Gigatech Solutions for Gigaton Problems: Monetizing the Value of Coral Reefs for Climate Resilience

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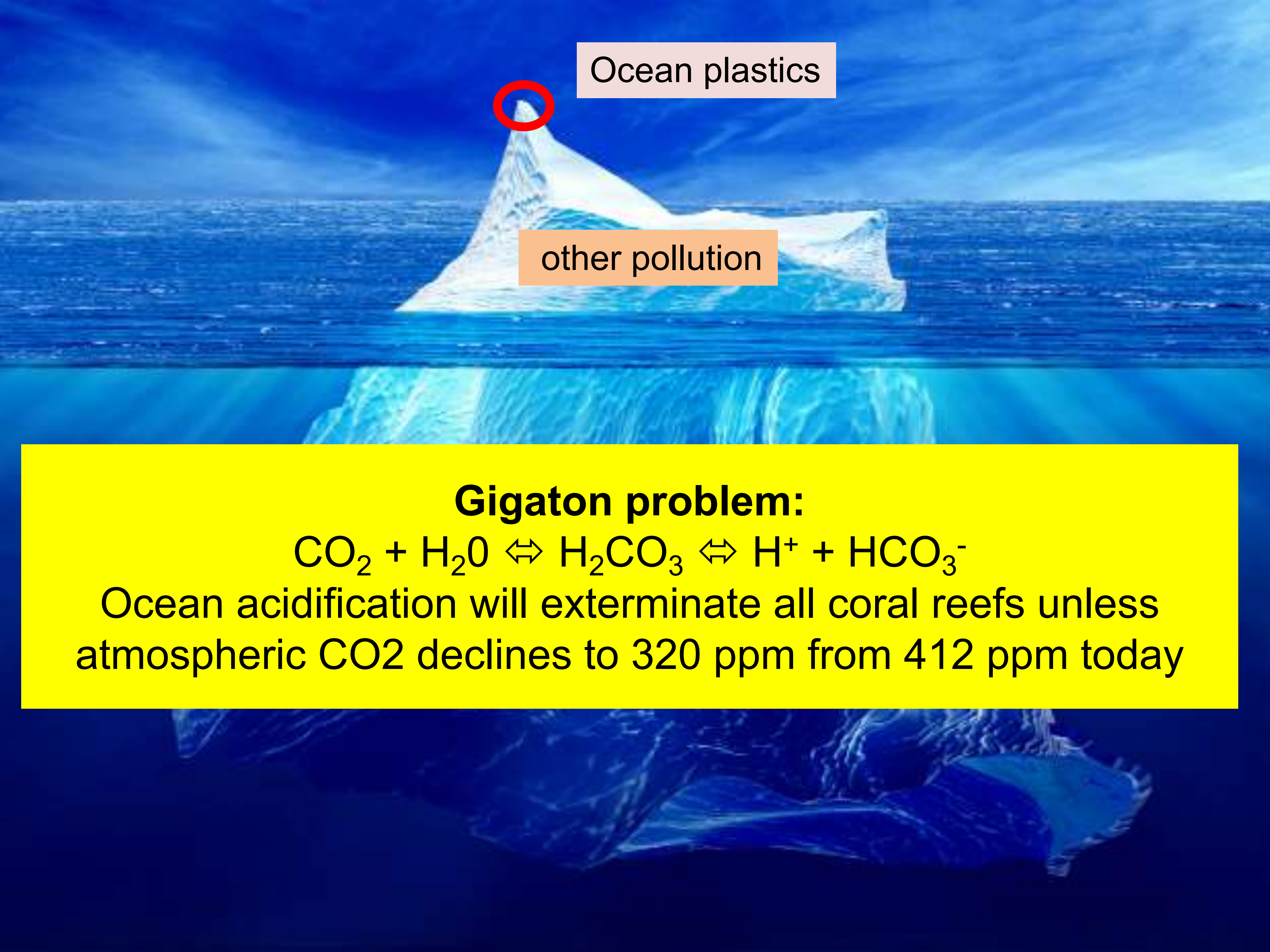


Gigaton problem:

$$CO_2 + H_20 \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$$

Ocean acidification will exterminate all coral reefs unless atmospheric CO2 declines to 320 ppm from 412 ppm today

Acidification

$CO_2 + H_20 \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$

Calcification

$Ca^{++} + 2\ HCO_3^- \Leftrightarrow CaCO_3$ (aragonite) + CO_2 (aqueous) + H_20

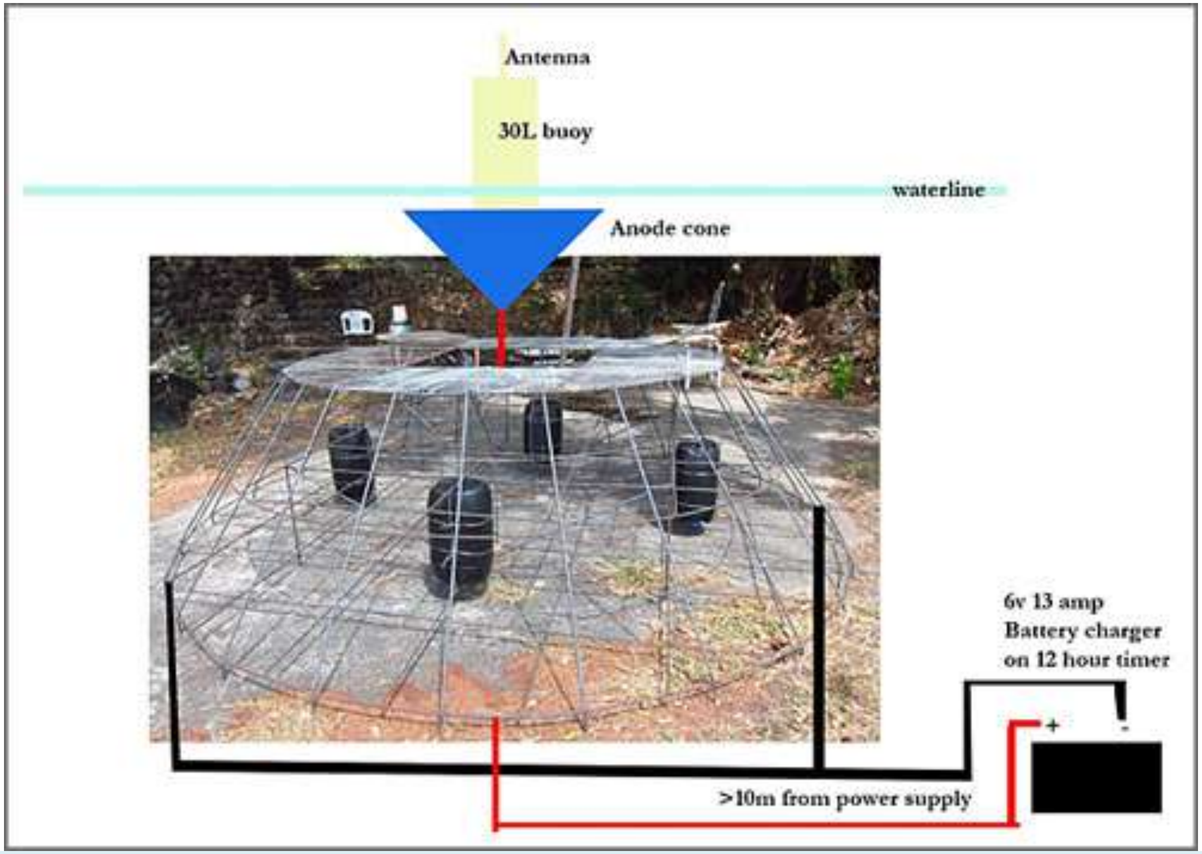
Gigatech solution:

- Grow reefs (and seagrasses) faster than climate change is killing them by mimicking natural processes

- ***Long-term:*** need to draw down 50 Gigaton CO_2 / year for 20 years

Step 1: 3-D Printing of $CaCO_3$ -- Proven science and engineering

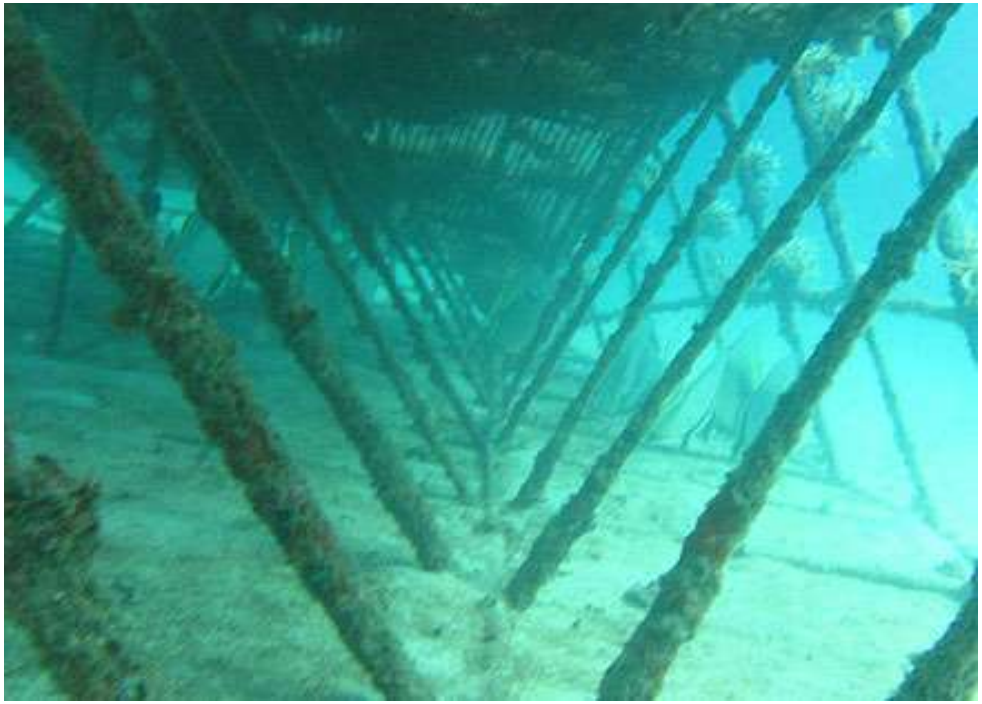
- Cathodic protection systems widely used in petroleum industry
- Anode plus cathode of shaped rebar
- "Trickle" charge: no safety issues to divers or marine life
- Off-the-shelf materials + semi-skilled labor



W. H. Hilbertz & T. J. Goreau, 1996, Method of enhancing the growth of aquatic organisms, and structures created thereby, United States Patent Number 5,543,034, U. S. Patent Office (14pp.).

Observed $CaCO_3$ growth rates:
1 – 2 centimeters / year radial growth around rebar

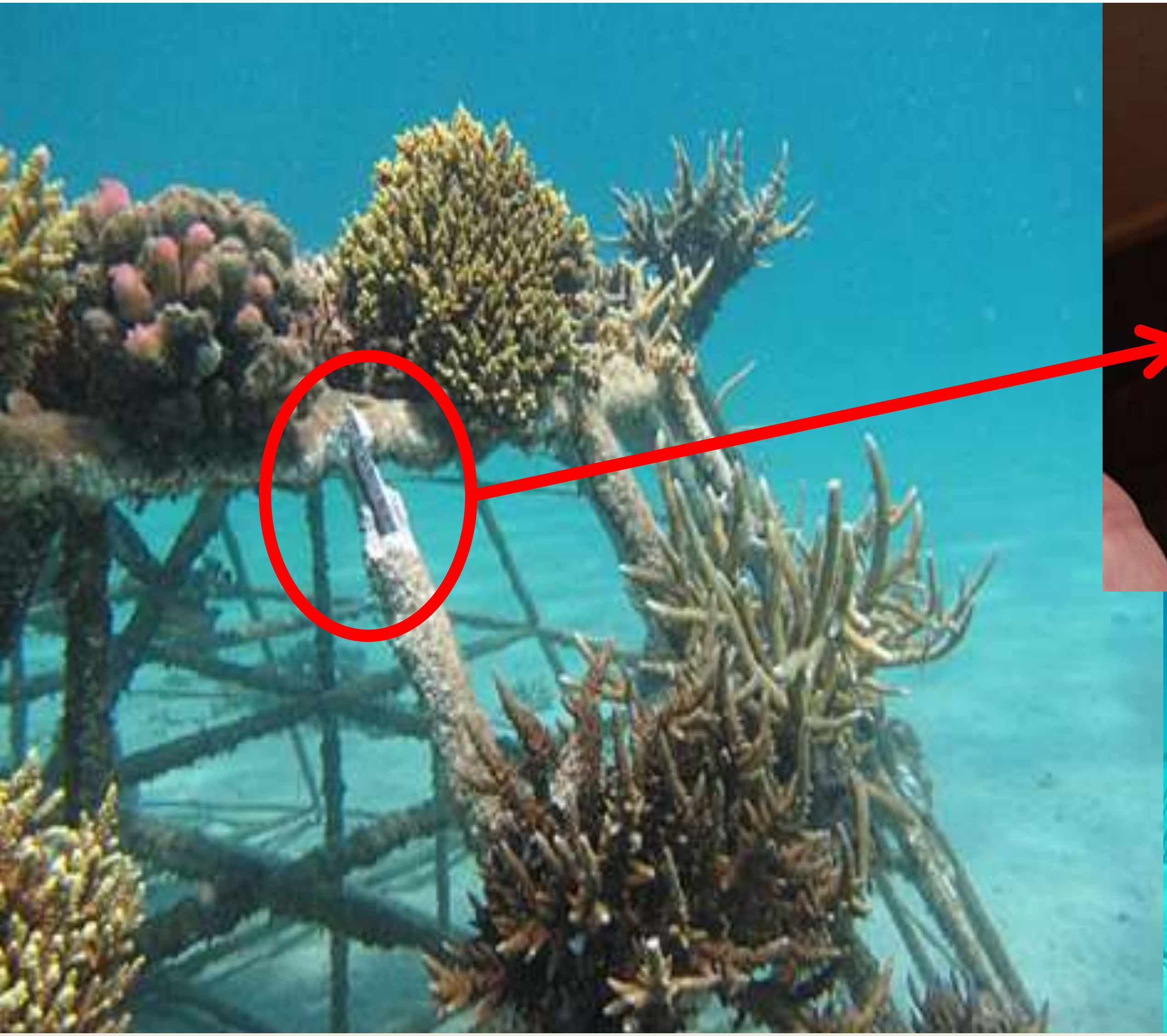
Observed yield:
0.5 – 0.6 tons of $CaCO_3$ per Megawatt-hour electricity



Step 2: + coral propagation; 1 year growth at Nasugbu, Philippines

Source: Coral Triangle Conservancy, ree.ph

Coral Triangle Conservancy – Nasugbu, Philippines
“reeph” production of limestone & e-reef



Photos courtesy of Scott Countryman, Coral Triangle Conservancy: ree.ph

How to monetize reef cultivation at scale?

Natural capitalism / circular economy

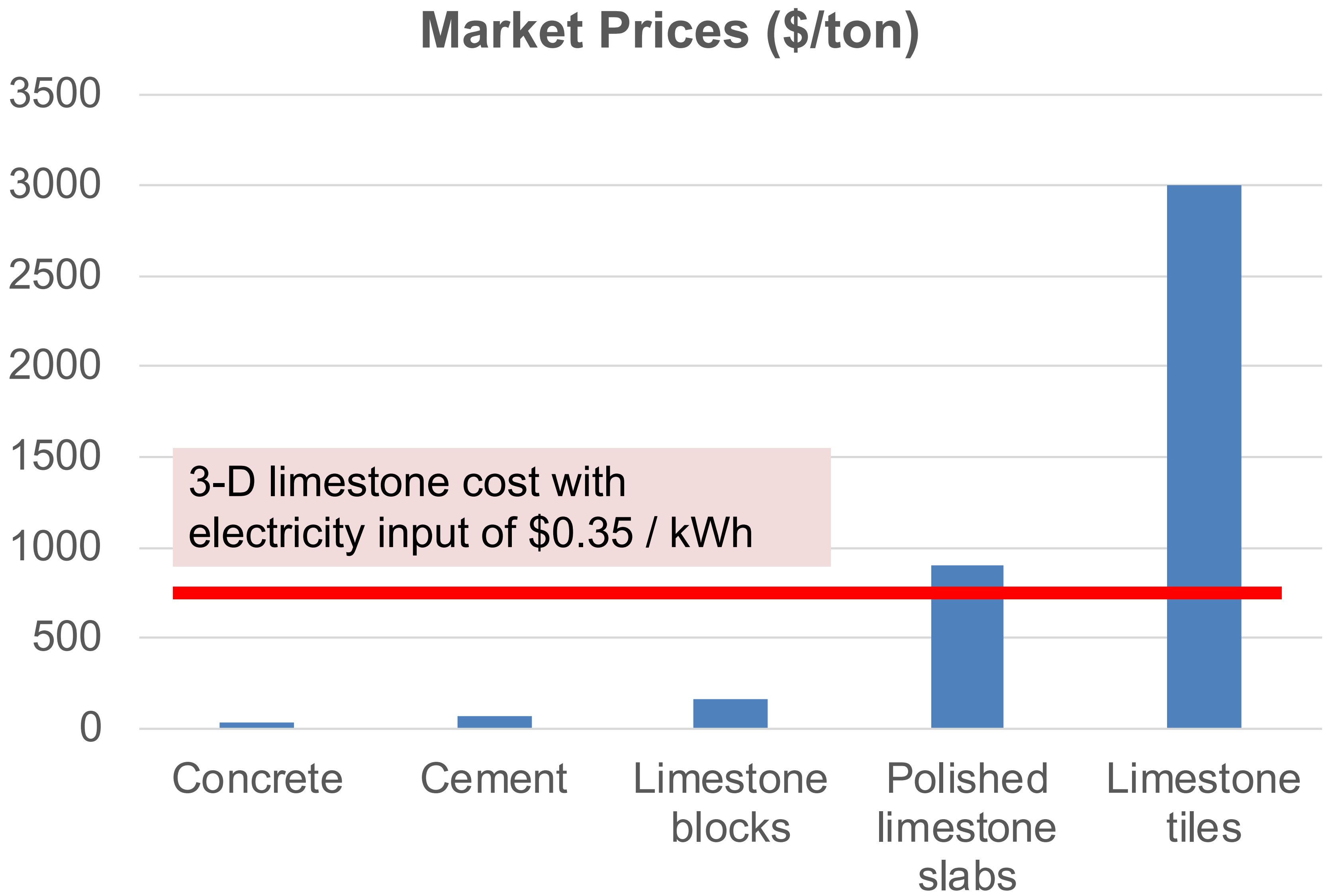
- Building products, floating docks, etc.
- Living breakwaters / nature-based defenses
- Insurance policies
- Marine aquaculture – shellfish, seagrasses, etc.
- Other???

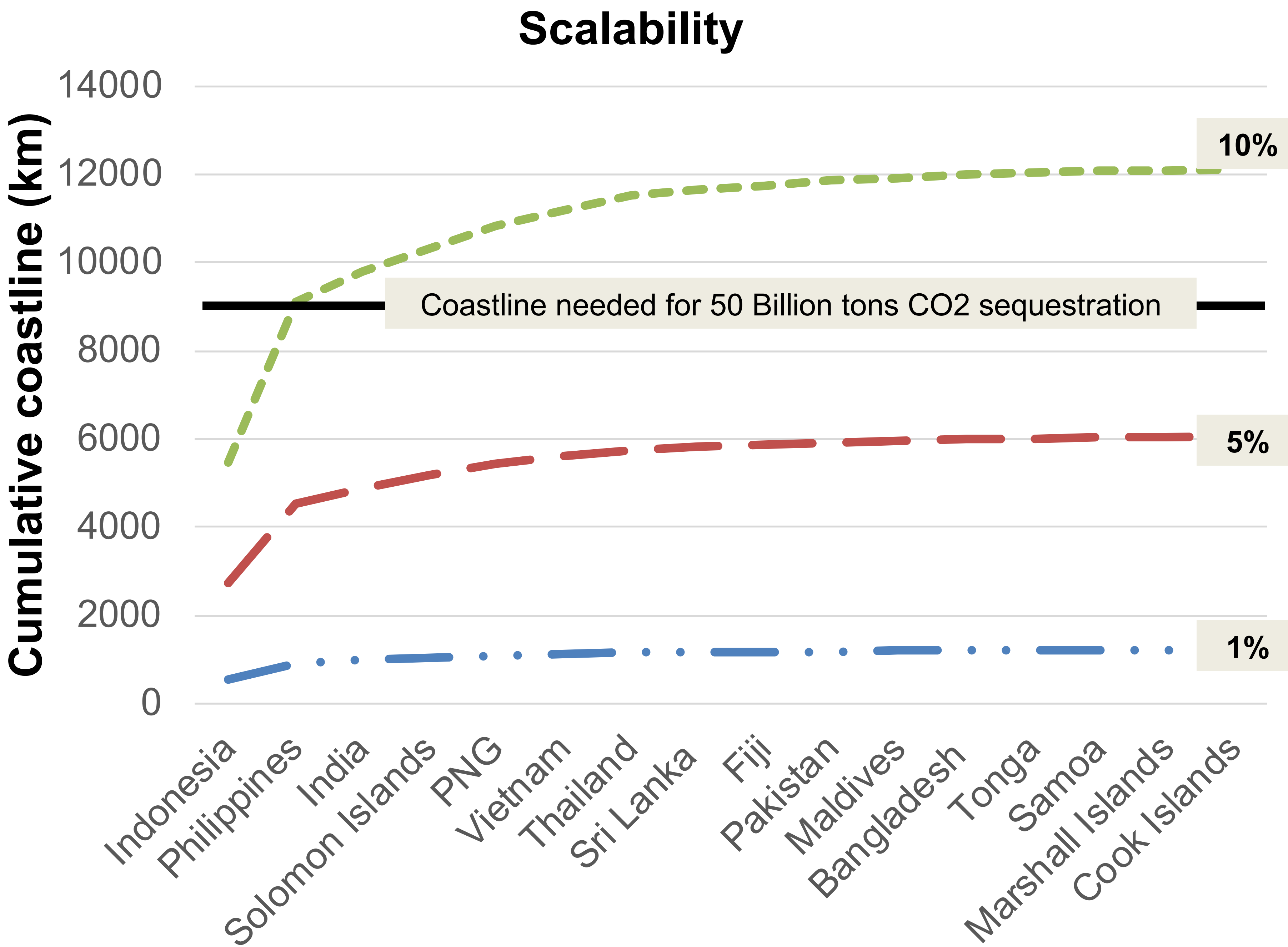
~ 1 year growth (left) and 5 year growth (right)

Hilbertz wanted to grow sustainable building materials….

Mineral accretion sample from Maldives which was grown electrolytically during **only five years.**

3-D Printing of Sustainable Limestone Building Materials

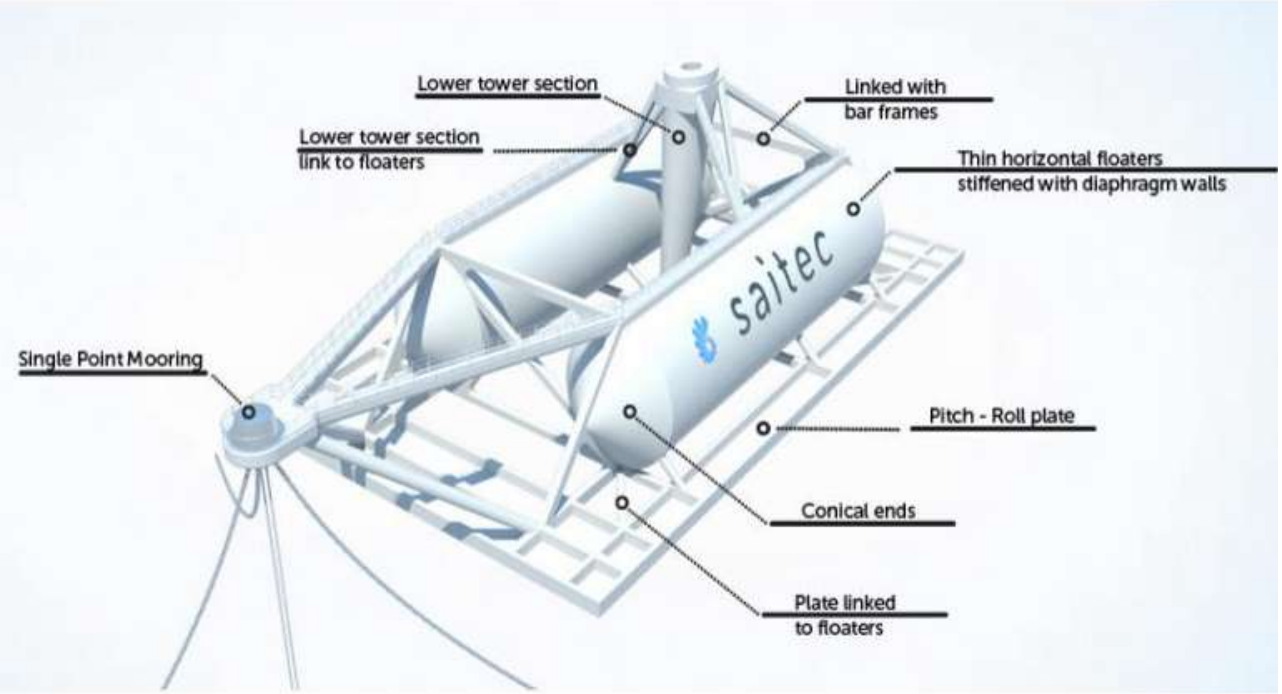




Scalability
Cumulative coastline (km)
14000
12000
10000
8000
6000
4000
2000
0
10%
5%
1%
Coastline needed for 50 Billion tons CO2 sequestration
Indonesia
Philippines
India
Solomon Islands
PNG
Vietnam
Thailand
Sri Lanka
Fiji
Pakistan
Maldives
Bangladesh
Tonga
Samoa
Marshall Islands
Cook Islands

Floating structures: Self-healing "ferro-cement" floatation?

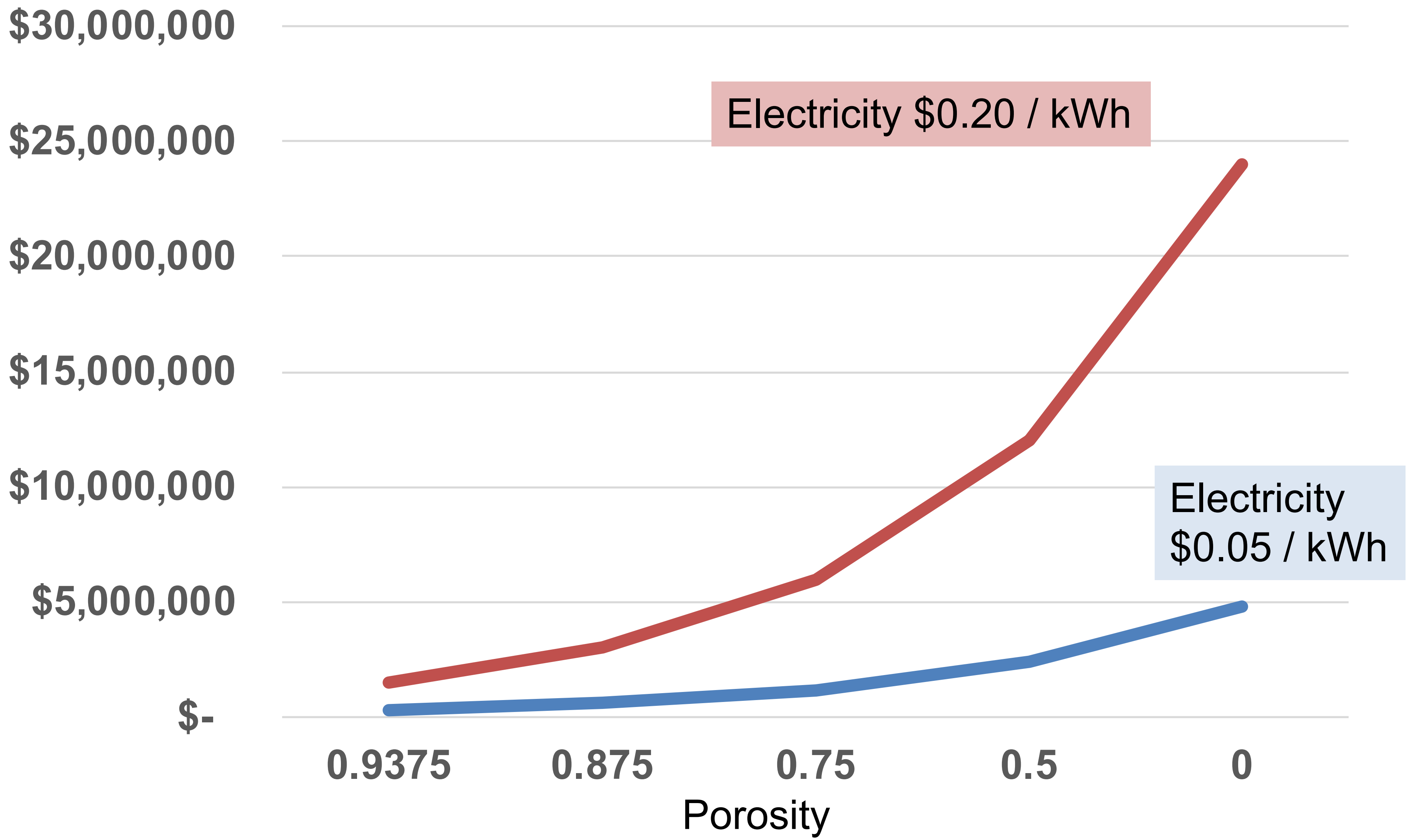
Prototype swing-around twin hull (SATH) design by SAITEC



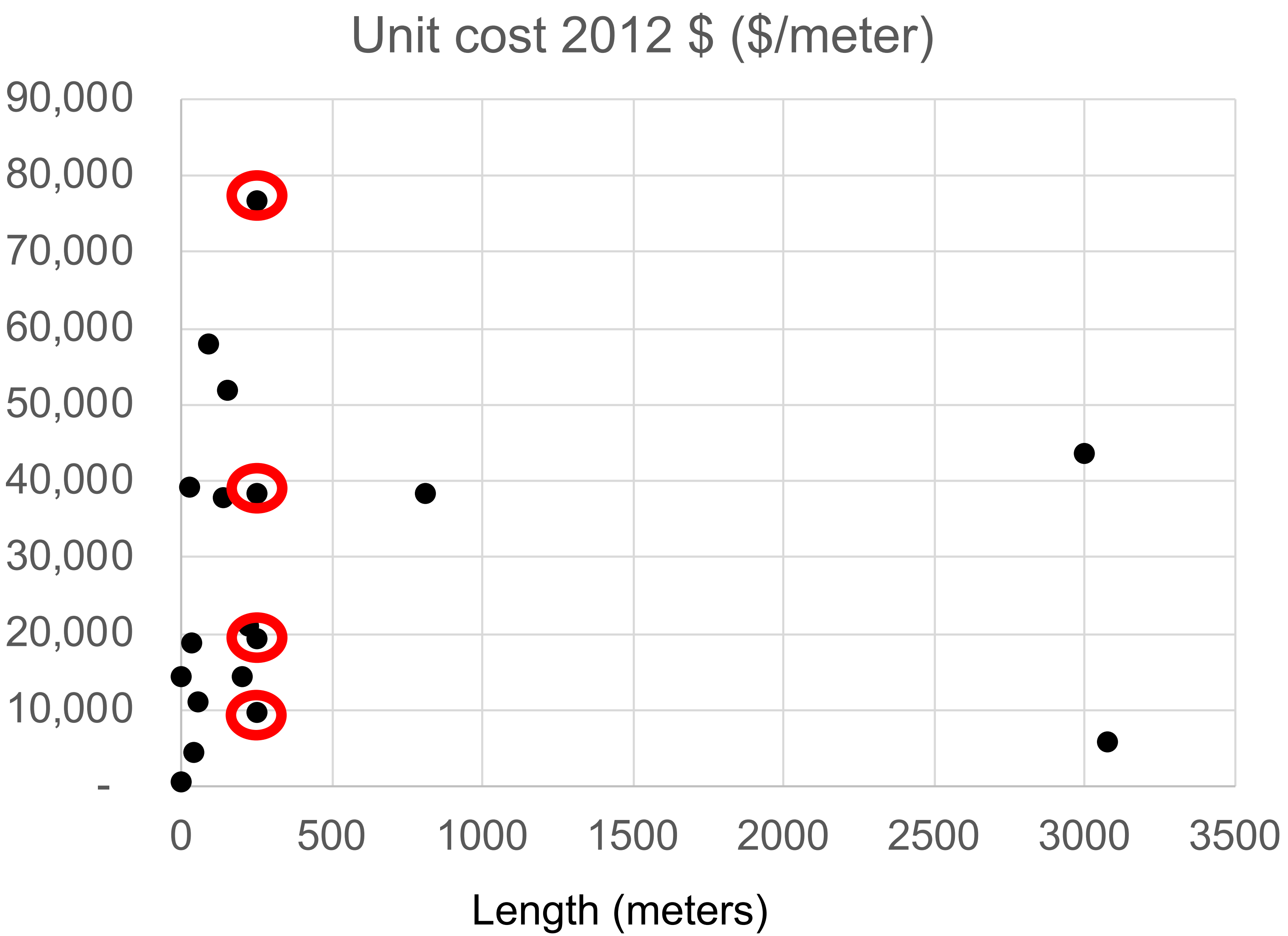
Barrier reefs are natural breakwaters… breakwaters can be grown in place and are also reefs which support marine fisheries and coastal livelihoods!

Source: Coral Triangle Conservancy, ree.ph

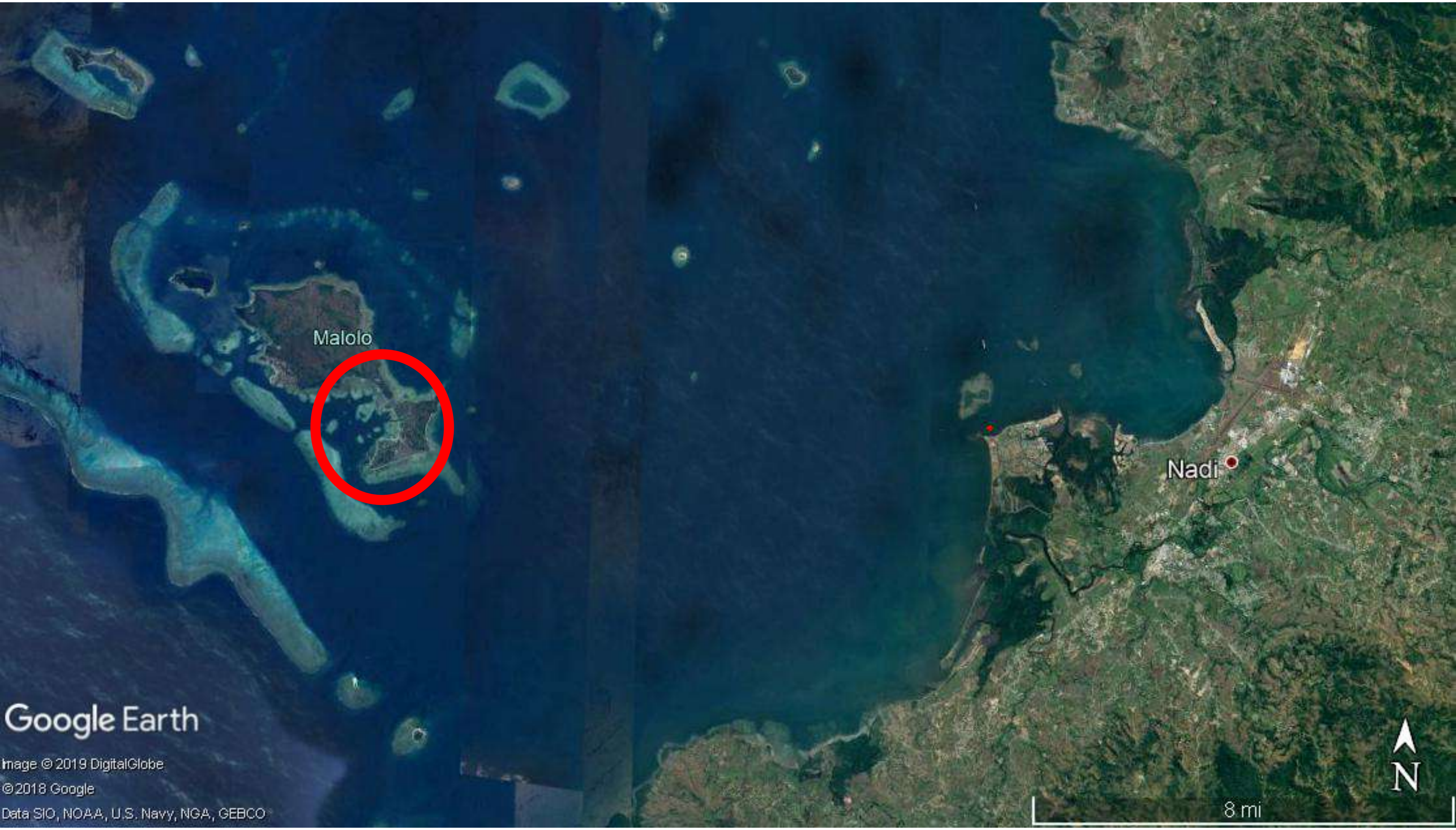
3-D Printing of Living Breakwaters: "Burke" class 250 m long x 5 m high x 5 m wide at top & 10 m wide at base



Breakwater unit costs vs. length in Asia-Pacific



Breakwater at Malolo ~ 250 meters long

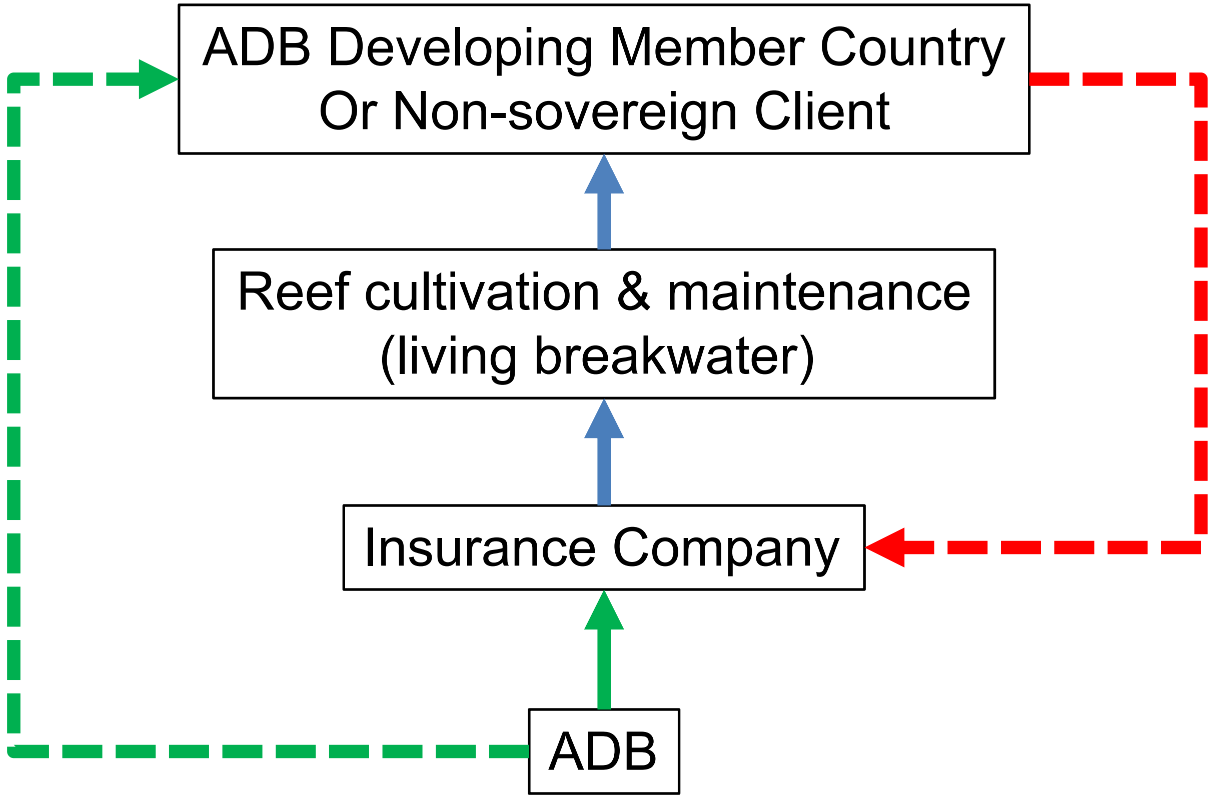


Breakwater at Malolo ~ 250 meters long

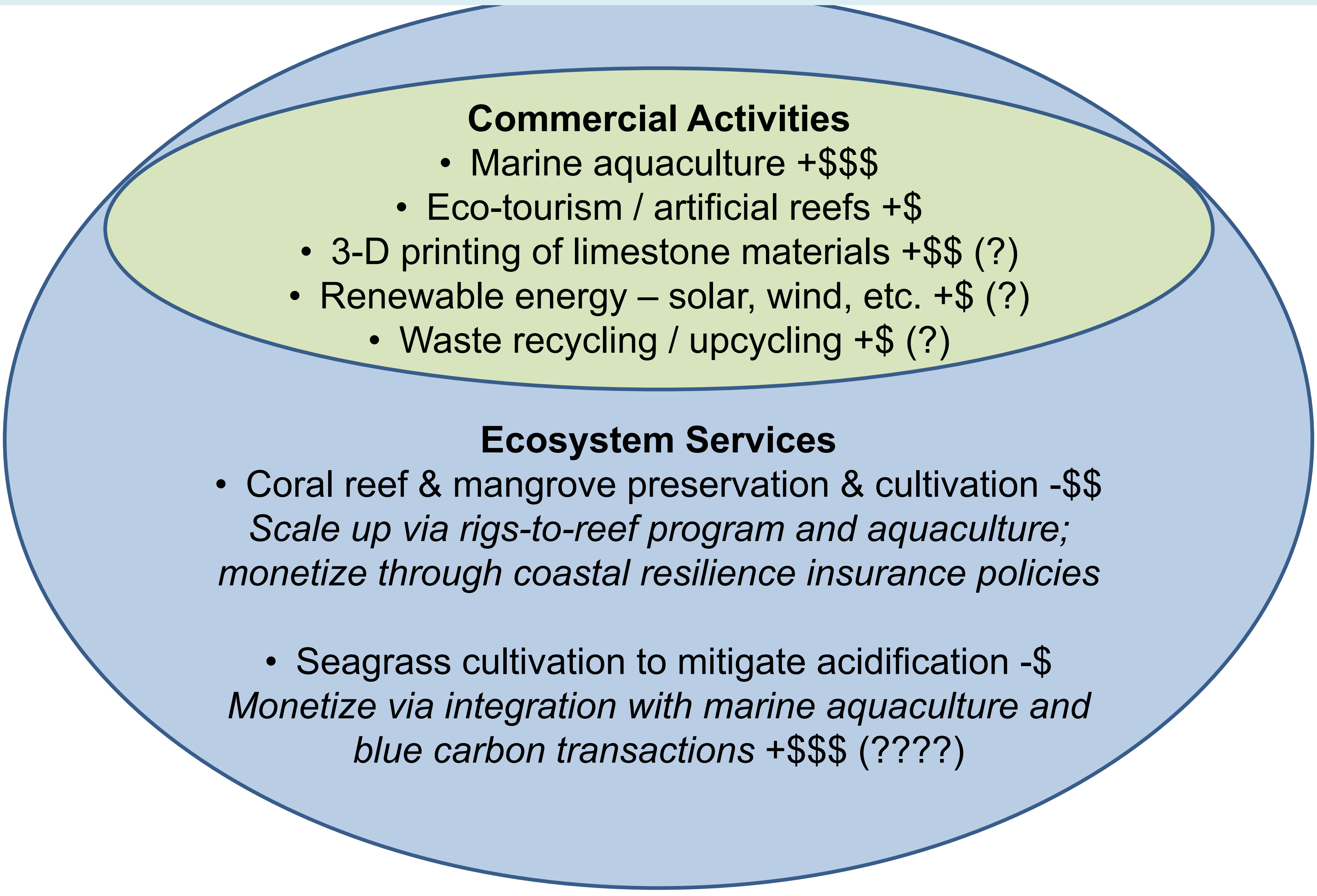
Breakwater at Malolo ~ 250 meters long

Coastal Zone Insurance Policy

- ADB underwrites coverage in partnership with insurance / re-insurance partners (e.g., SwissRe) to buy down cost vs. normal policy
- Country / Client buys policy from insurance partner
- Insurance partner procures reef as breakwater
- ADB can directly support Country / Client if necessary



Marine aquaculture, artificial reefs, renewable energy, & ecotourism for ecosystem services (MARES) investment program



21st Century Marine Aquaculture (Norway)

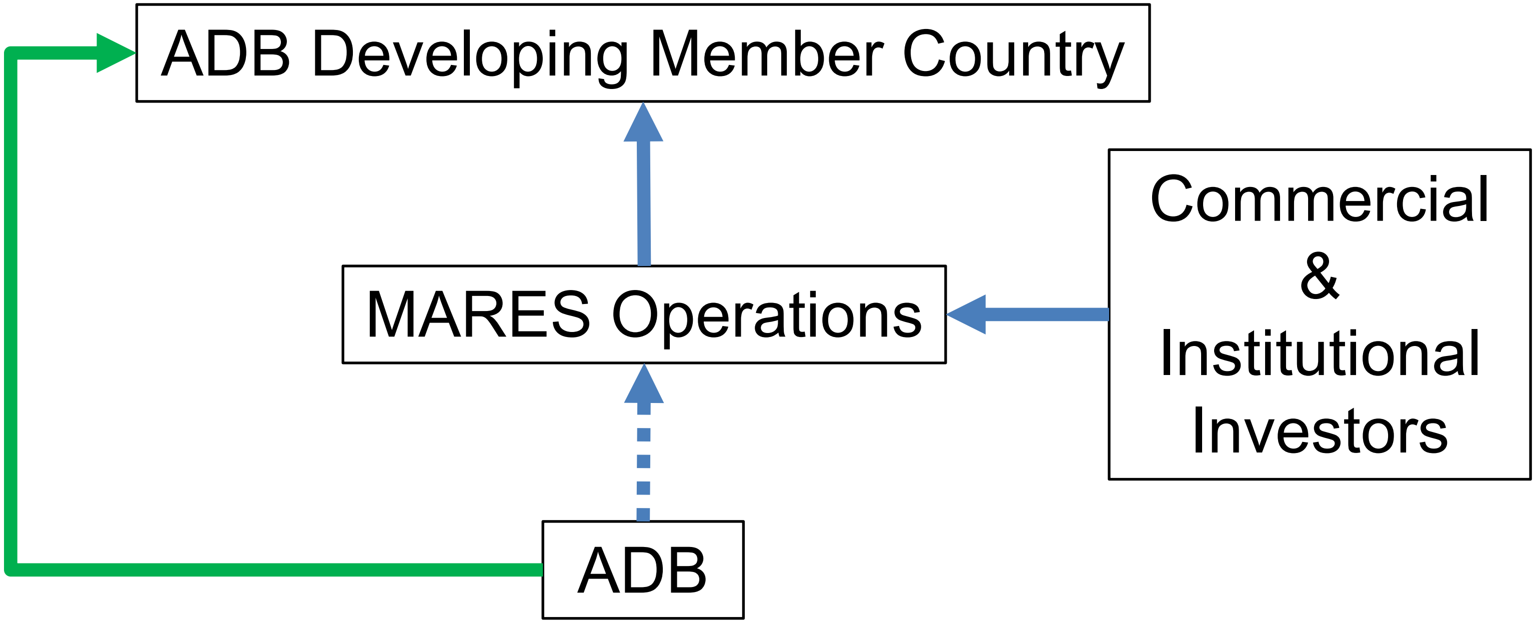
Rigs to reefs

US: 516 conversions from 1987-2016 (11% of retirements)

@ US conversion rate, > 100 candidates in SE Asia

Marine aquaculture, artificial reefs, renewable energy, & ecotourism for ecosystem services (MARES) investment program

- ADB facilitates DMCs' creation of public-private partnerships to crowd in commercial investment including institutional investors (P8, SWFs)
- DMCs tender space in exclusive economic zones (EEZs) to commercial operators & collects royalty on revenues / profits
- ADB / PSOD may support MARES operations directly



Summary & the way forward

- There is no payment for ecosystems services solution in view, so we need other business models to commercialize preservation and cultivation of reefs.
- 3-D limestone printing pioneered by Hilbertz & Goreau is proven technology. Living breakwaters, floating docks and other structures, and sustainable building materials may be commercially attractive but all require patient capital for pilot/prototype operations.
- It might be possible to jump-start a large-scale reef program in Southeast Asia if countries commit to a rigs-to-reef program, similar to that in the US.
- Integrated development of marine aquaculture (shellfish + seagrass), reefs, and ecotourism appears attractive but requires a demonstration project which requires government support
- ADB can help with knowledge transfer, advisory services for PPPs, project finance, blue bonds, etc. but only if DMCs and private sponsors request assistance: ***"there's money for the project if there's a project for the money."***

Transcendergy, L.L.C

solutions for a sustainable future

Thank you!

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Key References

Scott Countryman, 2017. *Sustainable Building Materials Grown In Seawater*. Asia Clean Energy Forum. Manila. [Presentation in main forum session on the Food-Energy-Water-Climate Resilience Nexus.]

Goreau, T.J. (2014) *Electrical Stimulation Greatly Increases Settlement, Growth, Survival, and Stress Resistance of Marine Organisms*, Natural Resources, 5, 527-537, http://dx.doi.org/10.4236/nr.2014.510048

Wolf H. Hilbertz, 1979, Electrodeposition of minerals in sea water: Experiments and applications, IEEE Journal on Oceanic Engineering, 4:1-19

Wolf H. Hilbertz, 1992, Solar-generated building material from seawater as a sink for carbon, Ambio, 21, 126-129

W. H. Hilbertz & T. J. Goreau, 1996, Method of enhancing the growth of aquatic organisms, and structures created thereby, United States Patent Number 5,543,034, U. S. PATENT OFFICE (14pp.).

Millison, D. and S. Countryman, 2017. *Sustainable Pre-stressed Concrete from Seawater*. International Conference on Sustainable Infrastructure; American Society of Civil Engineers, New York City, October 2017.

References (2)

In 2009, former chief scientist of the Australian Institute of Marine Sciences made a presentation to the UK Royal Society titled “Is the Great Barrier Reef on Death Row”. The massive bleaching that occurred in 2015-16 was clearly anticipated in the 2009 presentation: https://www.oceanarkalliance.org.au/dr-verons-coral-crisis-presentation-to-royal-society-london/

In April 2019, some scientists say marine life will be extinct by 2048 “it’s not a prediction”: https://earthmaven.io/sustainablehuman/old-story/salt-water-fish-extinction-seen-by-2048-Udxlu7LsXkisG0OmuzAbcA/?utm_campaign=meetedgar&utm_medium=social&utm_source=meetedgar.com

The first commercial operation in US federal waters combining seagrass plus shellfish is operating offshore California; see: https://catalinasearanch.com/ Catalina Sea Ranch’s initial 100 acre mussel farm was expected to have 50% profit margin; the operation is proposed to be expanded to 1000 acres with up to 90% profit margin. See: https://static1.squarespace.com/static/591e33d3e6f2e191e5349dc6/t/596f7ebf37c58152ae4aff2b/1500479170878/Aquaculture+NA.pdf

References (3)

The ability of kelp and other seagrasses to metabolize CO_2 and mitigate pH locally is noted here:
https://e360.yale.edu/features/kelp_seagrass_slow_ocean_acidification_netarts
https://www.dw.com/en/making-coral-grow-50-times-faster-than-nature/a-45794571

At least one company is attempting to commercialize coral farming based mainly on the micro-fragmenting method. See: http://www.coralvita.co/coral-farming

Two of the largest artificial reef programs using the "biorock" process are in Indonesia. The site at Gili Trawangan off the northwest coast of Lombok offers courses in reef surveying and protection, and how to design and grow electric reefs. See: http://giliecotrust.com/biorock/

Catalina Sea Ranch's website notes: The legs of three offshore oil platforms located about two miles away are teeming with marine life and blanketed with mussels and scallops thriving on their consumption of single-celled phytoplankton. See: https://catalinasearanch.com/offshore-aquaculture

References (4)

The inspiration for combining marine aquaculture with rigs-to-reefs is from the case studies on these topics in: OECD. 2019. *Rethinking Innovation for a Sustainable Ocean Economy*, OECD Publishing, Paris. *https://doi.org/10.1787/9789264311053-en*

Living breakwaters:
http://nrcsolutions.org/living-breakwaters/

New York City "living breakwater" for climate resilience 2017
https://stormrecovery.ny.gov/sites/default/files/crp/community/documents/Appendix%20D%20-%20Breakwaters%20Project%20Benefit%20Cost%20Analysis.pdf

Breakwater cost estimates:
https://www.researchgate.net/figure/Costs-versus-water-depth-and-wave-height-reduction-extents-of-Nature-based-Defence-NbD_fig3_301791321

Natural climate solutions (NCS) – US prospects
https://advances.sciencemag.org/content/4/11/eaat1869

Biomimetic CaCO3 formation with CO2 capture from air:
http://www.blueplanet-ltd.com/

References (5)

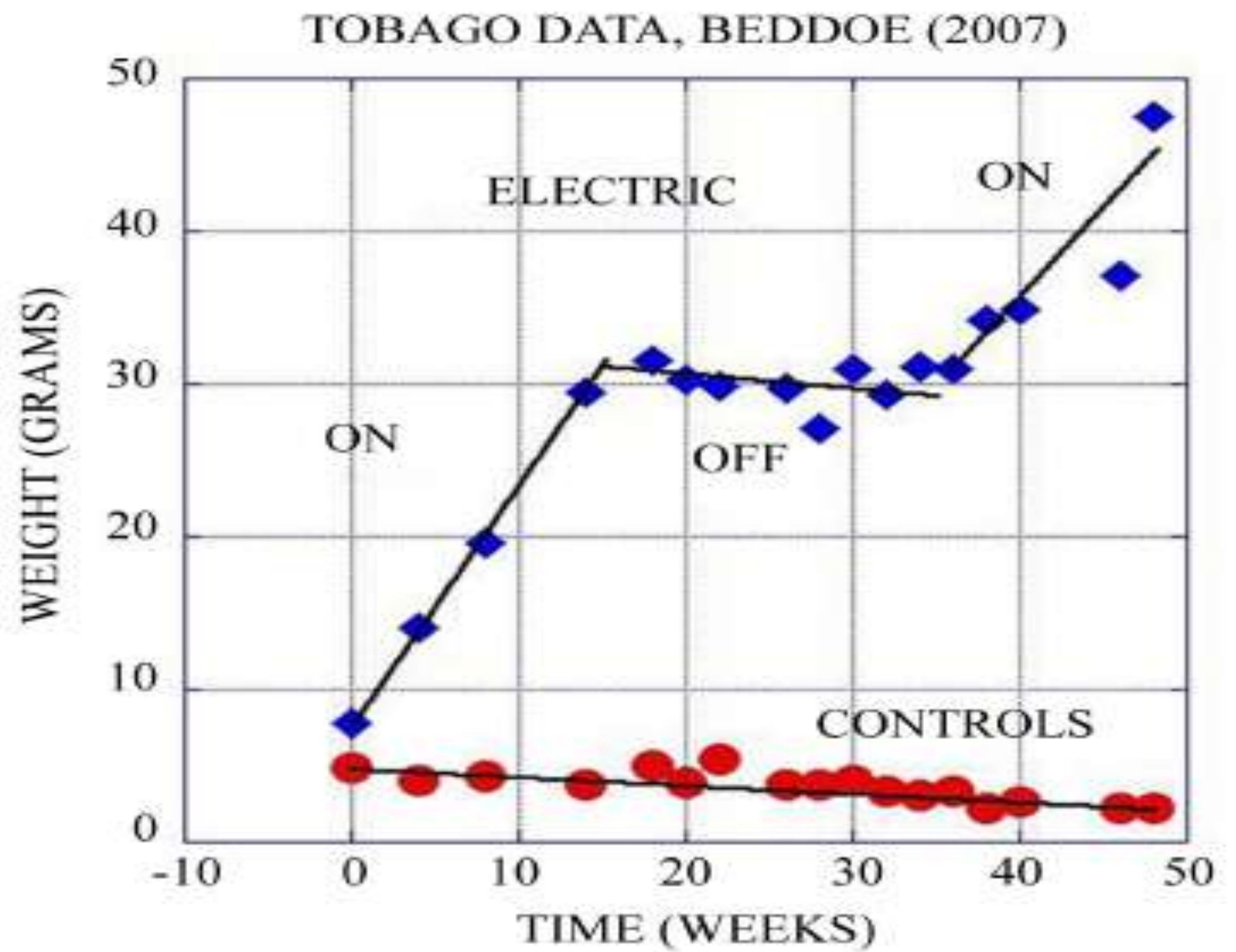
Breakwater project costs in Asia Pacific region:

https://www.researchgate.net/figure/Costs-of-construction-or-significant-maintenance-intervention-for-tropical-breakwaters_tbl1_262306245

Location	Source (refs)	Length (*m*)	Year	Original cost ($)	Cost* 2012 ($)	2012 Unit cost ($ m^{-1})
Sri Lanka	64	16,000†	1994‡	13,400,000	20,759,511	1,297
Maldives	16	1§	1997‡	10,000	14,305	14,305
Haleiwa, Hawaii	65	58	1975	150,000	640,132	11,037
Hilo, Hawaii	65	3,073	1946	1,500,000	17,661,077	5,747
Kalaupapa, Hawaii	65	35	1967	95,000	653,037	18,658
Kawaihae, Hawaii	65	808	1973	6,000,000	31,026,216	38,399
Manele, Hawaii	65	143	1965	742,850	5,414,410	37,863
Nawiliwili, Hawaii	65	152	1959	1,000,000	7,889,828	51,907
Pohoiki, Hawaii	65	27	1979	335,500	1,061,003	39,296
Auasi, American Samoa	65	206	1981	1,166,300	2,945,825	14,300
Aunuu, American Samoa	65	27	1981	2,018,400	5,098,048	188,817
Tau, American Samoa	65	88	1981	2,020,400	5,103,099	57,990
Agana, Guam	65	221	1977	1,220,550	4,624,273	20,924
Sungai, Malaysia	66	1§	2008	428	456	456
Korea	67	3,000	2010	124,000,000	130,561,214	43,520
Nakhon Si Thammarat, Thailand	68	40	2012	180,950	180,950	4,524

*Project costs were adjusted from year of project completion to 2012 US$ using the online inflation converter available at www.usinflationcalculator.com.
†Interventions located on the west coast of Sri Lanka (Negombo and Moratuwa).
‡Date of construction unavailable. Year refers to when the cost estimate was determined in the source publication.
§Costs originally given in $ m^{-1}.

Electric reefs appear to be resistant to acidification & bleaching & can be grown faster than the climate is changing…
therefore, grown in place breakwaters should be considered as climate change adaptation finance



Source: Goreau, T.J. (2014)

One of the richest countries in the world was not able to prevent loss of ~ 1/3 of the Great Barrier Reef

"Despite the massive death of corals from high temperature in 2016, Biorock reefs in Indonesia maintained under 24-hour power suffered no noticeable mortality at all, making it the only method that protects corals from dying from global warming."

-- Thomas Goreau

Accessed on 30 January 2017 from: http://www.globalcoral.org/2017-gcra-plans/

Catalina Sea Ranch (California) – start up with mussels, followed by phase in of kelp then other shellfish

R2R for Ecotourism: Seaventures Dive Rig, Malaysia