Precision Product Design

Case Study 2

Renewable Energy Choices

Alexander H. Slocum
Walter M. May and A. Hazel May Professor of Mechanical Engineering
Massachusetts Institute of Technology
slocum@mit.edu
http://pergatory.mit.edu
@ahslocum

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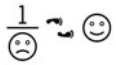
Due to our CO2 gassing
Heat records keep amassing
We grow yet wallow in pollution
We ignore that there is a simple solution

As corals & salmon die of heat before they can spawn
Carbon emitters must no longer turn their heads and yawn
On renewables we must ALL spend a reasonable part of what we earn
Or soon our atmosphere will be like that of Venus and it will be humanity's turn



https://www.kyuk.org/post/summer-chum-salmon-die-likely-caused-heat-stress-say-scientists

(Photo: NASA)

Our dependence on carbon fuels is causing global strife
The amazon burning should be a signal for all life
Nature and Physics simply do not care
We humans have no time to spare

Forget fake news
We have too much to lose
Money will not buy a place to hide
We must work together to stem the warming tide

https://www.theceomagazine.com/business/management-leadership/ostrich-strategy-ignorance-no-excuse/

What about YOU Personally?

- Are YOU willing to help with global warming?
  - Or its "the other person's responsibility!"
- Replacing old oil burning furnace with geothermal heat pump?

Replacing oil heat with geothermal heat pump dollars and kgCO2 assessment	
by Alex Slocum 2021.04.10	
Inputs in **BLACK**, outputs in **RED**	
Assumes annual maintenance costs will be similar	
Heating Days per year	150
Exisiting oil furnace	
Gallons oil used per year	1200
BTU/gallon	139000
Efficiency	0.85
Energy delivered (BTU)	141,780,000
Energy delievered (Joules)	1.50E+11
(kWhr)	41,573
24 hour average power over number of heating days (Watts)	11,548
Oil cost per gallon	$ 2.50
Total oil cost per year	$ 3,000.00
pounds of CO2/million BTU	161
CO2 generated (kg/gallon)	10.19
Oil system kg CO2 per year	12,229
Geothermal heat pump system (tons)	
upper floor	4
lower floor	4
BTUs/ton	12000
Total BTU/hour	96,000
Heating power potential (Watts)	28,135
Duty cycle for same average heating power as provided by oil	41%
Heat pump Coeficient of Power: CoP (power out/power in)	4.2
Annual	
kWhr heat produced	41,573
kWhr power consumed	9,898
kgCO2/kWh for natural gas generated electricity	0.196
kgCO2	1,940
Electric power cost $/kWhr (Bow NH)	0.21
Estimated annual electric cost	$ 2,079
From DoE annual operate cost est (Note NH crazy electric costs)	$ 739
Total installed system cost estimate	$ 60,000
Effective cost per Watt heat installed	$ 2.13
Tax credit	$ 13,200
Percent of system purchase	22%
Net cost to install geothermal system	$ 46,800
Conservative lifetime yrs	15
CO2 savings (kg/yr)	10,289

Put money where mouth is!?

Case 1: Pay cash for system	
Geothermal system (cash buy) effective annual cost	$ 3,120
Effective cost per tonne CO2	I pay $/tonne CO2:
	$ 11.66
Case 2: Geothermal system (financed buy) effective annual cost	
Annual interest rate (assume govt mandates prime rate)	3.25%
Capital recovery factor (monthly payments)	$ 0.0070
Monthly payment	$ 422
Annual total $/year - $ otherwise spent on oil	$ 2,059
Effective cost per tonne CO2	I pay $/tonne CO2:
	$ 200.13

And if there is a “Carbon tax”?

- Better get ahead of the curve before the rush!

Case 1: Pay cash for system	
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Effective cost per tonne CO2	I pay $/tonne CO2:
	$ 200.13
Case 3: Effect of carbon "tax" (e.g., a Greenhouse Gas Emissions Fee) on cost of oil if direct pass through	
Carbon tax of $100/tonne	$ 1.02
Resulting cost of oil (basic cost as above)	$ 3.52
Effective cost per tonne CO2	I pay $/tonne CO2:
	$ 81.27
Carbon tax of $200/tonne	$ 2.04
Resulting cost of oil (basic cost as above)	$ 4.54
Effective cost per tonne CO2	I am paid $/tonne CO2:
	$ 37.58
Carbon tax of $300/tonne	$ 3.06
Resulting cost of oil (basic cost as above)	$ 5.56
Effective cost per tonne CO2	I am paid $/tonne CO2:
	$ 156.44

And that old water heater?

LPG v Hybrid Electric Water Heater cost in dollars and kgCO2 assessment			
by Alex Slocum 2021.04.10			
Inputs in **BLACK**, outputs in **RED**			
Water			
input	Tin	**15**	C
output	Tout	**60**	C
Specific heat water	Cp	**4.184**	kJ/kg/C
Shower flow rate	Qshow	**4**	gpm
Length	tshow	**5**	minutes
Volume water	Vw	**75.7**	liters
Energy to heat water	Ejw	**1.43.E+07**	Joules
	Ekwhw	**4**	kWh
Heat pump water heater			
UEF	UEF	**3.4**	
"efficiency" by having a tank		**0.9**	
Net electric energy needed	Eenet	**1.3**	kWh
CO2 to produce electricity by gas	CO2e	**0.196**	kgCo2/kWh
Cost per kWh	coe	**$ 0.21**	$/kWh
cost for one shower	cose	**$ 0.27**	$
CO2 released per shower	CO2se	**0.25**	kgCO2/shower
Conventional resistance water heater			
cost for one shower		**$ 0.93**	$
CO2 released per shower		**0.86**	kgCO2/shower
Liquid Propane water heater			
Energy density	Elpg	**25.3**	MJ/liter
Combustion /heat transfer efficiency	etalpg	**0.85**	
Propane for 1 shower	Vp	**0.66**	liters
cost of LPG	cop	**2.5**	$/gallon
CO2 released from burning propane	CO2lpg	**1.62**	KgCO2/liter
cost per shower	clpgs	**$ 0.44**	$
CO2 released per shower	CO2se	**1.07**	kgCO2/shower
LPG/heat pump electric			
cost ratio		**1.6**	
CO2 ratio		**4.2**	

Ecophysovation
(economics & physics based innovation)

- Challenges are presented: Humanity is doomed…
  - ALL OF US unless we address global warming NOW
- Time to innovate!
  - People love to create and get clever…
    - Hackathons!
    - Wheeeeee, yellow sticky parties!
    - Pastries, mtgs, pretty colors!
- Be calm please and start with physics!
  - Nature does not give a sh!t about any particular lifeform
  - Physics does not care about courtesy or how you feel

Let's start with Macroeconomics

- Compare to buying a house: *What can we afford?*

	world
GDP (trillions)	$ 80
Population (billion)	8
Desired average 24/7 power use per person for everything (Watts)	2500
Total average power needs (Trillion Watts)	$ 20.00
Cost per renewable 24/7 Watt (including storage)	$ 3.00
Total investment required (trillions)	$ 60
% of GDP to be spent on renewables	3%
Trillions invested per year	$ 2.40
Years to 100% renewables	25.0

House price	$ 60,000
Annual income	$ 80,000
% downpayment	2%
Mortgage value	$58,800
Mortgage rate	4%
Years to pay back	25
Monthly payment	$ 310.37
Annual payment	$ 3,724.42
% of annual income spent per year	4.7%

"We must dare to be great; and we must realize that greatness is the fruit of toil and sacrifice and high courage." *Theodore Roosevelt*

Add Social Impact Factor: Carbon "Tax" regressive

- Tax revenue often spent by politicians to buy votes and donations…
  - Act important, start wars, blow stuff up!
    - Civil engineers design targets!
    - Mechanical and electrical engineers design weapons!
      - Wheeeeee
- At a peak of $128/tonne CO_2 tax
  - Electric power
    - $0.095/kWh from coal-based electricity
    - $0.025/kWh from natural gas combined cycle based electricity
    - <0.010/kWh for "renewables" based power
  - Driving: 20 pounds $C0_2$ from one gallon of gasoline
    - $0.018/km gasoline costs for travel by automobile (40 mpg)
    - $0.029 per mile for CO_2 at $128/tonne
    - *Compare to $0.100 per mile for gasoline at $4/gallon*
  - Money collected to be distributed to poor who suffer most?
    - What will change for them as companies figure learn to avoid tax?

"All creation is a mine, and every man, a miner" *Abraham Lincoln*

No new taxes is key
So how about a Greenhouse Emissions Fee?

- A *Greenhouse Emissions Fee* (GEF) for using the service of the planet's finite environment to take up stuff that harms it
  - Pollutant: Gases, liquids, solids
  - "A pollutant is a substance or energy introduced into the environment that has undesired effects, or adversely affects the usefulness of a resource." Wikipedia
- "A distinction is drawn between a GEF and a carbon tax
  - A "fee" is collected for using a resource and then it *must only be spent* on maintaining the resource (e.g., tolls go to maintain a road)
  - A "tax", on the other hand, goes into a general fund
- Companies pay the GEF or invest equivalent on green energy systems or environmental remediation…
  - *They get to own the asset and make good long term profit!*
  - *Cheaters aggressively sanctioned!*

We must especially beware of that small group of selfish men who would clip the wings of the American Eagle in order to feather their own nests.

Franklin D. Roosevelt

Greenhouse Emissions "Fee" Progressive

- GEF funds *MUST* be spent on creating renewables and reducing greenhouse gas emissions
  - Machines, systems, installations, grid…
  - Insulate houses and install geothermal HVAC
  - Public transportation…
  - Trade in clunker for electric or hybrid…
- What is the value of better health and high self esteem jobs from sustainable systems?
  - We must leave no worker behind to bear the burden!

"All creation is a mine, and every man, a miner" *Abraham Lincoln*

Onward with 1/Problem=Opportunity

- Oceans rising and resource and migration wars will cost a hundred trillion…
- Take a deep breath (while you still can) and:
  - Trillions in existing hydrocarbon infrastructure is an insignificant sunk cost
    - *Black Into Green (BIG) ideas* must start NOW
  - Military spending and logistics resources focus on defend the environment to defend ourselves!
  - Social welfare focused on green jobs…
- Beware hype and focus on doable (even if boring)

Beware Hype *or* Hope
(Wolves in snakes' clothing! ☺)

- *The Naked Truth:*
  - *No costume the Emperor had worn before was ever such a complete success.*
  - *"But he hasn't got anything on," a little child said.*

THE EMPEROR'S NEW CLOTHES
a translation of Hans Christian Andersen's "keiserens nye klæder" by jean hersholt

- E.g., Energy is required to run CO2 sequestration and conversion systems
  - Complete carbon accounting disclosure rarely given , and often hidden beneath false veil of "its proprietary…"
- *We DO want academics to please keep trying though!*

So What About Carbon Capture?

- What about it?!
  - CO2 is very stable, the result of a cheap exothermic reaction
  - “It isn't a noble gas, but it’s noble enough to put out fires”
- Capture and pump to store? *David Gessel*
  - What happens when reservoir burps?
- Technology to convert it to something?
  - To consume it requires an endothermic reaction
    - Many attempts seem to burn money for energy:
      - Calera => 183MM captured and sequestered
      - Blue Planet => mix with quicklime…
        - Heat crushed limestone to 1,100 C^{o}
    - **“Artificial Leaf” technology probably our best hope**
      - **Direct solar power-based conversion if proper catalyst can be found**
        - **Till then, natural leaves needed**

Financial Fairness

- How are costs calculated and presented to make the case for a technology?
  - Beware hype, hope, and hoopla!
- TRUE costs (financial, social, carbon) must be accounted for to cradle to grave cost of ownership!
  - “That’s proprietary” => “it does not really work but we hope and pray to make it work so give us $$$ and pray with us…
- Academics have a special role:
- Study and present the numbers and challenge those who claim ☺ to review and debate the analysis!

Example: PSH versus Batteries

- Consider chemical batteries v Pumped Storage Hydroelectric
  - PSH systems will last 80 years
    - PSH has a ramp up time of 90 seconds
    - Only feasible on large scale
    - Provides many local jobs
  - Li Ion will last maybe 10 years
    - Which is a better deal?
    - Batteries ramp in few seconds
    - Modular: start small and add
    - Provides few local jobs

All Y'all figure this out

True long term cost of storage options		
Written initially by Alex Slocum 2021.04.19		
Inputs in **BLACK**, Outputs in **GREEN**		
Discount rate	**5%**	
Capital recovery period set equal to battery life (years)	**10**	
Number of battery replacement cycles	**8**	
	PSH	Battery
Power (MW)	**100**	**100**
hours storage	**4**	**4**
Assumed life	**80**	**10**
Historical based maximum life	**100**	
Life assumed for comparison	**80**	**10**

All Y'all figure this out

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Historical based maximum life	**100**	
Life assumed for comparison	**80**	**10**
cost to install ($/W), assume with time cost of batteries stays same as tech gets better	**$ 2.05**	**$ 1.61**
initial investment ($MM)	**$ 205**	**$ 161**
Single-Payment Future Worth Factor (value of initial investment at end of life) ($MM)	**$ 10,140**	**$ 263**
Single-Payment Future Worth Factor (value of initial investment at end of life) with replacement cost at every end of life period ($MM)	**$ 10,140**	**$ 20,276**
Total equivelent effective cost ($/W)	**$ 1.27**	**$ 2.53**

Great idea:
Gravity, and mass are virtually free!

- Many have said “pumping water silly as its not heavy, move something more dense!

Gravity_mass_energy_storage_cost.xls					
Alex Slocum August 12, 2019					
Enter numbers in **BLACK**, Outputs in **BLUE**	**symbol**	**value**	**unit**	**equation**	
Mass moved					
Mass of body raised and lowered	Mb	**1000**	tonne		
Material price per tonne (including container)	ppt	**200**	$/tonne		
Total cost of mass	tcm	$ 200,000	$	: =ppt*Mb	
Mechanism (includes generator and motor)					
Mass mechanism/mass moved	mmr	**3**			
Total mass mechanism	mm	3000	tonne	: =Mmr*Mb	
Cost per kg construction equipment as reference	cpkg	**10**	$/kg	: range is $10-20/kg	
Total cost of mechanism	tcmm	$ 30,000,000		: =cpkg*Mm*1000	
Total cost of mechanism and mass	tcms	$ 30,200,000		: =tcmm+tcm	
Borehole					
Height of storage borehole	h	**750**	m		
Mass length/diameter ratio	LDr	**3**			
Mass density (concrete)	rhoc	**2400**	kg/m^3		
Diameter mass	Dm	5.61	m	: =(4*Mb*1000/(PI()*rhoc*LDr))^(1/3)	
Length mass	Lm	16.84	m	: =Dm*LDr	
Radial annulus around mass for guides, access	ram	**1**	m		
Diamter of borehole	Dbh	7.61	m	: =2*ram+Dm	
Volume of borehole to be excavated	Vre	34,140	m^3	: =PI()*Dbh^2/4*h	
Unit cost of tunnel and liner	ttpcm	1,139	$/m^3	: =ttpcm	
Cost of borehole to be excavated and lined	cbh	$ 38,888,160	$	: =Vre*ttpcm	
Total capital cost of entire systm					
Total system cost	tces	$ 69,088,160		: =cbh+tcms	

Physics (and finance) do not care…

	symbol	value	unit	equation
LEC				
potential energy per cycle	EpJ	7,350,000,000	Joules	: =9.8*h*Mb*1000
	EpWh	2042	kWh	: =EpJ/3600/1000
$/kWh of just mechanism	cwhm	$ 14,792	$	: =tcms/EpWh
$/kWh/cycle installed of entire system	cwhs	$ 33,839	$	: =tces/EpWh
Cycles per day	cpd	2		
Years to payback	ytpb	15	years	
total number of cycles	tnoc	10950		: =365*ytpb*cpd
Annual Interest rate	air	5%		
Capital Recovery Factor	crf	0.0963		: =air*(1+air)^ytpb/((1+air)^ytpb-1)
Annual payment	atp	$ 6,656,111		: =crf*tces
% capital cost/year for maintenece & operation	pmo	5%		
Annual maintenance and operation cost	amoc	$ 332,806		: =pmo*atp
Total annual cost	tac	$ 6,988,917		: =amoc+atp
Total cost per cycle	tcpc	$ 9,573.86		: =tac*ytpb/tnoc
Cost per kWh dispensed	cpkwhd	$ 4.69		: =tcpc/EpWh
Charging Teslas				
Tesla Model 3 battery	Etesla	270	MJ	
	Eteslamwh	0.075	MWh	: =Etesla/3600
Teslas per mWh	Ntes	13		: =ROUNDDOWN(1/Eteslamwh,0)
Teslas per the system sized herein	Ntestotal	27		: =ROUNDDOWN(EpWh/Eteslamwh/1000,0)
Single charge cost	ctct	$ 351.69		: =1000*Eteslamwh*cpkwhd

Back to Systems…

- Can we do it?

Biden's 10-Year Climate Plan

He's committing the U.S. to a far-fetched CO2 emissions goal without a vote of Congress.

By The Editorial Board
April 22, 2021 7:00 pm ET

PRINT TEXT 1,027

President Joe Biden speaks during climate change virtual summit from the East Room of the White House on April 22.

PHOTO: BRENDAN SMIALOWSKI/AGENCE FRANCE-PRESSE/GETTY IMAGES

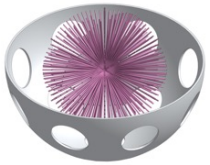
LOTSA Minerals will be needed for all those electric cars: A Road to Ocean Mining

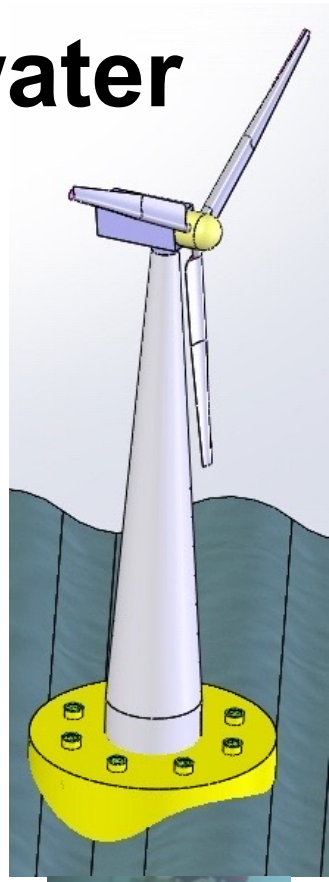
- Collocate vast arrays of offshore wind turbines with ocean mining by adsorption
  - The turbine support structure does double duty
- Deep ocean mining of nodules assisted by cargo ships
  - As ships travel between ports, in one direction if they are lightly loaded…
    - Stop to load up with ore from deep ocean mining operations

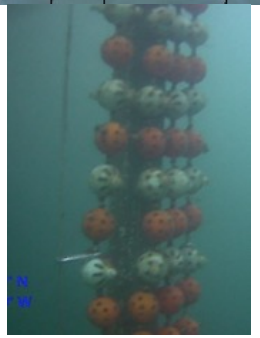
"As yet, the wind is an untamed, and unharnessed force; and quite possibly one of the greatest discoveries hereafter to be made, will be the taming, and harnessing of the wind" *Abraham Lincoln*

Harvesting Minerals From Seawater

- Shell enclosure for mineral adsorbing polymer decouples chemical & mechanical requirements:
  - Ocean tested: >30% cost-reduction in seawater uranium production cost.
- "strategic" minerals can be harvested
  - E.g., Cobalt, Vanadium needed for batteries
  - Deep (>100m) warm offshore Caribbean water
- Great potential to reduce conflicts between countries







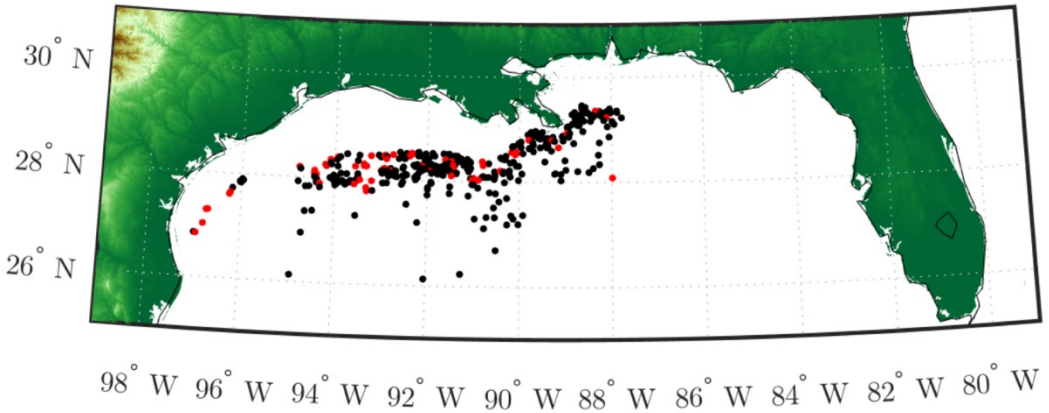
"We must plant the sea and herd its animals using the sea as farmers instead of hunters. That is what civilization is all about - farming replacing hunting."

Jacques Yves Cousteau

Copper, Lithium, Cobalt, Uranium, Vanadium…

New Offshore Opportunity for Underwater Cobalt Harvesting (NO OUCH)

- Warm waters and offshore platforms could create a mineral harvesting bonanza for all countries
  - And help usher in a clean energy future without a WWIII fight for scarce minerals!



M.N. Haji, A.H. Slocum, "An offshore solution to cobalt shortages via adsorption-based harvesting from seawater", Renewable and Sustainable Energy Reviews, Volume 105, May 2019, Pages 301-309, https://doi.org/10.1016/j.rser.2019.01.058

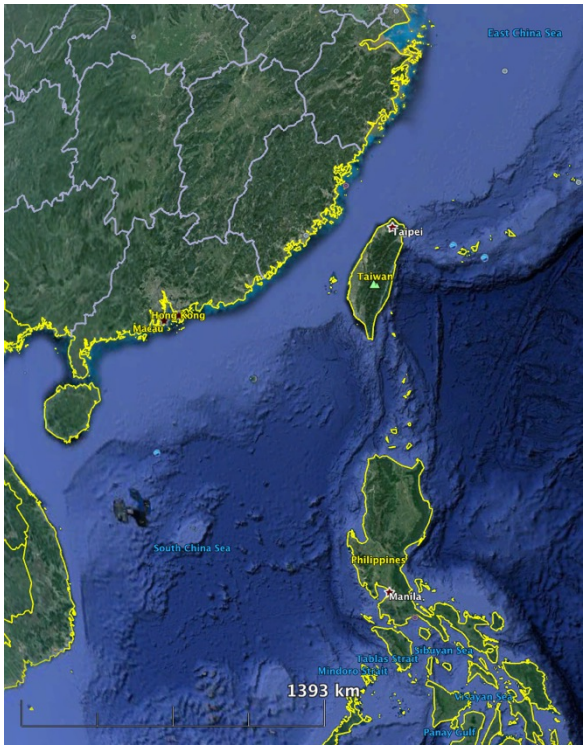
- Offshore platforms all over the world can be used…

Take Me Home, Country Roads

John Denver

Example: Cobalt for batteries

- China Sea potential for offshore wind and minerals
  - A belt to help us get on the road to the future!

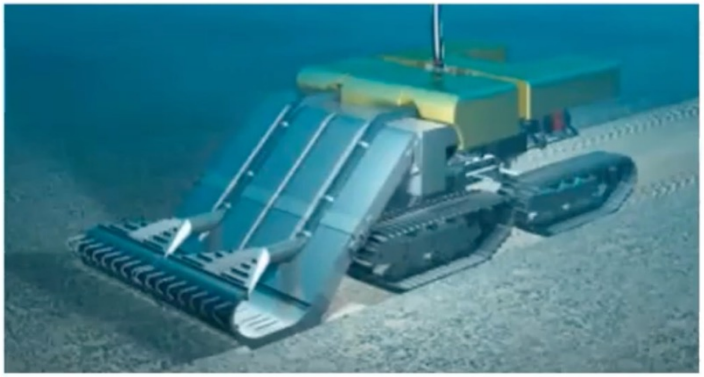


Area of China Sea continental shelf (km^2)	1,000,000
% utilized	5%
Square km	50,952
Structures per square km	1
Total number of structures	50,952
Wind turbine peak power (MW)	7
Capacity factor	40%
GW 24/7 wind power potential	143
Power from uranium adsorbed	143
Watts per person	1500
Persons served by wind power	190,220,800
Tonnes Cobalt per structure per year	2
Total tonnes Cobalt per year	101,904
kg Cobalt per car	10
Electric cars per year supplied	20,380,800

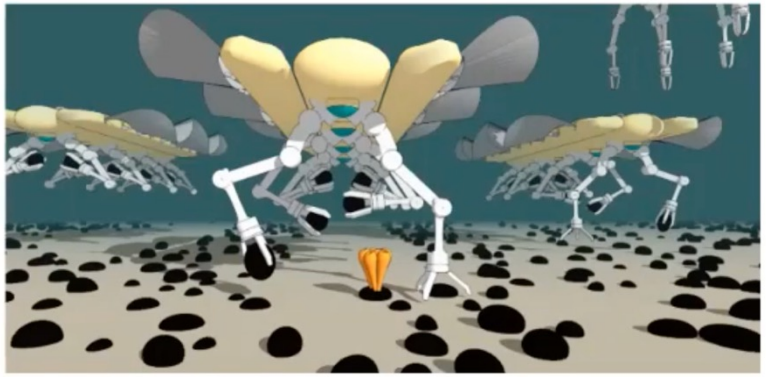
Foundation for an entire renewables industry from electric cars and energy storage to wind and solar energy harvesting machines

Deep Ocean Mining

- Giant machines and suction risers?
  - Path some large companies are taking
    - Risk: Destroy ocean floor before we know more
    - Risk: If machine or riser fails, huge losses start accumulating rapidly
- Small machines and lift bags filled with nodules?
  - Less disturbing, more robust, but economical?



19th Century Approach



21st Century Approach

https://www.youtube.com/watch?v=AknUVCAR1TQ&feature=youtu.be&t=2280

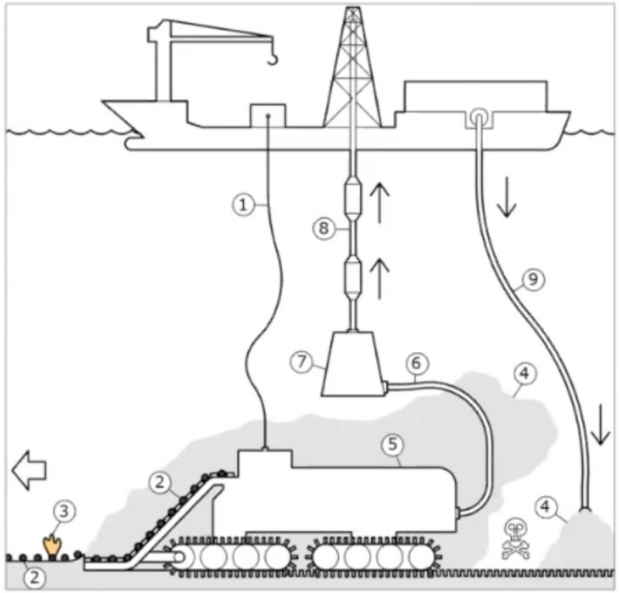
To hell with circumstances; I create opportunities

Bruce Lee

Getting the Ore to the Surface

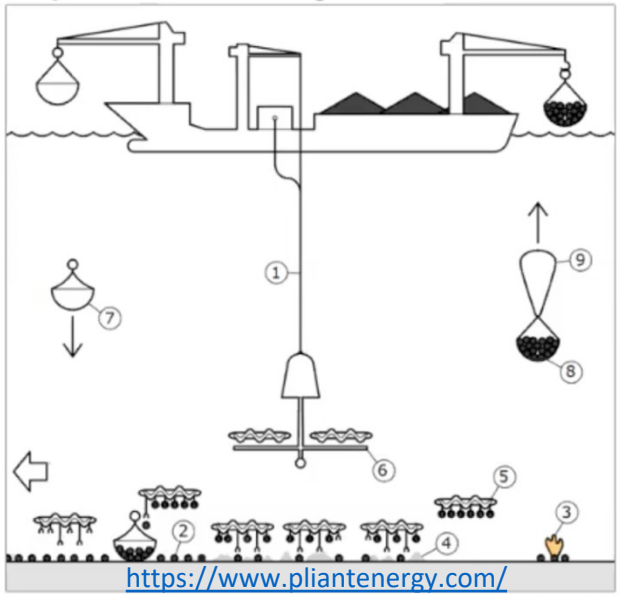
- Still much work to do to make energy efficient…
  - 40x expansion on way to surface!
    - ***Details matter!***

Current Nodule Mining Method



1 Power & Comms
2 Nodules
3 Life
4 Sediment plumes
5 Tracked crawler
6 Pulverized nodule slurry
7 Slurry pump
8 Riser
9 Tailings return

Proposed Nodule Mining Method



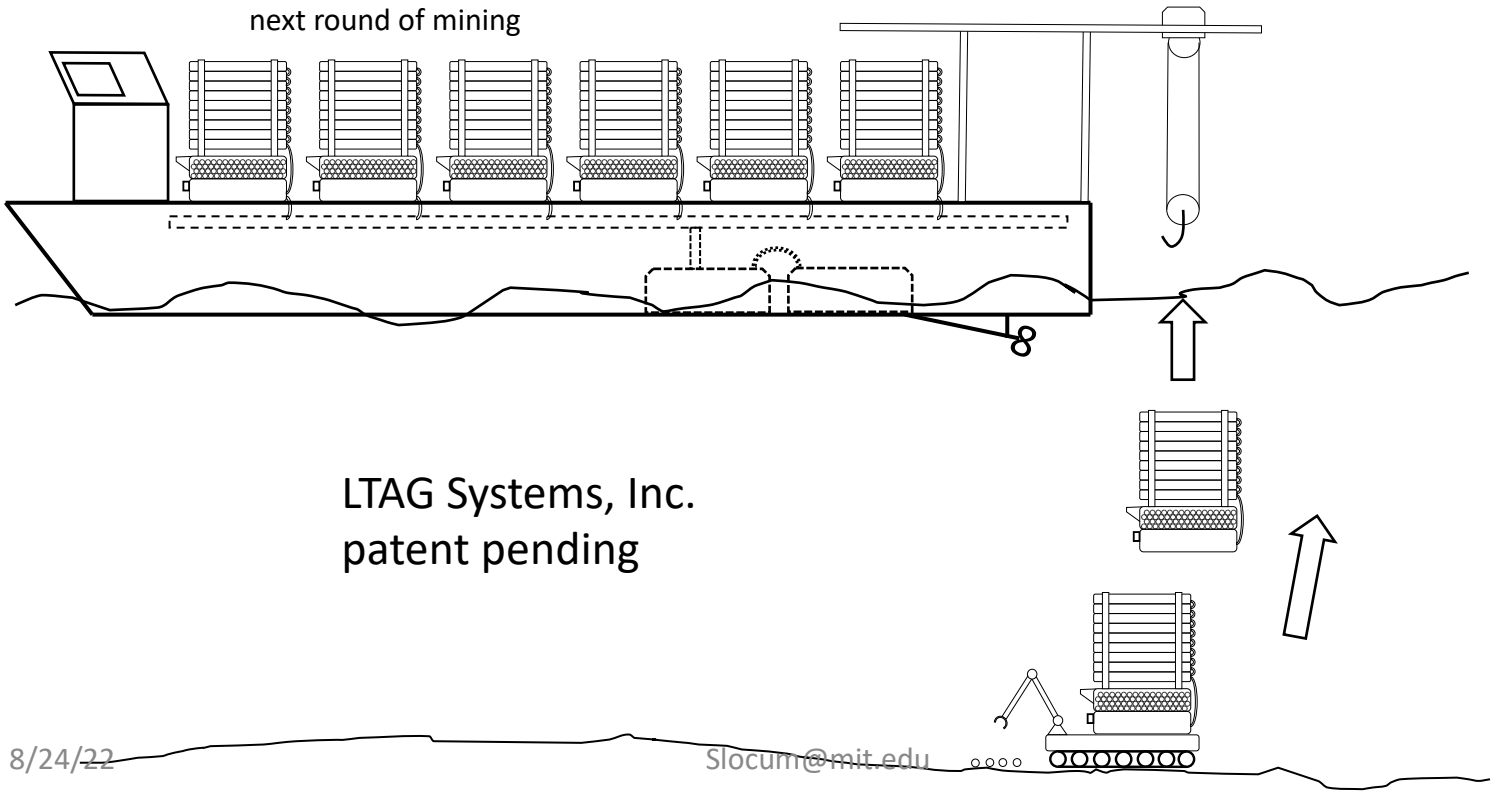
https://www.pliantenergy.com/

1 Power & Comms
2 Nodules
3 Life
4 Sediment plumes
5 Autonomous robot miners
6 Wireless charge station
7 Empty nodule cage
8 Full nodule cage
9 Lift bag

https://www.youtube.com/watch?v=AknUVCAR1TQ&feature=youtu.be&t=2280

Solution: Closed Loop System

- Energy costs can be exorbitant
  - Solution: a symbiotic approach using in-situ hydrogen generation from aluminum fuel
    - Hydrogen generated on the robot powers tools
    - Exhaust displaces water from high pressure container which then lifts the system to the surface
    - Hydrogen under pressure is used for fuel cells to cleanly power the ship back to port and back again for next round of mining



LTAG Systems, Inc.
patent pending

Density of H2 at depth	**35.95**	g/L	rhod	_=rho_stp*d/10
Density of Water (seawater)	**1029**	kg/m^3	rhow	
Activated Aluminum Fuel and Hydrogen				
Volume of Hydrogen Generated by 1g Al at STP	**1.25**	L	VH2STP	
Volume of Hydrogen generated by 1g Al at depth	**0.003**	L	VH2D	_=VH2STP/(d/10)
Bouyant Force of H2 from 1g Al at depth	**0.03**	N	bfource	_=VH2D/1000*rhow*9.8-VH2D/1000*rhod*9.8
Mass of Al required to lift 1 ton of ore at depth	**322**	kg	m_al	_=m_ore*9.8/(bforce*1000)
Mass of H2 generated from 1 kg of Al	**0.112**	kg/kg	H2_alum	
Mass of H2 needed to raise 1 ton of ore at depth	**36**	kg/ton	m_H2	_=m_al*H2_alum
Volume of H2 to raise 1 kg of load	**0.0010**	m^3/kg	VH2_pld	_=(1/rhow)*(1+rhod/1000)

Energy				
Energy Density of H2 (LHV) for ICE	**119.93**	MJ/kg	H2LHV	
Energy Density of H2 (HHV) for Fuel Cell	**141.86**	MJ/kg	H2HHV	
Compressed H2 energy stored per 1 Ton of Ore Raised (LHV)	**39**	GJ	E_LHV	_=H2LHV*m_al/1000
Compressed H2 energy per 1 Ton of Ore Raised (HHV)	**46**	GJ	E_HHV	_=H2HHV*m_al/1000
Conventional ship ICE Bunker Fuel Energy Density	**40.1**	MJ/kg	Bunker_EngD	
Equivalent Bunker Fuel Generated by H2 per ton of Ore Raised	**108**	kg	Bunk_eqvgen	_=m_h2*H2LHV/Bunker_EngD
Surface Vessel				
reference container ship size	**8,000**	TEU	Ship_size	(20' eqvlnt unit)
Approximate net mass of TEU (ore in TEU)	**20,000**	kg	TEU_Mass	
Mass of ore nodules per ship	**2.58E+08**	kg	m_oreship	_=TEU_mass*Ship_size*m_systemgross/1000
Total Aluminum needed to lift ore for ship	**1.34E+08**	kg	AAFtot	_=m_al_total/m_ore*m_oreship
H2 generated to fill ship with ore	**2.79E+07**	kg	m_H2ship	_=m_oreship/1000*Bunk_eqvgen
Conventional 8000 TEU Container ship bunker fuel/day cruising	**150,000**	kg	m_fuelcons	
Equivalent days of ship travel from H2	**186**		m_fuelship	_=m_H2ship/m_fuelcons

High Pressure Bouyancy tanks				
Outer Diameter of Tank	**0.5**	m	OD_tank	
length of tank	**3**	m	L_tank	
allowable wall stress	**1000**	Mpa	sig_max	
Pressure at depth	**40000000**	Pa	P_tank	_=d/10*10^5
Required wall thickness	**0.01**	m	t_tank	_=P_tank*OD_tank/(2*sig_max*10^6)
density of tank material	**2000**	kg/m^3	rho_tank	
Volume of tank	**0.60**	m^3	V_tank	_=4/3*PI()*((OD_tank-2*t_tank)/2)^3+L_tank*PI()*(OD_tank-2*t_tank)^2/4
Volume of tank material	**0.05**	m^3	v_tankwall	_=(4/3*PI()*((OD_tank)/2)^3+L_tank*PI()*(OD_tank)^2/4)-B36
Mass of tank	**107**	kg	m_tank	_=v_tankwall*rho_tank
Mass of hydrogen tank per cubic meter of H2	**179**	kg/m^3	m_tankton	_=m_tank/V_tank
Mass of hydrogen tank per kg raised	**0.180**	kg/kg	mtank_mpld	_=m_tankton*VH2_pld
System Mass				
Ratio of ancillary machine weight to raised ore mass	**0.2**	kg/kg	ratio_machine	
Gross System Mass	**1613**	kg	m_systemgross	_=m_ore/(1-ratio_machine-mtank_mpld)
Empty Weight of Machine	**613**	kg	m_systemempty	_=m_systemgross-m_ore
Mass of Aluminum needed to raise ore and machine	**520**		m_al_total	_=(ratio_machine+1)*m_al

Pumped Storage Hydro

- For Example:
  - Raccoon Mountain
    - https://www.tva.com/energy/our-power-system/hydroelectric/raccoon-mountain
      - six miles from Chattanooga, TN)
  - Max Power: 1,6 GW
  - Max. electricity Storage: 35.2 GWh
  - Surface of the upper & artificial reservoir: 2.14 km^2

If we are to be most successful
Going green must not be stressful
Needs of the people must be heeded
Economic and social impact factors needed

See Raccoon mountain in Tennessee
Energy storage for power carbon free
Built in the past for people's future needs
More than 1.21 gigawatts (1.6 GW) the grid it feeds

For energy storage and people it plays a big part
Built by 1600 workers in our Nation's heart
1970 to 1978 it cost $300 million dollars
Many more can be built those hollers!

Many a mountain top mine has left a hole
But they can be reborn to play a green role
As upper Pumped Storage Hydro reservoirs
They can become energy storage shining stars

From nearby wind and sun power generation
To old coal country power lines can run,
where prime geotechnical entourage
welcomes energy storage arbitrage

Coastal Pumped Storage Hydro & Desalination Systems

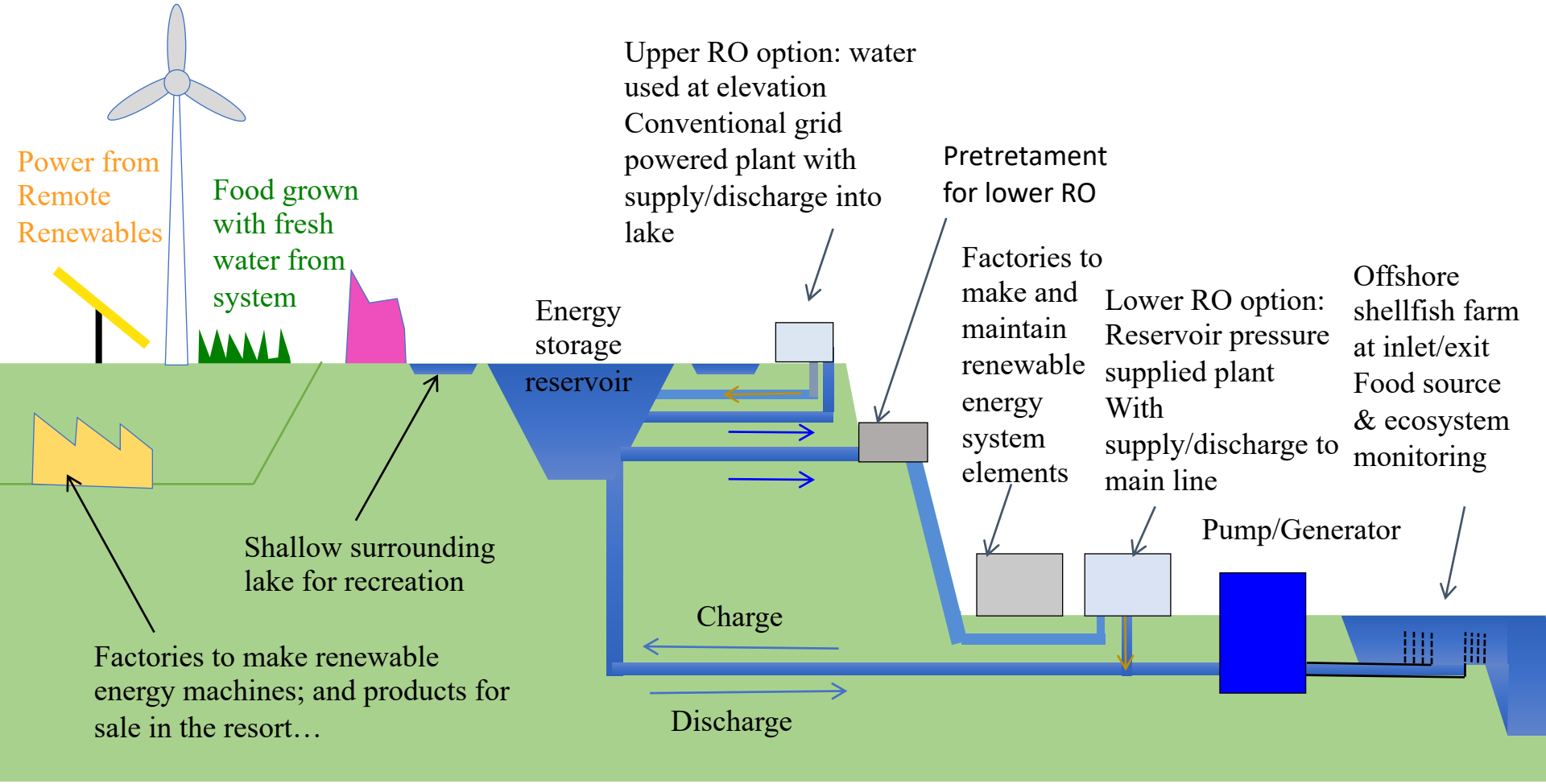
- Many drought stricken coasts have mountains near coast
- Pumped Hydro Head = 500-700 m, = RO desal head
  - http://www.sciencedirect.com/science/article/pii/S2213138816300492
  - https://www.oceanus.pw/
- 20m^3 water => 2kWe, 1 m^3 => 500l freshwater
- **With wind & solar farms, 1 km² lake @600m serves power & freshwater needs for 1 million people!**
  - ***Install cost on the order of $5/Watt for 24/7 power and water***
  - ***LCOE on order of $0.05-0.08 /kWhr***
- Long term vision, finance, and cooperation are required

"We are all visitors to this time, this place. We are just passing through. Our purpose here is to observe, to learn, to grow, to love… and then we return home."

Australian Aboriginal saying

IPHROS: Integrated Pumped Hydro Reverse Osmosis System

Supplying renewable energy, fresh water, and jobs for an entire region

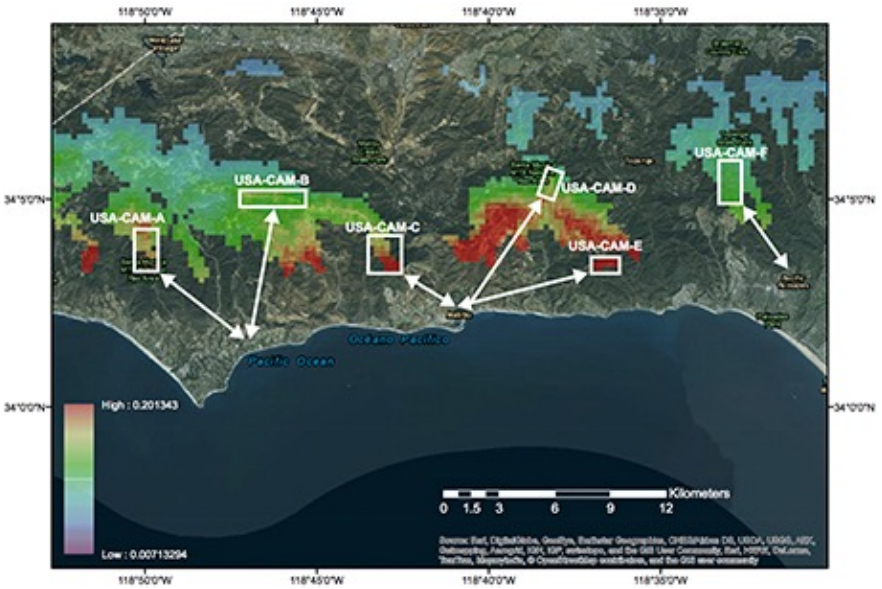


Back then they did not have hydraulics

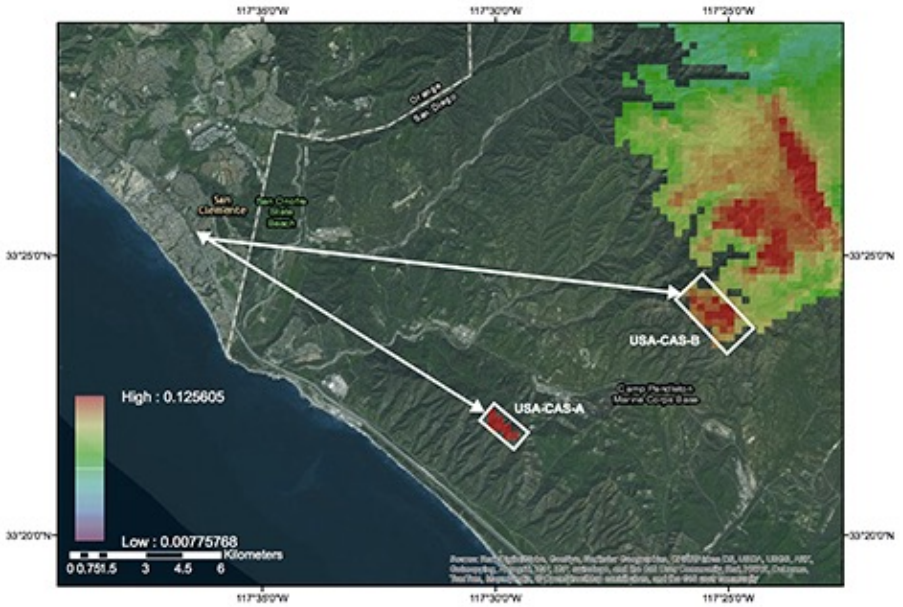
Although now we have social media & more lawyers

https://waterandpower.org/museum/Construction_of_the_LA_Aqueduct.html

California: Malibu & San Clemente



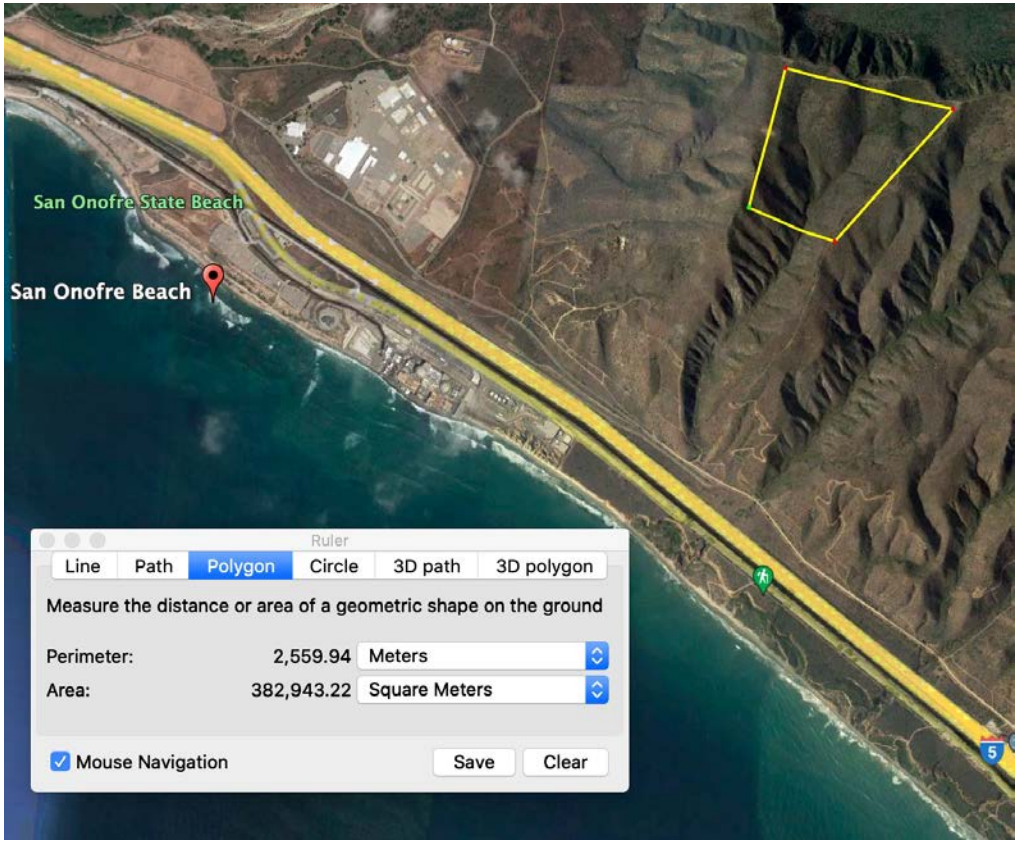
Malibu, CA, USA



San Clamente, CA, USA

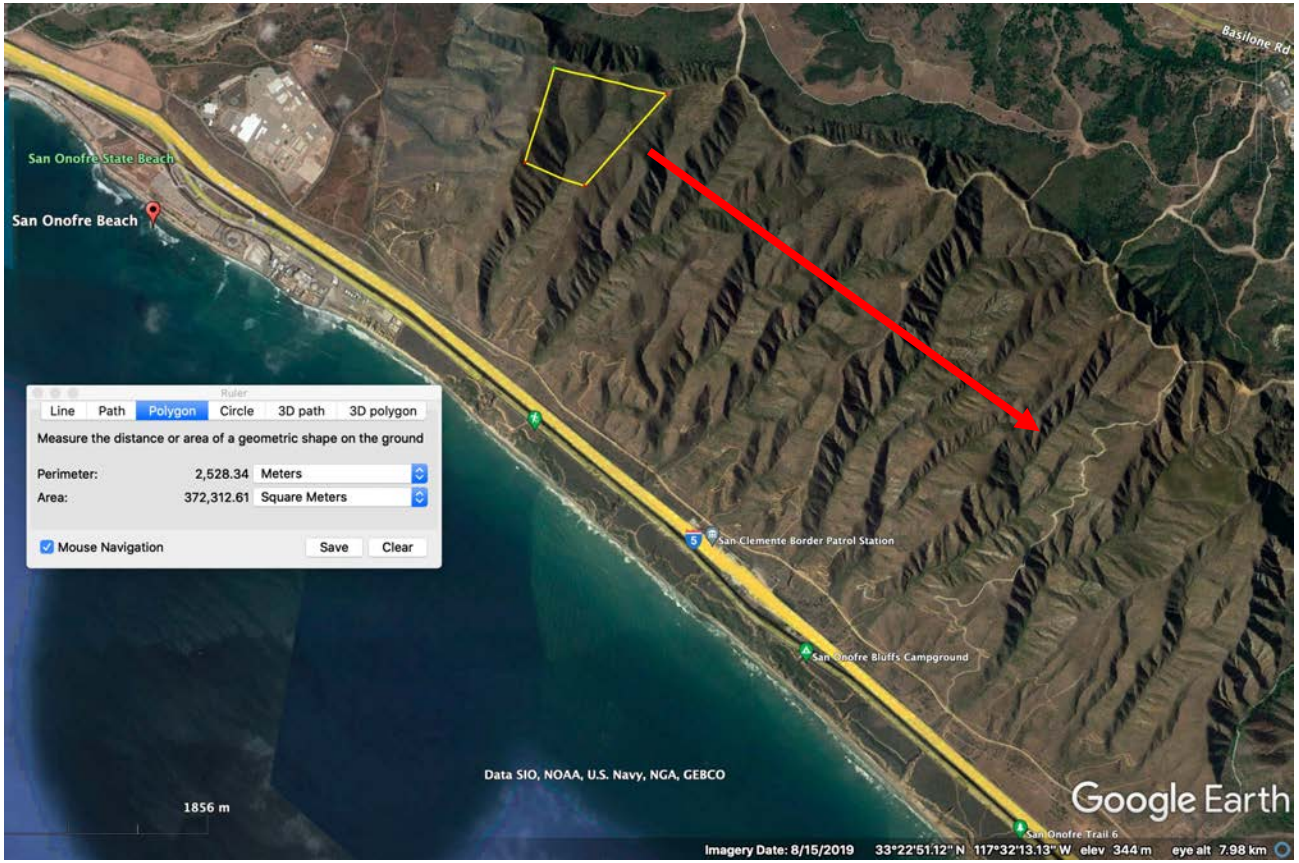
Region	Head (m)	Surface area (km^2)	Distance from coast (km)	A-Index	Nearest major city (NMC)	Distance to to NMC	Energy potential (GWh/cycle)
USA-CAM-A	612	2.9	5.2	0.112	Malibu	5.9	119
USA-CAM-B	684	2.2	7.7	0.089	Malibu	8.8	101
USA-CAM-C	528	1.7	4.3	0.123	Malibu	3.3	59
USA-CAM-D	678	0.9	6.9	0.098	Malibu	8	42
USA-CAM-E	518	1.3	2.7	0.192	Malibu	8	44
USA-CAM-F	545	2.4	7.2	0.076	Pacific Palisades	7.9	89
USA-CAS-A	505	0.5	4.1	0.123	San Clemente	14	17
USA-CAS-B	552	2.8	13.3	0.042	San Clemente	20	104

San Onofre Nuclear Power Site: still has transmissions lines and switchyard,

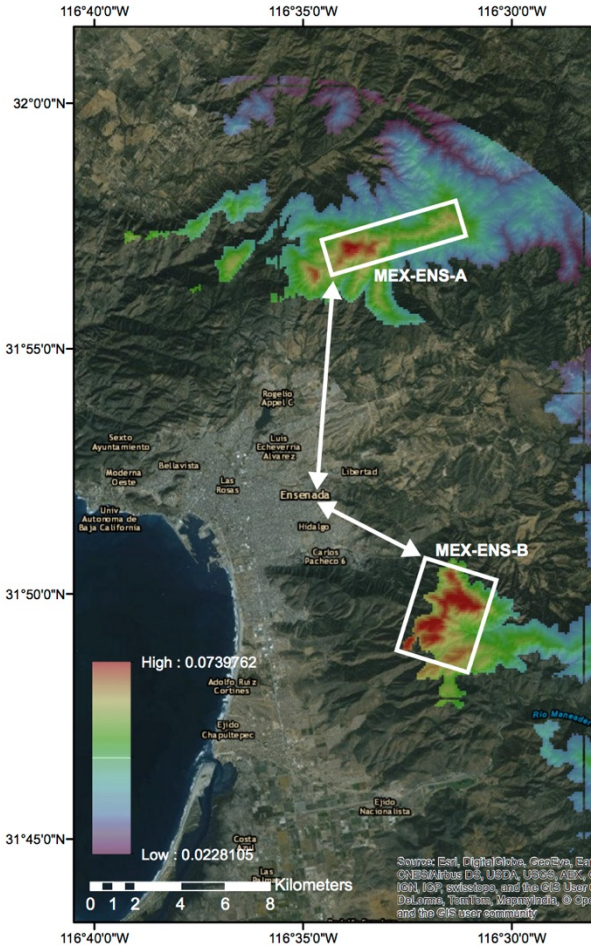


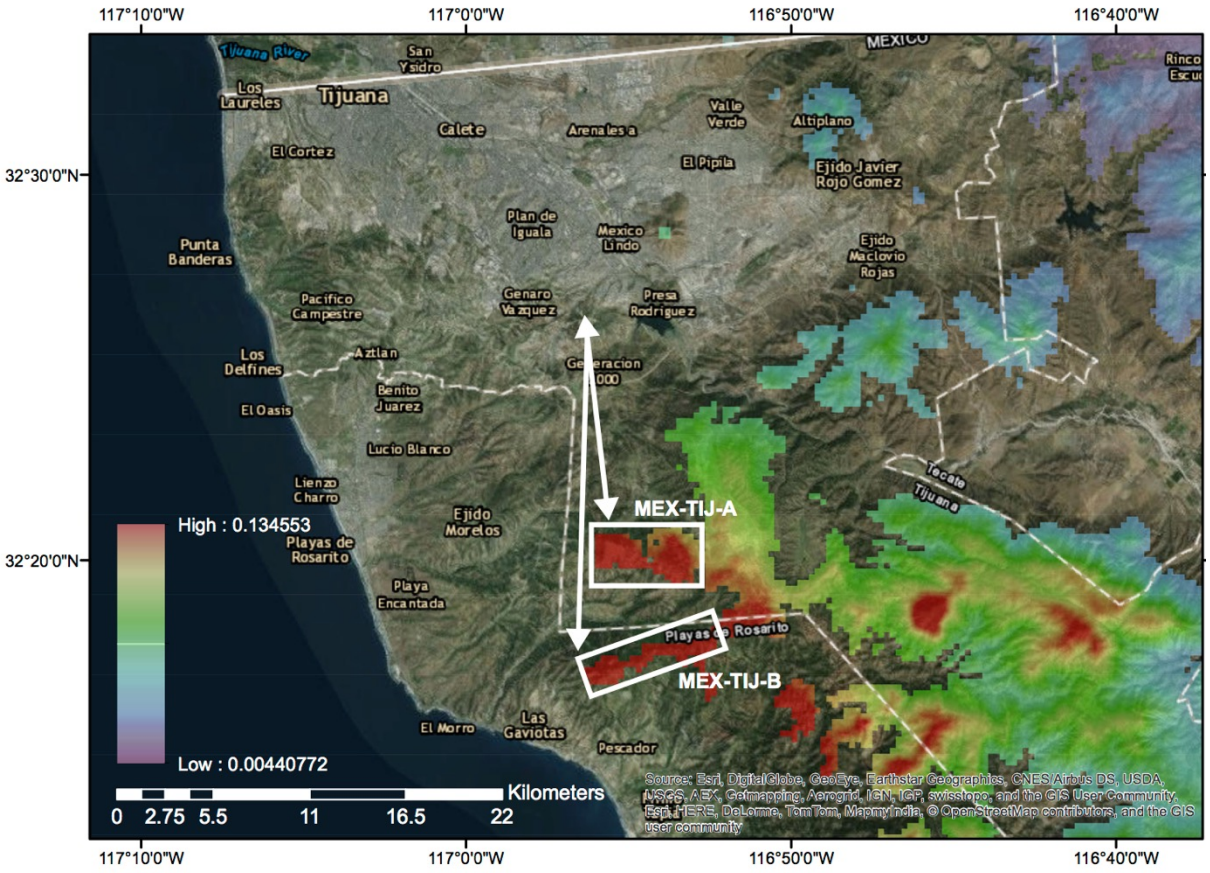
0.38 km^2 system at 330 m head and 40 m drawdown cycle could serve as the battery for about 400,000 people

Add IPHROS systems in valleys as needed…



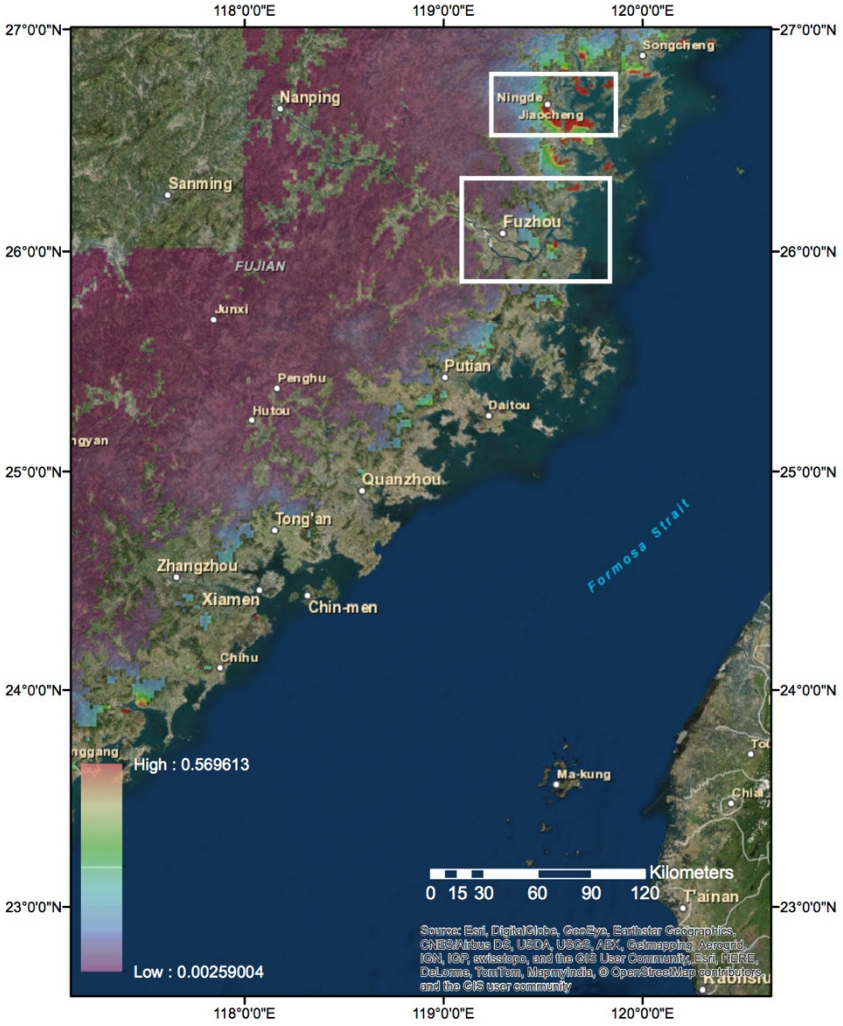
Mexico: Ensenada & Tijuana

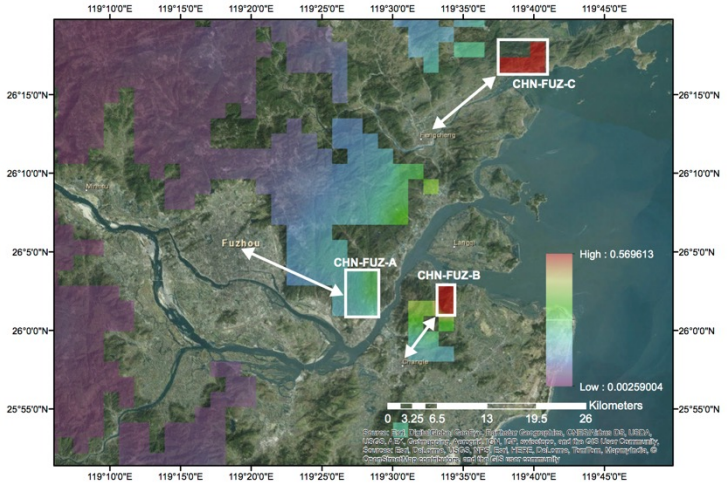


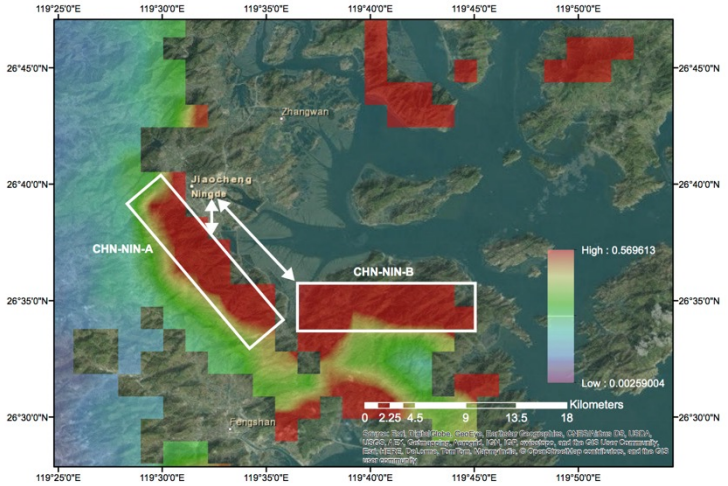


Region	Head (m)	Surface area (km^2)	Distance from coast (km)	A-Index	Nearest major city (NMC)	Distance to to NMC	Energy potential (GWh/cycle)
MEX-ENS-A	886	3.5	15	0.059	Ensenada	9.2	119
MEX-ENS-B	636	2.7	9.6	0.066	Ensenada	7.6	101
MEX-TIJ-A	567	14.5	12.7	0.045	Tijuana	12.8	483
MEX-TIJ-B	542	10.7	8.2	0.066	Tijuana	18.8	388

China


118°0'0"E
119°0'0"E
120°0'0"E
27°0'0"N
26°0'0"N
25°0'0"N
24°0'0"N
23°0'0"N
Songcheng
Nanping
Ningde
Jiaocheng
Sanming
Fuzhou
FUJIAN
Junxi
Putian
Penghu
Hutou
Daitou
Quanzhou
Tong'an
Zhangzhou
Xiamen
Chin-men
Chihu
Formosa Strait
Ma-kung
T'ainan
High : 0.569613
Low : 0.00259004
Kilometers
0 15 30 60 90 120
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS user community


119°10'0"E
119°15'0"E
119°20'0"E
119°25'0"E
119°30'0"E
119°35'0"E
119°40'0"E
119°45'0"E
26°15'0"N
26°10'0"N
26°5'0"N
26°0'0"N
25°55'0"N
CHN-FUZ-C
Fuzhou
CHN-FUZ-A
CHN-FUZ-B
High : 0.569613
Low : 0.00259004
Kilometers
0 3.25 6.5 13 19.5 26


119°25'0"E
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119°45'0"E
119°50'0"E
26°45'0"N
26°40'0"N
26°35'0"N
26°30'0"N
Zhangwan
Jiaocheng
Ningde
CHN-NIN-A
CHN-NIN-B
Fengshan
High : 0.569613
Low : 0.00259004
Kilometers
0 2.25 4.5 9 13.5 18

From where will we get all the green energy and carbon capture?

- No-till farming and wind power
  - No-till corn production puts carbon back into the soil, feeds people, ethanol plants & animals (corn and distiller's grain)
  - Wind turbines are not unsightly to farmers, they are cash generators!
- Right-of-ways
  - Power Lines: 5.5 million miles in US, under which carbon sequestering plants can be planted and animals grazed…
  - Pipelines: Pipelines to be "double hulled" and come with underground transmission lines to also transmit green energy
- Re and Afforestization
  - Can be a big part in resilient decarbonization
  - Part of GEF can go to paying "rent" to landowners that grow trees
  - Encourage invest in land that is left to grow trees
    - Valuable timber can be grown and selectively harvested for buildings where the carbon is locked up for many decades

agrarianpress.com

"The land is my mother. Like a human mother, the land gives us protection, enjoyment and provides our needs – economic, social and religious." *Djinyini Gondarra*

Example: Laying the Groundwork

Parameter	name	value	units	Equation, note
Rotor speed	wrpm	8.9	rpm	:=wrps*60/(2*PI())
Desired power	P	7	MW	
Electromagnetic shear (atm)	tau	0.15	atm	
Ratio motor rotor length/diameter	gam	0.25		
Required generator rotor diameter	Dm	8.41	m	:=(P*1000000/(PI()*tau*100000*gam))^(1/3)
Rotor width	Wrotor	2.10	m	:=DM*gam
Speed sound air	vsos	343	m/s	
Air density	rhoair	1.2	kg/m^3	
Coeficient of performance	cp	0.4		
Wind speed	vwind	12	m/s	
Required rotor diameter	Drotor	146.6	m	:=SQRT(8*P*1000000/(PI()*rhoair*vwind^3*cp))
				https://www.raeng.org.uk/publications/other/23-wind-turbine
Mach number at blade tip	mach	0.2		https://iopscience.iop.org/article/10.1088/1742-6596/1037/2/022003/pdf
Velocity blade tip	vbt	68.6	m/s	:=mach*343
Rotor speed	wrps	0.94	rad/s	:=2*vbt/Drotor
Axial force	Faxial	583,333	N	:=P*1000000/vwind

Establishing Symbiotic Potential:

Center pivot irrigation		
USA total electric sales (2018) GWh	**3,859,185**	
Average 24/7 power (GW)	**441**	https://www.eia.gov/electricity/annual/html/epa_01_02.html
USA average electric power generation		
1996 data (https://www.ars.usda.gov/ARSUserFiles/21563/center%20pivot%20design%202.pdf)		
Total number of center pivot irrigation machines	**125000**	(about 125,000 machines on approximately 19.5 million acres
Total number of acres	**1.95E+07**	
Acres per machine	**156**	
Area per machine (m^2)	**631,310**	
Diameter of irrigated circle (m)	**897**	
Turbine size to be located between fields (MW)	**7**	
Rotor diameter (m)	**147**	
Spacing / rotor diameter	**7**	https://sciencing.com/much-land-needed-wind-turbines-12304634.html
Ideal spacing for turbines (m)	**1026**	
Resulting assumed spacing between fields (or change turbine spacing or newer machines larger)	**-130**	
Assumed percentage of fields that could have turbines placed with them	**50%**	
Potential number of wind turbines	**62500**	
capacity factor	**0.4**	
Total 24/7 average power (GW) installable	**175**	
Percent of US total	**40%**	
kWh/year from 1 turbine	**24,528,000**	
Dollars per kWh wholesale cost aid to turbine owner	**0.05**	
% to land owner	**5%**	
$/turbine per year to landowner	**$ 61,320.00**	
yield dollars/ acre to landowner	**$ 393.08**	

It looks like 7 MW wind turbines with cop circles on 1 km pitch can be an ideal combination ☺

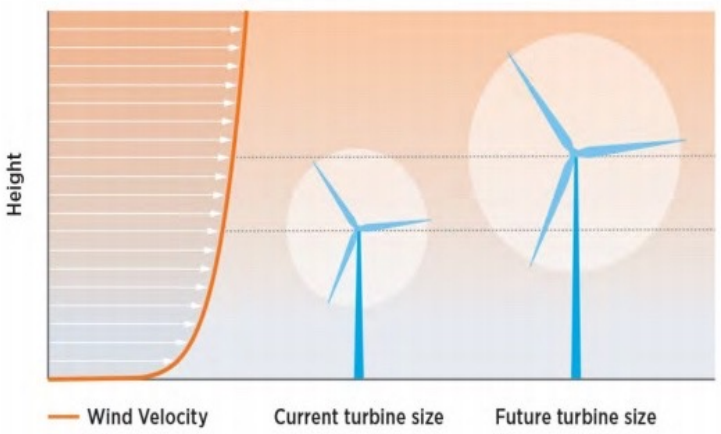
Details…*(and identifying opportunities)*

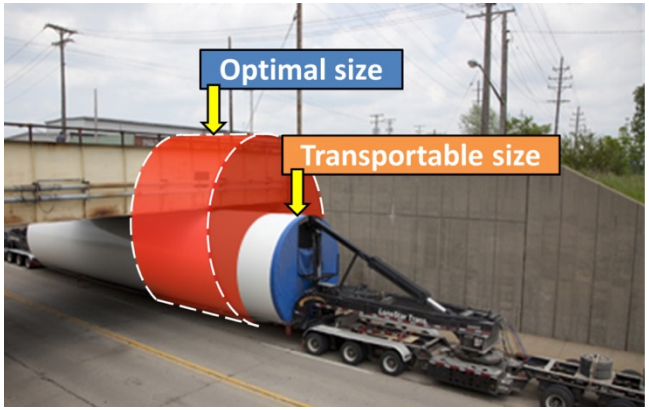
- And we see the need for a new way to rapidly make tall towers efficiently…

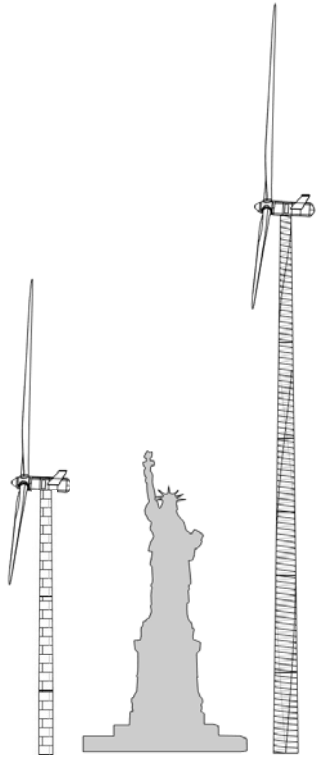
Ratio Hub Height/ Blades' Diameter	**1**	
Turbine Power (MW)	**7**	
Blades' diameter (m)	**147**	
Hub height (m)	**147**	
Axial force (N)	**583,333**	
Design stress (MPa)	**100**	
Required moment of inertia/distance to neutral axis (mm^3)	**8.55E+08**	
Wall thickness at base (mm)	**30**	85
Required aproximate diameter (D^3t/20 approx = I)		
Diameter (m)	**7000**	4250
Moment of inertia (mm^4)	**3.99E+12**	**2.41E+12**
Moment of inertia/distance to neutral axis Ioc (mm^3)	**1.14E+09**	**1.14E+09**
Stress	**75**	**75**
Cross sectional area (mm^2)	**6.57E+05**	**1.11E+06**
How much less steel used by big diameter thin wall pole?	**41%**	
Mass ratio	**1.69E+00**	
Thin wall large diameter strength estimate		
ESTIMATED Ioc = D^2*t	**1.47E+09**	
error	**22%**	

In-Situ Mfg: Lowering Cost of Wind Energy by 10%

- Must go bigger:
  - Class III @ 80 m sites => Class 4 sites @ 120-140m
    - Maine goes from 6 GW potential to 60 GW potential!
- Tower cost a function of physics
  - Stiffness =>D^3t strength => D^2t Mass => Dt
- "They" said "can't be done…"
  - So we MIT geeks did it! ☺







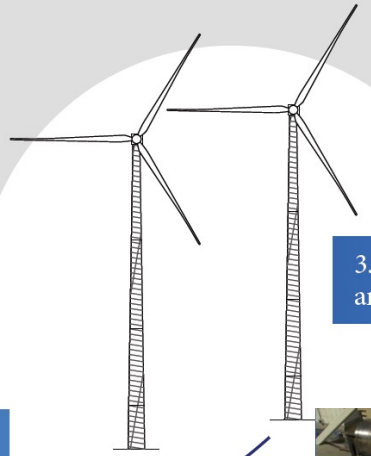
www.keystonetowersystems.com

Founded by MIT alums (including Alex ☺)

The BIG Idea!

ON SITE SPIRAL WELDING

The pipe industry has already shown that on-site spiral welding is an attractive way to get around transportation limits. Keystone's innovations bring this technology into the wind industry, unlocking the potential of much taller towers.

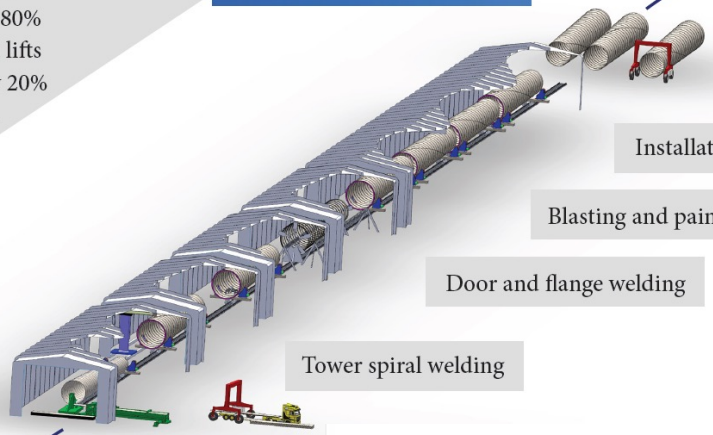


3. Tall towers are erected

ON SITE SPIRAL WELDING ENABLES LARGE DIAMETER TALL TOWERS

- 100+ tons of steel saved per tower by increasing diameter
- Standard trucks reduce shipping costs by over 80%
- Larger tower sections enable fewer flanges and lifts
- Larger base flange reduces foundation costs by 20%
- Thinner walls allow use of lower cost steel coil rather than plate
- Locally manufactured towers may satisfy local content requirements

2. Towers are spiral welded at the wind farm



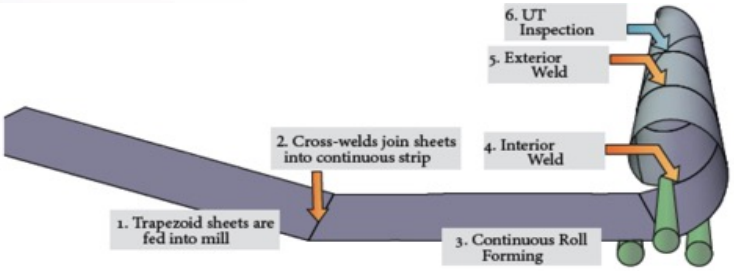
Installation of internals

Blasting and painting

Door and flange welding

Tower spiral welding

1. Steel is shipped as flat sheets



Slocum@mit.edu

Aligning PV with Lower Costs

- Tilting on one direction is good enough!
- Sunfolding Inc., (2012) by MIT Alum Dr. Saul Griffith
  - T29 Single Axis Tracker
    - Hundreds of MW installed
    - 90% of the benefit of tracking the sun
    - Far less complex than two-axis tracker
    - Central pneumatic system most of the be[illegible] cost of servo motors

Projects

With 26 projects currently operating or under construction, the Sunfolding T29's motor-free tracker rows are bringing a suite of advantages to projects across the U.S.

Opportunities

- More than just technology, we must seize opportunities to cooperate and collaborate
  - With each other
    - Indigenous Energy
    - Desertec
  - With Nature
    - Endemic waste to energy
    - SoS carbon
    - Symbiotic land use

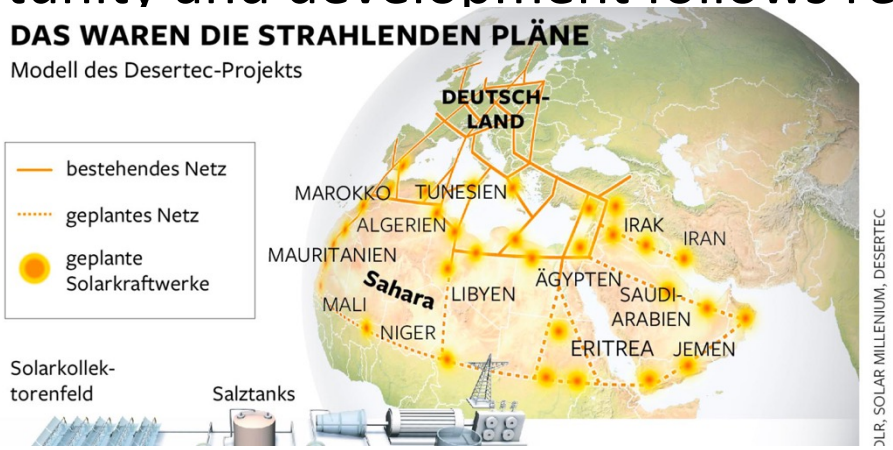
Indigenized Energy

- ***Native Lands have enough good wind and solar sites to provide ALL US energy needs!***
- *Cody Two Bears:*
  - "How does renewable energy bring people out of poverty? How does it create jobs? That's what we're at”
  - "We're the original environmentalists of this land. It makes sense for us to utilize this technology with our cultural values."

https://www.forbes.com/sites/jamesellsmoor/2019/07/27/standing-rock-fights-back-with-clean-energy/#c68ebad41d52

Desertec Resurgence

- The name for idea of supplying a large part of the world's population with solar power from deserts
  - Idea was developed by Club of Rome, which had founded a Desertec Foundation with the German Aerospace Center.
    - https://www.erneuerbareenergien.de/zehn-jahre-desertec-wuestenstrom-fuer-europa
    - https://www.welt.de/wirtschaft/energie/article133207028/Drei-Gruende-warum-Desertec-scheitern-musste.html
- Think American Southwest too!
  - Native American reservations: Indigenous Energy Production for US all
- Great economic opportunity and development follows resulting in inherent security…



Endemic Wastes to Energy

- “Natural” biological wastes create huge volumes and huge headaches
- Hurricane damage
  - 72 million tons (550 million trees) from Hurricane Michael in Florida (2018)
  - Over 1 million tons from Hurricane Maria in Puerto Rico (2017)
- Invasive Aquatic Plants
  - 540 million tons (5 million acres) annual in India
  - 6 million tons coverage on Lake Tana

Source: WSJ (2018)

Source: NPR (2016)

Endemic Waste Cleanup as Opportunity

- Wastes already incur high costs and require labor, centralization, landfilling, shredding…
  - Not cleaning can cause ecosystem die-off, blocked fishing or recovery efforts

Source: Twitter, Global Coalition for Lake Tana Restoration

Source: V. Peng

Source: http://en.kunming.cn/index/content/2010-12/29/content_2384707.htm

"Cleanup" effort = supply chain → Energy, Fertilizer, More

Endemic Wastes as Opportunity

- Can be cheaper than fossil fuel baselines AND carbon negative
  - Offsets landfill fees and decomposition
  - Increases local energy production, local jobs, energy security
  - Pushes technology instead of trashing feedstock
- In-situ processing reduces costs
  - In-situ processing of hurricane debris
  - Bag tow of aquatic plants

Source: terex.com

Source: Aquamarine

Caribbean Sargassum Invasion =>

Sargassum Ocean Sequestration of Carbon

MIT MANAGEMENT
LATIN AMERICA OFFICE

Prof. Alexander Slocum

Andrés Bisonó León

Luke A. Gray, MIT BS ‘18 MS ‘20

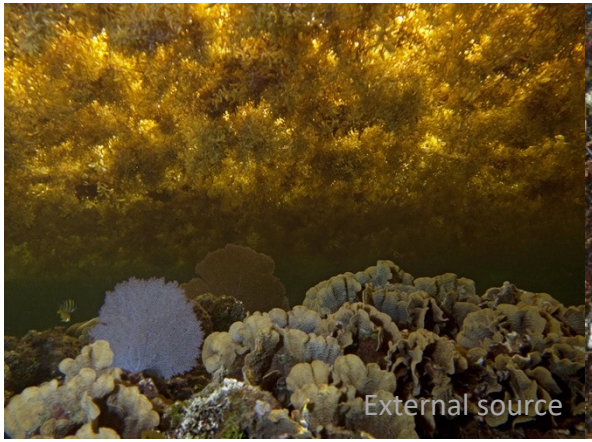
SOS CARBON

https://soscarbon.com/

Sargassum problem in the Caribbean

Affects:

- Tourism
- Public-health
- Local Economies
- Environment
  - Ecology
  - CO2
  - Corals



Littoral Collection Module (LCM)

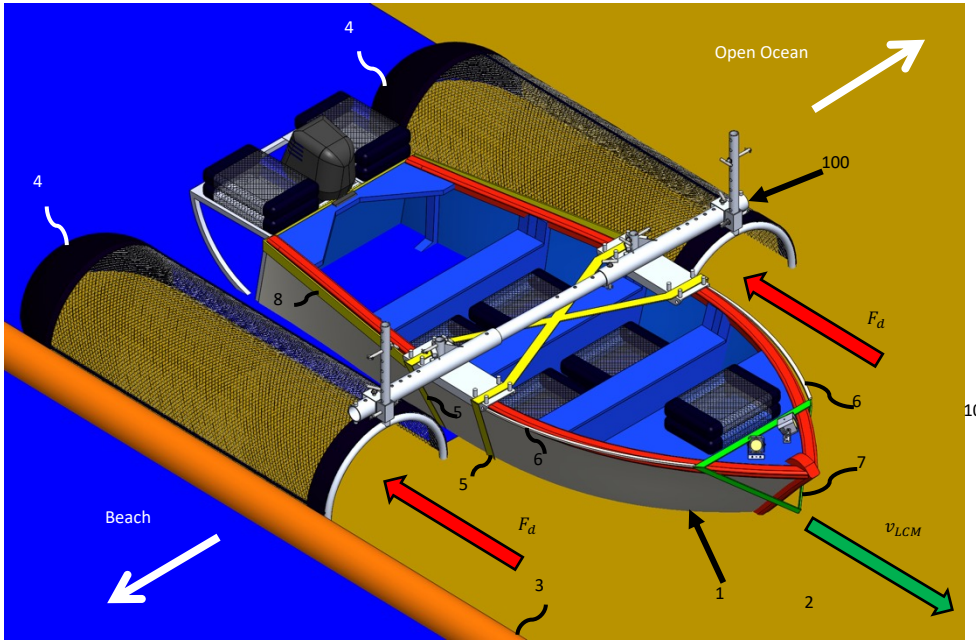
LCM system, Punta Cana, Dominican Republic

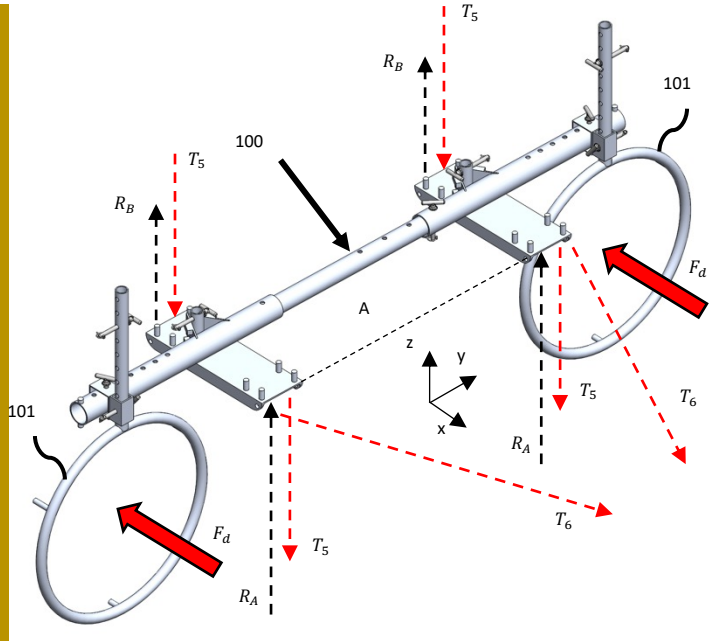
Buoyant net, Punta Cana, Dominican Republic

Aerial of LCM system, Punta Cana, Dominican Republic

Engineered for:

- Maximum operator safety
- Mass manufacturing





Patent-Pending

Fits on any small watercraft

Usable by small craft operators Caribbean-wide

Symbiotic GEF: Local and Global

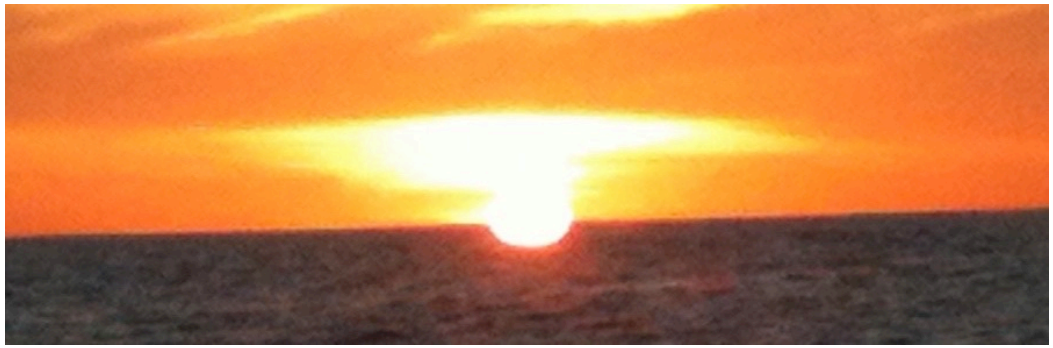
- Portion of GEF to fund “leave it alone” fees to owners of big forests
  - Local forest owners paid for CO2 absorption
  - Rainforests more valuable left standing
    - E.g., portion of GEF collected funds Brazilian MAGGAM efforts

YES! The Future Is Ours!

- Engineering is a blend of science and statistics to paint our future
- We are all responsible for the canvas of life
  - We CAN work and invest together to create a sustainable future…
  - … and walk the path to a green sustainable peace!

Do not let old ways hold you back
Carbon pollution youth must attack

Take charge of what your future will be
Scientific truth and focus can set us all free



So it has been written:

This Is The Way

人 太阳 風水 土地 和谐
道

Rén Tàiyáng Fēngshuǐ Tǔdì Héxié
Dào

People Sun Wind Water Earth Harmony
The Way

Isaiah 30:21 Surah Ar-Rum 30:20-24 Pancha bhuta

Knowing is not enough, we must apply. Willing is not enough, we must do
Bruce Lee

To mask or not to mask?
is not the question to ask
We all must no longer dwaddle
We need a renewable economic model

From COVID-19 economic ashes we can rise
Powered by focus on harvesting energy from the skies
Rapid testing isolation and treatment can open up the store
Harmony and balance with nature we can all economically restore

The economy we must stimulate
Doing things for all that are great
Trillions of dollars are going to spent
Later we must not wonder where it all went

Build and install sustainables for the world to flower
Fossil fuels that now generate many gigawatts of power
Money to buy and replace carbon power generation assets
Some to upgrade grid and add sufficient storage to hedge bets

And to make it all, invest 10% in a strong manufacturing base
$5/Watt provides a really powerful economic stimulus case
Instead of a trillion-dollar war, lasting jobs create
On climate and each other we can stop the hate

"I'm the village Crazy lady—that's my job"
Moana's Gramma Tala

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