We Live on Planet Sea

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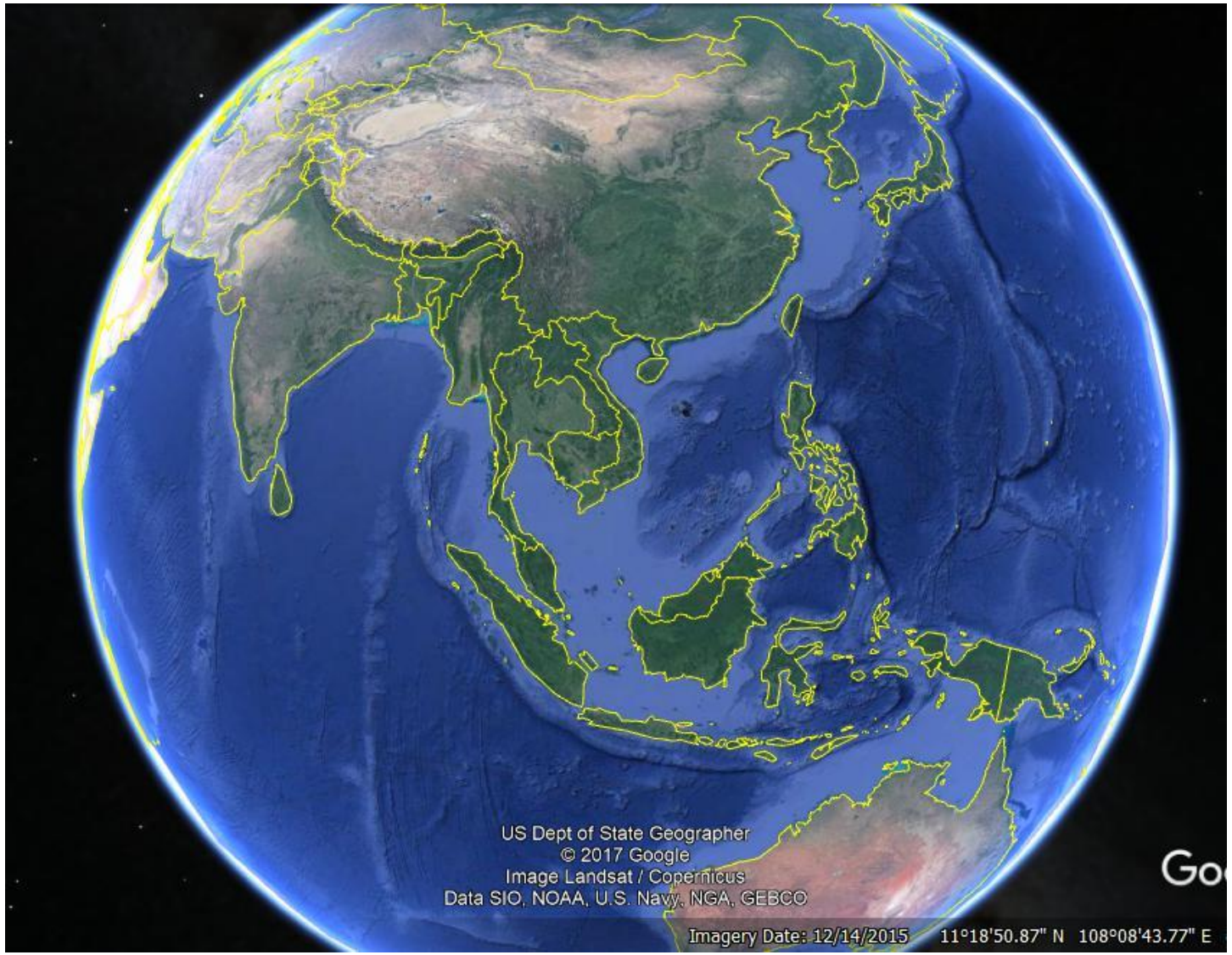
The energy transition is well underway <u>onshore</u> – *but this is not enough to save the planet*

**Like oil & gas fields, but no carbon, no drilling required, no blowouts, no spills, reserves never decline*

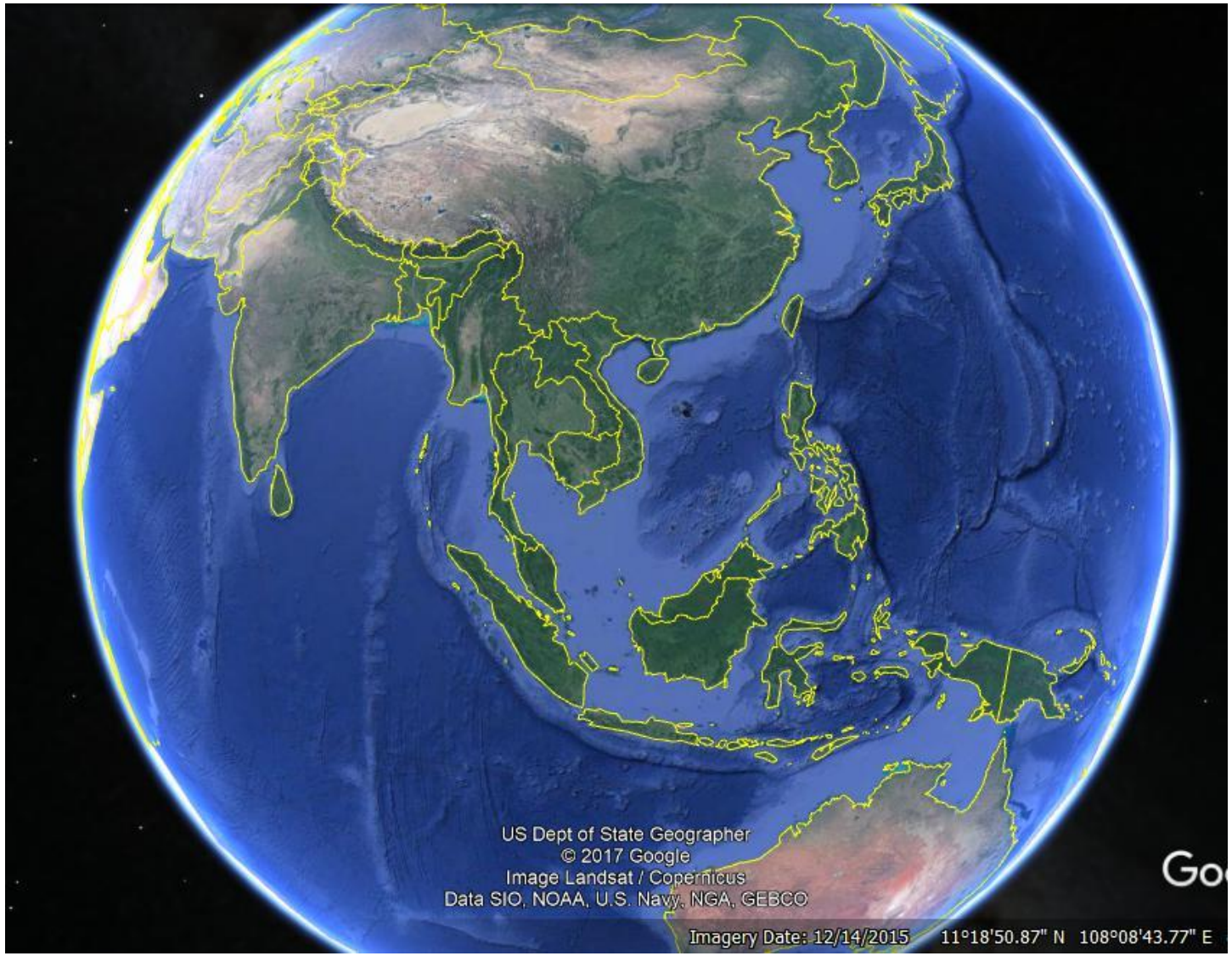
Photo courtesy of Anne Rasmussen



The Big Picture

More than 70% of the Earth's surface is covered by the oceans…

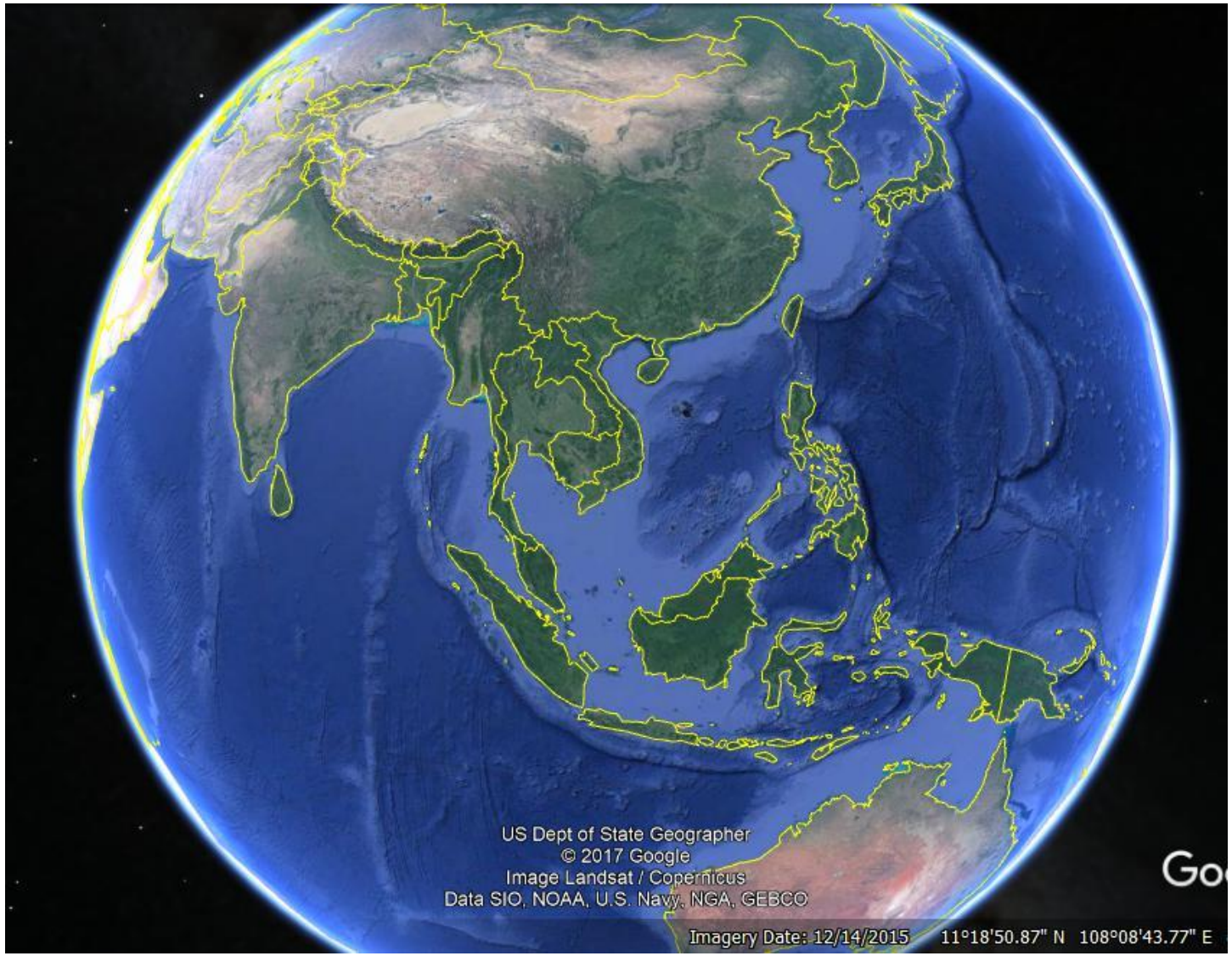
What problems are we trying to solve?



- Sea blindness*
- Wealth Blindness*
- Ocean Acidification**

* https://medium.com/natural-security-forum/from-sea-blindness-to-wealth-blindness-2251dd804bf5#.8h4s0sfoy

** https://www.goesfoundation.com/



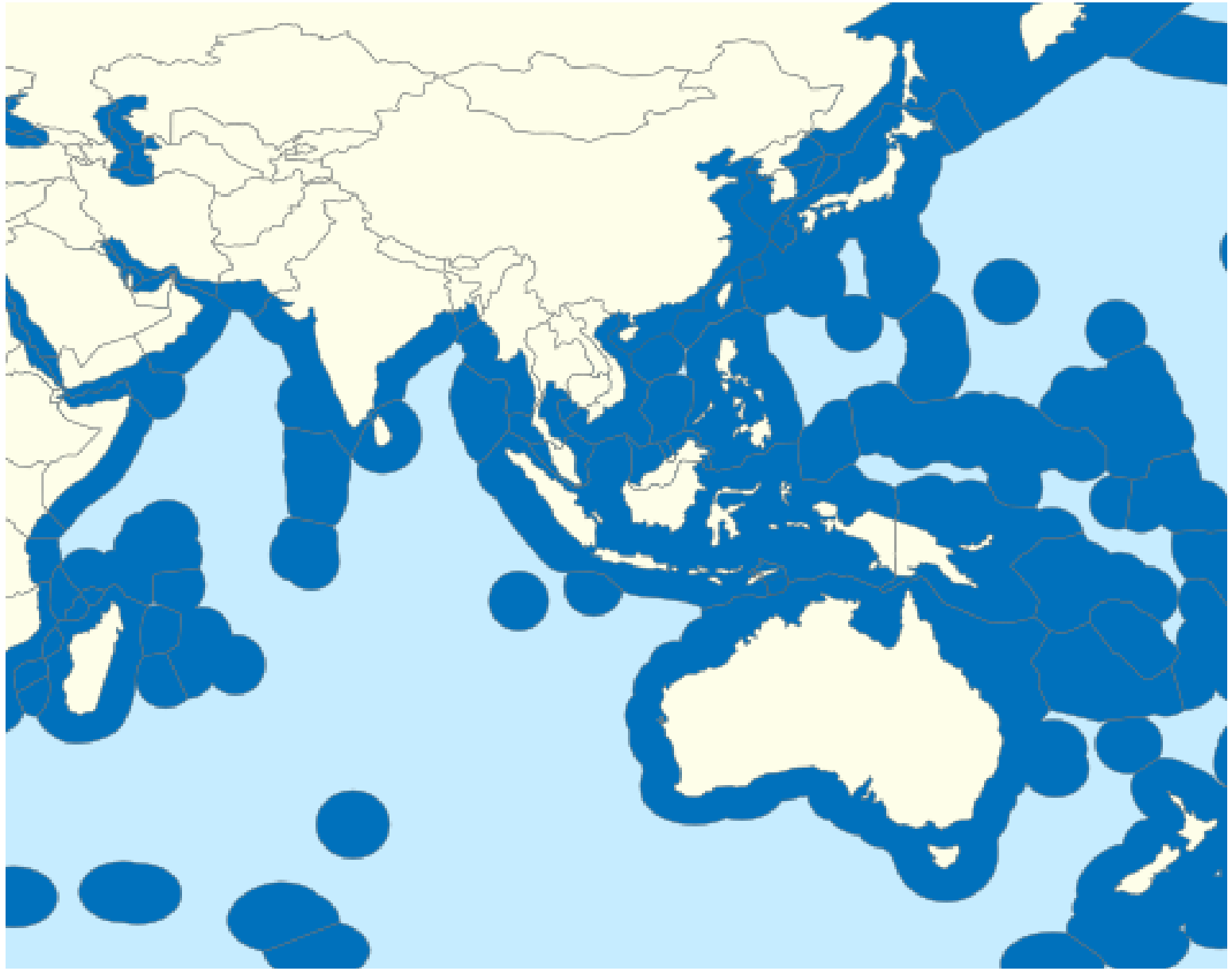
Sea blindness

The oceans provide 50-75% of the oxygen we breathe… and were mentioned only once in the Paris climate accord.

The UNFCCC process will not save the oceans.

The Paris targets of 450 ppm atmospheric CO2 and +1.5 C are the death penalty for tropical reefs*

* J.E.N. Veron. 2009. *Is the Great Barrier Reef on Death Row?* Presentation to the UK Royal Society.

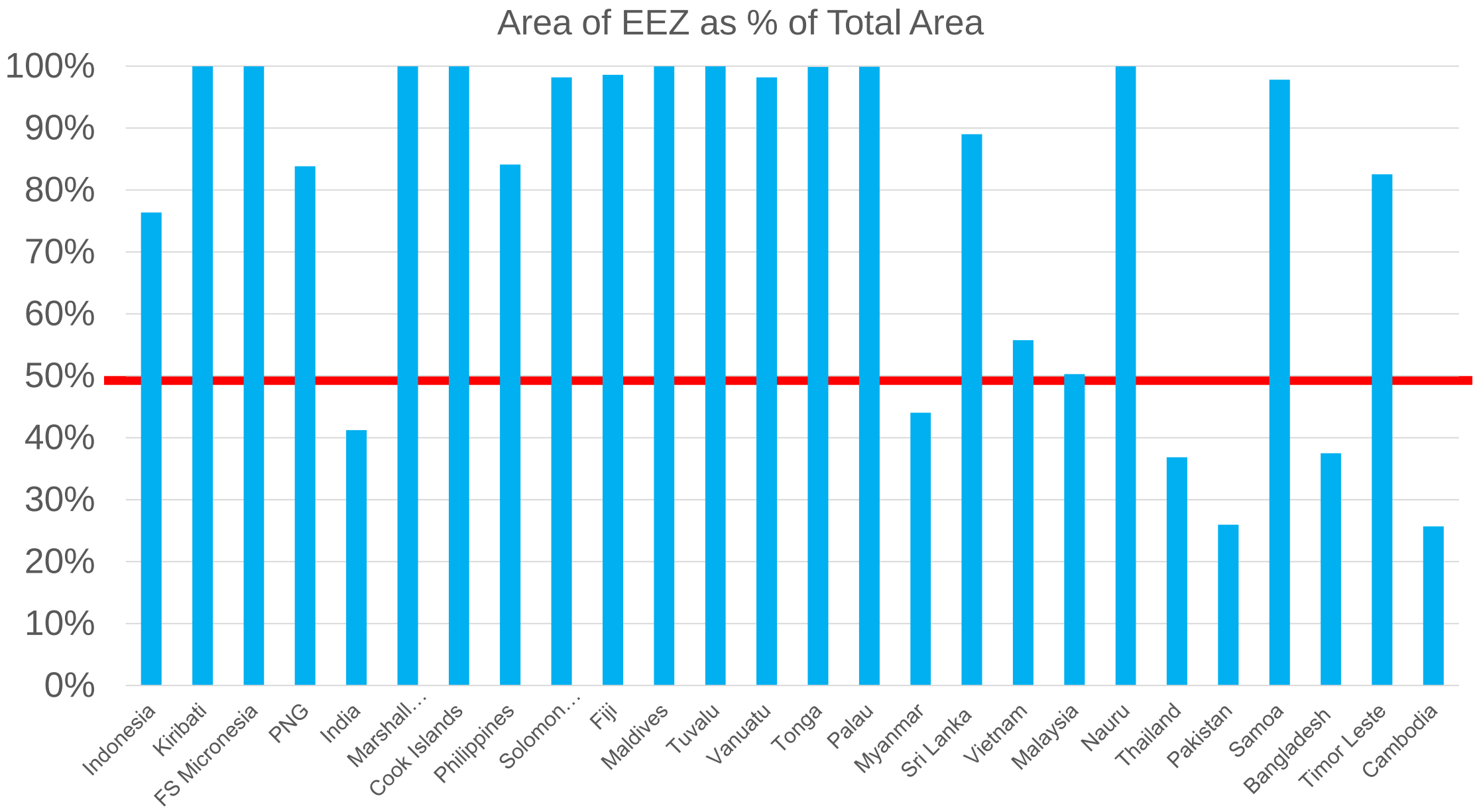


Wealth blindness

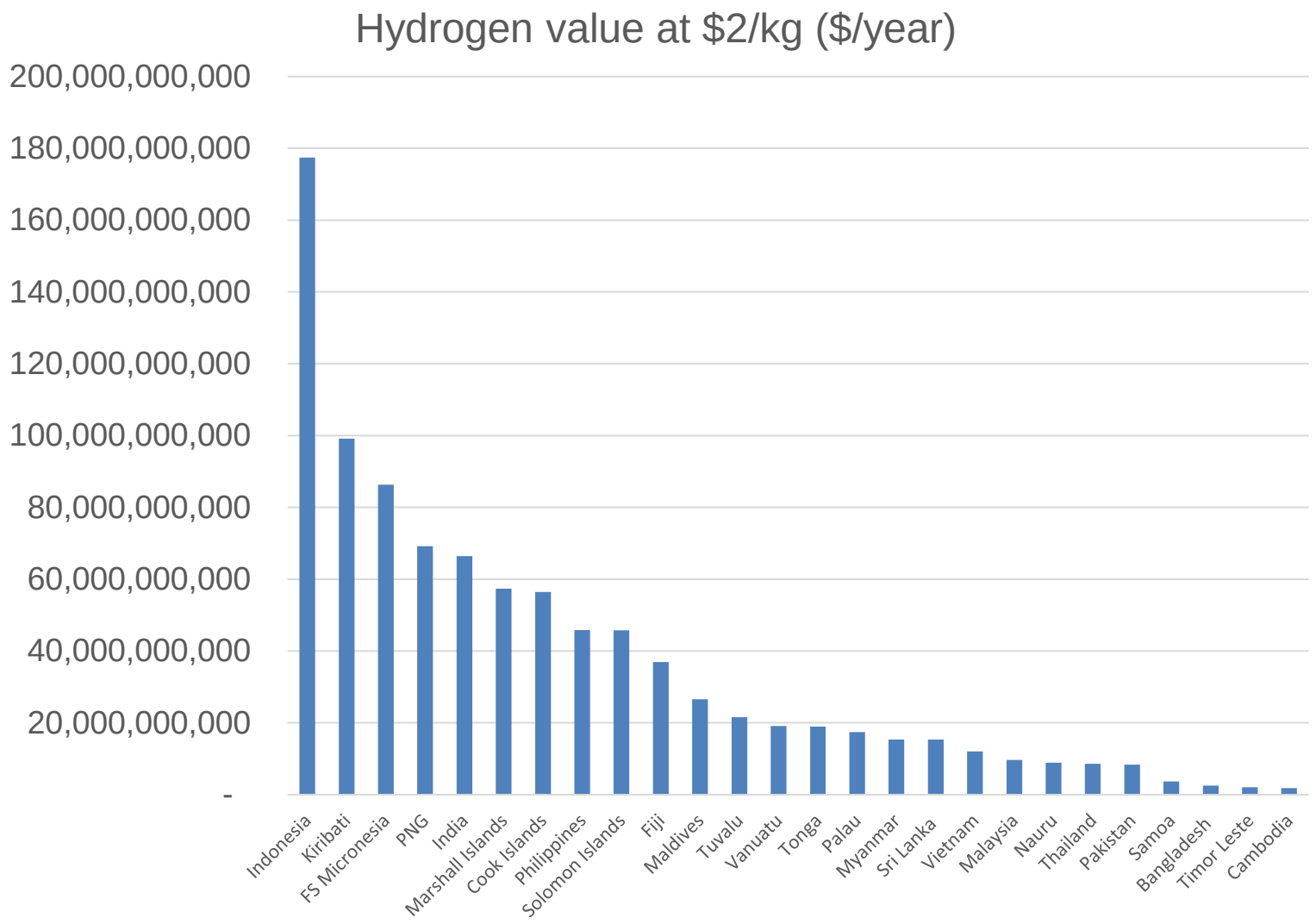
Exclusive Economic Zones

- 12 - 200 nautical miles from coastline
- 27 ADB DMCs have EEZs
- 20 DMCs are mostly EEZ

Wealth blindness?



Offshore Renewable Energy to H2* Potential in ADB DMCs



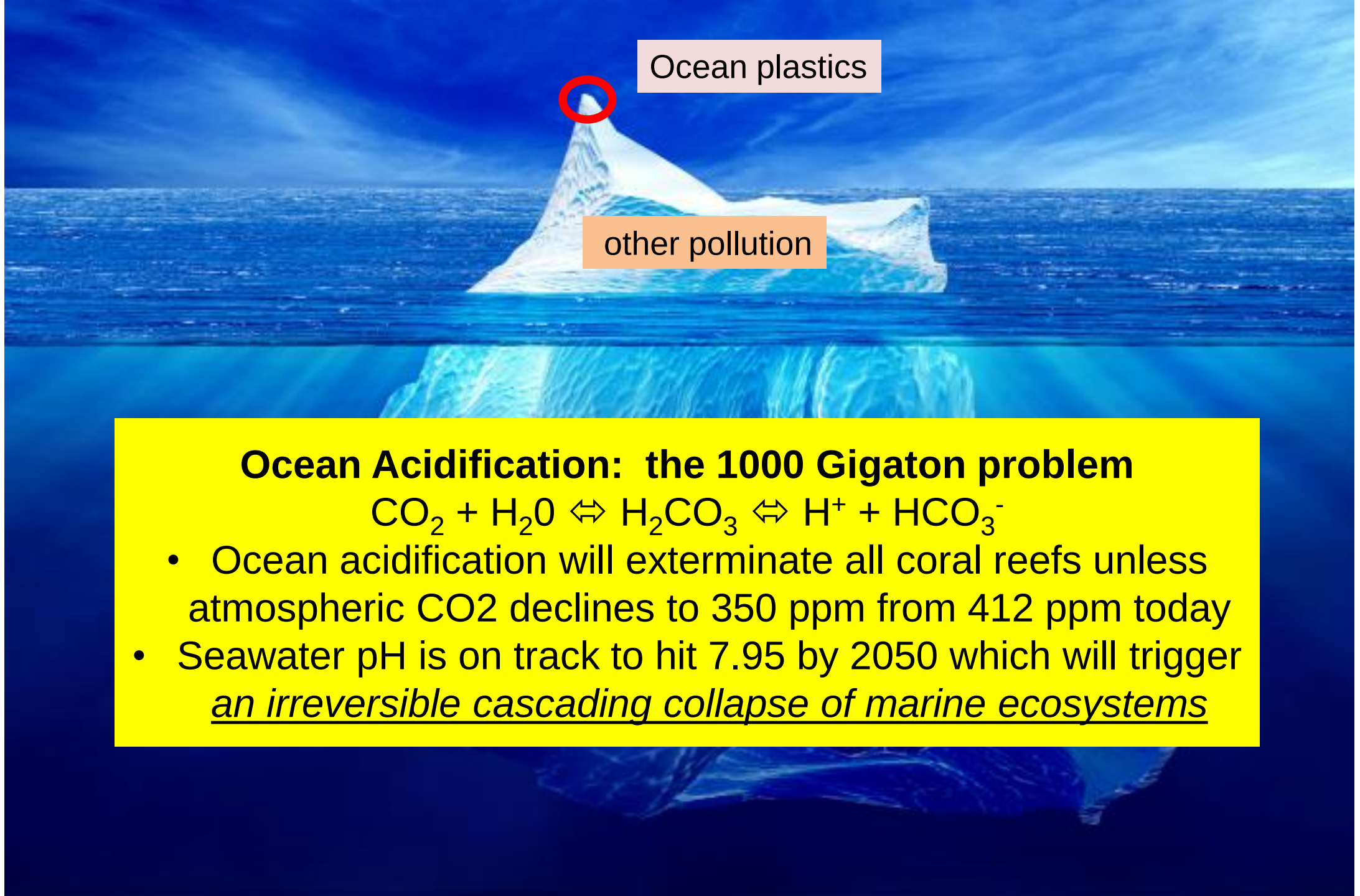
Assumptions:

- 1% of DMCs' EEZ area
- RE @ 50 MW/km2 @ 16% capacity utilization factor
- Conversion @ 50 MWh/ton H2

RESULTS:

- 23,000 TWh/y = current global electricity output!
- displace ~ 40% of global natural gas production (2019)
- avoid ~ 5 Billion tons CO2e/year.
- *New industry with revenues of **$1 Trillion/year.***

**Like a natural gas field, but no carbon, no drilling required, no blowouts, no spills, reserves never decline*



Ocean Acidification: the 1000 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 350 ppm from 412 ppm today
- Seawater pH is on track to hit 7.95 by 2050 which will trigger *an irreversible cascading collapse of marine ecosystems*

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 solutions:

- Grow reefs, seagrasses, and shellfish faster than pollutants are killing them by mimicking natural processes
- Grow other marine carbon sinks (*Deep 6 Carbon* ©)

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

**Note to carbon market experts: an avoided emission does not drawdown CO2, and the ocean knows this even if you don't*

New Organizing Principle: the *three 3s*

A typical person can live for

- *3 weeks without food*
- *3 days without water*
- *3 minutes without oxygen*

These are not luxuries.

The 6th great extinction includes *homo sapiens*.

The Ocean Economy Today

- ***Energy*** *– > 99% oil & gas*
- ***Fishing*** *– a nautical version of strip mining*
- ***Tourism*** *– mostly unsustainable*
- ***Shipping*** *– transformation began in 2020 due to IMO cleaner shipping regulations*

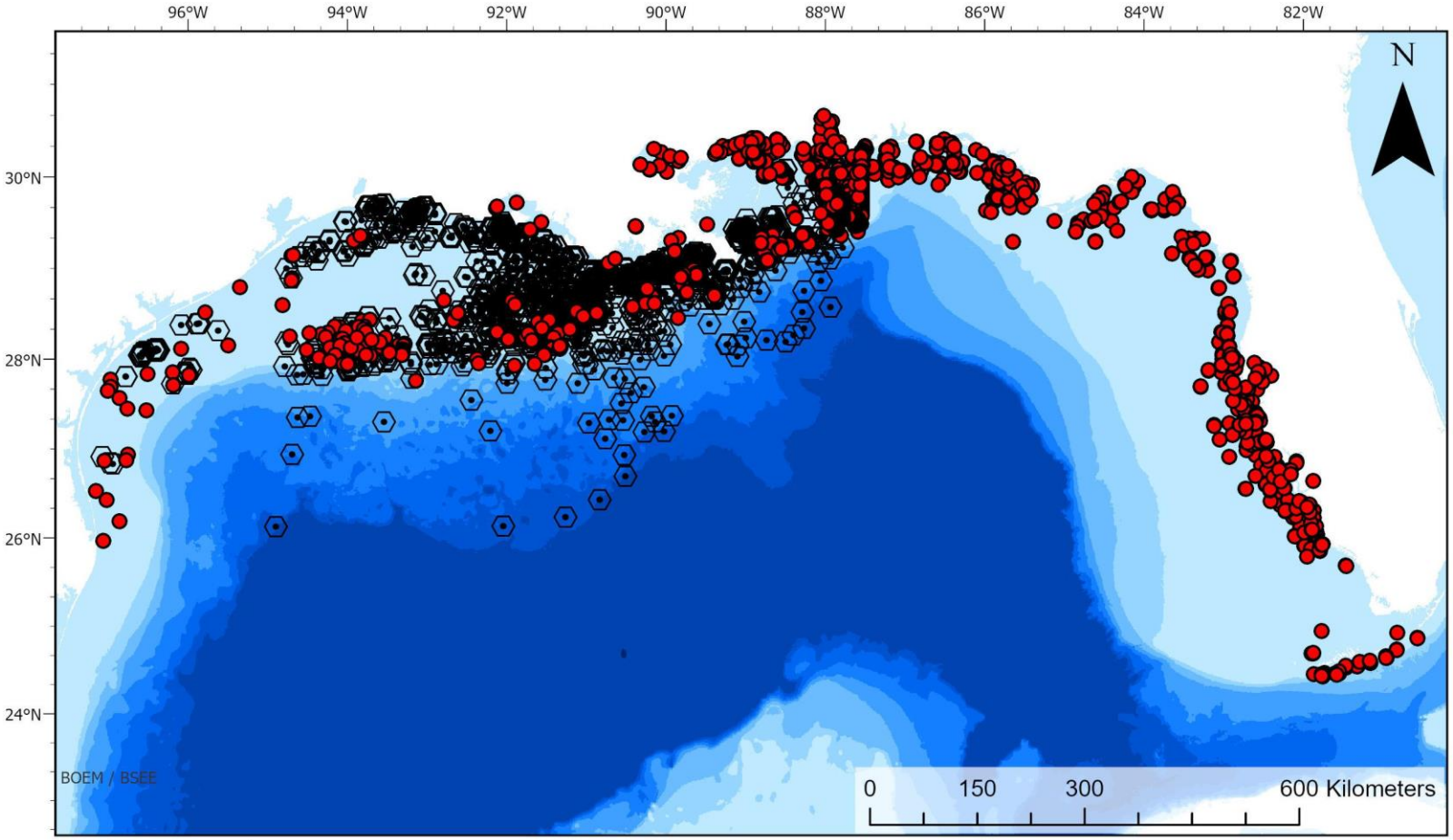
The Ocean Economy To Help Save The Planet

- ***M**arine **A**quaculture*
- ***Reefs***
- ***R**enewable energy / offshore (ORE)*
- ***Ecotourism***
- *… all for preservation, restoration and growth of **E**cosystem **S**ervices*

MARES aligns with
SDG 14, SDG 7
ADB Strategy 2030 Operational Priority 3
ADB healthy oceans plan for $5 billion new investment

Don’t forget cleaner shipping!

MARES v0: Gulf of Mexico Rigs to Reefs (R2R) and other cultivated reefs



Legend

- Artificial Reefs
- OCS Drilling Platforms

Bathymetry (m)

- -1 - -49
- -50 - -99
- -100 - -199
- -200 - -499
- -500 - -999
- -1,000 - -1,499
- -1,500 - -1,999
- -2,000 - -2,499
- 2,500 - -3,999
- ≤ -4,000

MARES v0: Gulf of Mexico Offshore Oil & Gas R2R Program

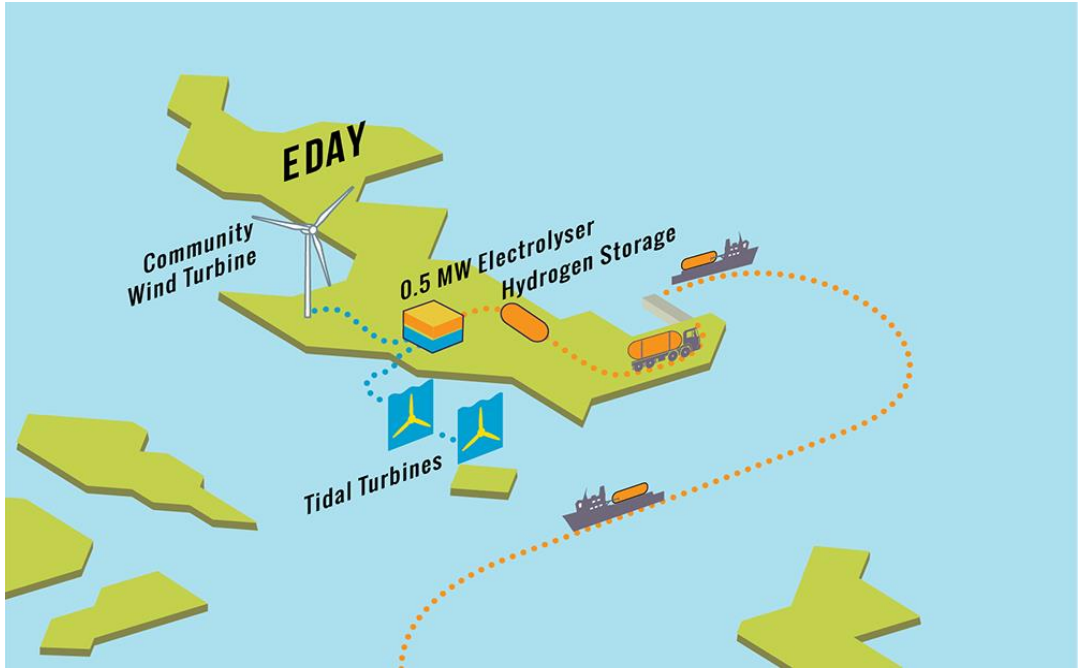
1987- 2020
~ 11% of retirements
558 conversions supporting sport diving, sport fishing, & regional commercial seafood production

***The 27 rigs offshore southern California support more marine biodiversity than in California's marine protected areas*

@ US conversion rate,
100+ candidates in SE Asia
7 in the Philippines
20 – 30 pending in Thailand
Indonesia? Malaysia?

MARES in the 21st century: the use of offshore renewable energy (ORE) to make H2 has been demonstrated successfully in the Orkney islands, Scotland.
Orsted, Total and Siemens, *et al*, are expanding capacity in ORE to H2.
This is just the beginning -- and the North Sea is a small place….

https://www.surfnturf.org.uk/
Orkney Islands – Surf ‘n turf hydrogen project

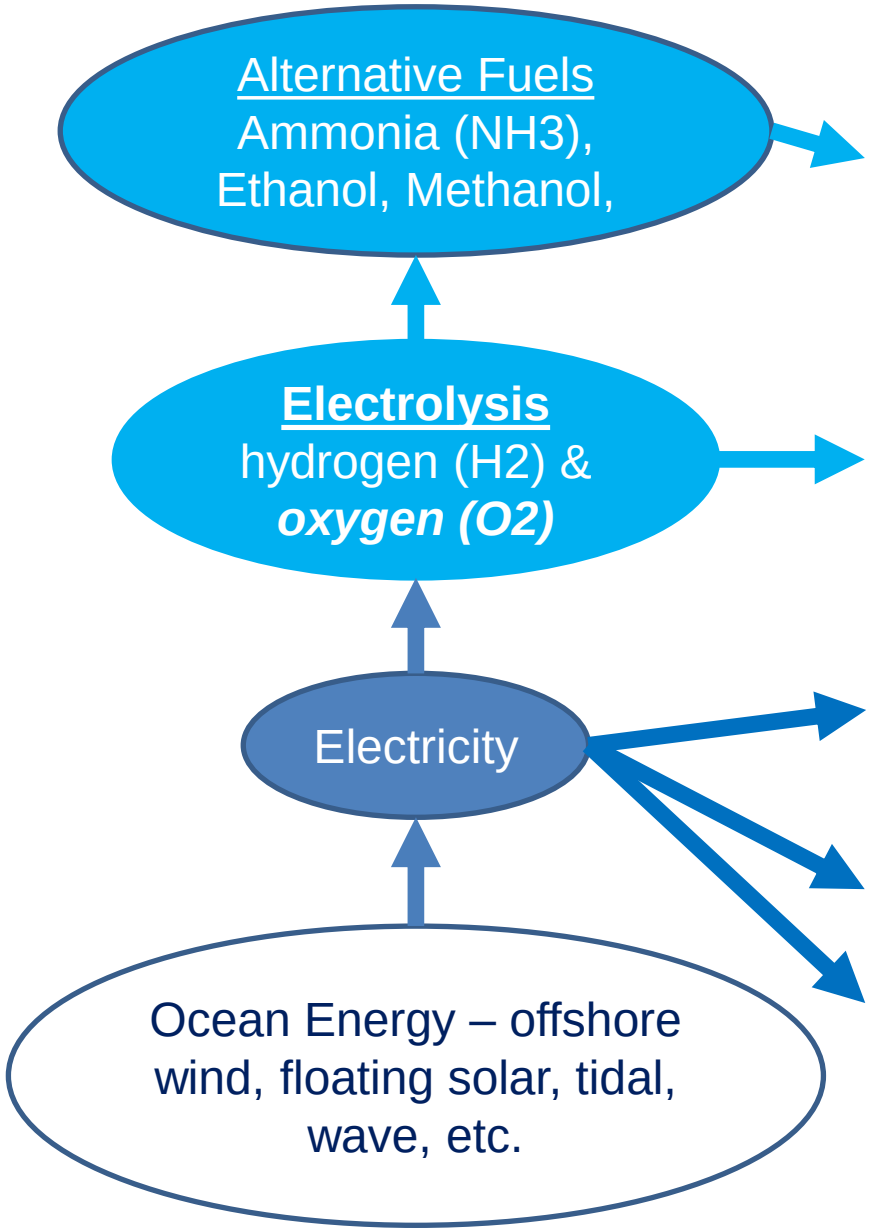


https://www.climatechangenews.com/2020/08/24/orsted-backs-danish-offshore-wind-powered-hydrogen-project/nshore
Orsted’s offshore wind to onshore hydrogen project

*IEA estimates the technical potential of offshore wind at **420,000 Terawatt-hours per year (TWh/y)***
vs. total global energy (electricity + everything else) production today of about 175,000 TWh/year
Floating wind & other Offshore Renewable Energy (ORE) will be required
for global decarbonization and CO2 drawdown!!!!

3 proven systems from the offshore petroleum industry (left to right):
(i) spar, (ii) semi-submersible, & (iii) tension-leg platform

Regenerative Mining of Offshore RE (MORE ©) – a.k.a. "power to X"



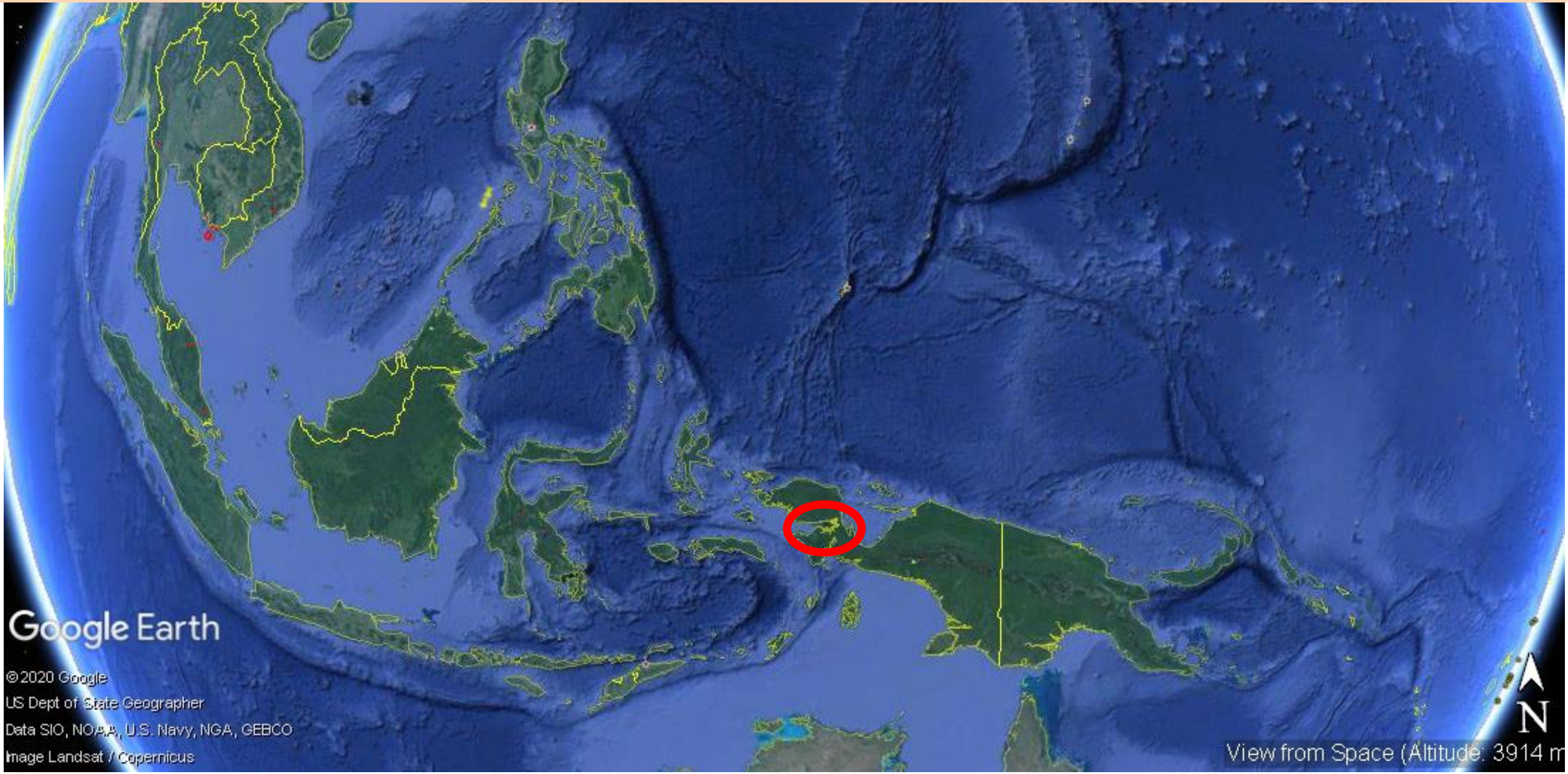
USE CASE	SCALE UP	
Marine Transport (Shipping)	Learning from existing business models. ***IMO cleaner shipping regulations***	H2 AMC supported for target production price
Aviation Transport		
Local Marine Transport		
Bulk Transport to existing markets for fuels to be sold at commodity prices, albeit with regenerative fuel premium.	Hydrogen Fuel Advanced Market Commitment Fund – $5 Billion to catalyze supply chain and create market for Hydrogen @ US$2/kg	
Nature Based Defenses - coastal zone reefs / living breakwaters	Learning from existing business models.	New Insurance Product Line
Cultivated Reefs including ***rigs to reefs – 100+ candidates in ASEAN***		
Regenerative Marine Aquaculture	Learning from existing business models.	PSOD Industry Support
Wrecks to Reefs – 10,000+ candidates globally	Pacific Blue Shipping Program driven by IMO regulations US$ 500 M Carbon **reduction** finance	

MARES in the 21st Century

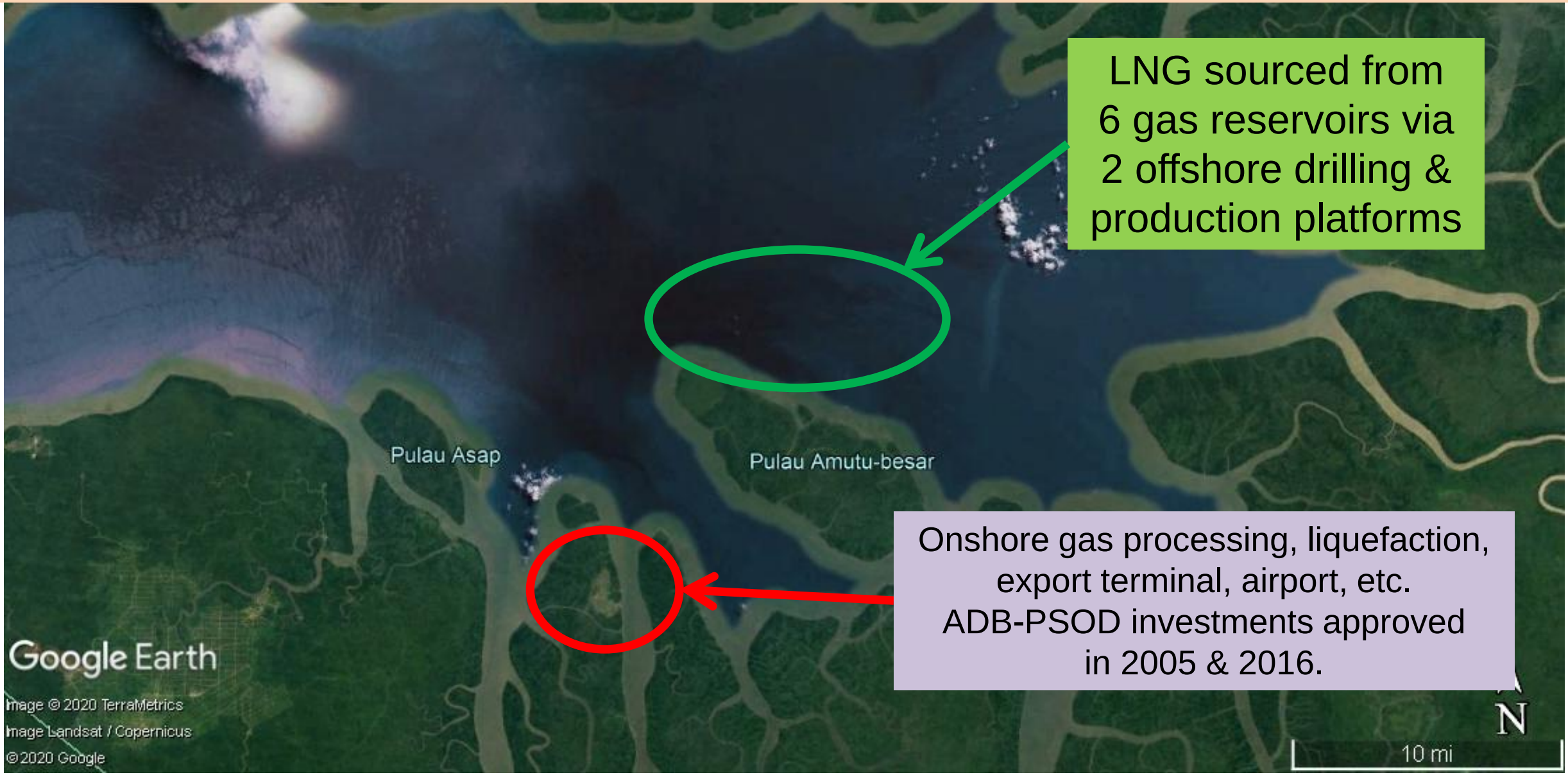
Possible projects / programs

(i) Brownfield – build / retrofit on existing sites
(ii) Bluefield – modification of existing marine sites
(iii) Greenfield – new projects

Brownfield: we can do MORE© starting today…



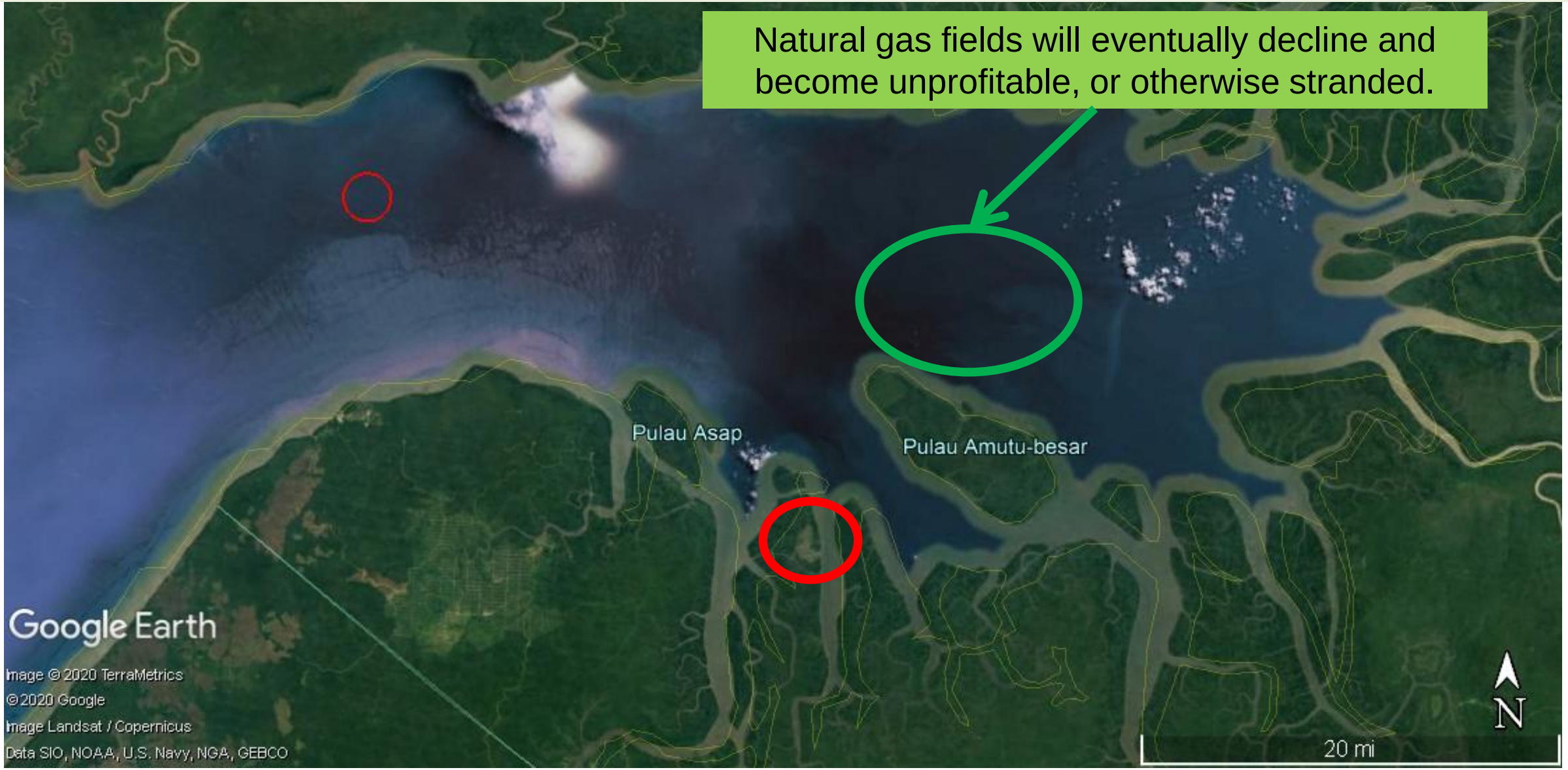
Tangguh - Indonesia's 3rd LNG export project



When the natural gas runs out, do MORE© at Tangguh

Reference case: Brunei natural gas-to-H2 for export to Japan.

Sarawak Energy Bhd. will eventually add green H2 from Sarawak's surplus hydropower output



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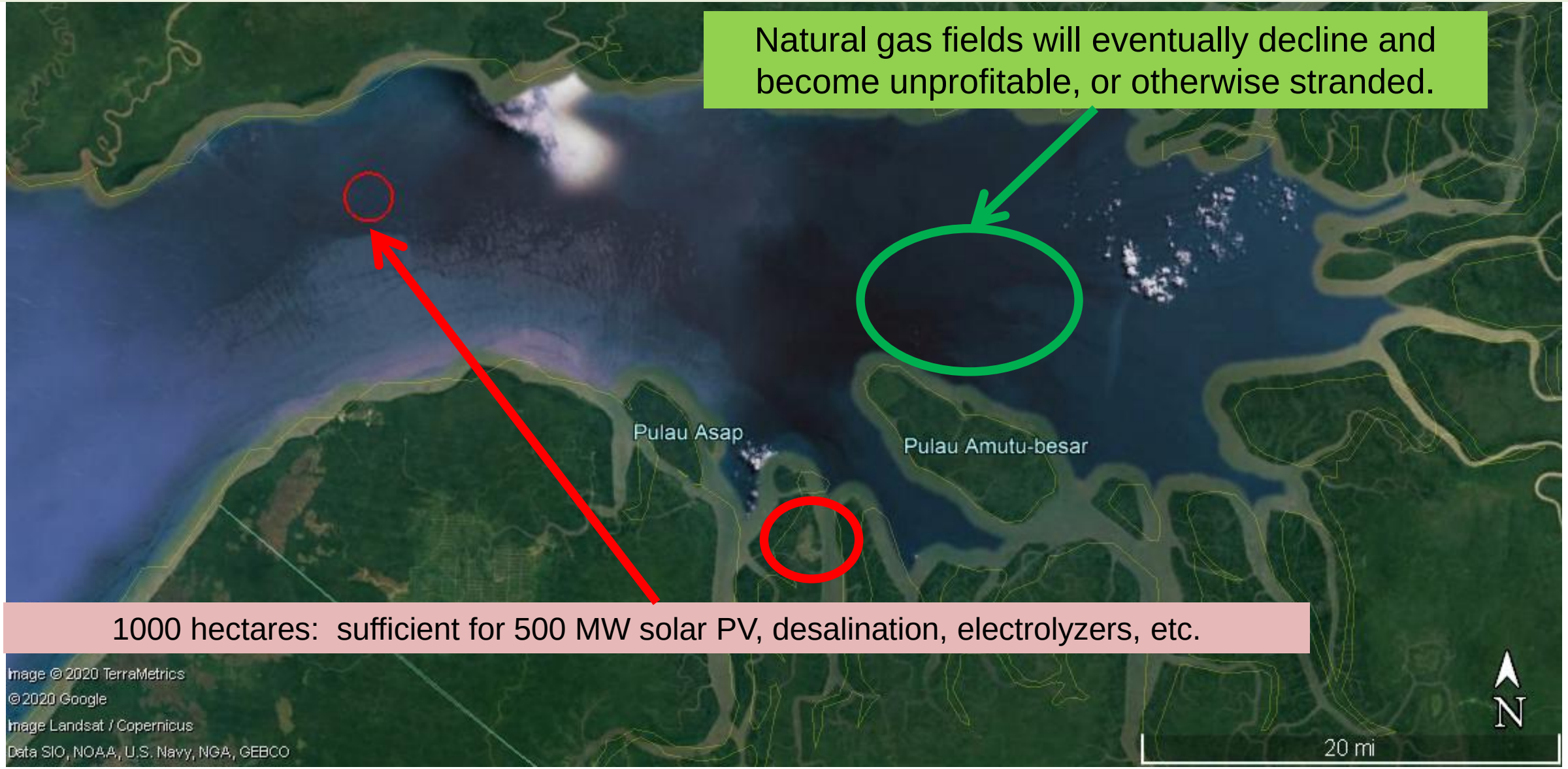

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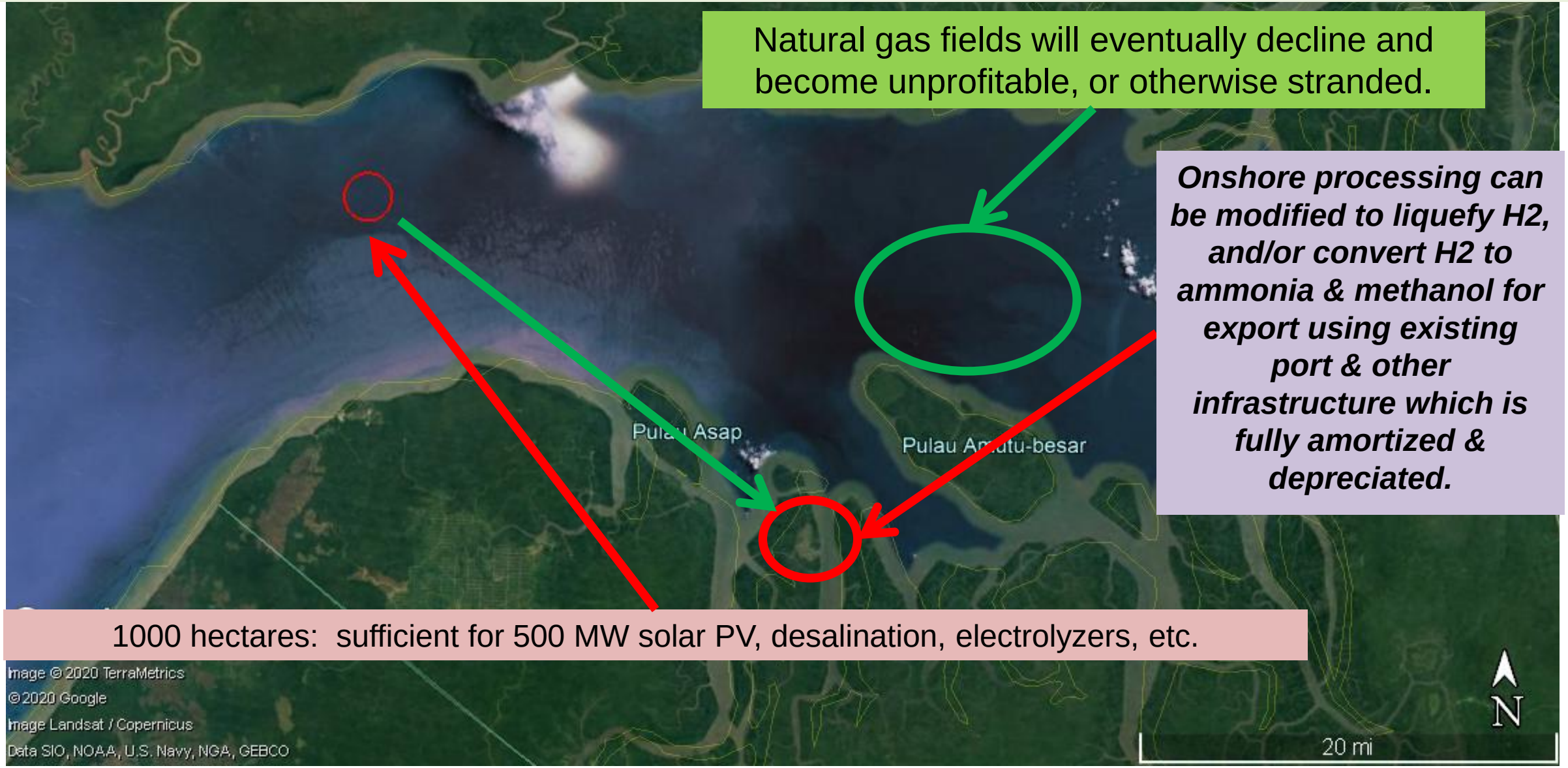

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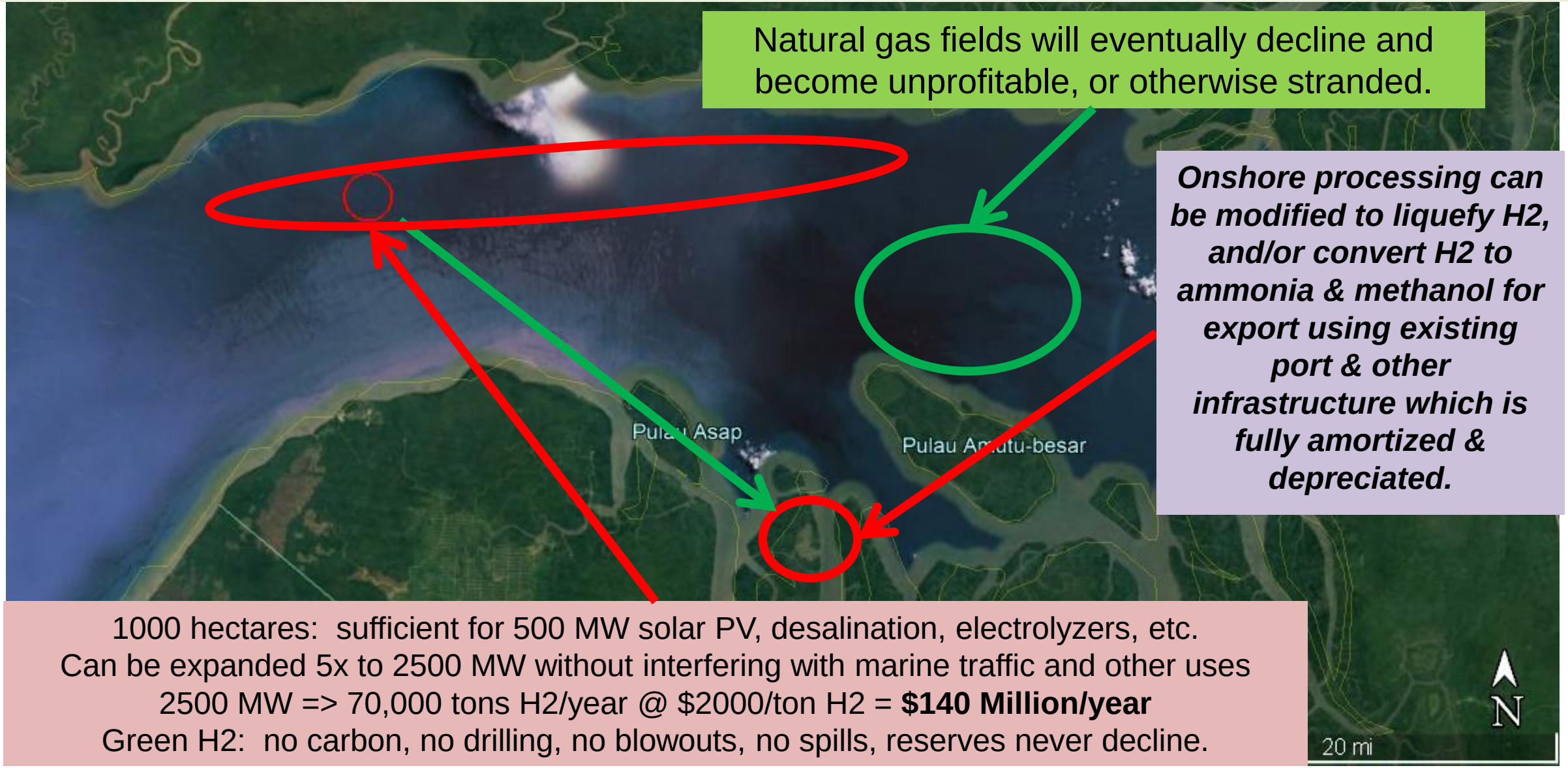
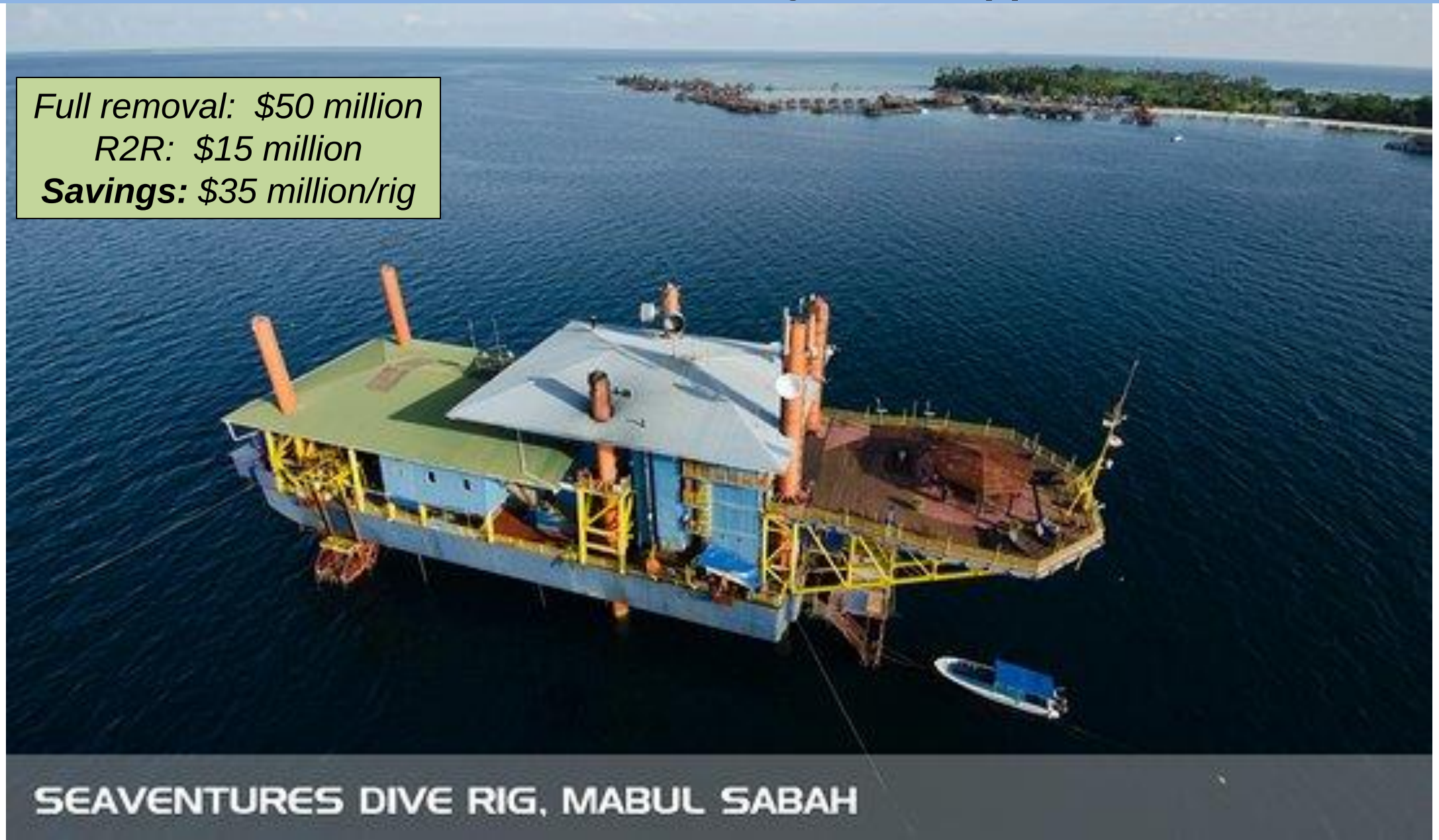


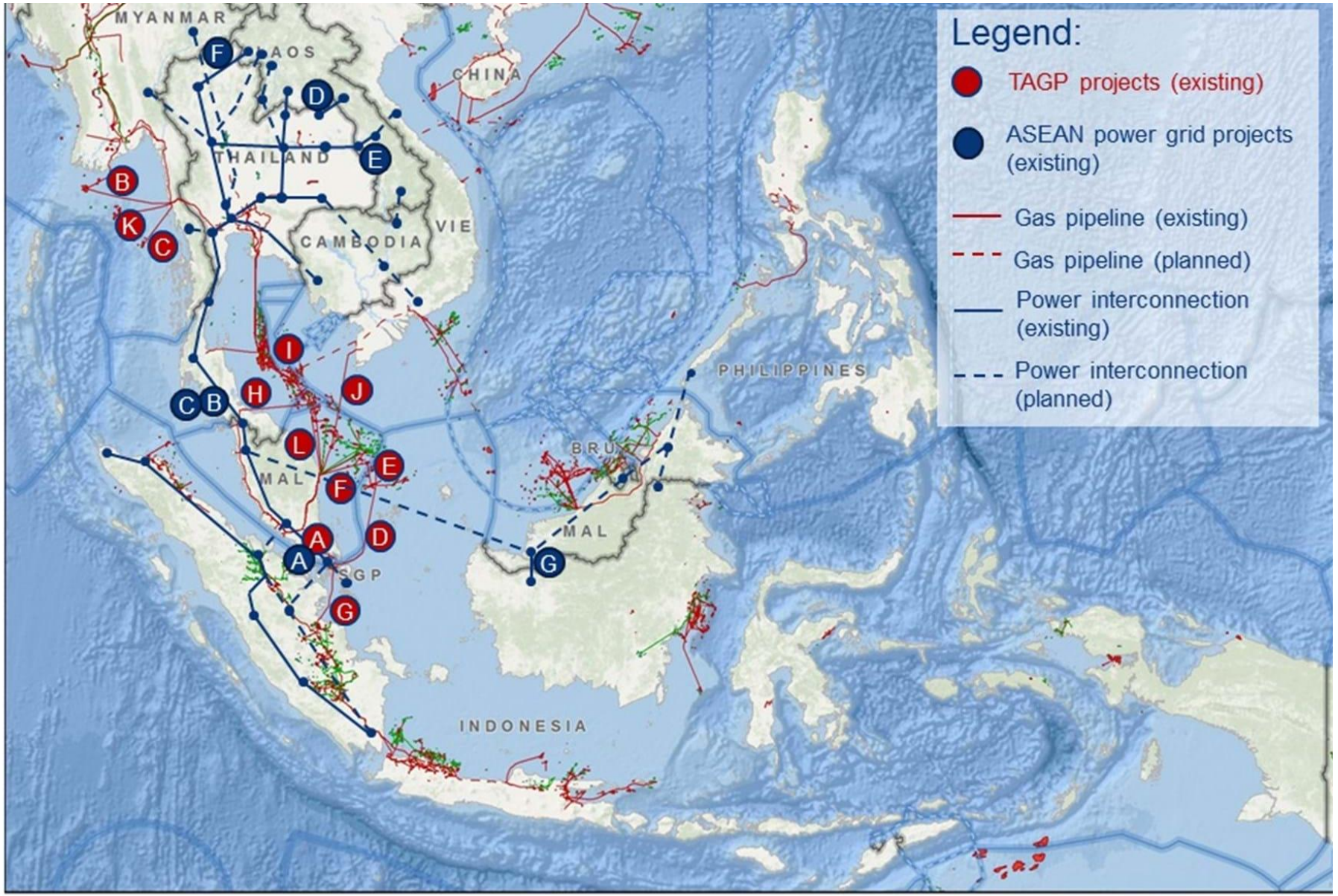
1000 hectares: sufficient for 500 MW solar PV, desalination, electrolyzers, etc.
Can be expanded 5x to 2500 MW without interfering with marine traffic and other uses
2500 MW => 70,000 tons H2/year @ $2000/ton H2 = **$140 Million/year**
Green H2: no carbon, no drilling, no blowouts, no spills, reserves never decline.

From brownfield to blue: R2R for Ecotourism
100+ candidates in Indonesia, Malaysia, Philippines, Thailand

Full removal: $50 million
R2R: $15 million
***Savings:** $35 million/rig*



100+ R2R candidates in Indonesia, Malaysia, Thailand, Timor-Leste, Vietnam



R2R for ecotourism can be integrated with marine aquaculture…

Rigs-to-reefs (R2R) conversion preserves a micro-marine protected area** with topsides used as marine laboratory, ranger station, ecotourism facility, etc. **> 100 R2R candidates in SE Asia**

***The 27 rigs offshore southern California support more marine biodiversity than in California's marine protected areas*

Aquaculture is developed around the R2R-micro marine protected area. Coral, seagrass & shellfish sequester CO_2.

Brownfield to blue: International Maritime Organization (IMO) regulations for cleaner marine fuels are driving transformation of the global shipping fleet – 50,000 vessels are subject to IMO regs

Retire 20 year old ships early

Typical Panamax vessel:

- 10 years avoided fuel
  = 1 million tons avoided CO2e

- New ship meets IMO 2050 target of 50% CO2 reduction

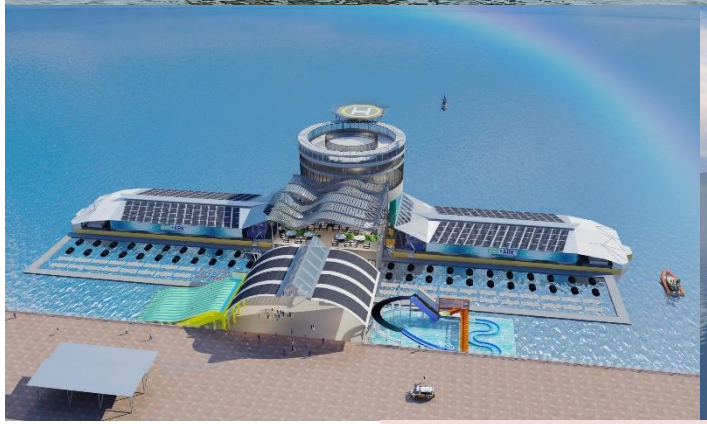
- 0.5 million tons net CO2 reduction value @ $35/ton CO2e (social cost)
  = $17.5 million per ship retired

- ADB helps monetize this value to retrofit ships for MARES operations

Brownfield to blue: International Maritime Organization (IMO) regulations for cleaner marine fuels are driving transformation of the global shipping fleet – 50,000 vessels are subject to IMO regs

Creating natural capital

- Avoided CO2 value = $17.5 million per ship retired
- ADB financial assistance TBD
- $10 million per ship for retrofit (?)
- 100 ships by 2030 (?)
- Global scale-up to 10,000 ships (?)



Photos courtesy of Leow Ban Tat, ACE Eco Ark

Retrofit for MARES operations:
marine aquaculture, reef cultivation, ecotourism, powered by top side solar, wind, in-stream tidal, etc. modular desalination / electrolysis / H2 production => floating filling station, seafood market & dive resort… setting aside some revenue for cleanup and ultimate retirement as reef.

IMO compliance-driven market: reverse cash for clunkers + wrecks-to-reefs

Globally there are more than 1900 W2R sites of which more than 1700 are in US waters.
27 of ADB's DMCs can have a wrecks-to-reefs program (other DMCs could buy in…).

Accelerated ship retirement

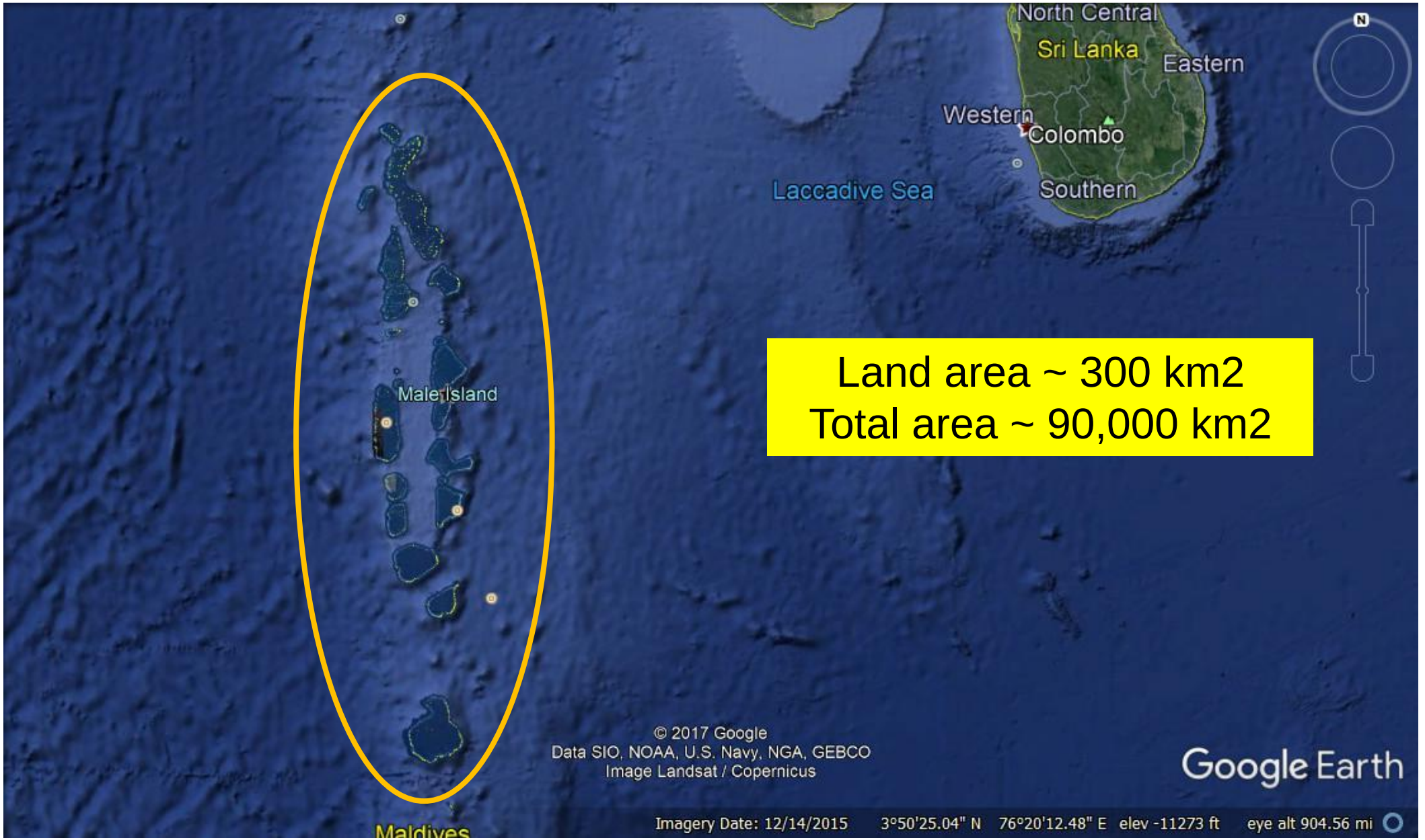
- Avoided CO2 value of $17.5 million per ship retired, partly monetized via MARES operations offsets clean-up cost up to $15 Million per ship

ADB provides customized financial solutions to monetize life-cycle savings and deliver $$ as up-front project financing

USS Oriskany – the "Great Carrier Reef"

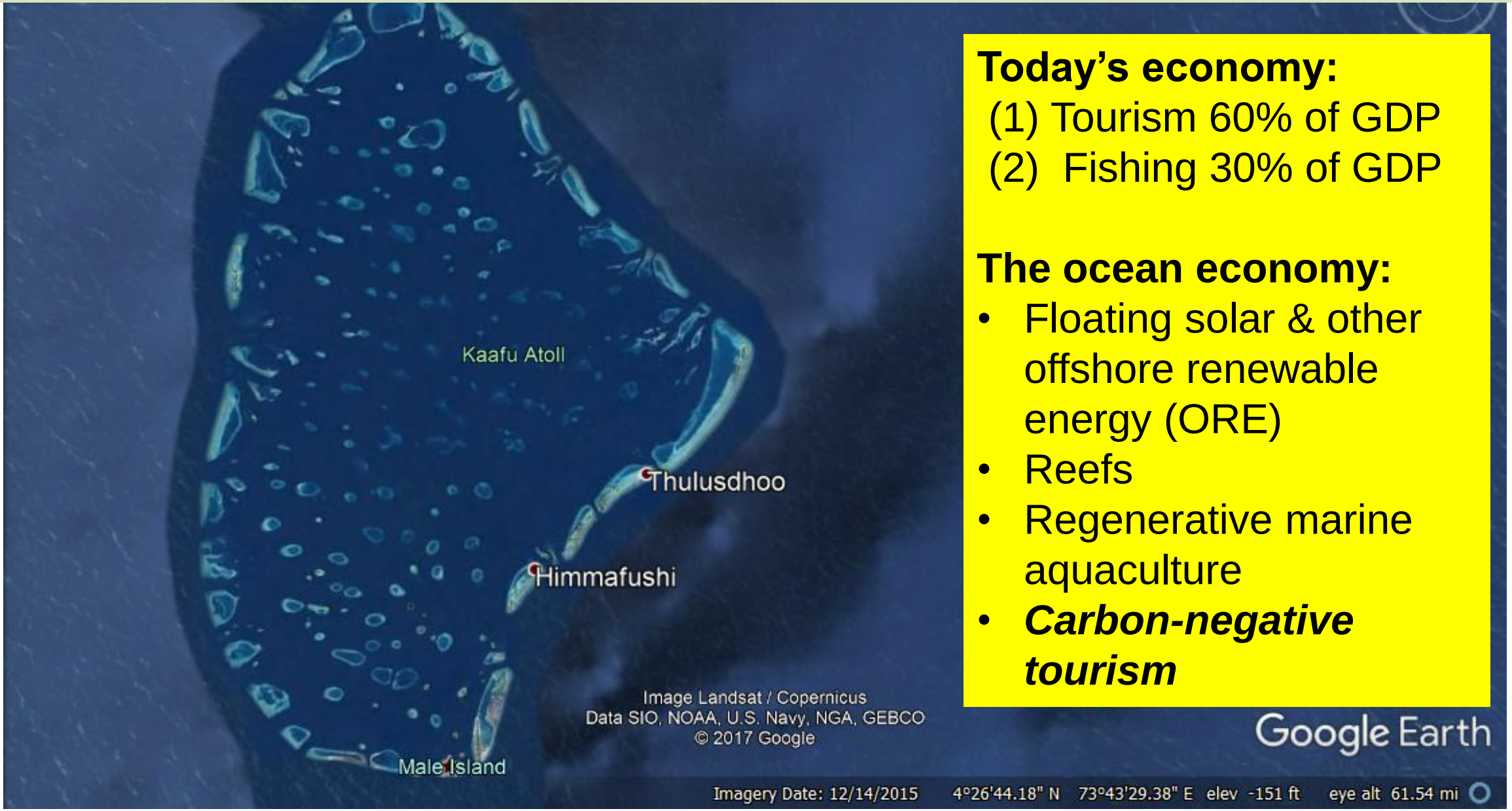
Retired ships are sunk for use as breakwaters & more reef cultivation – possible adaption credit??
0.44 tons CO2 are stored in each ton of CaCO3 -- additional CO2 credits?
W2Rs serve as anchoring/mooring points for dive boats, floating solar & wind, marine aquaculture, etc.

Bluefield: the Maldives is an Ocean Economy…



Bluefield: opportunity to create a 21st century ocean economy.

The private sector tourism industry can lead the transition.



Today's economy:

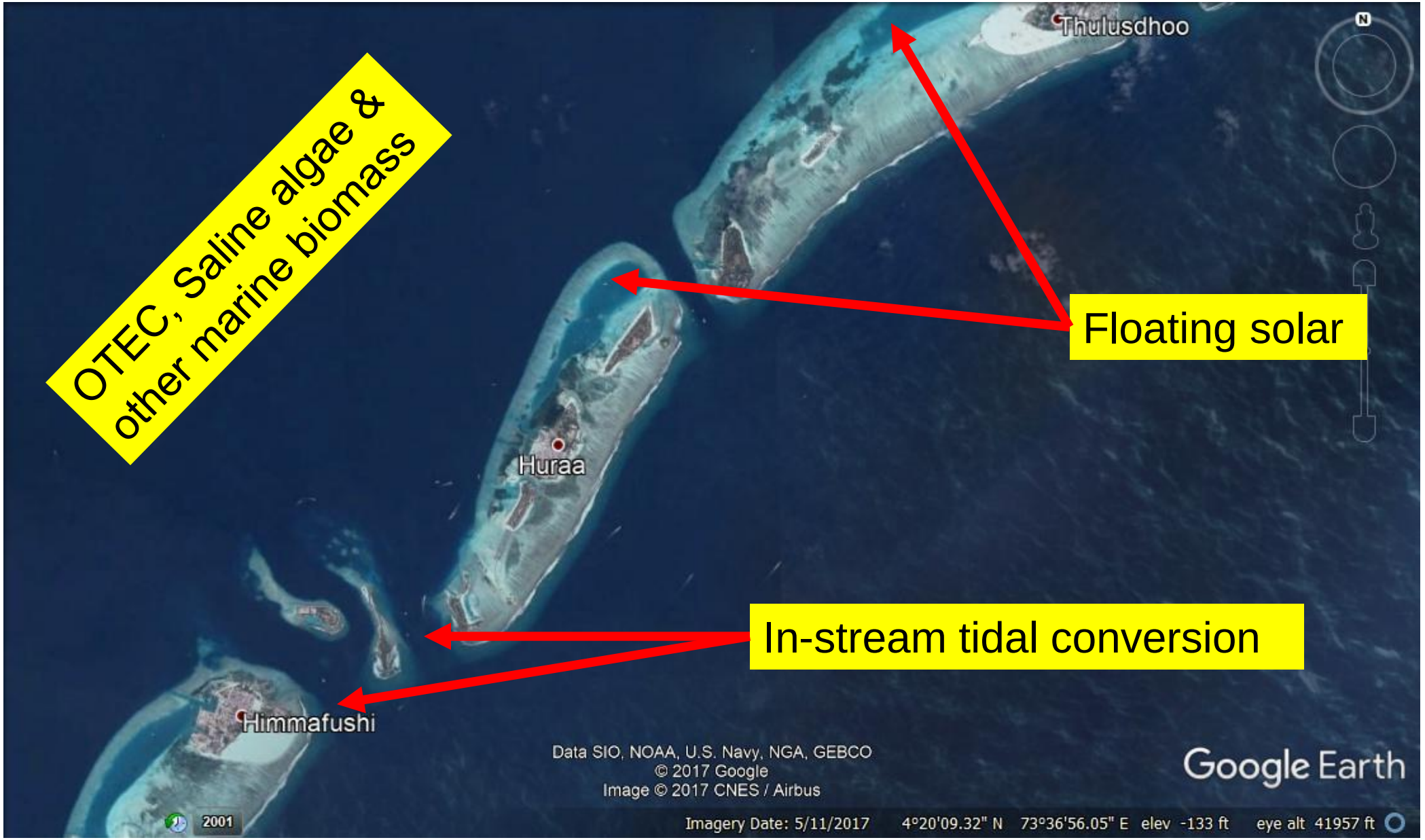
(1) Tourism 60% of GDP

(2) Fishing 30% of GDP

The ocean economy:

- Floating solar & other offshore renewable energy (ORE)
- Reefs
- Regenerative marine aquaculture
- ***Carbon-negative tourism***

Private resorts can host next-generation offshore renewable energy (ORE) development by partnering with technology vendors and sharing of new intellectual property rights



21st Century ecotourism – how to make it regenerative?

DESTINATIONS		
Assets	**Activities**	**Actions needed**
Lodging	Green buildings powered with RE 3-D print sustainable building materials	LEED rating or equivalent Add storage & heat-to-power modules to existing diesel gensets to reduce fuel consumption Add solar &/or other RE => ***floating solar*** *Seawater cooling* *Limestone farms co-located with cultivated reefs*
Beaches	Keep clean!	Barge-mounted WtE
Water sites	Sport fishing	Reef rehabilitation & marine aquaculture
	snorkeling, scuba diving	Reef rehabilitation & protection
	Sport fishing, diving, & commercial aquaculture	Rig-to-reef and wreck-to-reef sites can host regenerative seafood production.
Cultural heritage sites	Operations & Maintenance support	Limit number of visitors per day / month / year
	Transit to / from	Electric / other clean vehicles
Other Infrastructure	Coastal zone protection	Nature-based defenses, e.g., mangroves, living breakwaters

21st Century Ecotourism – how to make it regenerative?

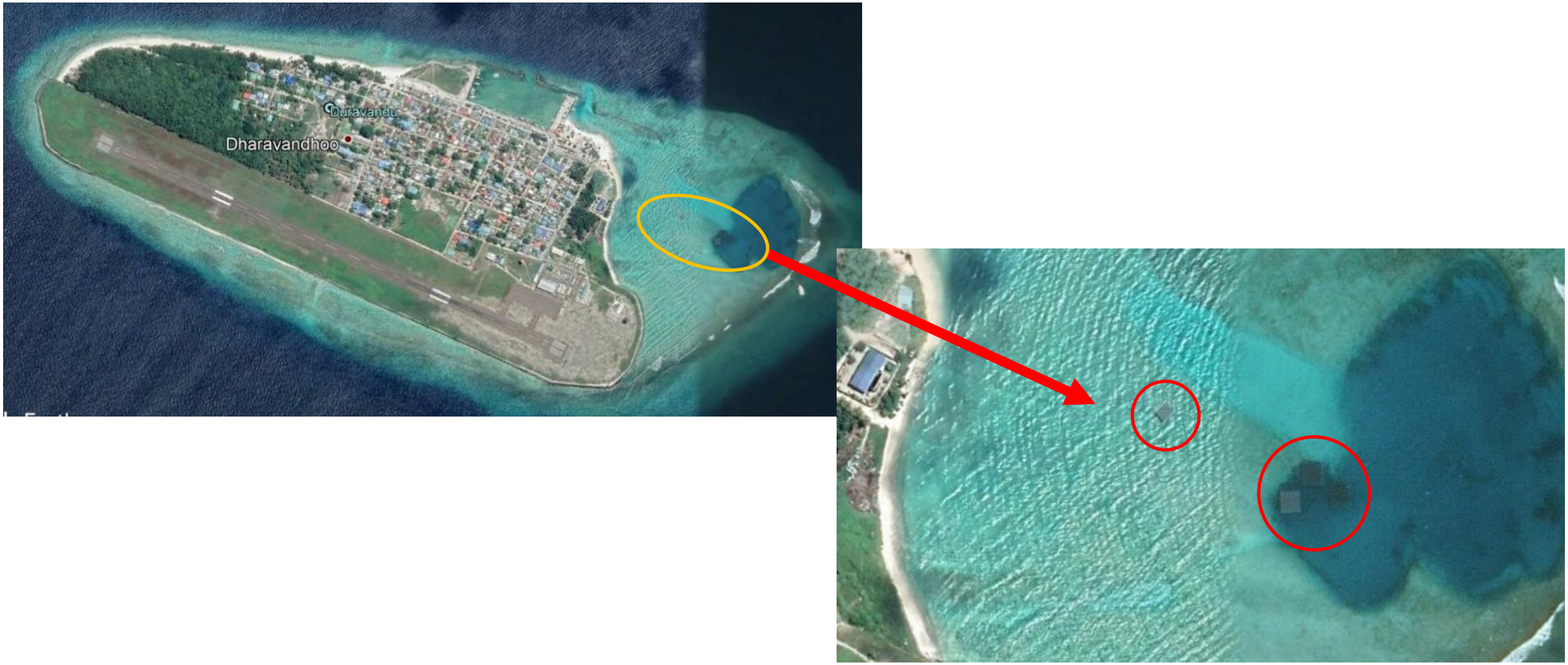
TRANSPORT CONNECTIONS		
Assets	**Activities**	**Actions needed**
Airports	Green buildings Green buildings powered with RE 3-D print sustainable building materials	LEED rating
Ferries	Inter-island services	Convert fleet to hybrid / electric / fuel cell Identify financing modes and implementation plans for retrofit vs. new vessels
Seaplanes	Inter-island services and daily tours	Deployment of next generation electric planes & other aircraft
Land transport	Transfers between airports & ferry terminals & destinations	Convert fleet to hybrid / electric / fuel cell
Local water transport	Transport between lodging and other destination features	Electrify boats or acquire new electric/hybrid boats

Quick-look assessment: candidate areas are inside the barrier reef, with no obvious coral growth, either darker water or lighter/white bottom (highlighted) are appropriate; on-site surveys are required!

Possibly suitable – Site survey required

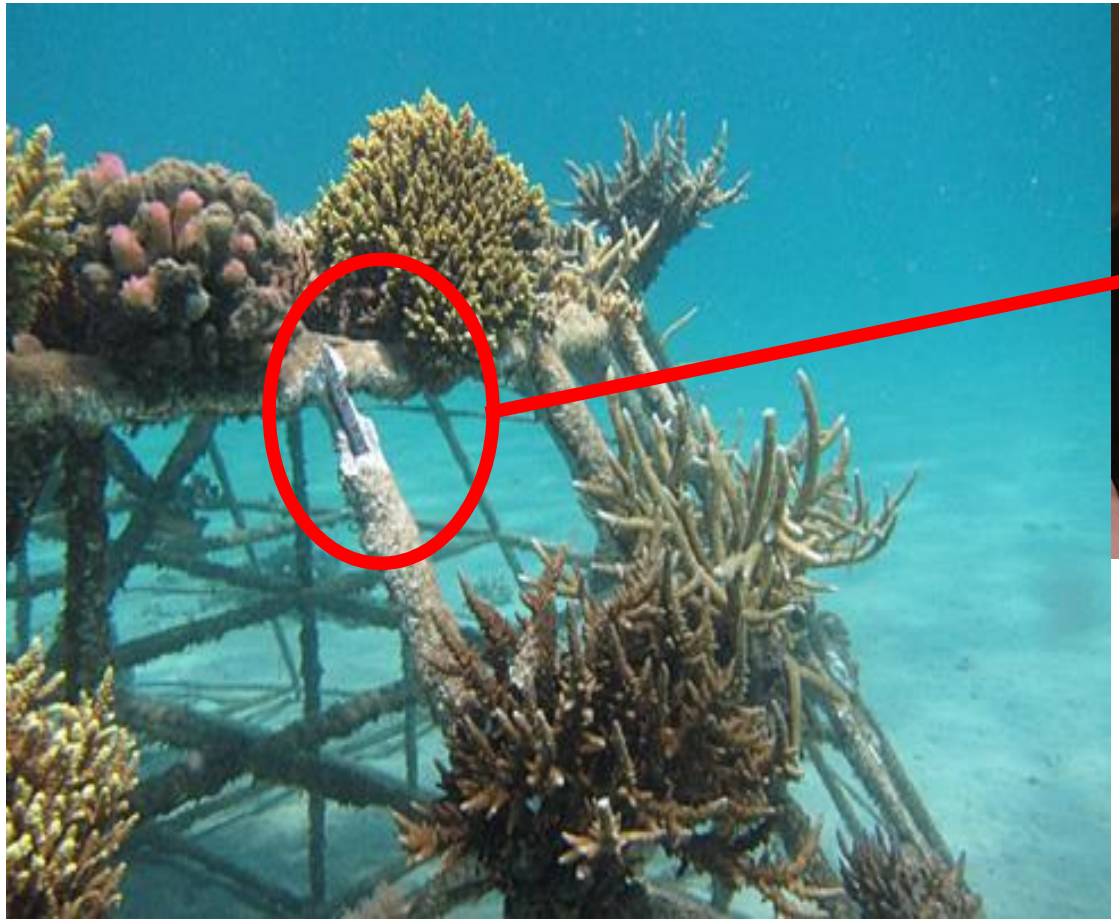
Not suitable

Existing floating solar at B. Dharavandhoo – Swimsol units are visible in photo at right, which indicates minimal reef on the seafloor in this area.



Integrating Cultivated Reefs and Aquaculture

Step 1: Limestone ($CaCO_3$) grown* using trickle charge electricity to augment coral propagation, nature-based defenses, and mitigate any energy infrastructure impact while directly mitigating local ocean acidification.



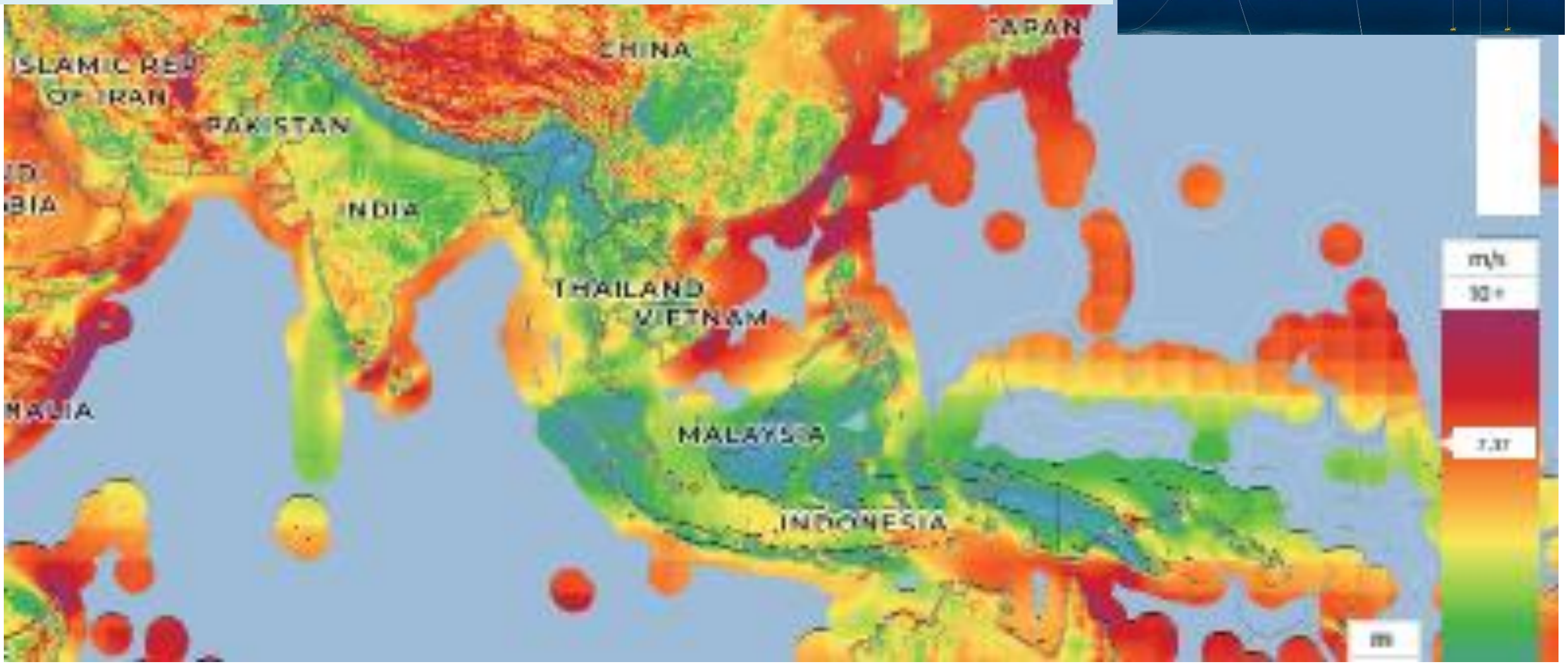
This technique has been demonstrated at multiple sites in Asia for more than 10 years.

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

**** Each ton of $CaCO_3$ sequesters 0.44 tons CO_2***

Greenfield: offshore wind to H2 / power to X

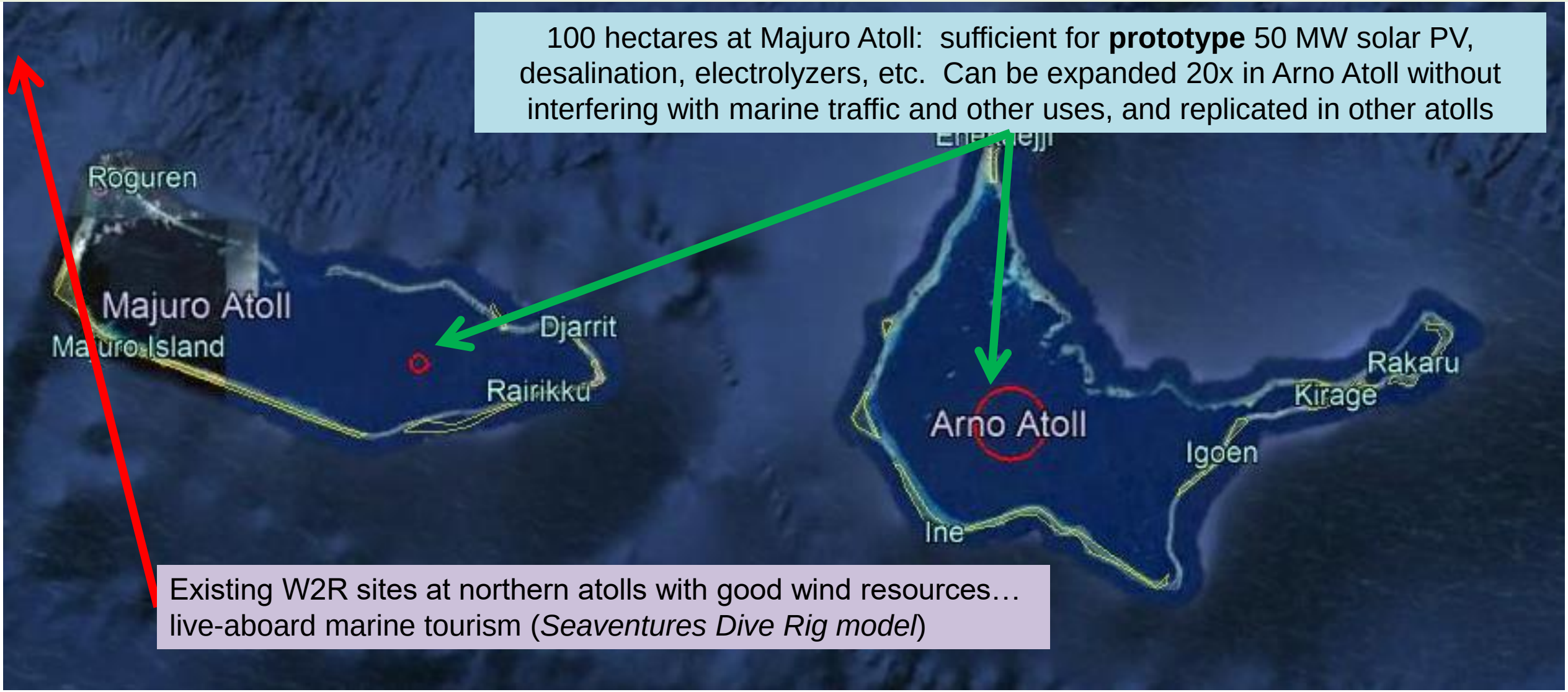
- Blend H2 in existing natural gas pipeline networks in Pakistan, India, Vietnam, Philippines; bring onshore in others, e.g., PNG, Sri Lanka
- Palau, RMI, others: H2 to ammonia, methanol, etc. for sale into cleaner marine fuels and other industrial markets



Greenfield: regenerative H2 from solar and wind in RMI

1000 MW solar to H2 @ $2000/ton H2 = $ 56 Million/year = 25*% of 2019 GDP*

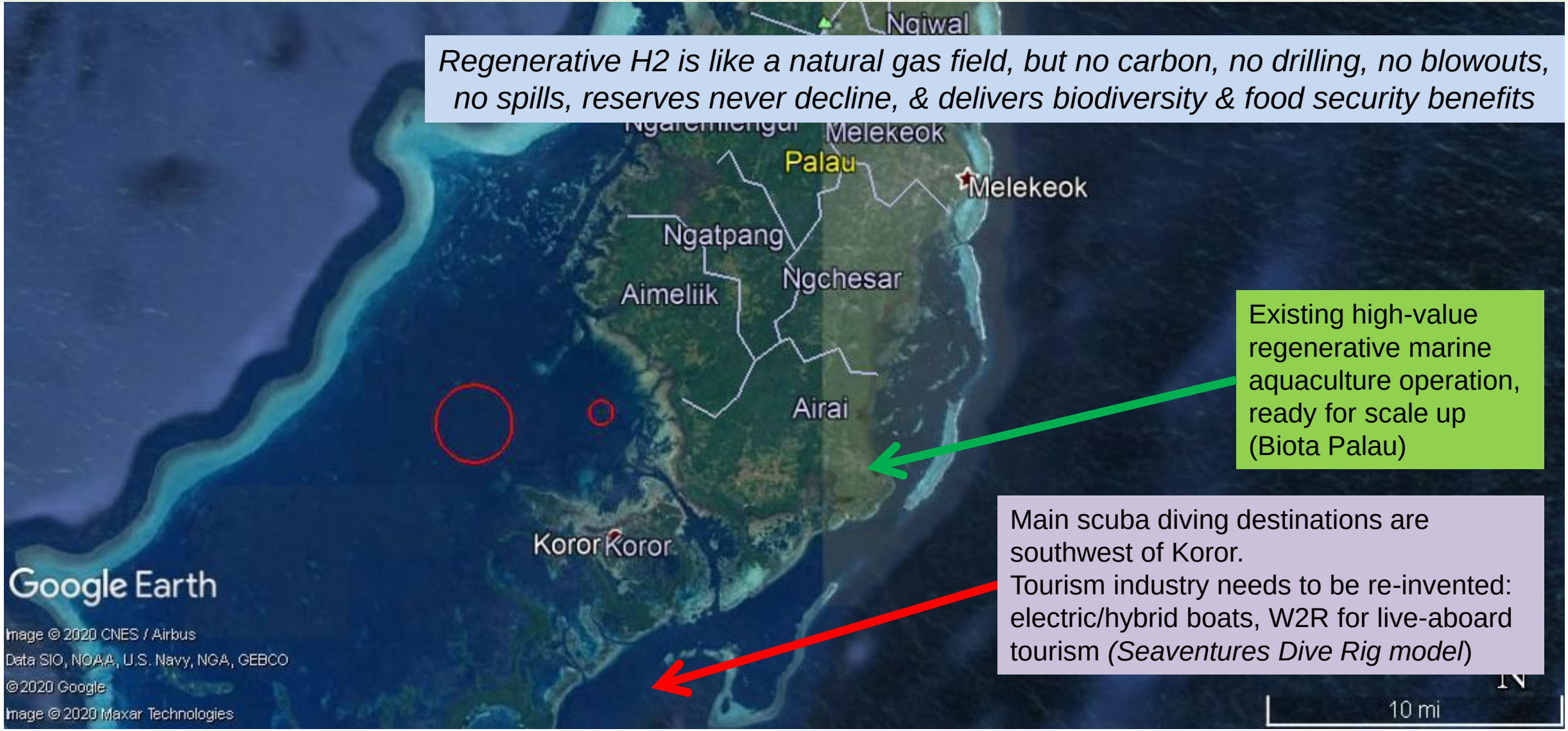
Scale up to 1% of EEZ: *$57 BILLION / year = 25,900 % of 2019 GDP*



Greenfield: regenerative H2 – indicative concept for Palau

500 MW solar to H2 @ $2000/ton H2 = $28.8 Million/year = *10% of 2019 GDP*

Scale up to 1% of EEZ: *$17.3 BILLION / year = 6125% of 2019 GDP*



Regenerative H2 is like a natural gas field, but no carbon, no drilling, no blowouts, no spills, reserves never decline, & delivers biodiversity & food security benefits

Existing high-value regenerative marine aquaculture operation, ready for scale up (Biota Palau)

Main scuba diving destinations are southwest of Koror.
Tourism industry needs to be re-invented: electric/hybrid boats, W2R for live-aboard tourism *(Seaventures Dive Rig model)*

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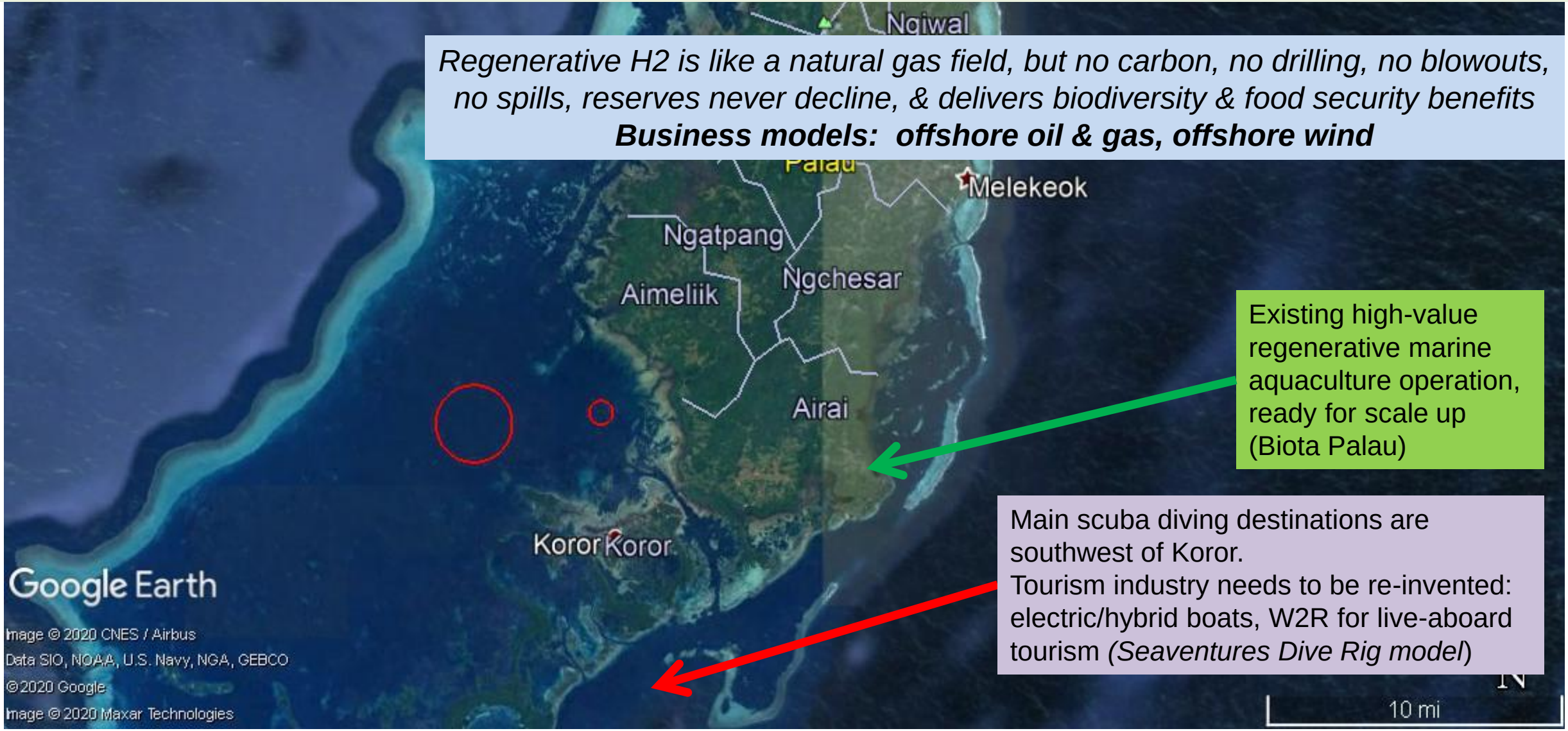

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Business models: offshore oil & gas, offshore wind

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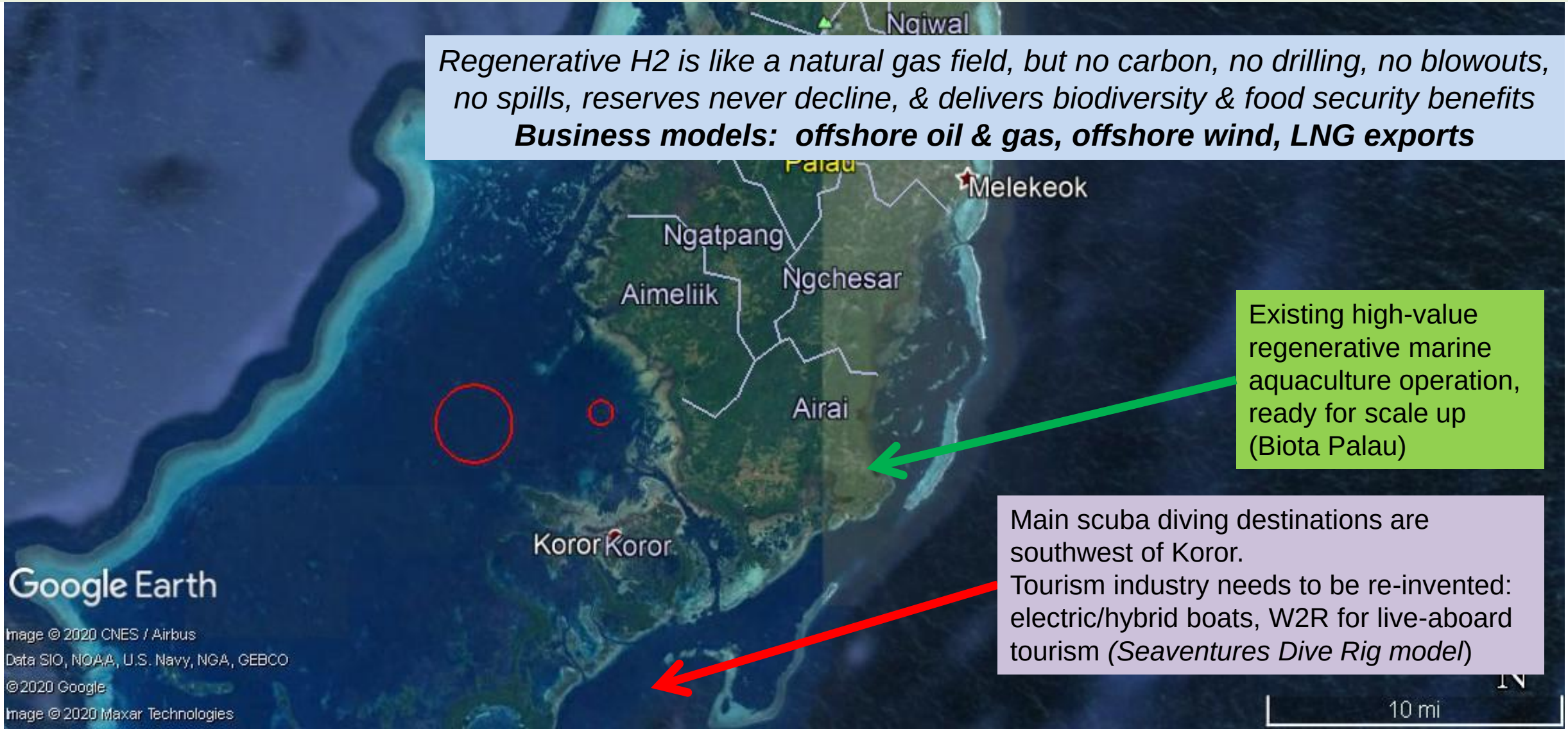

Regenerative H2 is like a natural gas field, but no carbon, no drilling, no blowouts, no spills, reserves never decline, & delivers biodiversity & food security benefits

Business models: offshore oil & gas, offshore wind, LNG exports

Existing high-value regenerative marine aquaculture operation, ready for scale up (Biota Palau)

Main scuba diving destinations are southwest of Koror.
Tourism industry needs to be re-invented: electric/hybrid boats, W2R for live-aboard tourism *(Seaventures Dive Rig model)*

Greenfield: regenerative H2 – indicative concept for Palau

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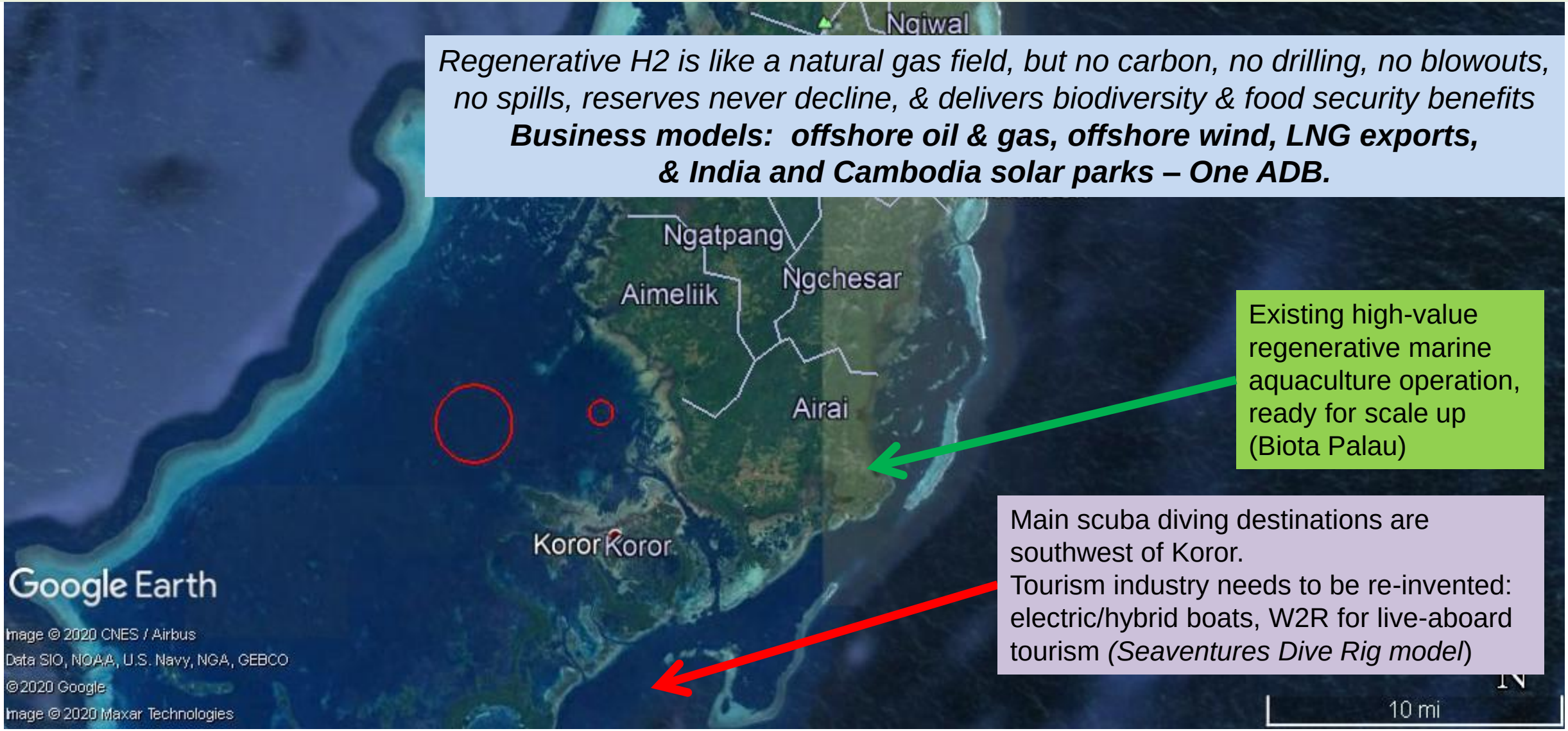

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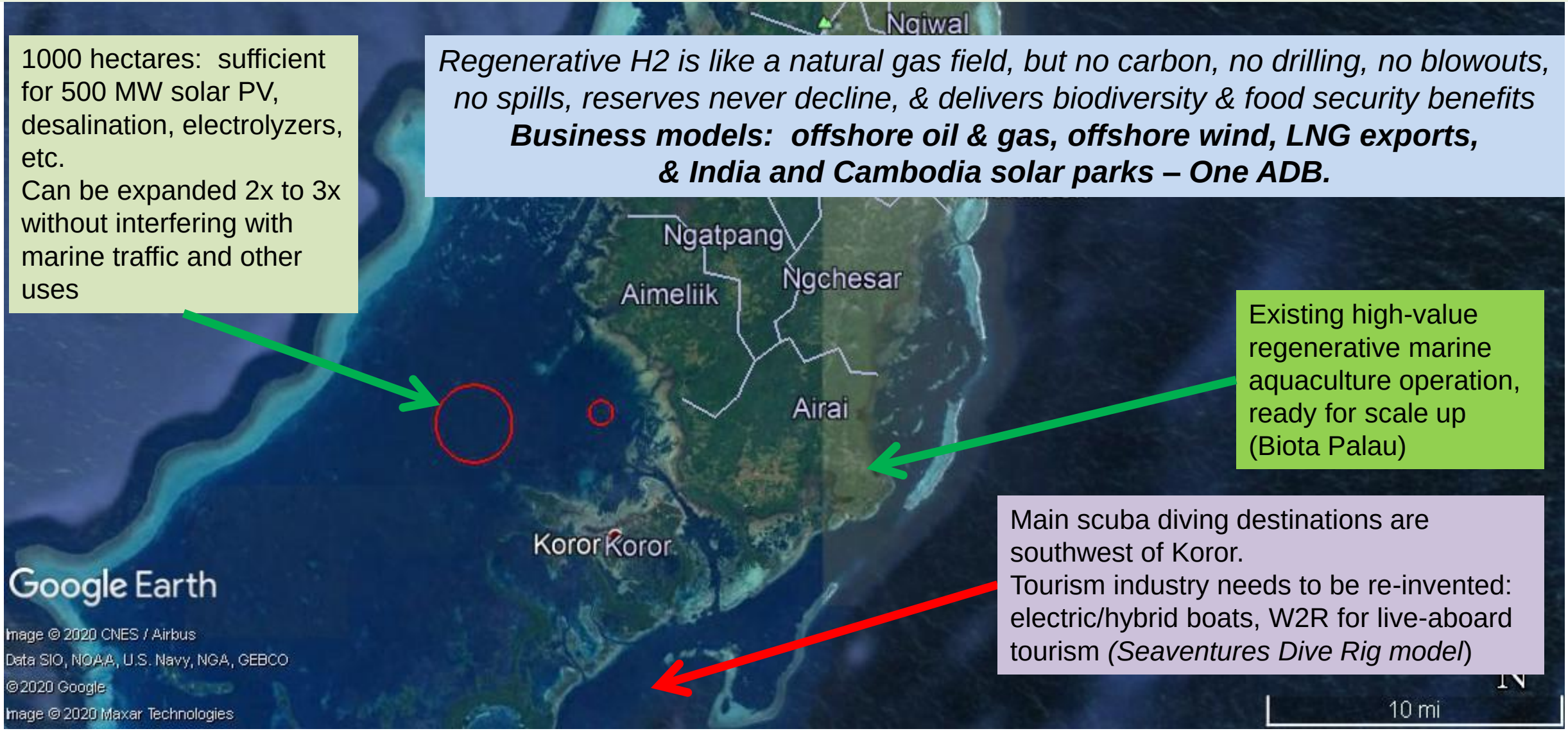

1000 hectares: sufficient for 500 MW solar PV, desalination, electrolyzers, etc.
Can be expanded 2x to 3x without interfering with marine traffic and other uses

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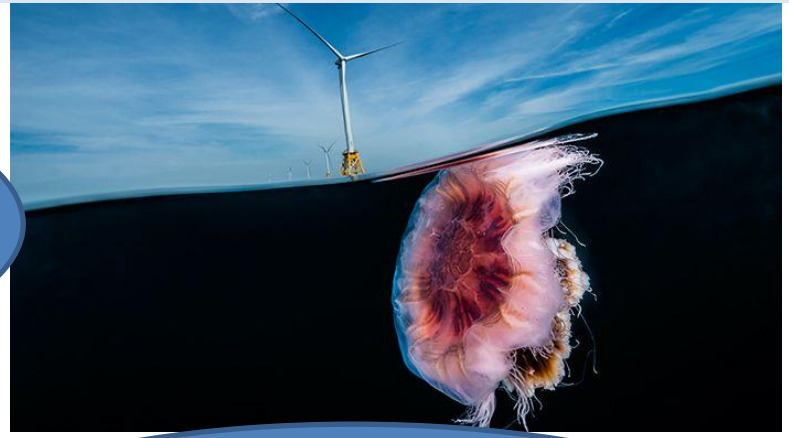
Regenerative **H2 enhances ocean health while providing revenue from**
(i) H2, (ii) oxygen, (iii) fresh water, (iv) reefs, (v) seafood, (vi) tourism, (vii) carbon $$$?

Advanced **marine aquaculture** output could be 100 times current global seafood consumption



Reefs can be cultivated and grown faster than natural reefs are dying

Offshore RE can power new industries: REGENERATIVE H2, carbon-negative building materials, climate-proof water, etc.

Ecotourism developed around reefs and integrated with marine aquaculture and offshore RE

MARES: $25 – 50 Billion investment

Thank you!

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 CO2 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/

FLOATING SOLAR – integrate with EMA reefs, etc.

	Cost for 100 MW [US$ million]	US$/W*
Module	34.0	0.34
Inverter	9.0	0.09
Electrical work	19.6	0.20
Total PV equipment	62.6	0.63
Floating structure	16.9	0.17
Anchoring	4.2	0.04
Total floating PV	83.7	0.84
Grid connection cost	-	-
Infrastructure	21.0	0.21
Total investment cost	104.7	1.05

- Based on these assumption and the available solar resources, the cost of solar electricity would be in the range of: **US$ 0.075 / kWh**
  - Based on estimates prepared for Sambor Hydropower reservoir site in Cambodia in late 2017
  - Current range for marine floating solar in the Maldives is $0.8 – 1.2 million / MW

Floating solar potential at typical resort islands in the Maldives

Indicative potential:

- Some resorts appear to be surrounded by coral reefs, which limits floating solar potential due to shading effects. Others appear more favorable, i.e., mostly devoid of surrounding reefs.
- Shading can be offset by growing reefs with electrolytic mineral accretion (EMA) systems in the affected areas.
- Alternative is to install floating solar at nearby uninhabited islands and connect to resorts with submarine cable; or shuttle batteries and/or hydrogen to the resorts with electric/hybrid vessels.

Key Assumptions:

- 2 hectares / 1 MW solar PV
- 20% capacity utilization factor (CUF) – 5 hours/day 350 days/year at rated MW capacity
- 15 MW solar @ 20% CUF can displace at least 6.5 million liters diesel per year
- Floating solar CAPEX ranges from $0.8 / Watt installed to $1.2 / Watt installed
- Floating solar + storage should be cheaper than diesel generation (4-5 year simple payback?)
- Integrated solar + batteries + hydrogen should be cheaper than diesel generation (based on HDF's Latin America and Caribbean experience)
- 1st-generation kits from can withstand 1-2 meter seas. Netherlands has had a prototype in the North Sea since late 2019 which has been tank-tested to 11+ meter seas

Additional considerations:

- Use some solar energy to power EMA to grow reefs which support regenerative marine aquaculture for carbon-negative seafood at resorts. EMA system can be used to 3-D print living breakwaters and to 3-D print sustainable building materials for modular construction of new buildings.
- Artificial upwelling might be integrated to ensure “no feed” aquaculture and provide seawater cooling for new buildings.
- Electric / hybrid boats are possible… including for taking tourists to & from the floating solar installations and reefs.
- “Blue carbon” credits or other marine biodiversity credit might be possible (e.g., fishreef.org).
- *Private resorts can be proving grounds for a new and unique brand of regenerative tourism.*

Looking beyond the core resort operations:

- New opportunities exist via modification of desalination systems for zero brine discharge and recovery of edible salts and high-value elements for sale into global markets. E.g., Lithium carbonate and lithium hydroxides can theoretically be recovered with EMA systems; these minerals currently wholesale at > $10,000 per ton. Some R&D is needed and could be pursued via partnership with battery, EV, and mining companies: the resort makes sites available for prototype operations and the industrial partners do the heavy lifting.
- This seawater “mining” scenario could provide 3 additional revenue streams / business lines in the future: (i) climate proof water production; (ii) sustainable edible salt production (e.g., Himalayan Pink salt); and (iii) regenerative mining of Lithium and other strategic metals to displace “conflict” minerals in other countries. It may be possible to sequester CO2 in mineral processing fluids for geologic disposal into saline aquifers (CCS) which presents an opportunity for carbon credit transaction / 4th revenue stream.

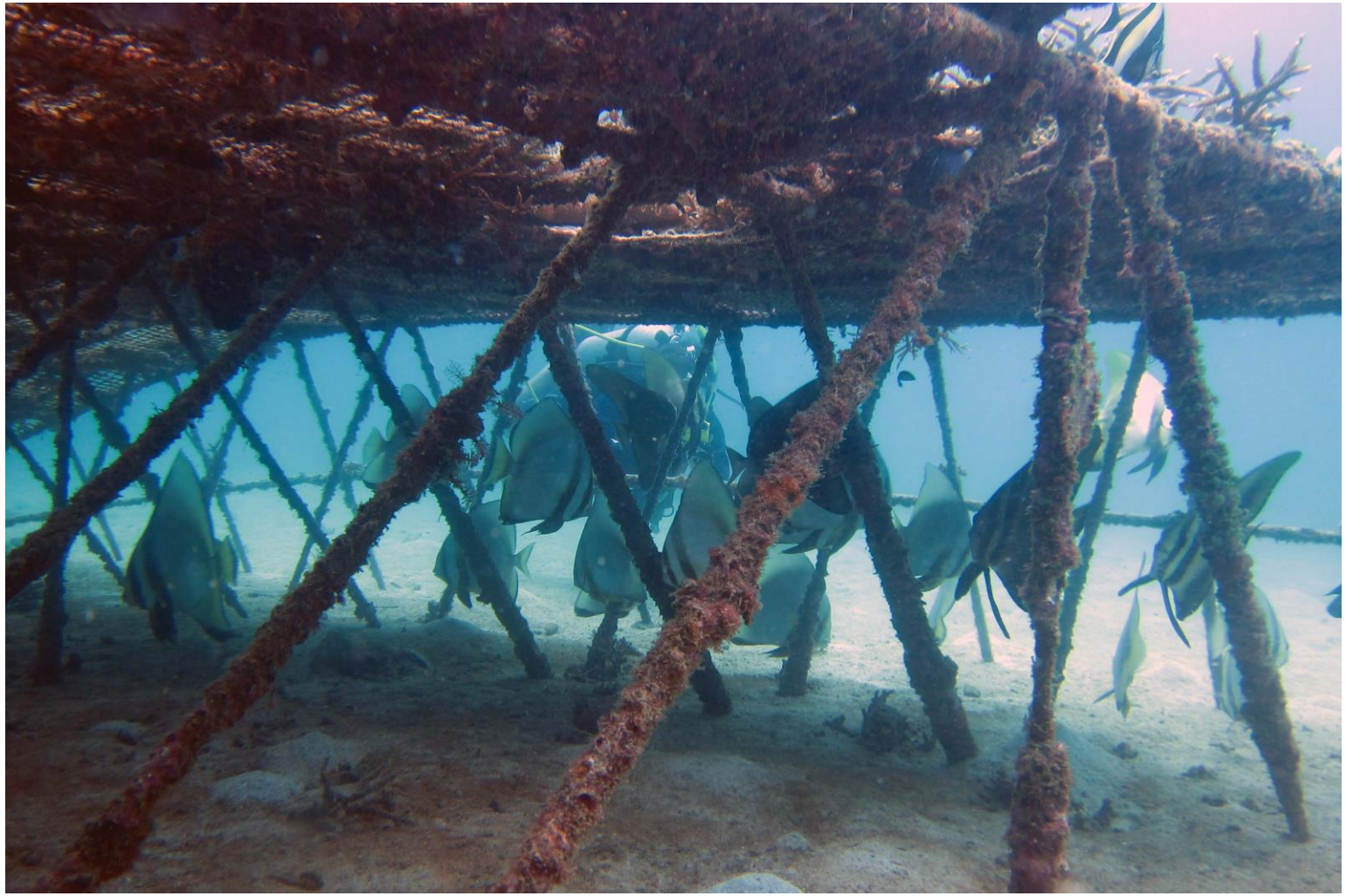
Observed $CaCO_3$ growth rates:
1 – 2 centimeters / year radial growth around rebar

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

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

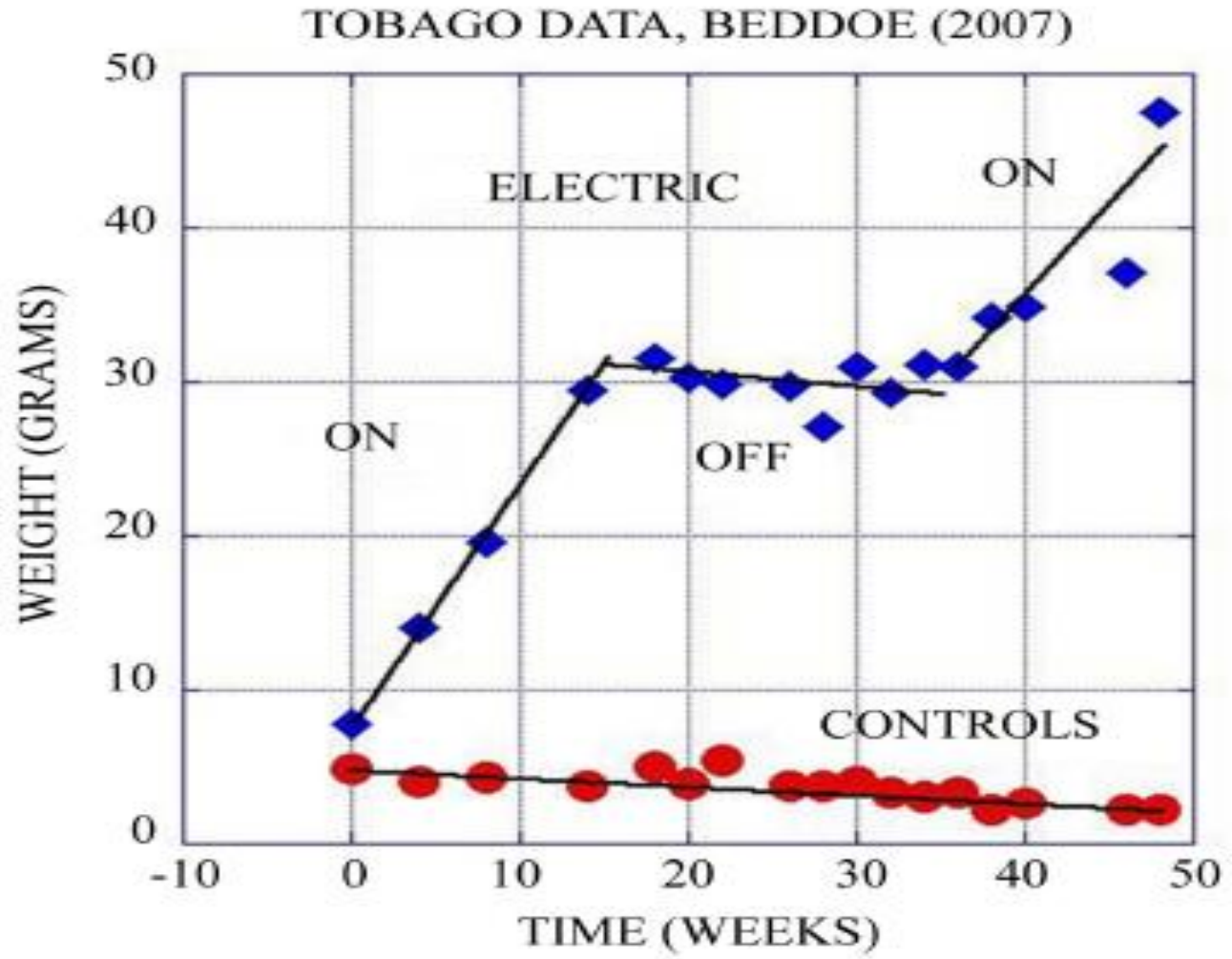
Source: Coral Triangle Conservancy, ree.ph

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

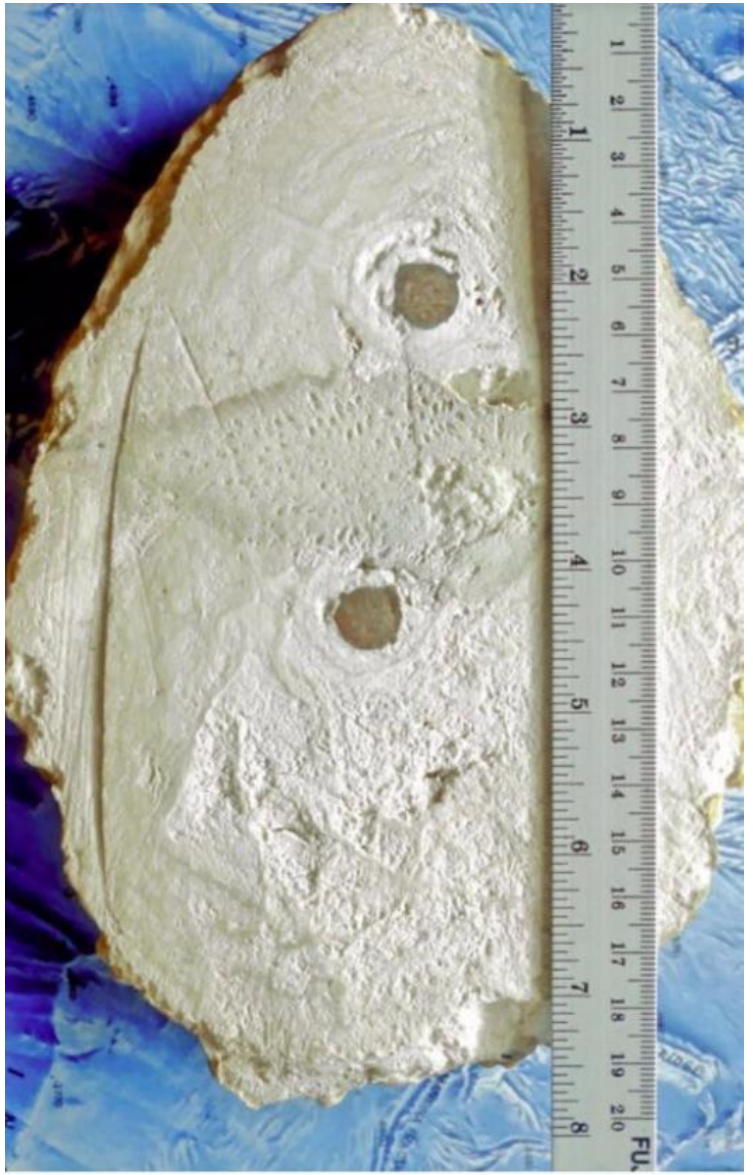
Electric reefs appear to be resistant to acidification & bleaching & can be grown faster than the climate is changing…
therefore, grown in place breakwaters are a form of climate change adaptation



Source: Goreau, T.J. (2014)

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

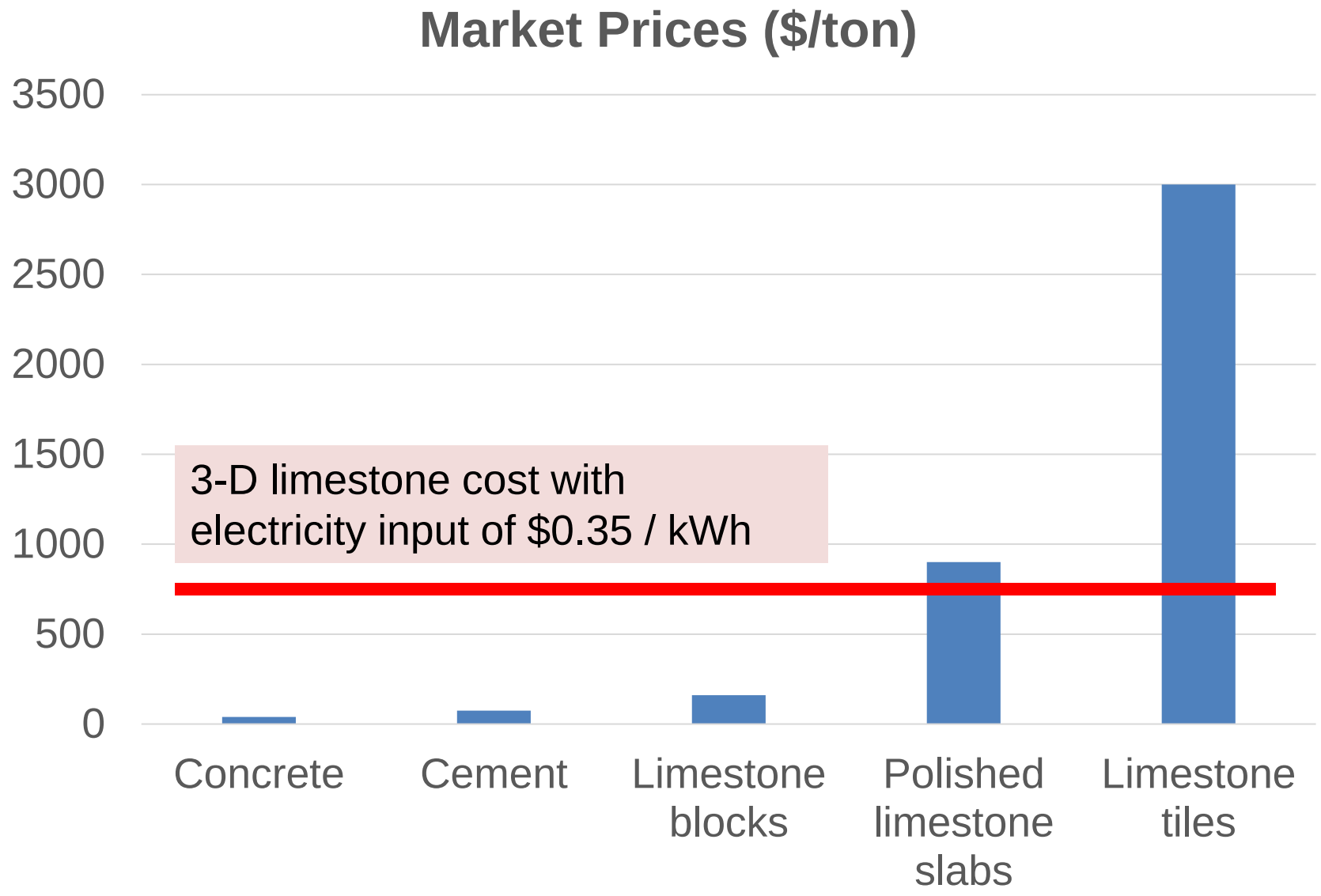
Hilbertz wanted to grow sustainable building materials…
and structures for OTEC….



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

3-D Printing of Sustainable Limestone Building Materials… and floating docks and over-water villas, etc.

Lithium carbonate and
lithium hydroxide wholesale
> $10,000/ton



Sustainable “mining” of Lithium & other high-value metals from seawater

(some assembly required)

Existing / new desalination plants:

Power with RE for sustainable & scalable climate proof water ($$)

Develop new packaging to eliminate plastic bottles

Modify brine treatment system for low- or zero-discharge

Recovery & sale of edible salts ($$)

Produce carbonates from concentrated brine with modified EMA system

- Treat carbonates with acid solution for recovery of Lithium and/or other high-value elements: wholesale prices for Lithium carbonate and lithium hydroxide are > $10,000 / ton ($$$$$)
- CO2 from seawater is retained in the acid process solution

Carbon capture and storage

Dispose of acidic solution with CO2 into saline aquifers – proven technology but requires exploratory drilling to confirm suitable aquifers

Possible to monetize carbon credits as a 4th revenue stream? ($$??)