are more than willing to assist you to make this project a reality. You have our full support in this endeavor.

Thank you!

Sincerely,

Leo Rafael M. Cueva
City Mayor
Sagay City, Negros Occidental
Philippines

Budget:

Item #	Project Component	Items and Materials	Cost ($USD)
1	BioRock Structure	Steel bars 1/2” diameter, total length ~50meters (for cylindrical BioRock structure ~2m diam. x ~1.5m height.)	$400
		Steel wire to fasten together BioRock structure	$50
		Lead-based anchors to secure BioRock structure in sea-bed	$200
		Copper cables for electric connection to BioRock™ structure (100meters length)	$300
		BioRock™ structure anode material (Ti-based alloy)	$700
2	Gorlov Helical Turbine	Plastic based Gorlov turbine blades with supporting housing structure	$500
		Lead-based anchors to secure Gorlov structure in sea-bed	$200
		Housing and shaft for Gorlov turbine	$200
3	Electric Alternator Motor	DC electric motor to convert tidal energy to electricity	$100
4	Construction Labor	Wages for up to five (5) Sagay-based workers involved with First-Step Coral ($5/day for 2weeks total time)	$350
5	Education and Outreach Program	Purchase of training/educational materials to teach fishing populace in Sagay	$200
		Printing of educational/training materials to help indoctrinate training course in Sagay	$200
6	Plane Tickets	2 Roundtrip plane tickets for team members from Boston to Sagay City, Philippines ($1200/ticket)	$2400
7	**Total**		**$5800**