OTEC Technologies

Open-Cycle

- When tropical ocean's warm surface seawater is placed in a low-pressure container, it boils.
- The expanding steam drives a low-pressure turbine attached to an electrical generator.
- The steam, which has left its salt behind in the low-pressure container, is almost pure fresh water.
- It is condensed back into a liquid by exposure to cold temperatures from deep-ocean water.

Open-Cycle OTEC

- In 1984, the National Renewable Energy Laboratory developed a vertical-spout evaporator to convert warm seawater into low-pressure steam for open-cycle plants.
- Energy conversion efficiencies as high as 97% were achieved.
- In May 1993, an open-cycle OTEC plant at Keahole Point, Hawaii, produced 50,000 watts of electricity during a net power-producing experiment.

OTEC Technologies

Hybrid

- These systems combine the features of both the closed-cycle and open-cycle systems.
- In a hybrid system, warm seawater enters a vacuum chamber where it is flash-evaporated into steam, similar to the open-cycle evaporation process.
- The steam vaporizes a low-boiling-point fluid (in a closed-cycle loop) that drives a turbine to produce electricity.

Ocean Tidal Power (OTP)

- Some of the oldest ocean energy technologies use tidal power. All coastal areas consistently experience two high and two low tides over a period of slightly greater than 24 hours. For those tidal differences to be harnessed into electricity, the difference between high and low tides must be at least five meters, or more than 16 feet. **There are only about 40 sites on the Earth with tidal ranges of this magnitude.**
- Currently, there are no tidal power plants in the US. However, conditions are good for OTP generation in both the Pacific Northwest and the Atlantic Northeast.

The world's oceans provide two forms of energy powered by the sun: (1) Thermal energy: offshore wind and ocean thermal/OTEC; and (2) mechanical energy: waves, currents and tides. Only OTEC, currents and tides are consistent and predictable 24/7.

OCEAN CURRENTS

One of six 36 kW current turbines being installed by Verdant Power in NYC's East River in 2007.

"Ocean currents can provide vast potential for power generation - some are five times as energy-dense as the world's best wind power sites." - Florida Atlantic University's Center of Excellence in Ocean Energy

WAVE ENERGY

Ocean Power Delivery's Pelamis wave device operating today off Portugal's coast.

"The total power of waves breaking on the world's coastlines is estimated at 2 to 3 million megawatts. Each day the oceans absorb enough heat from the sun to equal the thermal energy contained in 250 billion barrels of oil." - DOE's Energy Effciency and Renewable Energy website

OFFSHORE WIND

A wind farm operating today off Denmark's coast installed by Vestas Corporation.

"Today wind power provides 20% of Danish electricity consumption; it is to increase to 50% by 2025, mostly offshore." - Denmark Ministry for Transport and Energy

OTEC ENERGY

An OTEC facility on Keahole Point, Hawaii produced 50,000 watts in 1993 outpacing a Japanese system's 40,000 watts in 1982.

"The U.S. Department of Energy concluded in 1976 that OTEC could produce twenty million kilowatts by the year 2000, an amount three-and-a-half times the U.S. energy demand." - U.S. Department of Energy

"The Rance (France) Tidal Power Plant has operated for over 30 years without major incidents or breakdowns for 160,000 hours and has generated 16 billion kWh at a price lower than our non-tidal generation costs." - Electricite de France (The French Government's Electric Utility)

TIDAL ENERGY

The world's largest tidal power plant is now under construction today off South Korea's west coast.

Areas highlighted above indicate locations of major ocean energy activities today.

To learn more about the various types of ocean energy, visit www.oceanenergycouncil.com

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Tidal Power Technologies

Barrage or Dam

Tidal Fences

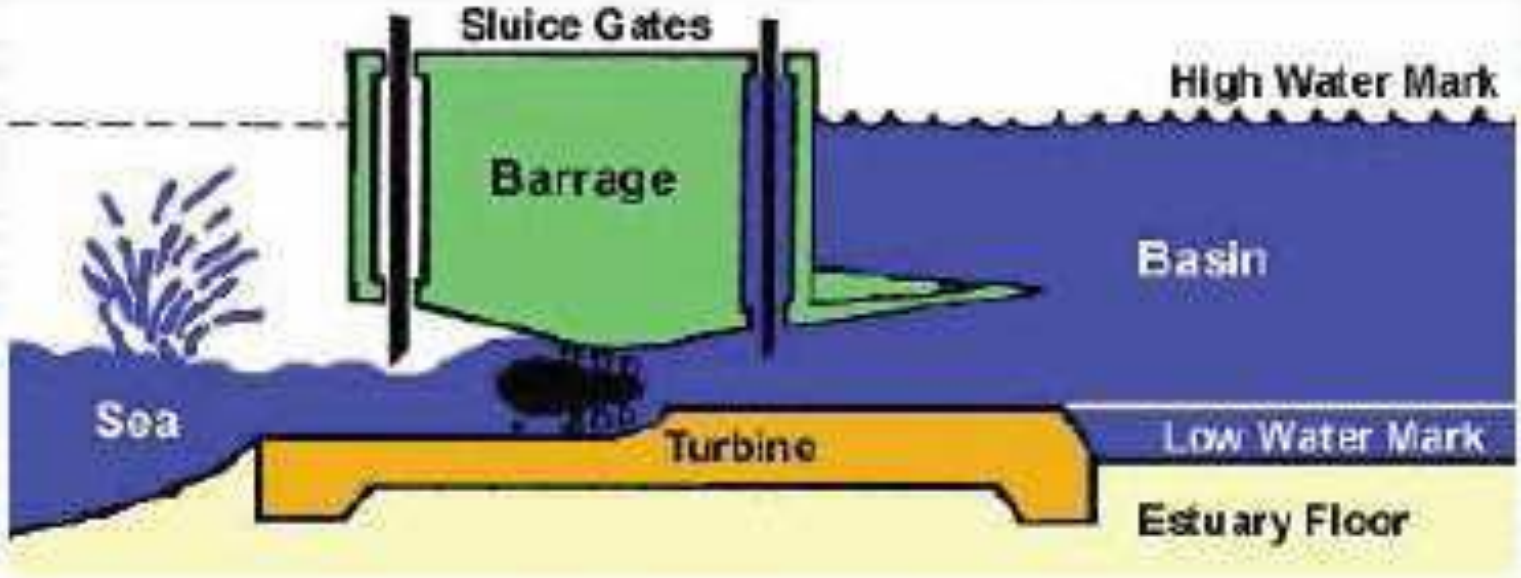
Tidal Turbines

Barrage or Dam

- A barrage or dam is typically used to convert tidal energy into electricity by forcing the water through turbines, activating a generator.
- Gates and turbines are installed along the dam.
- When the tides produce an adequate difference in the level of the water on opposite sides of the dam, the gates are opened.
- The water then flows through the turbines. The turbines turn an electric generator to produce electricity.

Barrage or Dam

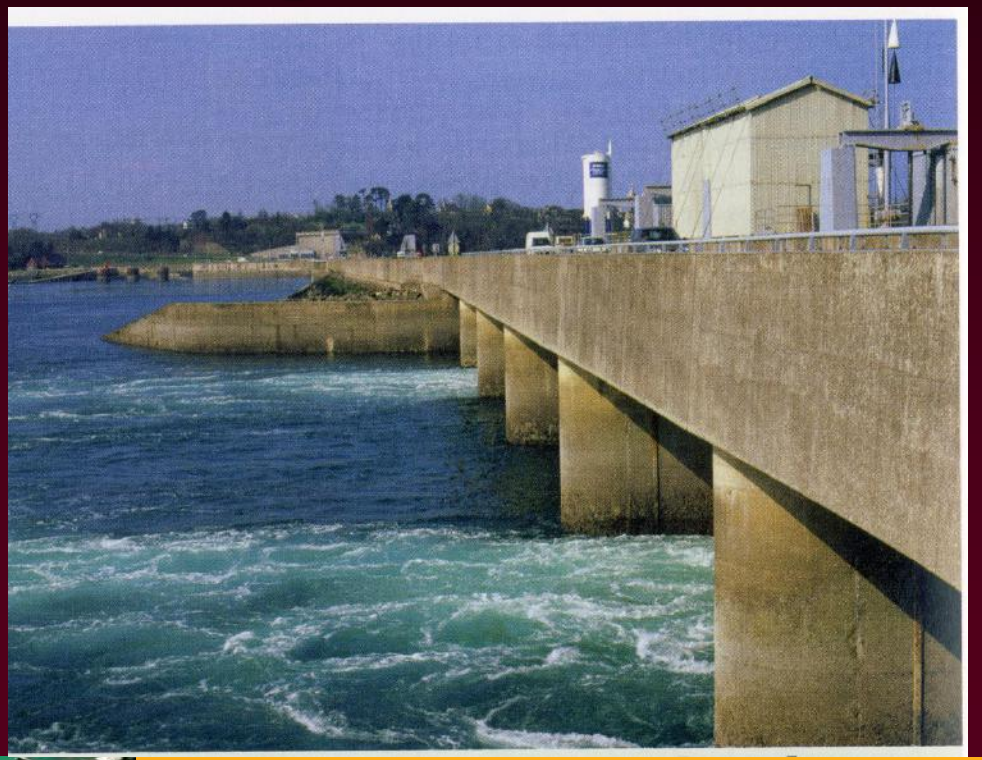
- Using level differences on either side of a suitable barrage constructed for the purpose



Source: (ACRE) Australian CRC for Renewable Energy LTD

Tidal Barrage, Rance Estuary in France

- The world's largest tidal power plant is at La Rance in France with 240 MW
- There are a few other smaller tidal plants in Canada, Russia and China.



- The UK has one of the world's best potential sites for tidal power scheme, in Severn Estuary.
- If built, its capacity will be 8600 MW to meet 6 % of UK's electricity demand

Tidal Fences

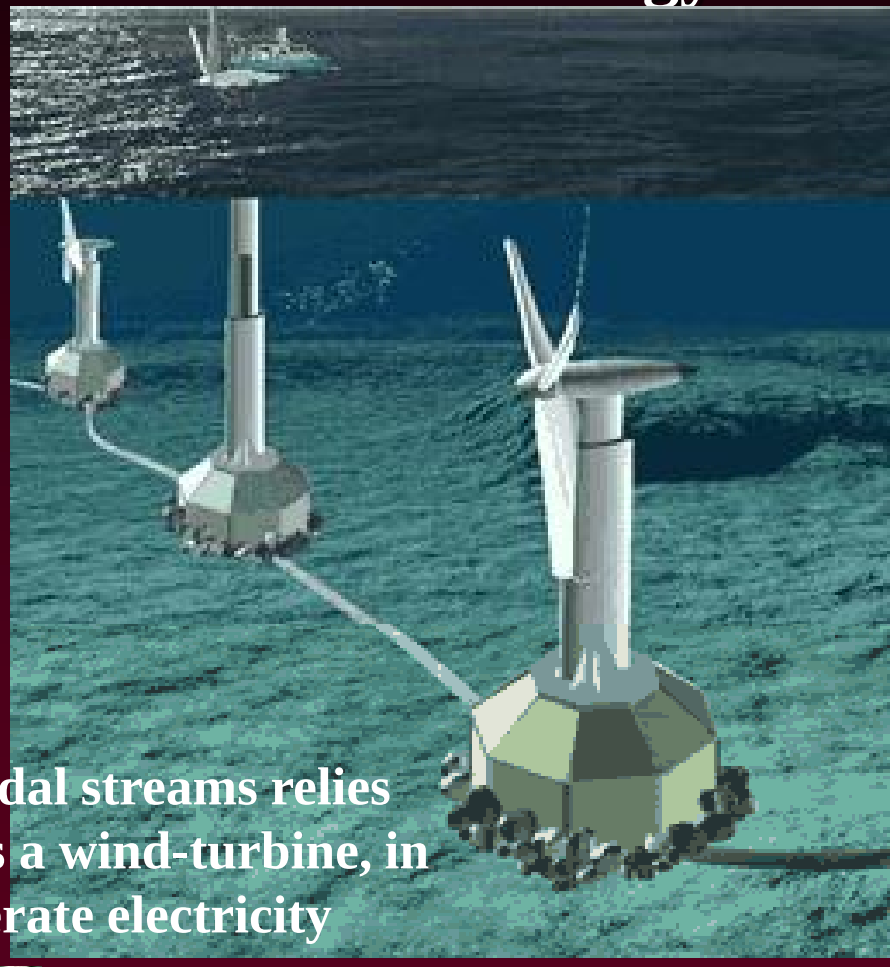
- Tidal fences look like giant turnstiles.
- They can reach across channels between small islands or across straits between the mainland and an island.
- The turnstiles spin via tidal currents typical of coastal waters.
- Some of these currents run at 5 - 8 knots (5.6 - 9 miles per hour) and generate as much energy as winds of much higher velocity.
- Because seawater has a much higher density than air, ocean currents carry significantly more energy than air currents (wind).

Tidal Turbines

- Tidal turbines look like wind turbines.
- They are arrayed underwater in rows, as in some wind farms.
- The turbines function best where coastal currents run at between 3.6 and 4.9 knots (4 and 5.5 mph).
- In currents of that speed, a 15-meter (49.2-feet) diameter tidal turbine can generate as much energy as a 60-meter (197-feet) diameter wind turbine.
- Ideal locations for tidal turbine farms are close to shore in water depths of 20–30 meters (65.5–98.5 feet).

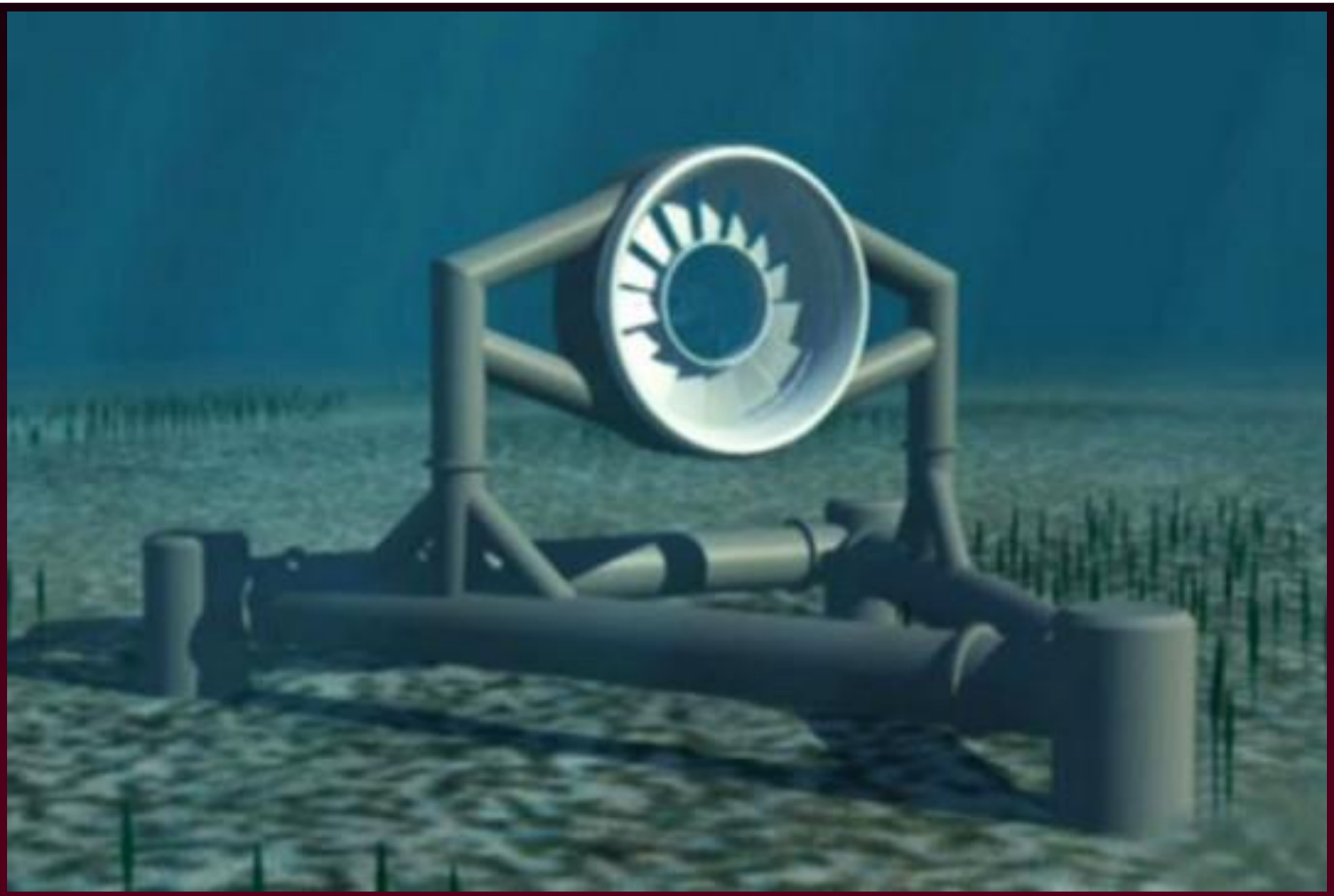
Tidal Turbines

- Directly using turbines to convert the kinetic energy of high tidal currents



The idea of harnessing tidal streams relies on the same principles as a wind-turbine, in that a rotor spins to generate electricity

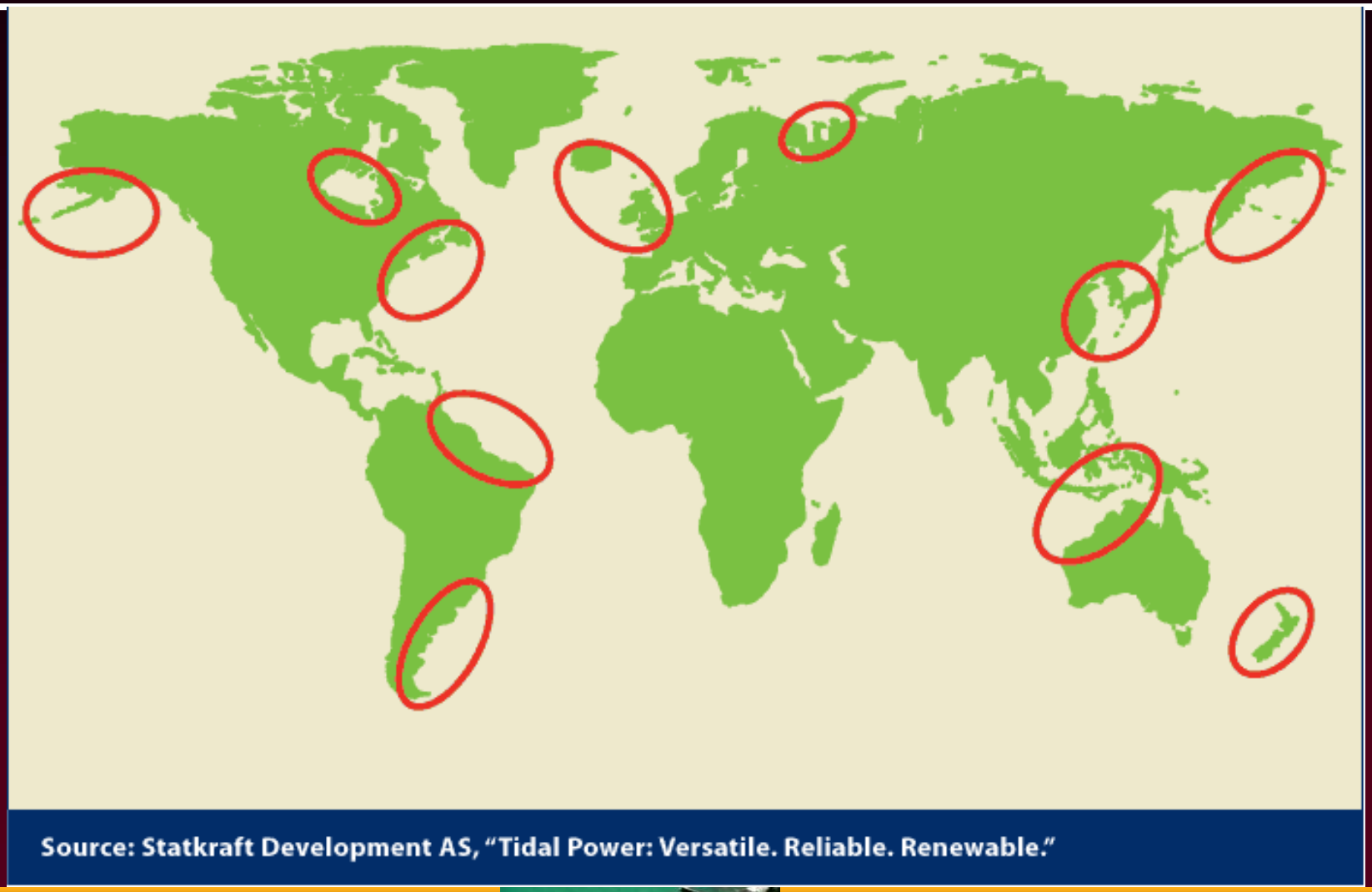
https://www.youtube.com/watch?v=u6dd-nW40zo



Environmental and Economic Challenges of OTP

- Tidal power plants that dam estuaries can impede sea life migration, and silt build-ups behind such facilities can impact local ecosystems.
- Tidal fences may also disturb sea life migration.
- It doesn't cost much to operate tidal power plants, but their construction costs are high and lengthen payback periods.
- As a result, the cost per kilowatt-hour of tidal power is not competitive with conventional fossil fuel power.

Areas Appropriate for Traditional Tidal Power



Source: Statkraft Development AS, "Tidal Power: Versatile. Reliable. Renewable."

Ocean Wave Power (OWP)

- Wave power devices extract energy directly from surface waves or from pressure fluctuations below the surface.
- Renewable energy analysts believe there is enough energy in the ocean waves to provide up to 2 terawatts of electricity.

Ocean Wave Power

- Uneven distribution of solar radiation results in wind movement over ocean and wind transfers part of the energy to ocean surface
- In regular waves of height H and period T ,

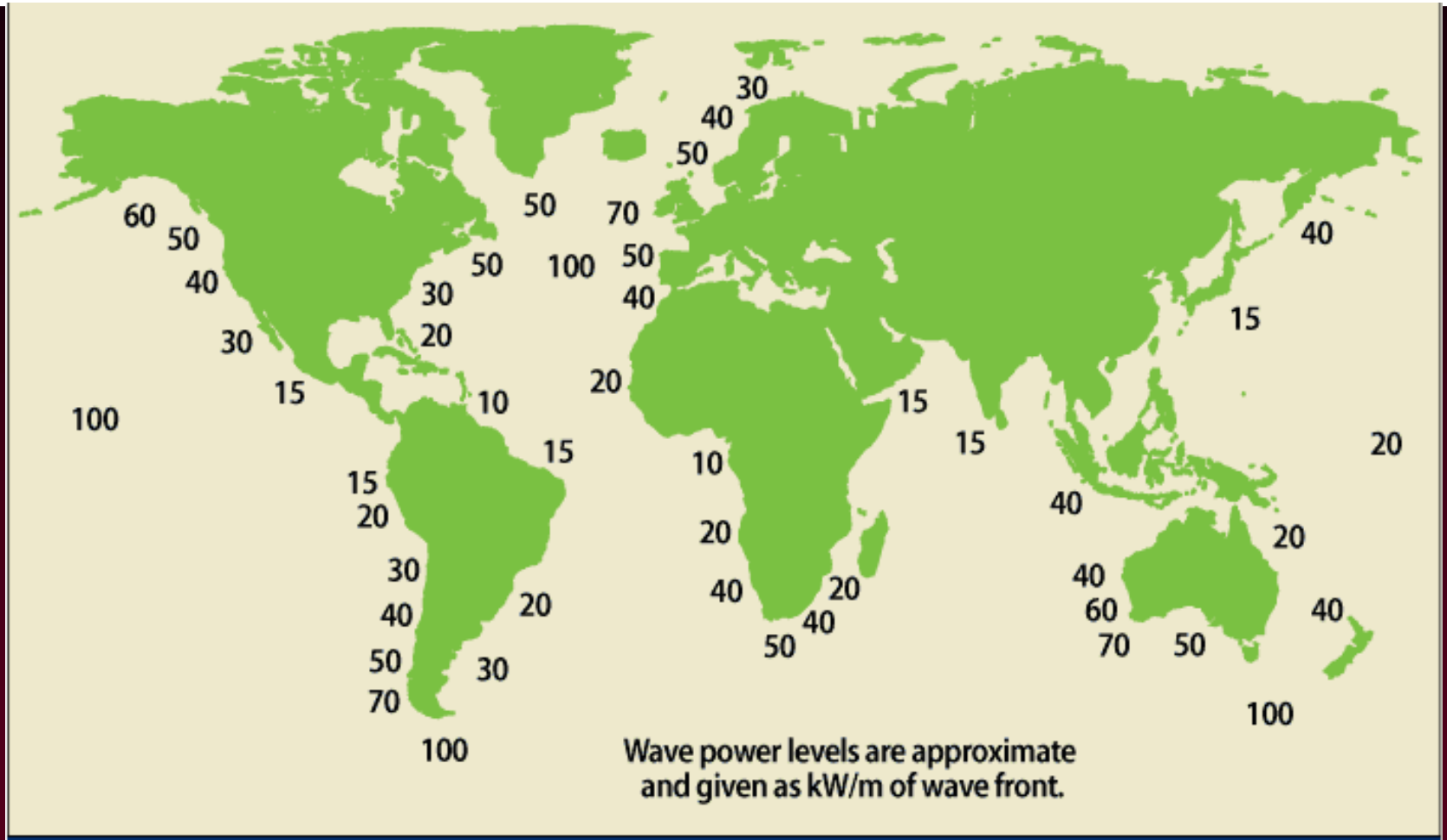
  Wave power, $P = \rho g^2 H^2 T/64\pi \sim 0.5\ H^2\ T$ (kW/m)
- where ρ is the density of water ($\rho = 1025$ kg/m^3) and g is acceleration due to gravity ($g = 9.8$ m/s^2).

Problem

- **Calculate ocean wave powers produced for wave heights of 1 and 1.5 m with a frequency of 0.1667 Hz. Assume an overall efficiency of 70 % for the turbine and generator.**

$$P = \rho\, g^2 H^2 T / 64\pi$$

Global Distribution of Wave Power Levels



Source: T.W. Thorpe, "An Overview of Wave Energy Technologies: Status, Performance and Costs."

Ocean Wave Power (OWP)

- Wave power can't be harnessed everywhere.
- Wave-power rich areas of the world include the western coasts of Scotland, northern Canada, southern Africa, Australia, and the northeastern and northwestern coasts of the United States.
- In the Pacific Northwest alone, it's feasible that wave energy could produce 40 - 70 kilowatts (kW) per meter (3.3 feet) of western coastline.
- The West Coast of the United States is more than a 1,000 miles long.

Ocean Wave Power

- Wave energy can be converted into electricity through both

Offshore Systems

Onshore Systems

Offshore OWP Systems

- Offshore systems are situated in deep water, typically of more than 40 meters (131 feet).
- Sophisticated mechanisms like the Salter Duck use the bobbing motion of the waves to power a pump that creates electricity.
- Other offshore devices use hoses connected to floats that ride the waves. The rise and fall of the float stretches and relaxes the hose, which pressurizes the water, which, in turn, rotates a turbine.
- Floating platforms also create electricity by funneling waves through internal turbines & then back into the sea.

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