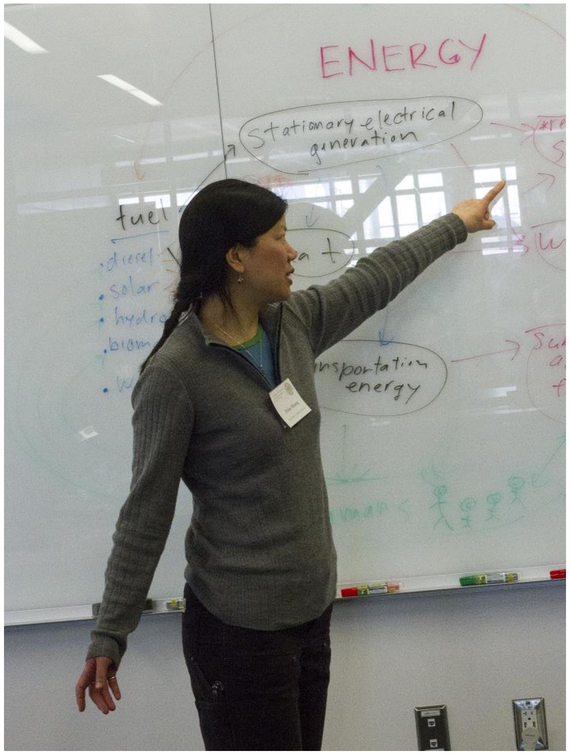
Renewable Energy Implementation in Alaskan Islanded Microgrids



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UAA Professional
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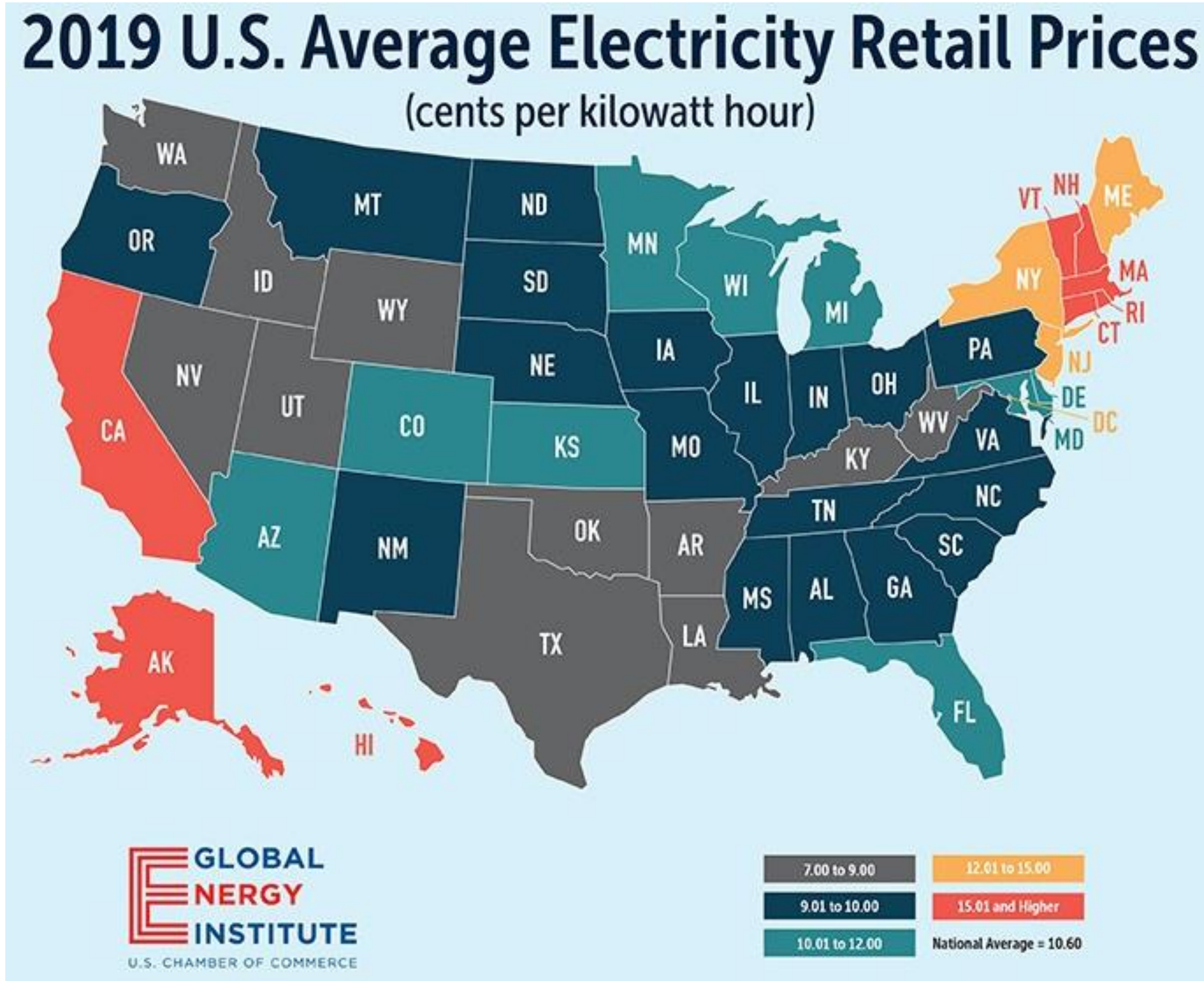
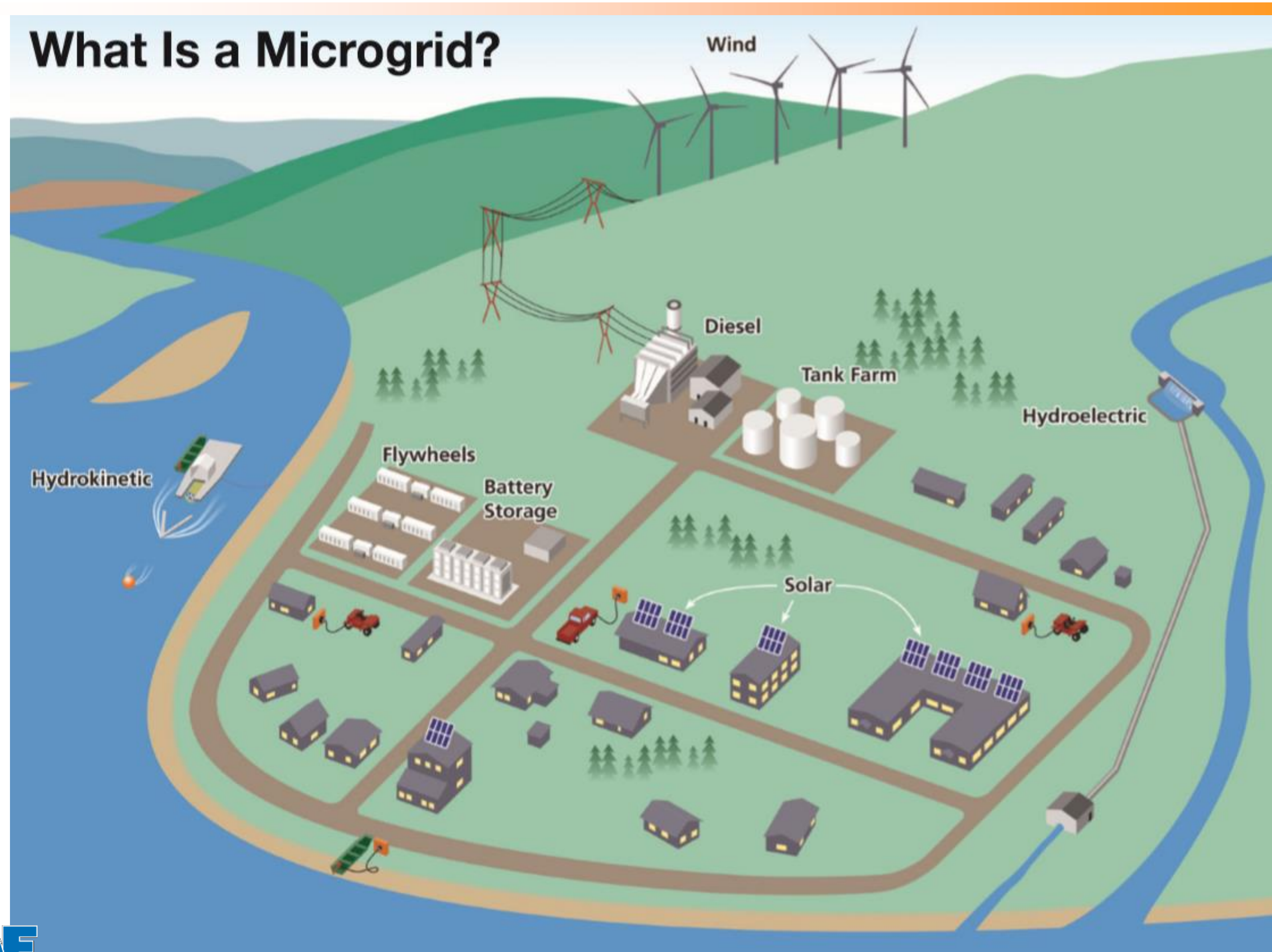
Alaska is rich in every type of energy imaginable, but we pay the highest power costs in the U.S.

- Oil
- Natural gas
- Coal
- Wind
- Solar
- Geothermal
- 365,000 miles of river (hydro potential)
- 6,640 miles of coastline (wave and tidal potential)



Power Cost Equalization (PCE)

- Power Cost Equalization, endowment fund established in 1986 to help offset the cost of power in electrically islanded communities that did not benefit from the large investments made in state electrical infrastructure on the Railbelt (such as Bradley Lake hydro, and the Intertie).
- Managed as a separate fund of the Alaska Energy Authority.
- About 29% of electricity sold in rural communities is currently eligible (per AVEC).
- First 500 kWhrs per month for residential customers
- Funding is renewed annually, and in theory could be cancelled any year.
- Cost of residential power in villages is set to the average of the cost of power of the three big “urban” centers (Anchorage, Fairbanks, and Juneau), plus ten percent.


What Is a Microgrid?
Wind
Diesel
Tank Farm
Hydroelectric
Flywheels
Battery
Storage
Hydrokinetic
Solar

What do we mean by “microgrid”?

- Average production of U.S. grid: 500,000,000 MW
- Average production of Railbelt grid: 600 MW
- Over 200 other “microgrids” in villages
- Average village is about 50 kW-400 kW.
- Hubs, such as Bethel, Nome, Kotzebue, are 3-5 MW.
- Each one is “islanded”.

Image source: http://blogs.lib.berkeley.edu/eart .php/visualizing-the-united-states-electric-g

Image source: http://energy-alaska.wikidot.com/diesel

What do we mean by “microgrid”?

- Outside Alaska, a microrgrid is defined as:
  - A small grid (<10s of MW).
  - That can be operated in islanded mode.
  - That possesses some of its own independent generation capability.
  - That possesses its own load demand.
  - That can balance its generation with its demand while in islanded mode.
  - By Outside standards, the Railbelt would be a microgrid.
- Within Alaska, our microgrids are:
  - Even smaller (10s-100s of kW).
  - Islanded, all the time, not by choice.
  - Must have redundancy; we have NO backup generation and NO transmission from elsewhere.
  - Must have low risk tolerance; without power in our harsh climactic conditions, people would die.
  - We can never at any time shut down an entire diesel fleet for repair or maintenance.

Why Microgrids?

- In rural Alaska, it is due to circumstance:
  - Small populations, widely dispersed.
  - Over 200 microgrids in Alaska
  - 70 have some renewable generation (~12% of renewably-powered microgrids in the world)
  - It is not economical to build transmission infrastructure for 100's to 1000's of miles to serve a small number of customer.
- In interconnected regions in the rest of the world, microgrids are a strategy:
  - To capitalize on distributed energy sources (which are often renewable)
  - To increase energy security (depending on local generation).
  - To increase energy resilience (disconnect from the main grid if there is a risk to the grid outside of your local community, such as a weather event, earthquake, tsunami…)

Why Diesel?

- In rural/isolated areas, we have no choice
  - Diesel is the most “shippable” fuel (energy-dense)
  - UAF and Fairbanks only have coal plants because we have rail to Usibelli mine.
  - Diesel-based power plants are scalable and can be very small or very large. For example:
    - Average load of Minto, population 210: 70 kW
    - Average load of Oahu, population 960,000: 1 GW
- Other places where diesel generation is used have these same characteristics:
  - Mines
  - Military forward operating bases
  - Remote research stations
  - Backup power for critical infrastructure in case of grid failure:
    - Hospital
    - Military base
    - School (often emergency gathering place in times of crisis)

The vastly predominant source of power in rural Alaska is isolated diesel generator sets

- Only exceptions:
  - Communities that have hydro (e.g. Cordova, Southeast)
  - Utqiagvik (long-term contract with the North Slope companies for inexpensive natural gas power).
  - Anchorage is mostly natural gas; Fairbanks is coal and buys from ANC via the intertie.
- Characteristics of rural Alaskan power houses:
  - Base load powered by diesel generators.
  - More than one generator carries the load.
  - There is sufficient redundancy to take a generator at a time offline for maintenance, service, and/or repair.
  - Generator "load dispatch" is selected by operator.
- In general, the minimum acceptable load on a diesel generator is 20%. This is *bare minimum*.

Goodnews Bay power plant:

Image source:
h
C%20Project.htm

Humpback Creek hydro plant in Cordova:

Image source:
http://www.akene
hydroelectric.html

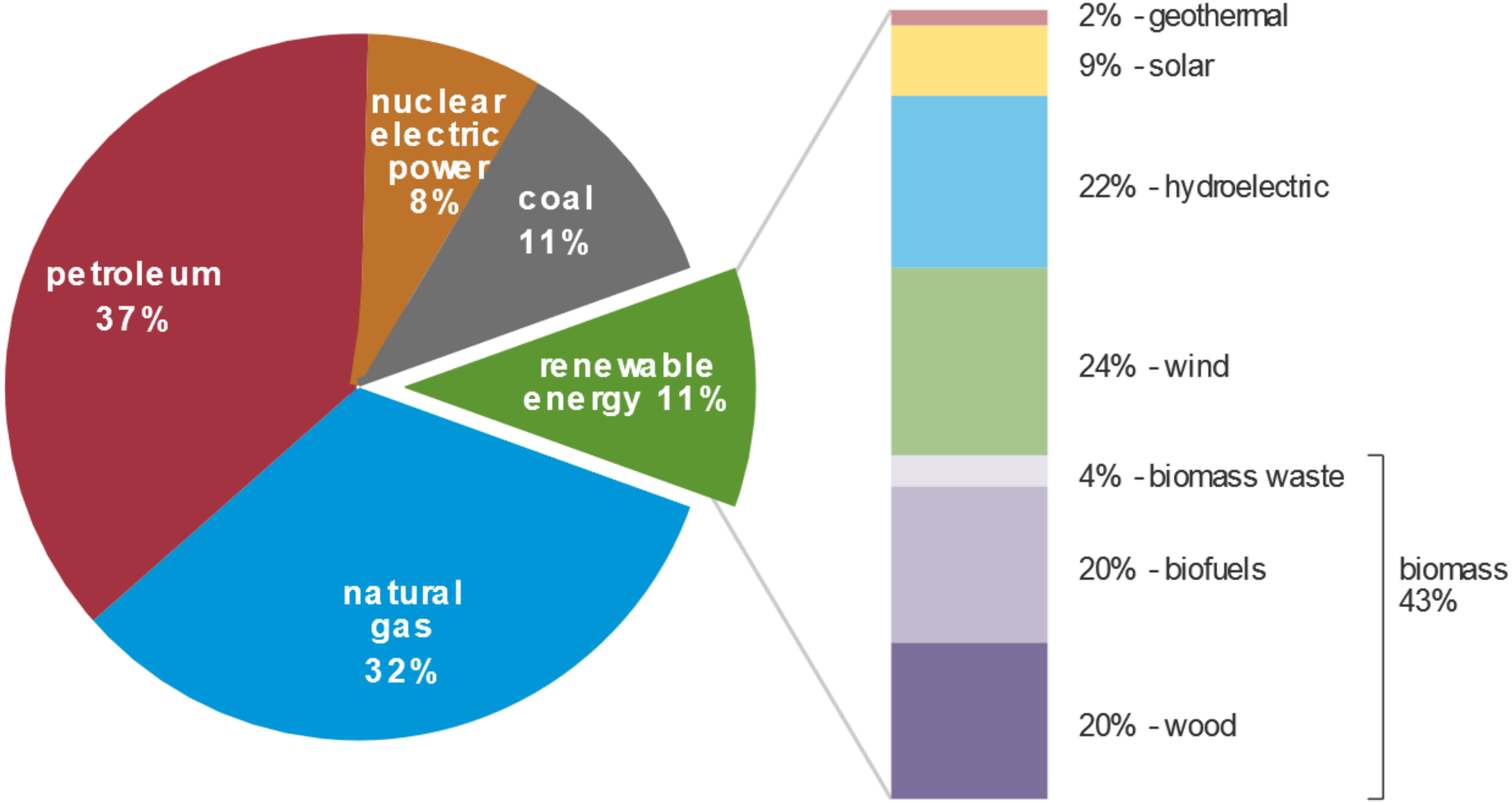
Renewable energy whats, whys

- Whats:
  - Draw energy from natural environment, rather than consumption of mineral fuels (coal, oil, gas, nuclear).
  - Ultimate source of most renewables (except geothermal) is sun.
  - 17.5% of U.S. stationary electricity production in 2019 (eia.gov)
  - 12.1% of world energy production in 2019 (eia.gov)
- Whys:
  - No worries about fuel supply availability.
  - Stabilizes costs at fixed values.
  - More uniform distribution worldwide than fossil fuels (indigenous energy sources for everyone!).
  - Governmental economic incentives.
  - Smaller environmental impacts.
  - Less emission of greenhouse gases.
  - No air/water pollution emissions *at the site*.
  - Saving the world! ☺

U.S. primary energy consumption by energy source, 2019

total = 100.2 quadrillion British thermal units (Btu)

total = 11.4 quadrillion Btu



Note: Sum of components may not equal 100% because of independent rounding.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2020, preliminary data

Barriers to renewable energy deployment

- Higher capital costs
- Intermittent supply
- Unpredictable supply
- In Alaska and other small, isolated (particularly rural) grids:
  - Even higher capital costs
  - Grid stability
  - Cannot load follow
  - Lack of local expertise

Primary renewables

Renewable Type	Electric Power	Electric Heat Economical?	Direct Heat	Base load?
Hydropower	√	√		√
Biomass	√		√	√
Geothermal	√		√	√
Wind	√	µgrids only		
Solar thermal	√		√	
Solar photovoltaic	√	µgrids only		
Ocean tidal and tidal current	√			In theory; under research
Ocean wave	√			In theory; under research
Ocean thermal	√			In theory; under research
Hydrokinetic (river)	√			In theory; under research

Characteristics of renewable energy

- Ubiquitous renewable energy sources
  - Some form available everywhere on earth!
- Low intensity of energy fluxes
  - Fossil and nuclear produce about 10^5 W/m^2; renewables are orders of magnitude lower.
  - Require larger infrastructure per W, larger area per W, larger right of way per W.
- Random, intermittent, unpredictable supply
  - Only hydro, biomass, and geothermal are predictable and mostly reliable (except in case of drought!); they also serve as energy storage.
  - Solar is theoretically predictable, except for clouds!
  - Wind is predictable in a stoichiometric sense, but not on a daily basis.
- High capital cost per watt

Annual average energy flux

Energy Type	Area	Heat (W/m^2)	Electricity (W/m^2)
Fossil, nuclear	turbine X-sectional area	10^5	10^5
Solar heating and thermal electric	collector	100	20
Photovoltaic	cell		40
Hydropower	drainage basin		0.01
Wind, turbine	turbine disk		40
Wind, farm	farm		2
Geothermal	field	0.1	0.02
Biomass	field	0.5	0.1
Ocean tidal and tidal current	tidal pond		1
Ocean thermal	source area		0.1
Ocean wave	farm		10
Hydrokinetic (river)	turbine X-sectional area		3000?

Solar Energy

- Solar energy comes from the sun; we are interested in two ways of harnessing it:
  - Electricity (photovoltaic)
  - Thermal (heat)
- Advantages of solar:
  - There is a looooot of it
  - No moving parts; don't break often
  - Sturdy components
  - Mature technology; prices dropping quickly
  - A 300W solar panel is about $300; you can buy them off-the –shelf (you do need other components though)

Image source: http://jaspak.com/store/300-watt-solar-panel

Global Growth of Solar Energy

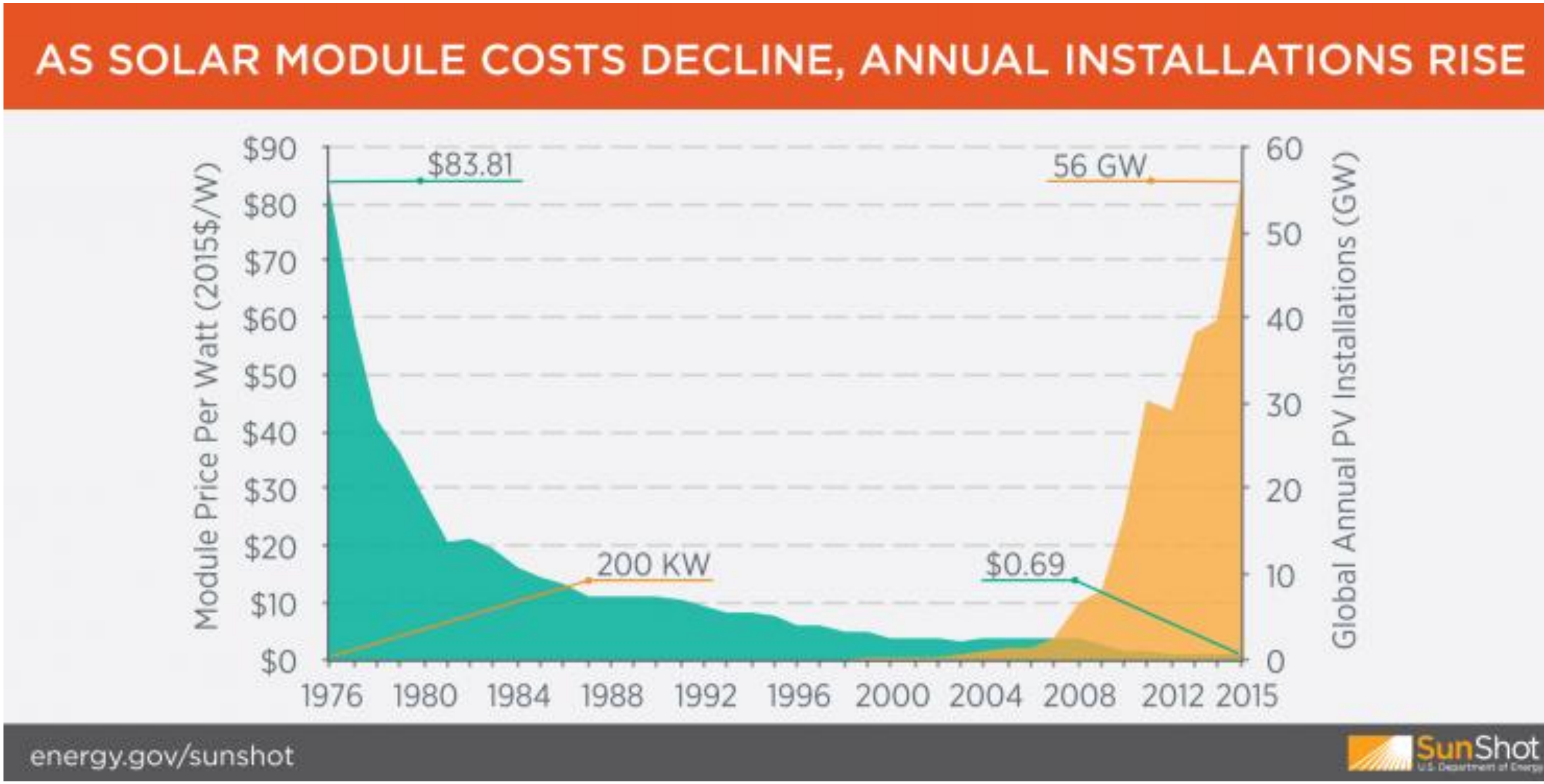


Image source: http://jaspak.com/store/300-watt-solar-panel

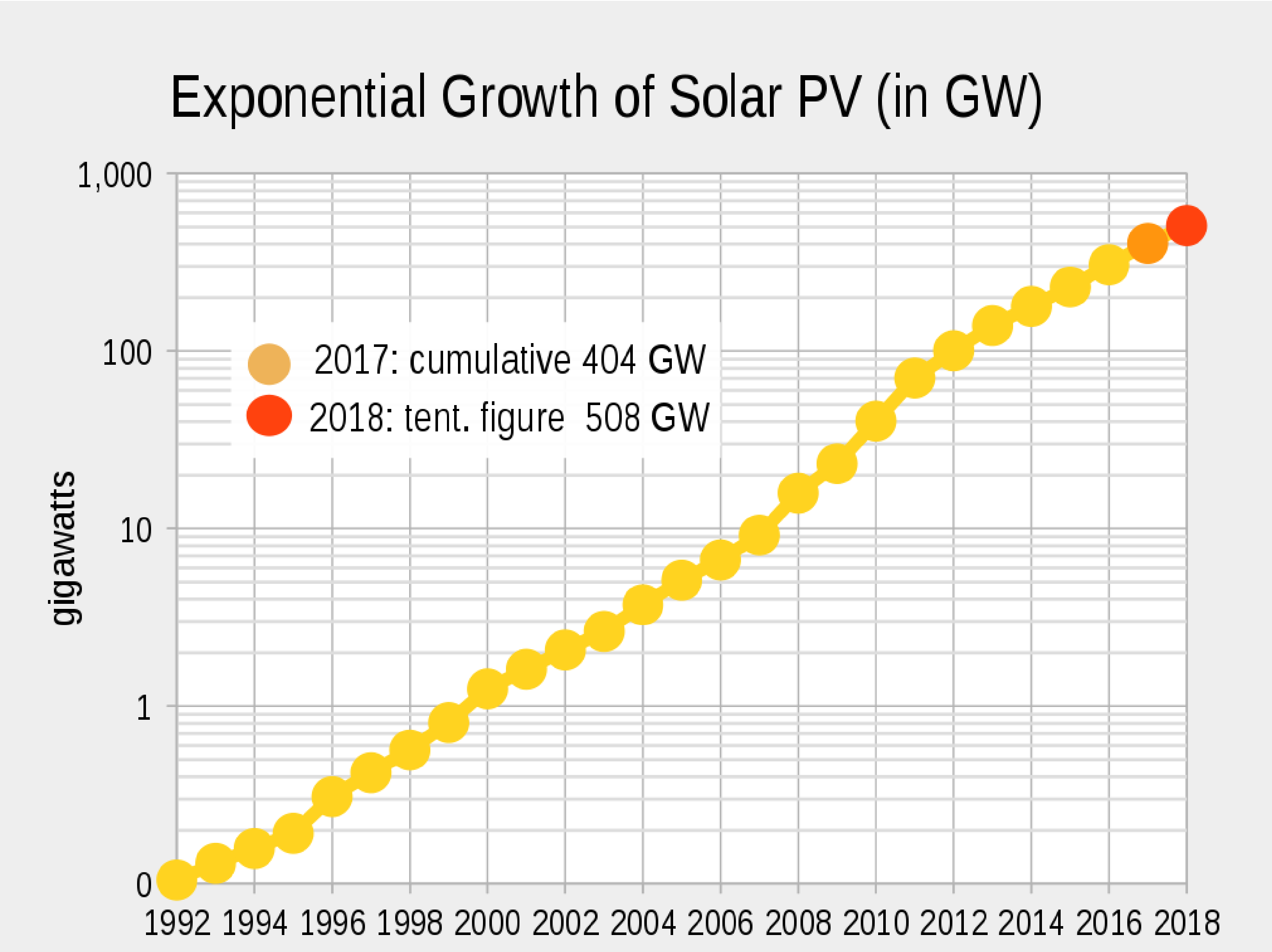


Image source:
https://en.wikipedia.org/wiki/Growth_of_photovoltaics#/media/File:PV_cume_semi_log_chart_2014_estimate.svg

GVEA Solar Farm in Fairbanks

- Installed 2018
- 563 kW solar array
- 1760 300-watt panels
- 2.5 acres

Image source: http://www.newsminer.com/gallery/news/gvea-solar-farm/image_789668c2-cea3-11e8-a123-6bd5b5d51927.html

A few background remarks

- Solar in Alaska? Hahaha, Hohoho. (insert eyeroll here)
  - Northwest Arctic Borough (~67° N latitude) in 2014 began installing what is now about 70 kW of rated capacity.
  - They only average about 10% capacity factor (produce annual average of 7 kW).
  - Still, the payback is about 10 years.
  - Cost Outside: $5000-7000 per kW installed at the time (as low as $1000 per kW today); cost in NWAB: $8250 per kW installed; arctic markup not too bad!

Noatak solar array:

Image source: I. Mathiasson

A few background remarks

- Why solar in the arctic:
  - PV is more effective at lower temperatures.
  - Clear air; Fairbanks has highest solar irradiation in March due to clear air + reflectivity off snow.
  - PV panels are mechanically robust and cold-tolerant, not something we can say of many things!

Shungnak solar array:

Image source: I. Mathiasson

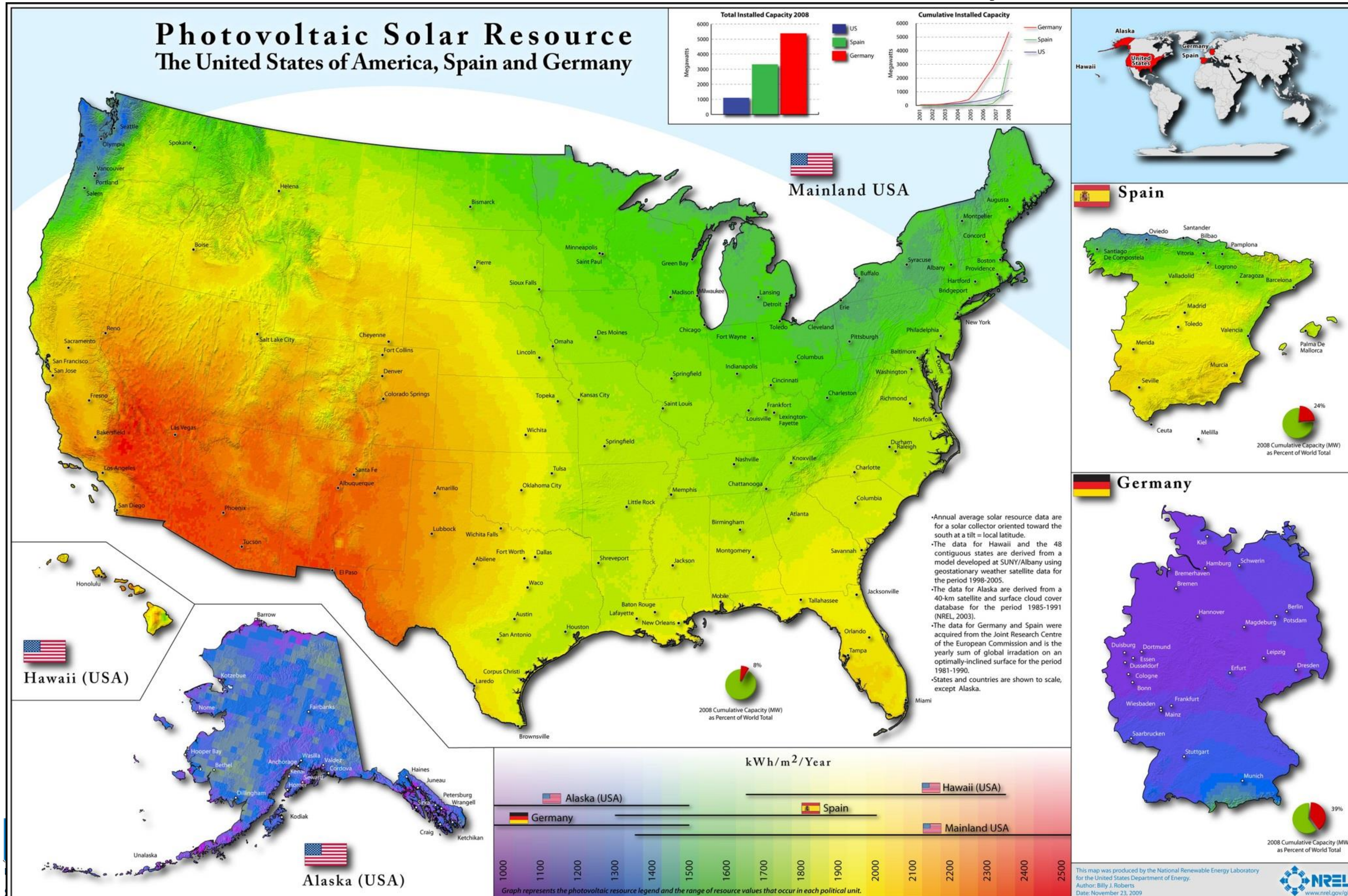
Trackers and angle

- Trackers on the whole do not make economic sense in Alaska for flat plate collectors.
  - Trackers ice and freeze up easily; they also take a parasitic load.
  - The cost of PV panels has come down so much that you are better off buying more panels and mounting them to cover more angles than you are buying trackers.
  - Don’t forget that for small installations, you can maximize solar angle for cheaper by manually adjusting the angle just twice per year (more than twice does not significantly add production)

Kobuk water tower:

Image source: I. Mathiasson

Solar Resource, AK vs. Germany



Germany example

- Germany has 31% average renewable penetration (~6-7 solar); on March of 2014 hit an instantaneous penetration of 74%.
- Has goal of 35% average renewable penetration by 2020; 100% by 2050.
- Their solar resource, like Alaska's, is poor (11-12% capacity factor).
- 40 GW installed solar as of 2016; average penetration is 7%; average high is 50% at noon.
- Started with aggressive feed-in-tariffs (government guarantees renewable energy producers a set amount for the electricity they produce under a long-term contract); being scaled back as renewable penetration is outpacing government goals. Most of the costs are being borne by consumers.
- Solar costs have reached grid parity (price of commercial solar equals retail electricity rates).
- Base load switching from nuclear to coal (plan is to eliminate nuclear entirely).

Data sources:
http://en.wikipedia.org/wiki/Solar_power_in_Germany
http://thinkprogress.org/climate/2014/05/13/3436923/germany-energy-records/

Wind Energy

Kotzebue wind farm (2.95 MW nameplate, 0.18 MW average, 2.5 MW average load):

Image source:
http://commons.wikimedia.org/wiki/File:Kotzebue_Wind_Farm.jpg

Wind resource classification

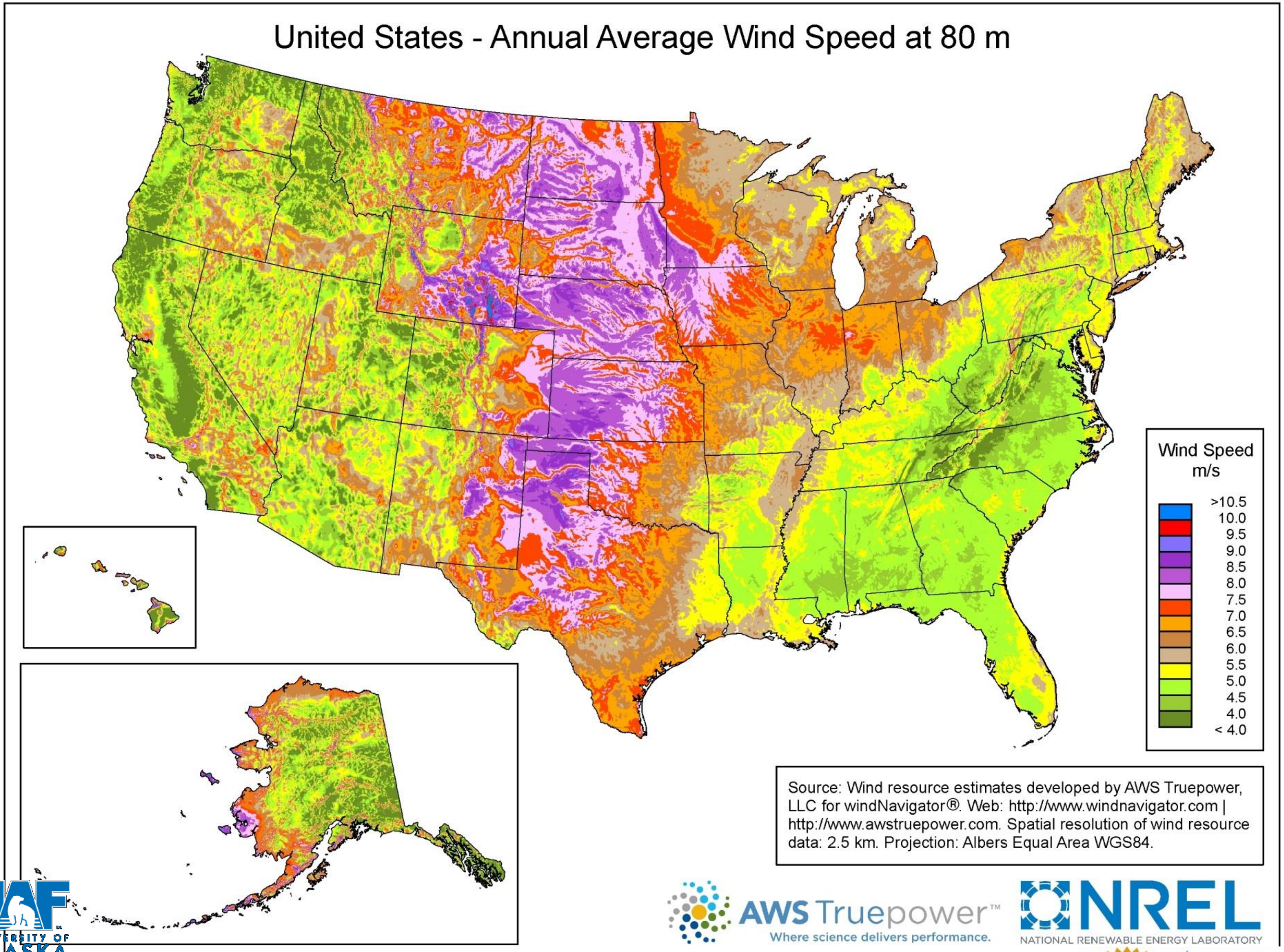
Table 1-1 Classes of wind power density at 10 m and 50 m[(a)].

Wind Power Class*	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density (W/m^2)	Speed[(b)] m/s (mph)	Wind Power Density (W/m^2)	Speed[(b)] m/s (mph)
1	0	0	0	0
2	100	4.4 (9.8)	200	5.6 (12.5)
3	150	5.1 (11.5)	300	6.4 (14.3)
4	200	5.6 (12.5)	400	7.0 (15.7)
5	250	6.0 (13.4)	500	7.5 (16.8)
6	300	6.4 (14.3)	600	8.0 (17.9)
7	400	7.0 (15.7)	800	8.8 (19.7)
	1000	9.4 (21.1)	2000	11.9 (26.6)

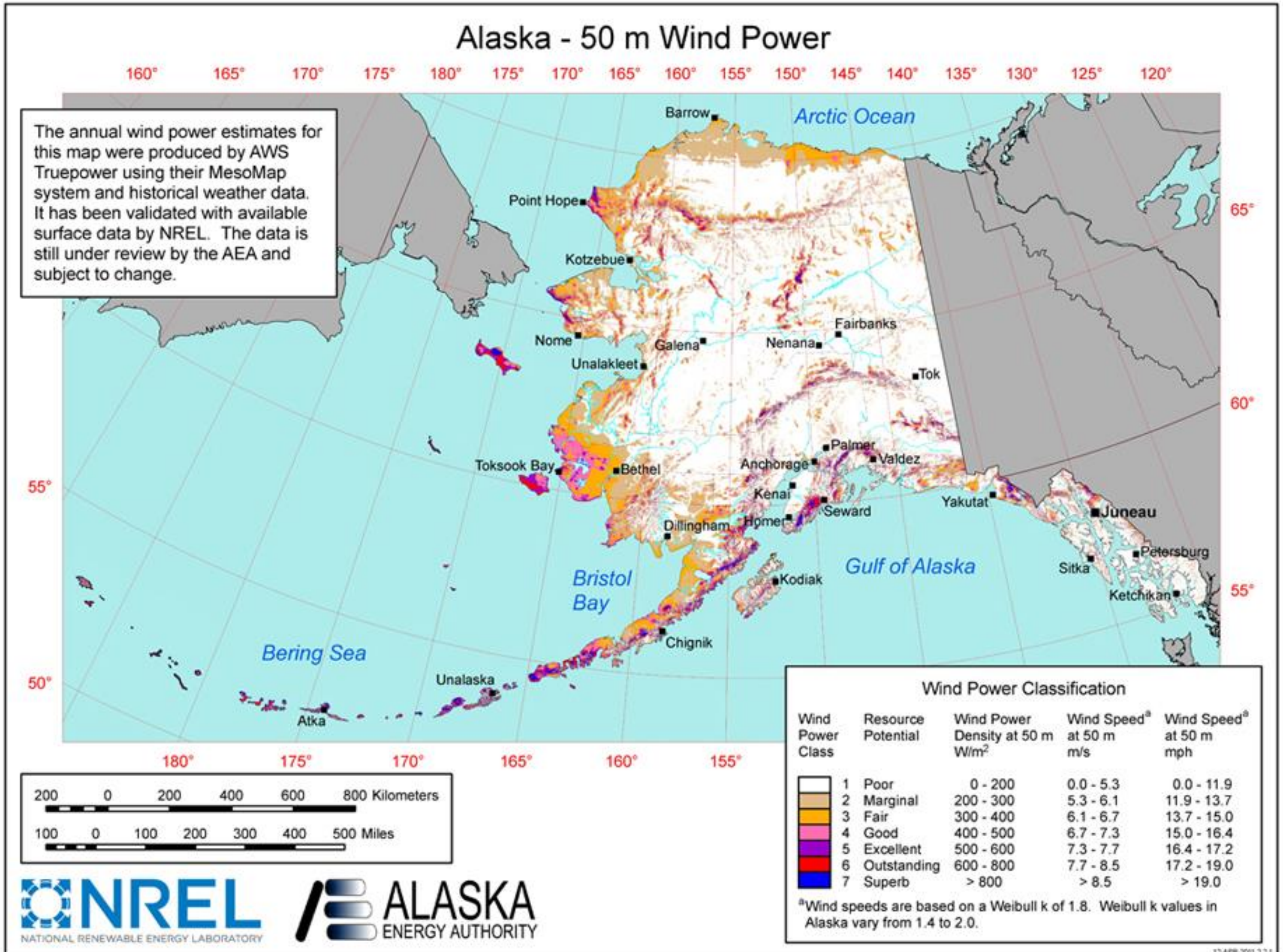
(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 3%/1000 m (5%/5000 ft) elevation.

Source: http://rredc.nrel.gov/wind/pubs/atlas/tables/1-1T.html


United States - Annual Average Wind Speed at 80 m
Wind Speed m/s
>10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
< 4.0
Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: Albers Equal Area WGS84.
AWS Truepower™
Where science delivers performance.
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Wind resource map, Alaska

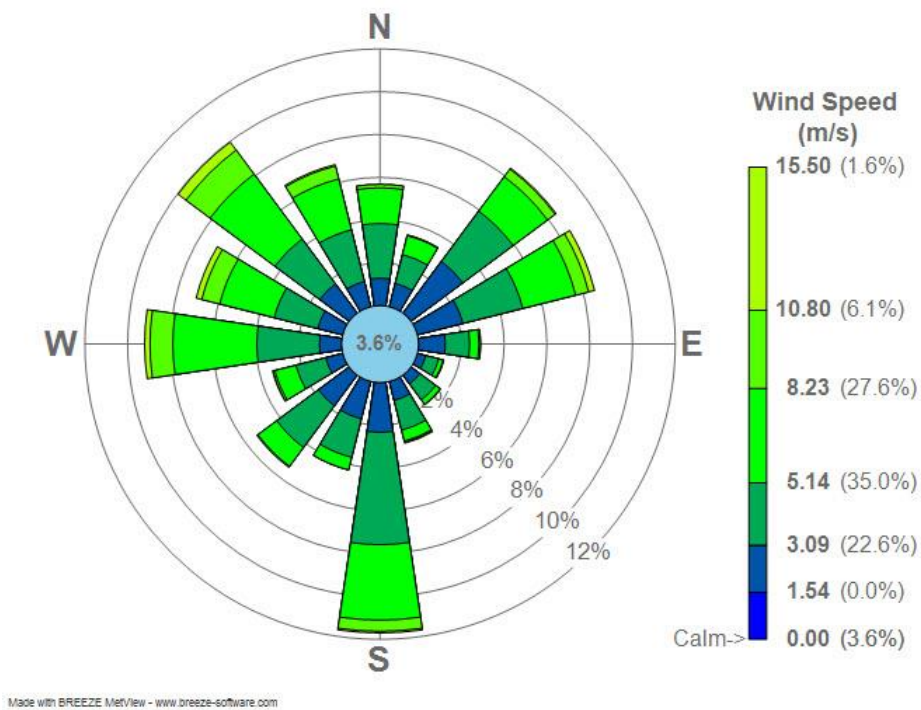


How to evaluate your wind resource

1) Put up an anemometer on top of a met tower, as tall as you can (100 feet is *bare* minimum).
2) Collect wind speed and direction at as high frequency as you can (1 pt per 10 sec is kind of normal).
3) Collect data for a minimum of one year, preferably two.
4) Evaluate your data to see the quality of your wind resource. Ideally, it should be strong, consistent, laminar winds that come from one direction. Wind that switches directions semianually is no big deal, but wind that switches directions every four seconds sucks.
5) But here's the thing—two years is a long time! If you already suspect that you have a good wind resource, you'll want your turbine up earlier to start making money sooner.
6) Weigh cost/benefit! Use your judgement!

Wind rose

Not so nice!



Very nice!

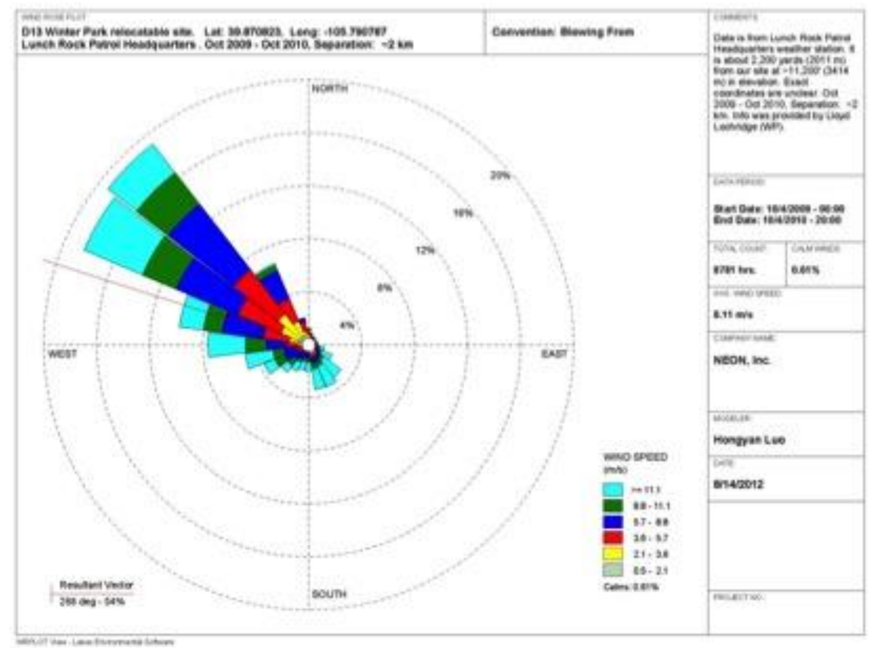


Image source: http://www.neonnotes.org/tag/alaska/

Image source: http://en.wikipedia.org/wiki/Wind_rose

Wind Farms, Wake effects

Image source: http://www.nrel.gov/news/features/feature_detail.cfm/feature_id=1995

Conventional "Dam" Hydropower

- Hydropower has been used for mechanical power for centuries, and still is, for pumping water. Before the development of steam engines, it was the primary source of water for industrial mills.
- Hydropower today accounts for 5% of U.S. and 3.8% of world energy production (45% of renewable in US).
- Average capacity factor is 51%.
- Most U.S. hydropower is small (average production 46 MW).
- There are only eight hydropower installations worldwide that generate over 5 GW; most are smaller.
- Divide into two types: dam, and run of river (or diversion along river)

Blue Lake Dam, Sitka:

Image source: http://www.hatch.ca/News_Publications/Energy_Innovations/August2012/bluelake.html

Hydrokinetic turbine, Eagle:

Image source: http://www.durangoherald.com/article/20110720/NEWS04/707209970/-1/taxonomy/A-liquid-quest-for-renewable-power

Tazimina:

Image source: http://hydropower.inel.gov/hydrofacts/hydropower_facilities.shtml

Novel Hydropower

- River hydrokinetic
- Wave
- Tidal

Hydrokinetic turbine, Igiugig:

Image source: https://www.kdlg.org/post/igiugigs-hydropower-launch-major-step-toward-independence-diesel,

Tidal energy generator:

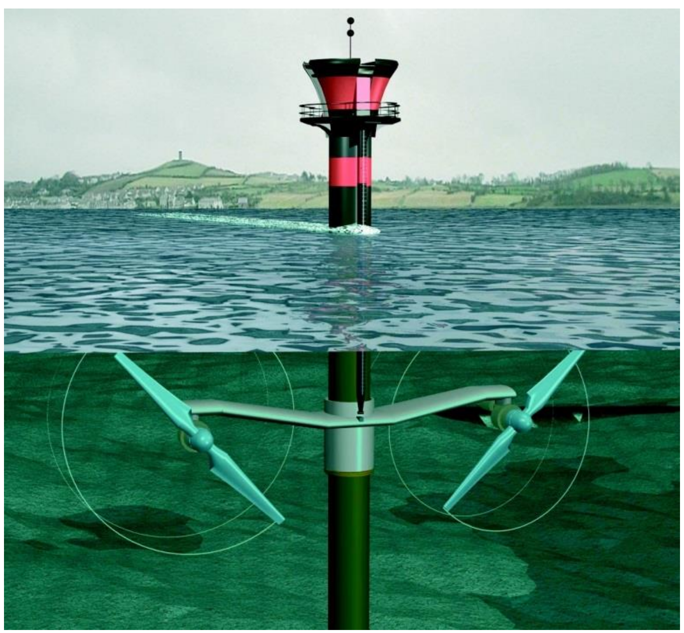


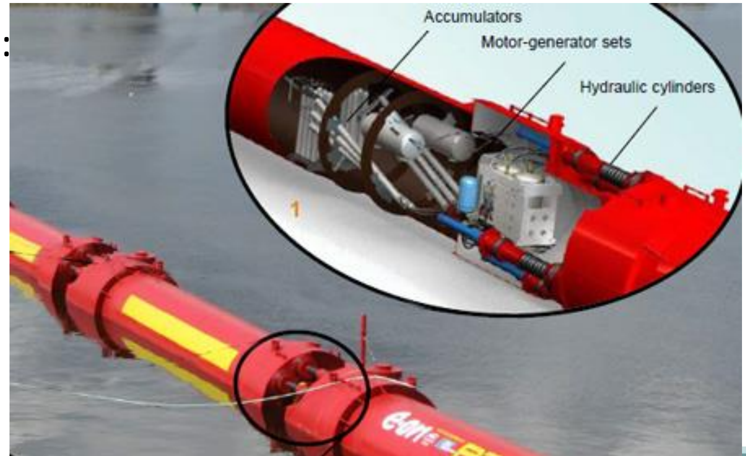
Image source: http://www.citelighter.com/technology/technology/knowledgecards/wave-and-tidal-energy/

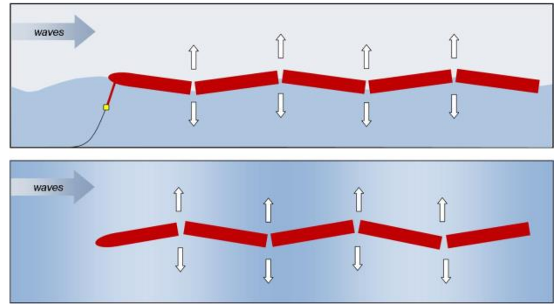
Hydrokinetic turbine, Eagle:

Image source: http://www.durangoherald.com/article/20110720/NEWS04/707209970/-1/taxonomy/A-liquid-quest-for-renewable-power

Ocean Wave Power Systems, examples

Pelamis:





The Pelamis generates power as waves flex the joints back and forth.

Image source:
http://www.expo21xx.com/renewable_energy/19446_st3_wave_power/, http://www.pelamiswave.com/pelamis-technology

Ocean Renewable Power Company:

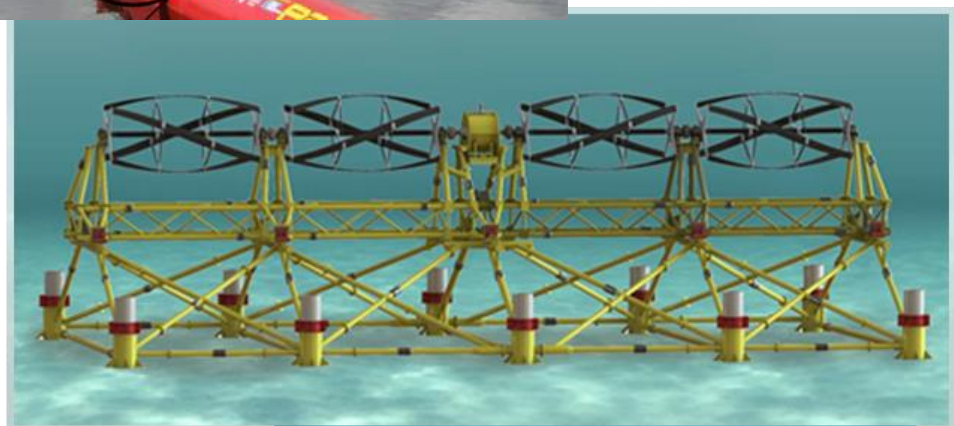


Image source:
http://www.orpc.co/orpcpowersystem_tidgenpowersystem.aspx

A flap design, from AW-Energy:

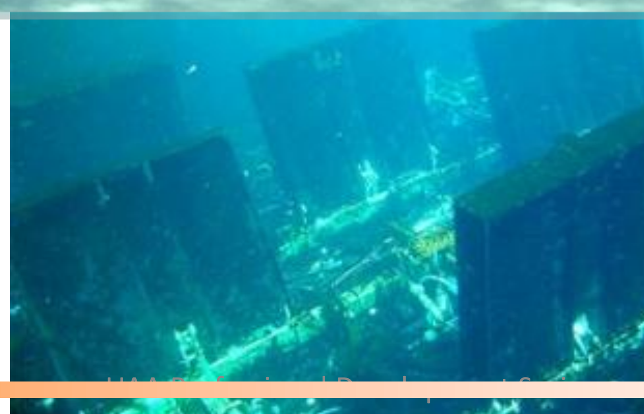


Image source:
http://www.greentechmedia.com/articles/read/the-flap-shoots-for-mainstream-in-wave-power

Thank you! Questions?

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