Exploring Ocean Energy and Resources

Student Guide

2016-2017

NEED
National Energy Education Development Project

INTERMEDIATE AND SECONDARY

Ocean Energy and Resources Informational Text

Valuable Resources Offshore

When you think of the United States, you may picture a map outlining the 50 states and their coastlines. However, the United States actually includes a huge area you can't see, 1.7 billion acres known as the **Outer Continental Shelf** (OCS). This area lies beneath the oceans off our coasts. We also refer to the land and water off our coasts as being "**offshore**."

Economically, the land and water surrounding our coastlines are very important to our nation. Most of the seafood we eat comes from the waters offshore. The submerged lands hold fossil fuels, such as petroleum and natural gas. More recently, **renewable** sources of energy are generating electricity offshore, including wind, waves, tides, currents, and ocean thermal energy conversion (OTEC). All of these resources are important to the United States when considering the world's increasing demand for energy.

It takes a lot of energy to harvest raw materials, to manufacture products, and to grow food. It takes a lot of energy to move our cars, trucks, planes, ships, and trains to bring goods and products we use to market. It takes a lot of energy to make life comfortable, to heat and cool our homes, to cook our food, and to generate electricity to run the technologies we can't live without – from cell phones and computers to TVs and gaming systems. Energy sources found offshore allow us to do all of these things.

The ocean environment and the lands offshore are a valuable resource for the United States. This area has the potential to supply a significant amount of our future energy needs, and to supply us with food and non-energy minerals such as sand and gravel.

Underwater Geography

At the edge of the ocean, where waves lap at the shoreline, is the **continental shelf**. It is a continuation of the North American continent we live on, and this landmass extends from the shore into the ocean as a gently sloping undersea plain. This undersea world is a fascinating place. The continental shelf can be as narrow as 20 kilometers (12 miles) along the west coast and as wide as 400 kilometers (249 miles) along the northeast coast of the United States. The water on the continental shelf is shallow, rarely exceeding a depth of 150 to 200 meters (490-650 feet).

The continental shelf drops off dramatically at the **continental slope** and **continental rise**, where the deep ocean truly begins. The deep ocean consists of **abyssal plains** that are 3 to 5 kilometers (1.8-3.1 miles) below sea level. Many of these plains are flat and featureless, while others are marked with jagged mountain ridges, deep canyons, and valleys. The tops of some of these mountain ridges form islands that extend above the water. Some ridge crests contain **hydrothermal vents** – underwater geysers. Rich deposits of minerals and amazing plants and animals have been discovered around these hydrothermal vents.

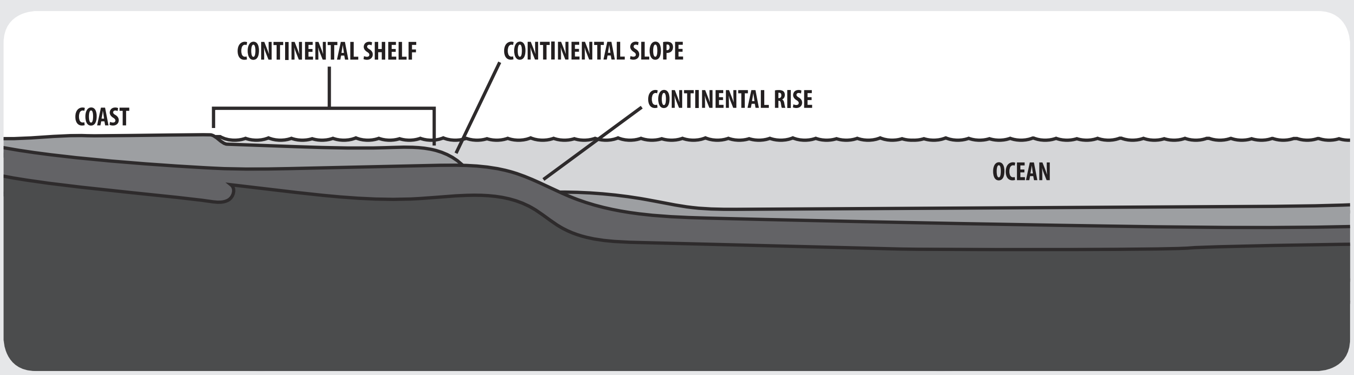


Image courtesy of the Bureau of Ocean Energy Management (BOEM)

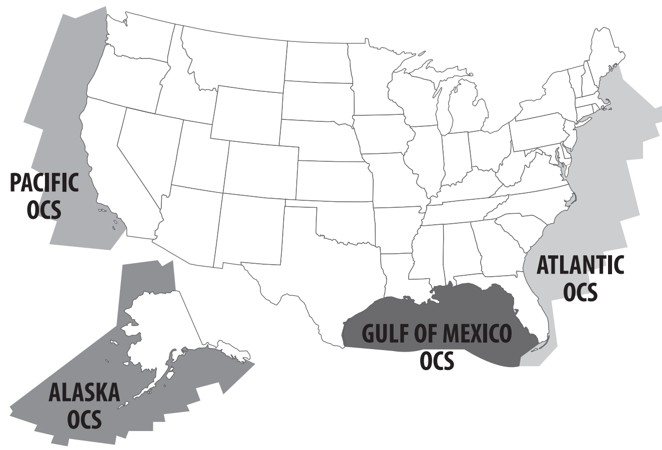
The Exclusive Economic Zone (EEZ)

In 1982, the United Nations adopted a law giving each country bordering an ocean the rights to an exclusive economic zone off its coast. The EEZ is an area of coastal water and seabed no more than 200 **nautical miles** (370 km) beyond the country's shoreline. Each country claims exclusive rights for fishing, drilling, and other economic activities. This includes production of energy from the water, winds, and currents. On March 10, 1983, President Ronald Reagan signed a Presidential Proclamation that set up the U.S. Exclusive Economic Zone (EEZ).

The Outer Continental Shelf (OCS)

The first three nautical miles offshore belong to the state that it borders. According to the **Outer Continental Shelf Lands Act**, the Federal Government controls the area beyond that, known as the Outer Continental Shelf, or OCS. The Outer Continental Shelf consists of 1.7 billion acres of submerged lands, subsoil, and seabed in a specified zone up to 200 nautical miles from the U.S. coastline to the edge of the EEZ, or even farther if the continental shelf extends beyond 200 nautical miles. The OCS is divided into four regions: the Atlantic Region, the Gulf of Mexico Region, the Pacific Region, and the Alaska Region.

Outer Continental Shelf



Data: Bureau of Ocean Energy Management (BOEM)

Petroleum and Natural Gas

Petroleum and natural gas impact our lives in many ways every day. Together, they supply more than 60% of our nation's energy. Petroleum provides most of the fuel for our sources of transportation – gasoline, jet fuel, and diesel fuel are all made from **crude oil**. Natural gas heats most homes in the U.S. and provides energy for hot water and cooking for a significant number of families. Some older homes burn fuel oil for heat, which is a product obtained from petroleum. Many electrical power plants throughout the Northeast and Midwest are fueled by natural gas because it is efficient, clean burning, and can be instantly ignited when electrical demand is high. Some areas, and Hawaii in particular, use petroleum to provide electricity. Petroleum and natural gas aren't just burned for energy, though. They are also used to manufacture many products such as soft drink bottles, dent-resistant car fenders, medicines, and sporting equipment like skateboard wheels and helmets. You probably are unaware of all the ways you encounter petroleum-based products every day.

Formation of Petroleum and Natural Gas

Petroleum is found beneath the surface of the Earth in many parts of the world. It is found both onshore and offshore. The word petroleum means "rock oil" or "oil from the Earth." It is a mixture of many different **hydrocarbon** molecules that exist sometimes as a liquid, called oil or crude oil, and sometimes as a vapor, called natural gas.

Petroleum and natural gas are **fossil fuels** formed from the remains of tiny sea plants and animals that died hundreds of millions of years ago, when a large portion of the Earth was covered by vast oceans. When the plants and animals died, they sank to the bottom of the oceans. Over time, the remains of these plants and animals were covered with layers of sand, silt, and mud sediments. They were buried deeper and deeper. Under enormous heat and pressure, the remains turned into **sedimentary rock**. As the layers increased in depth, pressure increased on the decayed remains at the bottom. Eventually the remains changed into hydrocarbons — crude oil and natural gas. Some of these natural hydrocarbons flowed into empty spaces, called traps, in **porous** rock. The hydrocarbons couldn't seep out. An oil-soaked rock, much like a wet sponge, was formed. The traps were covered with a layer of solid rock or a seal of salt or clay that kept the oil and gas from escaping to the surface.

Under these conditions, only about two percent of **organic material** is transformed into petroleum. Both oil and gas are classified as a **nonrenewable** energy source because they take hundreds of millions of years to form. We cannot make new petroleum reserves or natural gas deposits in a short period of time.

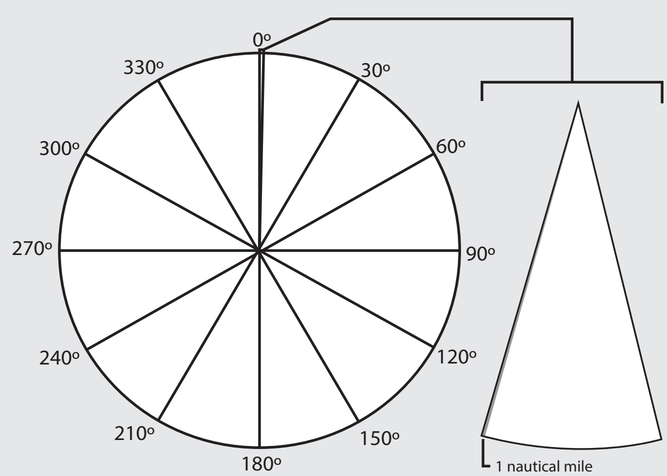
What's a Nautical Mile?

A nautical mile is based on the circumference of the Earth. Visualize this: cut the Earth in half at the Equator, pick up one of the halves, and turn it on its side. The Equator is the edge of the circle.

A circle is divided into 360 degrees. Each degree divides into 60 minutes. One nautical mile is one minute of arc on the planet Earth. Every country in the world uses this unit of measurement for travel in the air and on the oceans.

We are used to measuring distances in meters and feet. A nautical mile is equal to 1,852 meters, or 1.852 kilometers. In the English measurement system, a nautical mile is equal to 1.1508 miles, or 6,076 feet.

At the Equator, the Earth measures 40,075.16 km (or 24,901.55 miles). How many nautical miles is it around the Equator?



Oil and Gas Deposits on the OCS

There are rich deposits of petroleum and natural gas on the Outer Continental Shelf, especially off the Pacific coasts of California and Alaska, in the Gulf of Mexico, and in certain basins off the Atlantic coast. Thirty basins have been identified that could contain enormous petroleum and gas reserves within our nation's Exclusive Economic Zone. Several of these basins have been explored and are producing oil and gas at this time. The offshore areas of the United States are also estimated to contain significant quantities of resources in yet-to-be-discovered fields. It is estimated that 60 percent of undiscovered oil reserves and 40 percent of undiscovered natural gas reserves are contained in undiscovered fields on the OCS.

Oil and Gas Development

The Bureau of Ocean Energy Management (BOEM) manages the nation's offshore resources to ensure that production and drilling are done in an environmentally and economically responsible manner. Today, approximately 43 million acres of ocean are leased to energy companies developing oil and natural gas resources. The OCS is a significant source of oil and gas for the nation's energy supply. Currently, 6 percent of America's domestic natural gas production and 17 percent of America's domestic oil production come directly from the OCS.

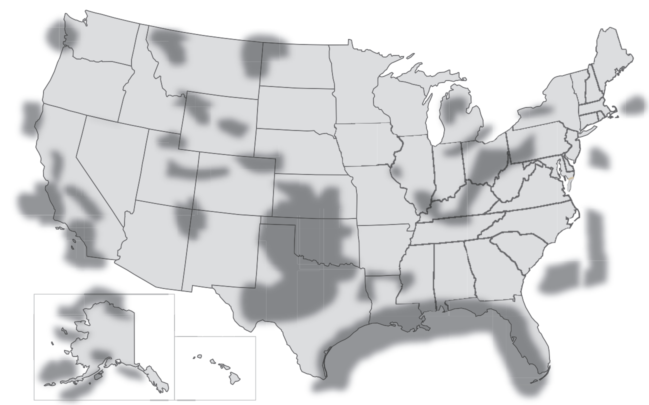
But no one is allowed to look for oil and gas or drill or recover it without permission from the Federal Government. The U.S. Department of the Interior grants permission to use offshore lands through **lease** sales operated by BOEM. The Five Year OCS Oil and Gas Leasing Program for 2012-2017 establishes a schedule that is used as a basis for considering where and when oil and gas leasing might be appropriate over a five-year period. An area must be included in an approved Five Year Program in order to be offered for leasing. Under the current Five Year Program, the majority of our country's OCS is not approved for leasing. This means no new exploration or drilling for resources will occur off the Atlantic or Pacific coasts, or offshore the southern and western coasts of Alaska.

Both the President of the United States and the Congress have the ability to declare a **moratorium** on offshore areas if they choose to. This has occurred several times for varying reasons. Currently, President Obama has withdrawn marine sanctuaries in Bristol Bay, offshore Alaska, from leasing consideration through 2017. As of 2017, no Congressional moratoria exist for energy development on the Outer Continental Shelf. However, by law, the Gulf of Mexico Energy Security Act of 2006 (GOMESA) is restricting access to waters within 125 miles of the eastern coast of Florida through 2022.

History of Offshore Exploration

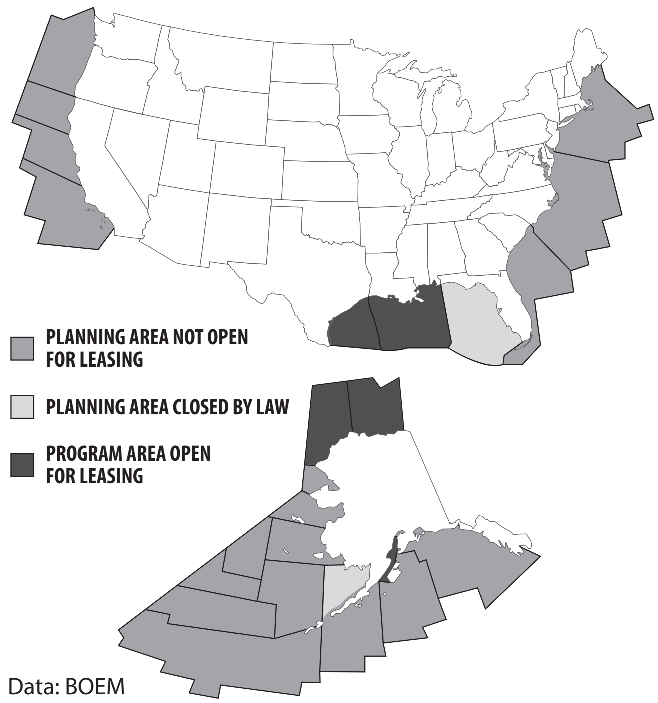
Off the coast of central and southern California, people often noticed a thin layer of oil floating on top of the water. They would walk on the beach and see tar-like substances washing up on shore. This oil came from natural oil and gas seeps that exist in great amounts off the coast of California. The petroleum and natural gas seep out of the ocean floor, making the water bubble in some places and allowing people to skim oil off the water. This oil and gas is released naturally into the ocean.

U.S. Oil and Gas Basins



Data: Energy Information Administration

OCS Oil and Natural Gas Leasing Program Areas



Data: BOEM

Total Acreage Offered in 2012-2017 Program Lease Sale

Total OCS	218.94 million
Alaska	125.19 million
Gulf of Mexico	93.75 million
ALASKA	
Chukchi Sea	55.11 million
Beaufort Sea	64.72 million
Cook Inlet	5.36 million
GULF OF MEXICO	
Western	28.58 million
Central	64.51 million
Eastern	0.66 million

Data: BOEM

It is the siting of these seeps that made early petroleum explorers look for oil off the California coast. That exploration began in 1897 from a wooden pier in Summerland, California. Henry L. Williams came up with the idea of building a pier and erecting a drilling rig on it. His first offshore well was drilled from a pier extending about 91 meters into the waters of the Pacific Ocean. He found petroleum in the rock formation and soon 22 other explorers joined the search for petroleum off the California coast. The longest pier stretched over 365 meters into the ocean. Within the next five years, approximately 400 wells were drilled. Some of these wells even produced oil and gas from as deep as 183 meters below sea level. These drilling piers were the cutting-edge technology of the day.

By 1910, America was using petroleum as its primary energy resource. Today, it is still the number one energy source in the United States. The invention of the car, and the internal combustion engine, greatly increased the use of gasoline for automobiles. At the same time, Americans were discovering new and faster ways to drill for and produce oil. For example, steel cable was used in place of rope for drilling, and the first diamond drill bit was used. As oil and gas exploration expanded, control over these resources was an important role that needed to be filled by the Federal Government and the states.

The discovery of the Creole Field in the Gulf of Mexico off the coast of Louisiana in 1938 marked the petroleum industry's first successful venture into open waters offshore. This discovery well was drilled from a drilling platform secured to a foundation of timber piles set in water less than five meters deep.

By the mid-1940's, significant changes in the oil industry were being made as America was making its transition from a wartime economy to a peacetime economy. The petroleum industry witnessed the end of government controls on crude oil prices and there was a huge public demand for oil and natural gas. In 1945, President Truman asserted federal jurisdiction over the entire OCS. In 1953, states were given **jurisdiction** over the lands within three miles of their shore lines.

Deepwater Oil and Natural Gas Technology

The success of offshore exploration and production from the 1950s to today is because of technological advances. These technologies have improved the efficiency and economics of offshore development and enabled exploration and production to occur in deeper ocean environments. Deepwater oil and gas development in the Gulf of Mexico, which began in 1979, continues to be vital for U.S. domestic oil and natural gas production. A water depth greater than 304.8 meters (1,000 feet) is generally considered to be deepwater. Over 1,524 meters (5,000 feet) deep is considered to be ultra-deepwater. It might be hard to imagine how deep that is. Ultra-deepwater is equal to about 33 Statue of Liberty statues stacked on top of each other.

The OCS is seeing an overall expansion in all phases of deepwater activity. Today, there are 5,789 active leases on our nation's Outer Continental Shelf, 3,433 of those are located in ultra-deepwater.

Seismic technology has revolutionized the search for oil and gas. Seismic surveys send high-energy sound waves into the ground and reflect information on underground rock layers back to the surface. Since sound travels at different speeds as it passes through various types of rocks, computers can use the seismic data to create a 3D map of what lies below the surface. When searching for petroleum under the sea floor, seismic equipment must be adapted for the marine environment. Boats carrying tow cables attached to sound devices, called **hydrophones**, send down vibrations. These vibrations are set off by releasing bubbles of compressed air. The bubbles send out sound waves as they contract and expand while rising to the surface.

Progress in offshore technology is demonstrated by advances in production platforms, too. The production platform provides a base for operations, drilling, and production. For many years, the standard method for offshore development was a fixed structure based on the sea bottom, such as an artificial island or man-made platform. Today, offshore drilling platforms can be tethered to the ocean floor with cables or float freely using **dynamic positioning systems**.

New technology is allowing production platforms to operate in deepwater. Early drilling was limited to areas less than 92 meters (300 feet) deep. Now, modern drilling rigs can operate to depths of three kilometers (1.86 miles). Once petroleum or natural gas is found, drilling rigs are replaced with huge production platforms. These platforms hold all the drilling and production equipment, as well as storage and housing areas for the work crews. Many offshore oil platforms contain libraries, gyms, medical facilities, movie theaters, and other entertainment options for the men and women who live and work onboard for weeks at a time.

Today, there are 2,110 active platforms in use producing oil and natural gas on our nation's Outer Continental Shelf. The majority operate in waters less than 200 meters (656 feet) deep. There are only 42 platforms operating in deepwater, and only 14 active platforms producing oil and gas in ultra-deepwater over 1,500 meters deep.

SEISMIC VESSEL

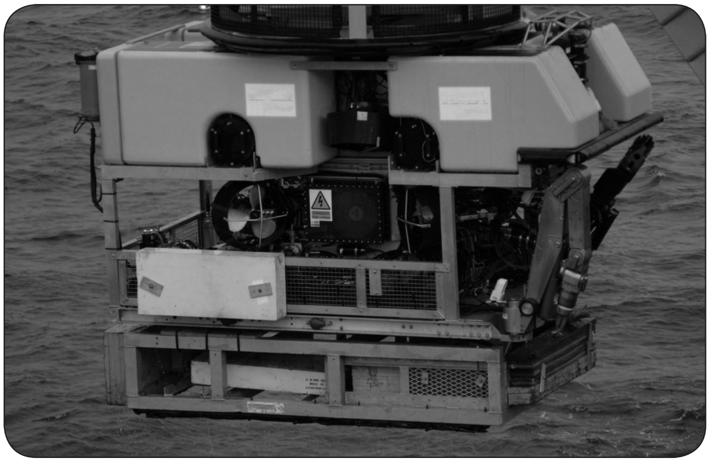
Image courtesy of PGS

The PGS Apollo is a multipurpose 3D seismic survey ship.

SEMI-SUBMERSIBLE OIL RIG

Special technology is required for the materials and equipment used in subsea environments. For example, well caps must be resistant to corrosion by saltwater and must be able to withstand the pressure deep in the ocean. Well operators do not regularly visit the ocean floor to check on the well caps. Instead, sensors are placed on the well caps so that the wells can be monitored from the platform. Advanced technologies such as Remote Operating Vehicles, or ROVERS, can make robotic repairs to the well. Operators on the platform use remote controls to direct the robot.

REMOTE OPERATING VEHICLE



Another area of technological innovation involves producing and transporting oil and natural gas resources using equipment installed deep on the ocean floor. It is not practical to build a production platform for every well. Instead, a series of gathering lines connect multiple wells to a single processing hub deep underwater. The oil gathered from many wells is transported to a single production platform. Oil, natural gas, and water recovered from the ground are separated there. A pipeline transports the clean oil to a refinery elsewhere or onshore. Using this advanced technology, energy companies can use a single production platform to develop resources from 64 kilometers (40 miles) away.

The most sophisticated systems don't use a production platform on the surface. They operate as a processing system underwater. These systems separate the oil, natural gas, and water thousands of meters under the ocean. The oil is sent directly into pipelines and transported to shore. Such advanced systems are being installed at depths of 3,000 meters (1.8 miles) in the Gulf of Mexico, where ultra-deepwater development plays a significant role in current and future energy production.

Methane Gas Hydrate

The Energy Information Administration projects that demand for natural gas will continue to increase significantly for the next 25 years. Fortunately, we have an abundant supply of domestic natural gas, but, the United States will need to increase production in order to keep up with the rate of consumption. Eventually, as demand increases, more supplies will be needed. Scientists are studying **methane hydrate** as a potential natural gas energy source.

Methane Hydrate Formation

Methane is an energy-rich gas, and is the main component of natural gas. Buried in the sediments of the ocean floor, bacteria break down the remains of sea animals and plants. In the process, they produce methane gas. Methane is almost always a by-product of organic decay. Under the enormous pressure and cold temperature at the bottom of the ocean, this methane gas dissolves. The molecules of methane become locked in a cage of water molecules to form crystals. These crystals look like white ice, and they cement together the ocean sediments. In some places, a solid layer of crystals, known as methane hydrate, extends from the sea floor down hundreds of meters. In addition to the methane trapped in crystals, scientists think that huge deposits of free methane gas are trapped beneath the hydrate layer.

When methane hydrate is "melted," or exposed to pressure and temperature conditions outside those where it is stable, the solid crystal cage turns to liquid water, and the enclosed methane molecules are released as gas. This process is called dissociation. Because methane hydrate can only remain solid at low temperatures and high pressures, it is difficult to recover methane hydrate samples intact, whether the samples are collected from the seafloor or from deeply buried sediments. As soon as a sample is brought to Earth's surface, it will **dissociate**.

Methane hydrate is a concentrated form of natural gas. The molecules of methane are packed together more closely than in liquefied gas. Upon dissociation, one cubic foot of solid methane hydrate releases about 164 cubic feet of natural gas. This is one of the reasons scientists are interested in methane hydrate as a potential energy source.

Methane hydrate represents a potentially vast methane resource for both the United States and the world. Recent discoveries of methane hydrate in arctic and deepwater marine environments have highlighted the need for a better understanding of this substance as a natural storehouse of carbon and a potential energy resource.

METHANE HYDRATE DISSOCIATING

Image courtesy of USGS

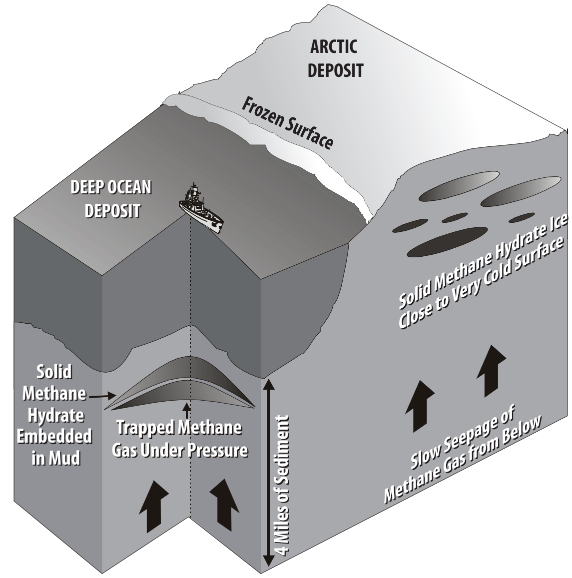
Dissociation can be demonstrated by lighting a match next to a piece of methane hydrate. The heat from the match will cause the hydrate to dissociate, and the methane molecules will be ignited as they are released. This results in the curious spectacle of what appears to be burning ice.

Where is Methane Hydrate Located?

Natural methane hydrate occurs when methane and water are present together and pressure and temperature conditions are suitable to form and sustain hydrate. On land, deposits are found in polar regions in sediments within and beneath the permafrost. In the ocean, deposits are found mainly in sediments of outer continental margins — areas where the continental shelf transitions to the deep ocean.

According to the United States Geological Survey, methane gas hydrate reservoirs may contain more carbon than all the world's fossil fuels combined. That's an enormous amount of energy. But estimates of how much methane hydrate exist vary widely, partly because hydrate is found in many different kinds of reservoirs, such as arctic sandstone, marine sands, and muds. There's no simple test to determine how much exists. Estimates continually change, as scientists obtain new information about locations and concentrations of methane hydrate using direct sampling, laboratory testing, modeling, and remote detection. The Federal Government, industry, and numerous universities are working together to actively assess and estimate the volume of **gas hydrate** in the subsurface of the OCS. Their research reflects in-place gas volumes only. It does not indicate how much gas hydrate may be technically or economically recoverable. This is because hydrate production technologies are in their infancy and sustained commercial production from gas hydrate reservoirs has not been demonstrated anywhere in the world.

Methane Hydrates



In-place resource: an estimate of the total volume of natural gas contained in methane hydrate deposits, without regard to individual accumulation size or technical recoverability.

Technically recoverable resource: the portion of the in-place resource that is recoverable using existing technologies, without regard to economics.

Methane Hydrate Production

At this time, the most promising area for recovering methane hydrate is not offshore. It is likely in sediments under the permafrost of arctic regions. Hydrate is concentrated here in reservoirs with high **porosity** and **permeability**. In addition, portions of these reservoirs are already located near existing oil and natural gas production infrastructure, reducing production costs.

Experts think conventional drilling and production technologies will be able to dissociate methane hydrate and gather the released methane at rates that will make commercial production a possibility. However, the production system will be more complex than conventional natural gas wells due to a number of technical challenges, especially offshore. Some challenges include: maintaining commercial gas flow rates with high water production rates; operating at low temperatures and low pressures in the **wellbore**; and ensuring the structural integrity of the well. Technologies exist to address all of these issues, but their implementation will add to overall development costs for producing natural gas from hydrate.

Recovering methane from hydrate deposits in sandstone or sandy reservoirs offshore may work like this: after drilling into a reservoir and building the well structure, pressure in the wellbore is reduced. Water trapped in the reservoir moves toward the well, lowering the pressure within the deposit. Reduced pressure causes the hydrate to dissociate and release methane. As water and gas flow out of the deposit, the pressure continues to reduce. Dissociation continues. More methane is produced and the cycle continues.

A complication is that hydrate dissociation is an endothermic process — it uses heat. A natural consequence of dissociation is potential re-freezing of the surrounding reservoir. To be successful, a methane hydrate production strategy will need to find a way to lower the pressure in the reservoir so the hydrate will dissociate, and heat the reservoir to keep the hydrate from returning to its natural, stable, frozen state.

Another challenge of producing natural gas from methane hydrate is to recover the methane safely and economically while protecting the environment.

How Does Methane Hydrate Affect the Environment?

Scientists are studying an important question, what effect will harvesting methane hydrates have on the global carbon cycle? Methane is a potent greenhouse gas that remains in the atmosphere for about a decade before turning into carbon dioxide. The amount of carbon stored in the world's supply of methane hydrate is immense. Releasing methane gas into ocean water and the atmosphere is a critical concern. The U.S. Department of Energy is supporting research projects studying how microbes in ocean water naturally consume methane, to determine how much methane makes its way up through the ocean and into the atmosphere. Research like this helps scientists understand methane hydrate's role in global climate processes and climate change.

Methane Hydrate Research in the U.S.

The United States has been studying naturally occurring methane hydrate since 1982 after launching a national research and development program. In 2000, the U.S. government signed into law the Methane Hydrate Research and Development Act of 2000, which mandated that the U.S. Department of Energy (DOE) lead the program and utilize the talents of federal, private, and academic organizations to carry out the research. The program was extended under the Energy Policy Act of 2005.

Current research focuses on: confirming the scale, nature, and producibility of methane hydrate through drilling and coring programs in the field, computer modeling and simulation, and laboratory experimentation; understanding and controlling the impact of methane hydrate on seafloor stability; and developing a better understanding of the role methane hydrate plays in **geohazards** and defining potential impacts of methane hydrate on the global **carbon cycle**.

Three major field research projects are currently underway in the U.S., including one offshore project to study methane hydrate in the Gulf of Mexico, and two onshore projects to study methane hydrate beneath the permafrost in northern Alaska.

The Gulf of Mexico Joint Industry Project is a cooperative research effort between DOE and international industry partners led by Chevron. During 2009, the team completed a successful drilling and logging expedition in deepwater on the OCS in the Gulf of Mexico. They successfully drilled seven wells including the deepest gas hydrate research wells in the world. During the drilling and logging expedition, scientists collected high-quality geological data, which they are currently studying. Results of the Gulf of Mexico project have led to improved techniques for hydrate detection, characterization, and sampling from the deep ocean. Also, several individual test wells confirmed the existence of quality methane hydrate that could be commercially viable in the future.

The first Alaskan project in the Prudhoe Bay Region, is a collaboration between DOE, BP, industry, government agencies, and academia. At the Mount Elbert test well, drilled in 2007, they are conducting long-term testing to evaluate how hydrate reacts to controlled pressure reduction. The project completed a short-term test proving the hydrate formation's ability to release gas through depressurization, a first time achievement on the Alaskan North Slope.

METHANE HYDRATE CRYSTALS

Image courtesy of Charles Fisher, Penn State

The second Alaskan North Slope project, in partnership with DOE, ConocoPhillips, and the Japan Oil, Gas and Metals National Corporation, made history by successfully completing the first ever field trial of a new production methodology using carbon sequestration. From February through April of 2012, a team of scientists injected carbon dioxide and nitrogen into a methane hydrate reservoir. CO_2 molecules swapped places with methane molecules underground, forcing the methane out of the well. Scientists are now analyzing the data collected from the field site. The data will help determine if using this approach of storing CO_2 during methane production from hydrate is efficient. In addition, this project completed the longest-duration field test of methane hydrate extraction via depressurization, which lasted 30 days.

In order to increase our understanding of methane hydrates' potential as a future energy supply, DOE also funds gas hydrate research projects at American universities. While research on methane hydrates is still in the early stages, and no commercial-scale technologies have been demonstrated, these research efforts may lead to significant new supplies of natural gas and further expand U.S. energy supplies.

Offshore Wind Energy

Humans have been using wind energy for more than two thousand years. Early windmills were built to control flooding, pump water, grind grain, and power saw mills. Today, wind energy is mainly used to generate electricity using wind turbines. In the United States, we've been using modern wind turbines to generate electricity for several decades. But harnessing energy from offshore winds is just beginning.

Wind Formation

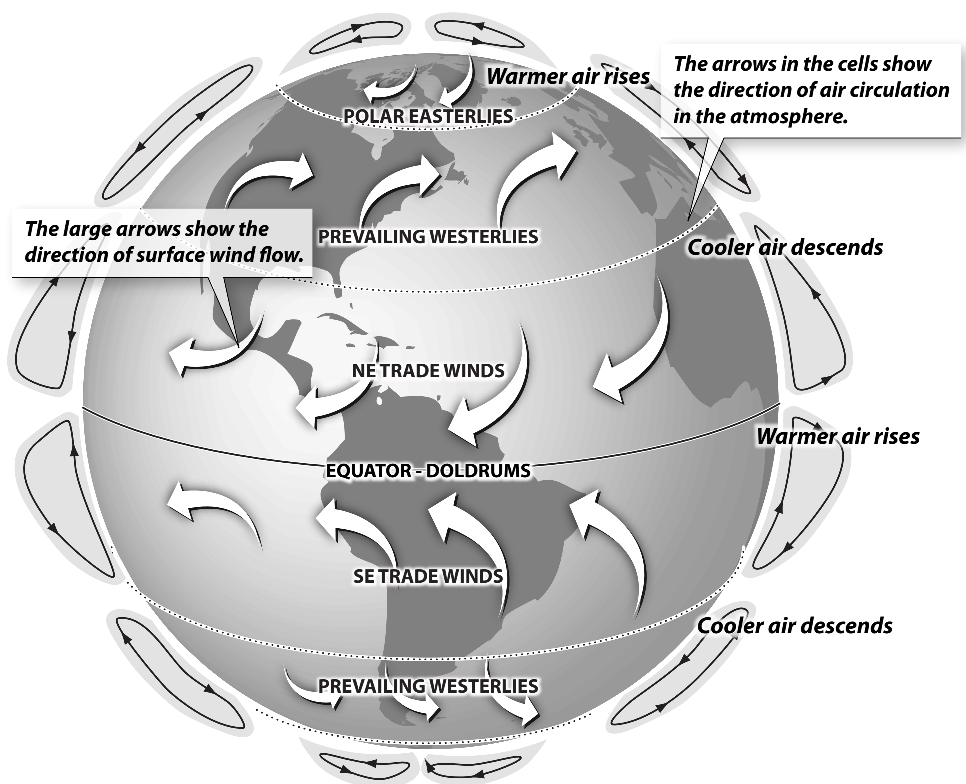
The energy in wind comes from the sun. When the sun shines, some of its radiant energy (light) reaches the Earth's surface. Some parts of the Earth absorb more radiant energy than others. When the Earth's surface absorbs the sun's energy, it turns the light into heat. This heat on the Earth's surface warms the air above it. The air over land usually gets warmer than the air over water. As air warms, it expands. Its molecules spread farther apart. The warm air is less dense than the air around it and rises into the atmosphere. Cooler, denser air nearby flows in to take its place. This moving air is what we call wind. It is caused by the uneven heating of the Earth's surface. Wind's motion energy can be harvested by wind turbines to generate electricity.

THE POWER OF WIND

$P=\frac{1}{2}\rho AV^3$	P = power in watts ρ = The air density (1.2kg/m^3 @ sea level and 20° C) A = The swept area of the turbine blades (m^2 square meters) V = wind speed (meters per second)

The potential energy produced from wind is directly proportional to the cube of the wind speed. As a result, increased wind speeds of only a few miles per hour can produce a significantly larger amount of electricity. For instance, a turbine at a site with an average wind speed of 16 mph would produce 50 percent more electricity than at a site with the same turbine and average wind speeds of 14 mph. Choosing where to site a wind farm is an important part of the process.

Global Wind Patterns



Offshore Wind Resources

Air is constantly moving between land formations and water. Because there are no obstacles to block the wind, the wind blows stronger and steadier over water than land. There is a lot of wind energy available offshore. The National Renewable Energy Laboratory estimates more than 4,000 **gigawatts** of wind power resources are available on the Outer Continental Shelf (OCS) — about four times the generating capacity of the U.S. electric grid today. Offshore wind resources have the potential to power a substantial portion of our nation's energy needs.

In the U.S., wind speeds off the Pacific Coast are stronger than the Atlantic Coast or the Gulf of Mexico. However, the Atlantic OCS has shallower water. Developing offshore wind farms there is the most economical option at this time. Hawaii also has a lot of potential for offshore turbines.

Only about 10 percent of our wind energy resources on the OCS occur over water shallow enough for modern turbine technology. Thus, in 90 percent of the areas offshore, the water is too deep to install a turbine. Engineers are working on new technologies, such as innovative foundations and floating wind turbines. Some day we will be able to generate electricity with turbines in deep waters.

Offshore Wind Turbine Technology

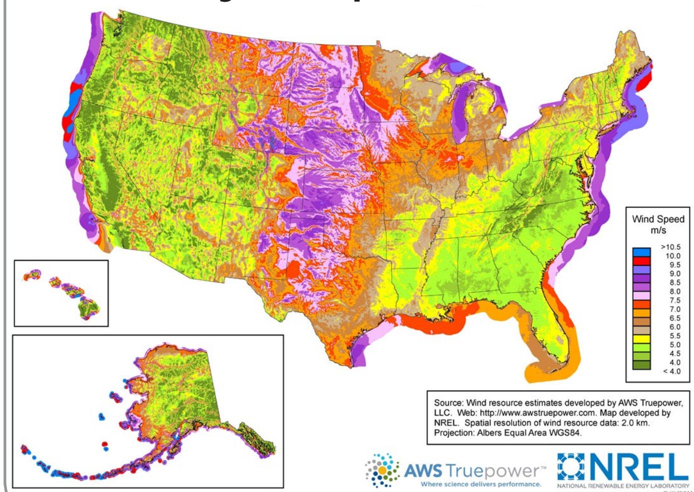
Building commercial-scale offshore wind farms depends on site-specific conditions, such as water depth, geology of the seabed, and wave attributes. In shallow water four to thirty meters (13-100 feet) deep, a large steel tube called a **monopile** is used as a foundation. A monopile may be six meters (20 feet) across. It is driven into the seabed 24 to 30 meters (78-100 feet) below the mud line. The monopile supports the tower and nacelle. Offshore turbine foundations must be designed to withstand the harsh environment of the ocean, including storm waves, hurricane-force winds, and even ice flows.

The **nacelle** is a rectangular box that encloses the **gear box**, **generator**, blade **hub**, and electronic components. It is specially designed to protect the machinery and electronics inside from corrosive sea water. The nacelle may have its own heating and cooling system, which maintains the temperature inside the nacelle and keeps gear oil working smoothly. There may be an automatic greasing system to lubricate bearings and blades. Wind sensors on the turbine are connected to a system that always keeps the nacelle facing into the wind. This maximizes the amount of electricity produced.

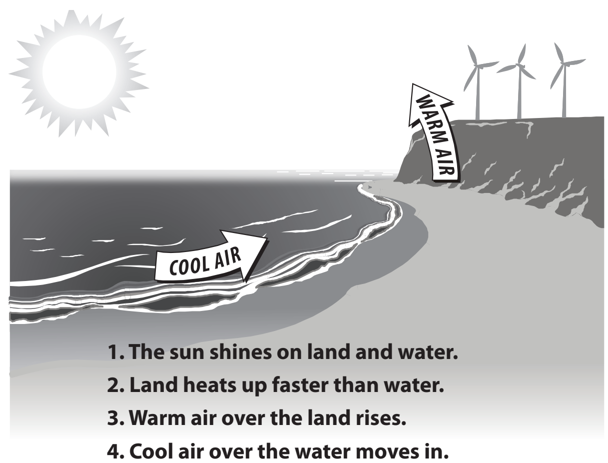
To minimize maintenance costs, turbines and towers have high-grade exterior paint. They are typically painted light grey or off-white to help them blend into the sky, reducing visual impacts from the shore. Lower sections of the support towers may be painted bright colors to increase navigational safety for passing vessels. Offshore turbines also include navigation and aviation warning lights.

To take advantage of the steadier winds, offshore turbines are bigger than onshore turbines and have an increased generation capacity. Offshore turbines generally have nameplate capacities between 2 megawatts (MW) and 5 MW, with tower heights greater than 61 meters (200 feet) and rotor diameters of 76 to 131 meters (250-430 feet). The maximum height of the structure, at the very tips of the blades, can easily approach 152 meters (500 feet), and turbines even larger than 5 MW are being designed and tested for future use.

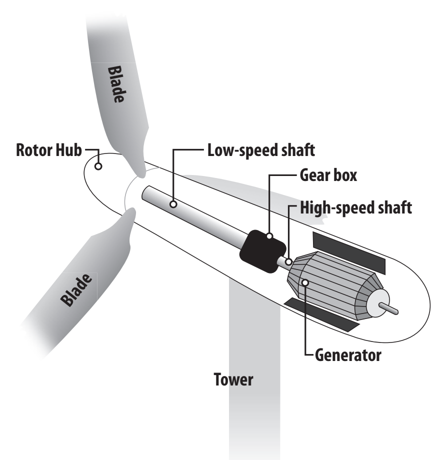
Annual Average Wind Speed



How Wind is Formed



Inside a Wind Turbine



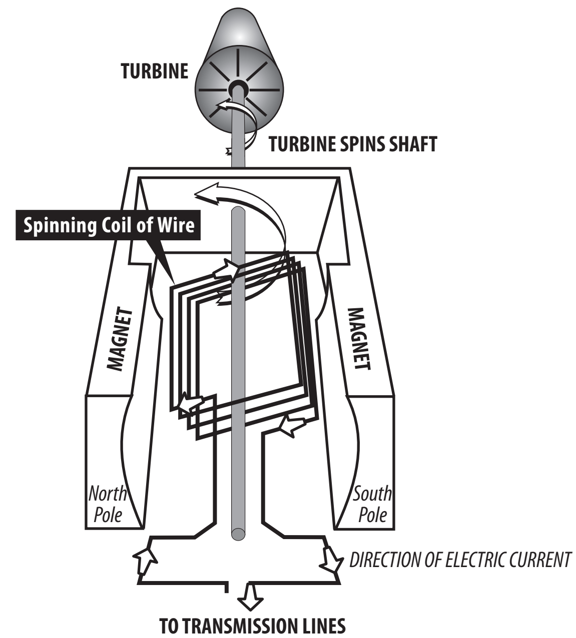
Generating and Transporting Electricity

Wind turbines work by slowing down the speed of the wind. All wind turbines operate in the same basic manner. As the wind blows, it flows over the **airfoil**-shaped blades of the wind turbine, causing the turbine blades to spin. The blades are connected to a shaft that turns an electric generator to produce electricity. The newest wind turbines are highly technologically advanced, and include a number of engineering and mechanical innovations to help maximize efficiency and increase the production of electricity.

Electricity generated by wind turbines needs to be transmitted to shore and connected to the **power grid**. Offshore, each turbine is connected to an **electric service platform** (ESP) by a power cable. In a large **wind farm**, the ESP might function as a central service facility, with a helicopter landing pad, communications station, crew quarters, and emergency backup equipment. The ESP works as a substation collecting the electricity generated by each turbine. High voltage cables transmit the electricity from the ESP to an onshore substation. Onshore, the power is integrated into the grid.

Power cables are typically buried beneath the seabed, where they are safe from damage caused by anchors or fishing gear and to reduce their exposure to the marine environment. The cables are very expensive, and a major factor in the cost of building an offshore wind farm. The amount of cable used depends on many factors, including how far offshore the project is located, the spacing between turbines, and maneuvering around obstacles on the ocean floor.

Turbine Generator



Offshore Wind Development

The first offshore wind project was installed off the coast of Denmark in 1991. Since that time, commercial-scale offshore wind facilities have been operating in shallow waters around the world. Europe currently leads the offshore wind farm industry with over 1,900 turbines installed and grid connected in Great Britain, Denmark, Germany, Belgium, the Netherlands, Sweden, Finland, Norway, and Ireland. Other areas of the world rely on offshore wind power, too, including China and Japan. The largest offshore wind farm in the world is the London Array in the United Kingdom, with 175 turbines and 630 MW of capacity.

Currently, there is only one commercial offshore wind farm operating in the U.S. However, several projects are in the concept and planning stages, mostly in the Northeast and Mid-Atlantic regions. Projects are also being considered along the Great Lakes, the Gulf of Mexico, and the Pacific Coast.

The first offshore wind farm in the United States, the Deepwater Wind project, southeast of Block Island in Rhode Island, began construction in 2015 and was completed in 2016. The five turbine, 30-megawatt wind farm will come online late in 2016, and will have the ability to power roughly 17,000 homes per year, reducing the reliance on diesel-fired electricity generation and improving air quality for residents.

The Cape Wind project on Nantucket Sound, off the coast of Massachusetts, is another offshore wind project in the works for the U.S. The Cape Wind project was proposed to consist of 130 wind turbines with a capacity to produce 420 MW of electricity. The project, however, has stalled after a decade of legal and logistical concerns. Cape Wind still controls the leased area, but is required by the U.S. Courts to undergo further study of the offshore area before allowing construction to begin.

Europe Leads the World in Offshore Wind

According to the European Wind Energy Association, as of July 2013, offshore development in the European Union included 1,939 fully grid connected offshore wind turbines, located on 58 wind farms across 10 countries. The turbines have a combined generating capacity of 6,040 MW.

BLOCK ISLAND WIND FARM, RHODE ISLAND

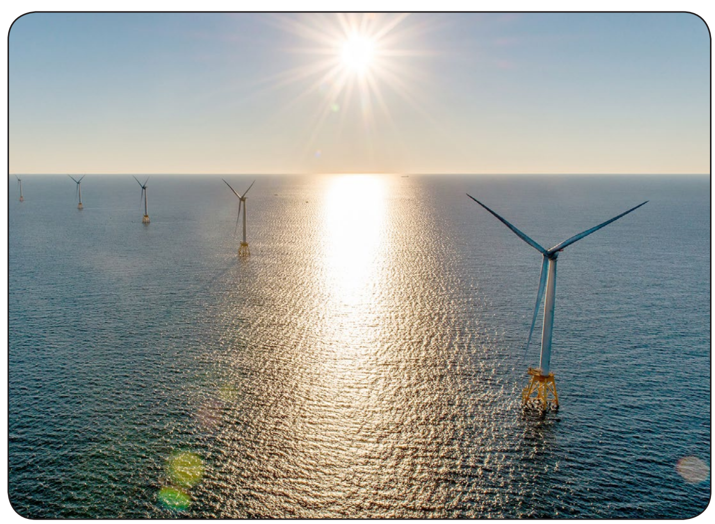


Image courtesy of Deepwater Wind

Floating Wind Turbine Technology in the U.S.

Developing a wind farm in the open ocean poses different technology challenges than a wind farm on land. In Maine, the best areas of wind potential are in deeper waters where conventional turbine technology is not practical. Here, floating wind turbines may provide the solution.

In 2013, the University of Maine installed a prototype concrete-composite floating platform wind turbine off the coast of Castine, Maine. This prototype is the first grid-connected offshore wind turbine to operate anywhere in the United States. It is also the first of its kind to be deployed in the world. The 20 meter-tall VolturnUS wind turbine is one-eighth the scale of a commercial installation. It is being used to collect data that will help engineers improve floating wind turbine designs.

Analyzing building materials and costs associated with building offshore turbines is an important aspect of this prototype project. The floating turbine design features a unique semi-submersible platform that uses a lower cost concrete foundation in addition to a lighter weight composite tower. The design may help reduce the overall cost of the system while ensuring high performance and efficiency.

VOLTURNUS PROTOTYPE

Image courtesy of CIANBRO

Image courtesy of University of Maine

Wind Energy Leases on the OCS

Before a company can build a wind farm out in the ocean, they must lease the space from the Federal Government. In 2013, the BOEM began a series of competitive lease sales for wind energy development on the OCS off the coasts of Rhode Island, Massachusetts, Virginia, Maryland, and New Jersey. In a competitive lease sale, interested companies have the chance to **bid** against each other in an auction for the right to build, or develop, a specific spot in the ocean.

There are several steps in the renewable energy leasing process. First, the BOEM determines which areas of the ocean they want to include in a lease sale. This may be several hundred thousand acres. Next, they publish a call for information and nominations, to see if any companies are interested in paying to develop the area, and offering the public an opportunity to present issues. Next, environmental assessments and impact studies are completed for the area. Public concerns are addressed, and companies submit nominations to participate in the sale. The next big step is publishing the proposed sale notice, with the proposed lease terms and conditions. There is also time for companies and the public to ask questions and make comments. Next, the **final sale notice** publicly announces the sale date, companies approved to participate in the sale, and all the details of the lease sale. Finally, the lease sale is held and a winner is chosen.

After winning the lease, the highest bidder pays the winning amount to the Federal Government. The company is also required to pay a yearly rental fee based on the number of acres leased. The company has six months to submit a site assessment plan to BOEM for approval. This plan describes everything the company needs to do, such as installing meteorological towers and buoys, in order to assess the wind resources and ocean conditions in the area where they want to build. Once this plan is approved, the company has four and a half years to complete their research and submit a construction and operations plan. This plan provides all of the details for constructing and operating the wind energy project. If the construction and operations plan is approved, the company can start construction, and will be able to operate for a term of 33 years.

Challenges

There are significant technological and economic challenges to developing offshore wind energy resources in the U.S. The depth of the OCS is too deep for modern offshore turbines, so we need to develop deepwater technologies. There are difficulties involved with water-based construction and performing regular maintenance, making offshore turbines more costly to build and operate than those onshore. Also, power transmission costs increase the farther a turbine is from shore.

Despite the challenges, offshore wind turbines are being used by a number of countries to harness the energy of strong, consistent winds over the oceans. In the United States, about half of the nation's population lives in coastal areas where energy costs and demands are high and land-based renewable energy resources are often limited. Abundant offshore wind resources have the potential to supply immense quantities of renewable energy to major U.S. coastal cities.

Wave Energy

There is tremendous energy in ocean waves. But harnessing wave energy, or extracting the power from a wave, is a big challenge. Wave energy devices extract energy directly from the surface motion of ocean waves and convert the energy into electricity. A variety of technologies and promising designs are undergoing demonstration testing around the world.

Wave Formation

Waves are caused by the wind blowing over the surface of the ocean, although, they can also be affected by tides, weather conditions, and underwater events. The size of waves depends on the speed of the wind, the duration the wind blows, and the distance of water over which the wind blows, known as the **fetch**. Usually, the greater the fetch, the higher the waves. A strong breeze of 48 kilometers per hour (30 mph) can produce waves three meters (10 feet) high. Violent storm winds of 105 kilometers per hour (65 mph) can produce waves nine meters (30 feet) high.

As the wind blows over the water, there is friction between the wind and the surface of the water. The wind pulls the surface water in the direction it is going. The water is much more dense than the air and cannot move as fast, so it rises and is then pulled back down by the force of gravity. The descending water's **momentum** is carried below the surface, and water pressure from below pushes this **swell** back up again. This tug of war between gravity and water pressure creates wave motion.

Ocean waves are, therefore, the up and down motion of surface water. The highest point of a wave is the **crest**; the lowest point is the **trough**. The height of a wave is the distance from the trough to the crest. The **wavelength** is the distance between two crests. Small waves may have lengths of a few inches while the crests of large storm waves may be several football fields apart. Waves usually follow one another, forming a train. The time it takes two crests in a train to pass a stationary point is known as the **period** of a wave. Wave periods tell us how fast the waves are moving.

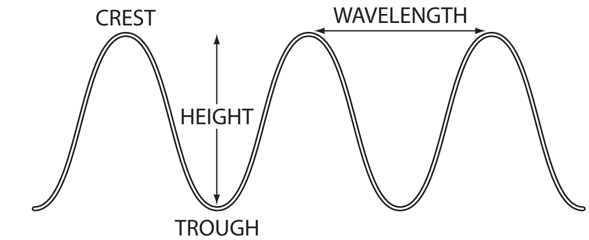
A common misconception is that a wave is water moving from far out in the ocean all the way to the shore. If that were true, there wouldn't be any water left in the middle of the ocean. Actually, in the open ocean, with each up and down movement, water rises to a crest, turns a somersault into a trough, and returns to about the same spot where it began. Near shore, the ocean becomes shallow; some somersaults hit the bottom and drag. The water at the top continues to somersault. The crests crowd together and get top heavy, tumbling over and rushing toward the shore.

Wave Energy Technology

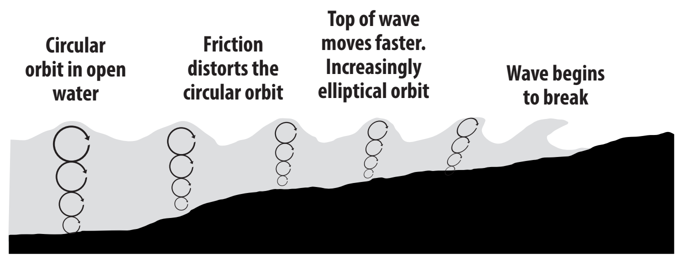
Research and development of wave energy is really just beginning. Worldwide, over a hundred conceptual designs of wave energy conversion devices have been developed, but only a few are built as full-scale **prototypes** or tested under real world conditions. So far, no particular technology is considered an ultimate solution.

Wave energy devices turn motion or mechanical energy into electric current. How motion energy is obtained from ocean waves is what makes each device unique. Wave energy technology can be grouped into five categories, each with a different method for harnessing energy from waves: attenuators, point absorbers, terminators, overtopping devices, and surge converters.

Wave Measurements



Wave Formation



There is one thing each kind of device has in common - in order for it to be economically successful, it must overcome some major technical challenges. It has to survive the harsh ocean environment, and it must efficiently extract energy from waves. Other major technological challenges include generating electricity in a water environment, and getting that power through the ocean to the existing electrical grid. There are additional challenges with the mechanical systems, **mooring** and anchoring the device, reliability, and predictability or wave forecasting.

In addition to technological challenges, developers must consider how a device may impact the surrounding marine environment. Some environmental concerns include migratory species, and changing the flow of sediments near the shore. In some places, citizens and business owners have concerns about losing commercial and recreational fishing grounds, and the impacts these devices have on recreational activities like surfing and kayaking.

▪ Wave Attenuator

An **attenuator** is a long, multi-segmented device that floats on the surface of the ocean. It is anchored in place perpendicular to the incoming waves. The device harnesses energy as the motion of the waves causes flexing between each segment. The mechanical motion of the flexing is converted to electrical energy using hydraulic motors and generators.

An example of this technology is in use by the Scottish company, Pelamis Wave Power. They invented a wave attenuator known as Pelamis, named after the scientific name of a sea snake. Each device is a series of five semi-submerged tubes that are linked to each other by hinged joints. Passing waves cause each tube to rise and fall like a giant sea snake. The motion tugs at the joints linking the segments. The joints act as a pumping system, pushing high pressure oil through a series of hydraulic motors, which in turn drive the electrical generators to produce electricity. The wave energy converters are anchored to the sea floor by moorings and then connected to the grid with subsea power cables.

In 2008, Pelamis Wave Power and the Portuguese utility Enersis built the world's first commercial wave farm off the coast of Portugal. Three first-generation Pelamis machines had an installed capacity of 2.25 megawatts and generated sustained power to the electric grid. However, the project ended later that year, with the Pelamis machines being towed back into harbor, due to the financial collapse of Enersis' parent company. Currently, Pelamis Wave Power has second-generation machines undergoing commercial-scale field testing off the coast of Scotland.

▪ Point Absorber

A **point absorber** looks much like an ocean buoy. It is a floating structure that captures energy from the vertical motion of waves. A point absorber is not oriented any particular way in relation to the waves because it "absorbs" the energy from waves from every direction. The up and down bobbing motion drives electromechanical or hydraulic energy converters to generate an electric current. Typically, a point absorber rises about three meters (10 feet) above the ocean surface, while about 46 meters (150 feet) extends below the surface. However, fully submerged point absorbers are also under development.

Several companies are successfully demonstrating this technology around the world. One example is Ocean Power Technologies' PowerBuoy®. Ocean Power Technologies received the first license for a grid connected wave power station in the U.S. They are currently developing the first commercial wave park in the U.S. off the coast of Reedsport, Oregon. Eventually, up to ten PowerBuoys® will generate approximately 4,000 megawatt-hours a year directly to the electrical grid. This is enough power for about 375 homes.

▪ Terminator

Wave energy devices known as **terminators** are oriented perpendicular to the direction of wave travel and can be located either onshore, built into cliffs along a coast, or offshore. One example is the oscillating water column. In this system, the column, or chamber, is permanently held in place, partially submerged in the water. As waves flow in and out of the chamber, the air inside the chamber is compressed and decompressed. The forced air spins a turbine. A generator attached to the turbine produces electricity. If the oscillating water column is located offshore, generated electricity is sent through a cable to a junction on the seabed. Several devices can be connected together and linked to shore through a single underwater cable. The energy generating capacity of a single terminator device can be up to 1.5 MW.

One example is the Limpet (Land Installed Marine Powered Energy Transformer) designed by Voith Hydro. A Limpet device was installed in 2000 on the island of Islay (EYE-la), off Scotland's west coast. The shoreline power plant is currently producing power for the national grid.

PELAMIS WAVE MACHINE

Image courtesy of Pelamis Wave Power

OPT POWERBUOY

Image courtesy of National Geographic

LIMPET 500

▪ Overtopping Device

One way to harness wave energy is to focus the waves into a narrow channel, increasing their power and size. The waves are channeled into a catch basin, or reservoir. Like a hydroelectric dam, the reservoir water is used to spin turbines and generate electricity. Overtopping devices have been demonstrated both onshore and offshore.

An example of this technology is the Wave Dragon, developed by the company Wave Dragon ApS. The Wave Dragon is an offshore floating wave energy converter. It has two wave reflectors focusing the waves towards a ramp. Behind the ramp is a large reservoir where the water that runs up the ramp is collected and temporarily stored. Utilizing the height difference between the level of the reservoir and sea level, gravity pulls water from the reservoir through hydropower turbines to generate electricity. A large scale Wave Dragon prototype underwent testing from 2003-2008 off the coast of Denmark. It was the world's first offshore grid-connected wave energy device. The Wave Dragon supplied electricity to the grid for more than 20,000 hours.

▪ Surge Converter

Surge converter technology harnesses energy directly from the surging and swelling motion of waves. It uses the swaying motion between a float, flap, or membrane and a fixed point. The movement creates a usable form of mechanical energy.

An example of this technology is Aquamarine Power's Oyster device. The Oyster device floats about half a kilometer from shore, attached to the ocean floor about 12 meters (40 feet) below. Oyster's hinged flap, which is almost entirely underwater, pitches backwards and forwards in the nearshore waves. The movement of the flap drives two hydraulic pistons, which push high pressure water onshore via a subsea pipeline. This water drives a conventional hydro-electric turbine. An Oyster 800 model is currently undergoing testing off the coast of Orkney, Scotland.

Wave Energy Potential

In many areas of the world, the wind blows with enough consistency and force to provide continuous waves. The total power of waves breaking on the world's coastlines is estimated at 2-3 million megawatts. The west coasts of the United States and Europe, and the coasts of Japan and New Zealand are good sites for harnessing wave energy. There aren't any big commercial wave energy plants, but there are a few small ones. Small, onshore sites have the best potential for the immediate future, especially if they can also be used to protect beaches and harbors. They could produce enough energy to power local communities. Japan, which must import almost all of its fuel, has an active wave-energy program.

WAVE DRAGON

OYSTER 800

Images courtesy of Aquamarine Power

Tidal Energy

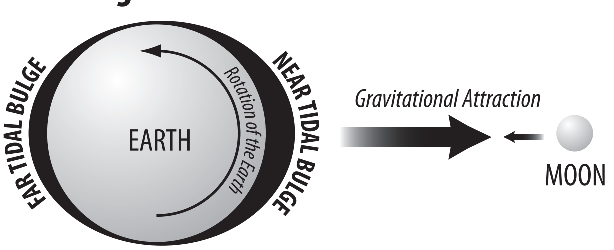
Tide Formation

Tides are caused by the interaction of gravitational forces between the Earth, moon, and sun. The force from the moon is much more powerful since it is closer to the Earth. The moon pulls on the ocean water that is closest to it. This creates a bulge in the surface of the water, called a tidal bulge. Because the Earth is rotating, the water on the opposite side of the Earth also forms a tidal bulge. These bulges produce high tides. The influence of the sun is apparent when it is aligned with the moon and the tides become higher than at other times.

Between the tidal bulges are lower levels of water that produce low tides. The tidal bulges move slowly around the Earth as the moon does. Halfway between each high tide is low tide. Most shorelines have two high and two low tides each day. However, the Gulf of Mexico only experiences one high and one low tide each day because of its geographic location.

On most of the U.S. coast, the tidal range, or the difference between high and low tides, is only about one to two meters (3-6 feet). When a high tide flows into a narrow bay where the water cannot spread out, the tidal range can be very large. These areas are potential locations for harnessing tidal power. The Bay of Fundy in Canada has the highest tides in the world, sometimes rising over 15 meters (50 feet).

Tidal Bulge



Harnessing Tidal Power

The main challenge to harnessing tidal power is geographical. There are few places in the world with significant enough tides to support tidal power stations. Coincidentally, only a few commercial scale power plants, and a few demonstration/prototype tidal power projects exist in the world. There are advantages to using tidal power as an energy source though, too. It is non-polluting, reliable, and very predictable. Its potential worldwide is enormous — if technology can be developed to harness it. The two ways to harness tidal energy include the tidal barrage and tidal turbine.

Tidal Barrage

A **tidal barrage** is a dam built across an **estuary**, the area where a river runs into the ocean. The water here rises and falls with the tides. The dam has **sluice** gates that are opened as the tide rises, allowing water to flow through into a catch basin. The sluice is closed and as the tide goes out, the water in the basin remains at a higher elevation. Using traditional hydropower technology, gravity pulls the water from the basin through turbines to generate electricity, then back to the ocean. In a two-way generation system, electricity is generated during both the incoming high tide and outgoing ebb tide. Some tidal barrage systems only generate electricity as water flows in one direction; some generate electricity in both directions.

The newest tidal barrage power plant is the Sihwa Lake Tidal Power Station opened in 2011 by the Korean Water Resource Corporation in South Korea. The tidal barrage is built into a previously existing flood control structure, and only able to generate electricity during the incoming tide. Collected water flows back to the sea during ebb tide. The power plant's generating capacity is 254 MW, making Sihwa the largest tidal power plant in the world, surpassing the La Rance barrage dam in France. The French dam was the world's first tidal power station. Operating since 1966, it has 24 turbines that generate electricity when the tide goes in or out. The only tidal barrage power plant in North America is the Annapolis Tidal Power Plant in the Bay of Fundy in Canada. It was built in 1984 with a generating capacity of 20 MW of electricity.

One disadvantage to new tidal barrage projects is construction costs. There is a high initial cost, with construction taking even a decade to complete the build. Another drawback is that tidal power has a low capacity factor, meaning it doesn't produce as much electricity as a traditional power plant. Also, tidal power is not always available during times of peak demand, since it cycles twice a day with the tides. During the time between tides, no electricity is generating, unless the barrage is equipped with a **pumped storage hydropower** system like some conventional dams.

SIHWA LAKE TIDAL POWER

Environmental Concerns

Using a tidal barrage can have an effect on the plants and animals that live within an estuary. Construction may harm local wildlife habitats. Building a tidal barrage in an inlet may change the tidal level in the area causing flooding of the shoreline, which can affect the local marine food chain. There is also concern about the movement of sediment and **turbidity** of the water.

One alternative to building a tidal barrage is a tidal fence. Composed of individual vertical-axis turbines that are mounted together within a single fence like structure called a caisson, a tidal fence allows water to flow through it. Because they do not require flooding a basin, tidal fences have much less impact on the environment. They are also significantly cheaper to install. Tidal fences have the advantage of being able to generate electricity once each individual module is installed. Tidal fences are not free of environmental and economic impacts, however, since the caisson can disrupt the movement of large marine animals and shipping. At this time, no commercial scale or demonstration project tidal fences exist.

Tidal Turbines

During the continual ebb and flow of the tides, ocean water is forced along shores and coastlines in naturally occurring paths. This horizontal flow of moving water is known as the tidal stream, or tidal current. The tidal stream is not the same as surface ocean currents, which travel in continuous, predictable patterns based on the Earth's rotation. The tidal stream changes speed, direction, and horizontal movement as the forces of the ebbing and flowing tide control it. A tidal stream is usually stronger nearer to the coast as it is shallower there and waters move faster than in deeper parts of the ocean. A tidal stream can also occur in river estuaries.

To harness the energy from the tidal stream, a **hydrokinetic energy system**, usually a turbine, is used. The kinetic energy (motion energy) of the flowing water spins turbine blades powering a generator. Electricity is transmitted to shore through undersea cables. Tidal stream generating systems work much like wind turbine technology. Of course, tidal turbines are driven by flowing water rather than air. Since water is about 800 times more dense than air, tidal turbine generators can be built smaller and rotate faster than conventional wind turbines. Tidal turbines may be partially submerged or fixed to the ocean floor.

There are two types of tidal turbines. The most popular design is the axial flow turbine. The other type is the cross flow turbine.

An example of an axial flow turbine system, the SeaGen S, was developed by Marine Current Turbines, Ltd. A single SeaGen S 1.2 megawatt demonstration device has been operating in Strangford Lough, a shallow bay situated on the east coast of Northern Ireland, since 2008. It generates about 6,000 MWh per year and is considered a commercial power station that regularly runs at full rated power. It has twin turbines that can be raised above sea level to allow maintenance workers access from small service vessels. This is an important feature because underwater maintenance by divers or remotely operated vehicles is difficult in locations with the strong currents needed for effective power generation. Environmental impact studies report that this technology has not had an impact on fish or marine mammals in the area.

SEAGEN S

Image courtesy of Marine Current Turbines Ltd.

TIDGEN TURBINE GENERATOR UNIT

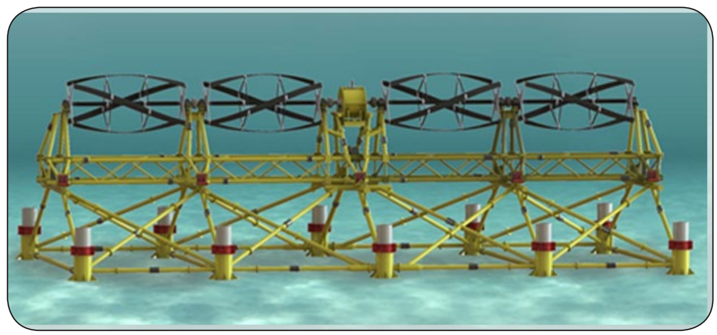


Image courtesy of Ocean Renewable Power Company

An example of a cross flow turbine is the Turbine Generator Unit, developed by the Ocean Renewable Power Company in America. The device has rotating foils that power a central permanent magnet generator. The Turbine Generator Unit works in rivers and shallow tidal currents as well as in deep ocean currents. Multiple generator units can stack together to generate more power. Built primarily with composite materials, it resists corrosion in salt water. Also, the unit is gearless, requiring no lubricants and emitting nothing into the surrounding water.

This tidal turbine system is currently generating power to the national grid off the coast of Maine (see page 18 for more detail). The company is also developing several pilot projects in the Cook Inlet of Alaska, an area of the U.S. with extremely large tides.

Tidal Power – Emerging Technology

Engineers around the world are working on developing new tidal stream generator designs. One new technology is a reciprocating device. An example of a reciprocating device, developed by BioPower Systems in Australia, resembles a shark's tail fin, swishing from side to side as if swimming in the water. A computer continually adjusts the fin to be aligned in the tidal current, giving it the swimming motion. Energy transferred from the side-to-side motion is converted to electricity.

OpenHydro, an Irish energy technology company, has designed a different style of tidal turbine — one with an open center. These tidal turbines are designed to be installed on the ocean floor, with no portion of the structure above the water level. The blades of the turbine turn in both directions, producing electricity during both ebb and flow tides. The open center turbines are designed to minimize environmental impacts. For example, the open center allows for safe passage of fish. The machine uses no oils, grease, or other lubricating fluids, eliminating potential pollutants. The blade tips are enclosed in the unit, preventing injury to large and small marine animals. Also, data gathered from the turbines show that the units produce low levels of sound.

As companies strive to lower costs and improve efficiencies, they are rethinking where tidal turbines must be located, too. One idea is to connect a tidal turbine to the underside of a floating barge or ship. This would allow easier access for maintenance, lower construction costs, and keep electrical equipment out of the water. Another idea is to attach a turbine to a bridge or barrage structure already in place.

Tidal Energy Generating Electricity in the U.S.

Cobscook Bay Tidal Energy Project

The Bay of Fundy, located on the border between eastern Maine and Canada, is home to one of the most robust tidal energy resources in the world. Here, the nation's first commercial, grid-connected tidal energy project began generating electricity off the coast of Eastport, Maine, in summer 2012. Developed by the Ocean Renewable Power Company (ORPC) in partnership with the Department of Energy, the Cobscook Bay Tidal Energy Project represents the first tidal energy project in the United States with long-term (20 year) contracts to sell electricity. Initially, ORPC's Cobscook Bay pilot project will provide enough clean, renewable electricity to power between 75 and 100 homes, with plans to install additional tidal energy devices to power more than 1,000 Maine homes and businesses.

Roosevelt Island Tidal Energy (RITE) Project

Since the project began in 2002, Verdant Power has been developing and testing tidal turbines that harness the energy in the ebb and flow of the tides in New York City's East River. The Roosevelt Island Tidal Energy (RITE) Project demonstration system stands as the first grid-connected array of tidal turbines in the world. After completing a successful demonstration phase with six turbines generating 70 megawatt-hours of electricity, the project received the first U.S. commercial license for tidal power, in 2012. With the license, Verdant Power plans to develop a 1 MW pilot project in the East Channel of the East River comprised of up to 30 commercial class (Generation 5) Free Flow System turbines, which will be installed in stages.

RECIPROCATING DEVICE

Image courtesy of BioPower Systems

OPENHYDRO TURBINE

Image courtesy of OpenHydro

COBSCOOK BAY TURBINE

Image courtesy of Ocean Renewable Power Company

RITE PROJECT

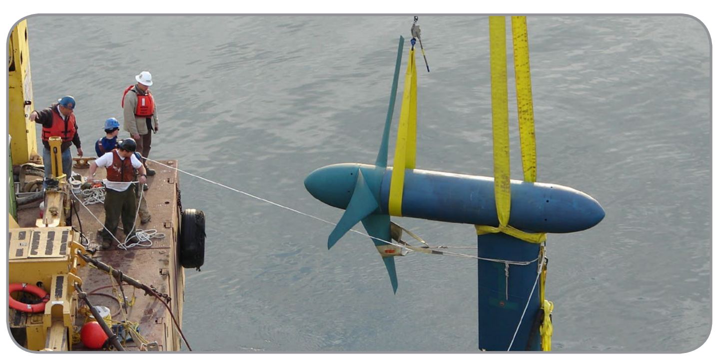


Image courtesy of Verdant Power, Inc

Ocean Surface Currents

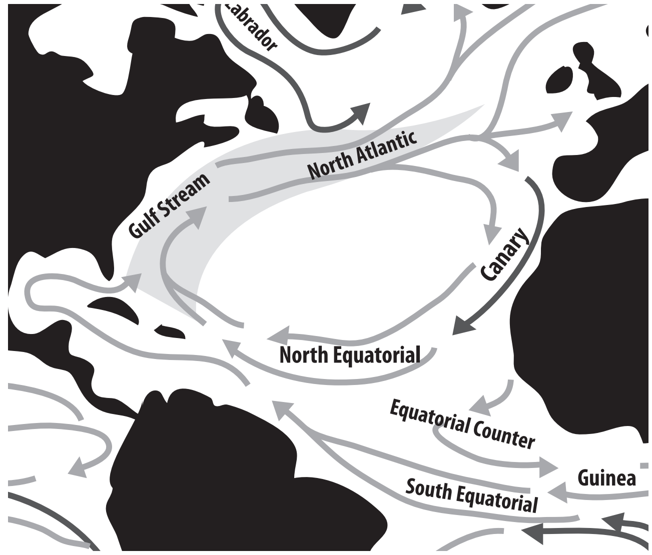
Global Ocean Currents

Ocean waters are constantly moving and flowing in complex patterns around the Earth called currents. Waters in the upper 400 meters (1,300 feet) are called ocean surface currents. They are formed by wind, water salinity, temperature, topography of the ocean floor, and the Earth's rotation. Moving water below 400 meters is considered deep water current and its movement is mostly driven by density differences and gravity. Ocean currents are relatively constant and flow in one direction.

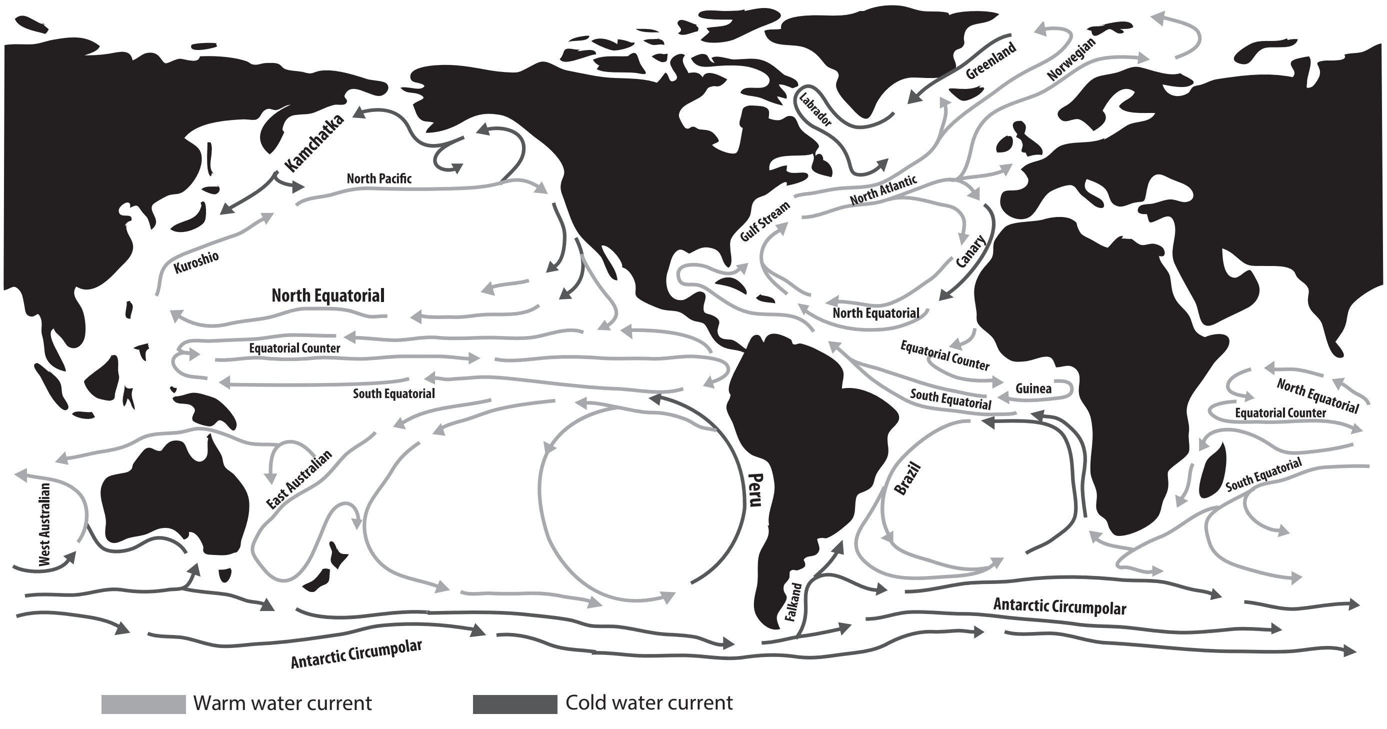
Ocean currents contain an enormous amount of energy because water is very dense. Ocean water is about 800 times more dense than air. This means slow flowing water exerts more force than a very strong wind over comparable surface areas. Capturing the energy potential remains a challenging technology problem.

Some of the ocean surface currents on America's OCS are the Gulf Stream, Florida Straits Current, and California Current. The Gulf Stream is a powerful current in the North Atlantic Ocean. It originates in the Gulf of Mexico, exits through the Strait of Florida, and follows the eastern coastline of the United States and Newfoundland. It travels 40 to 120 kilometers (25 - 75 miles) a day at speeds ranging from 1.75 km/hour to 5 km/hour (or about one to three knots). The Gulf Stream strongly influences the climate of the East Coast of the United States and many Western European countries. It keeps temperatures warmer in the winter and cooler in the summer compared to surrounding areas.

Gulf Stream



Global Ocean Currents



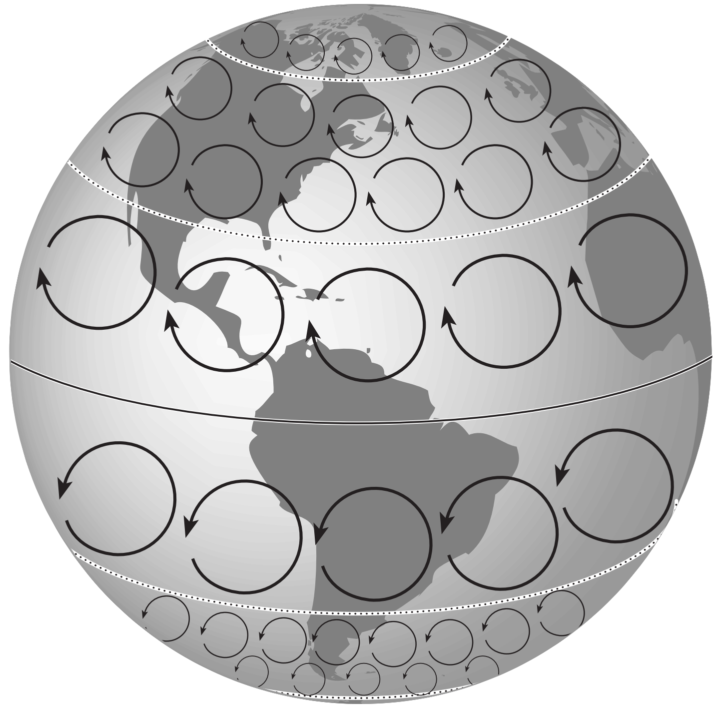
Ocean Surface Current Formation

Most ocean currents are driven by wind and solar heating of surface waters near the Equator, while some currents result from differences in density and salinity between surface and deeper waters.

As global winds drag on the ocean's surface, they pull the water in the direction that the wind is blowing. Because of the **Coriolis Effect**, major surface ocean currents curve to the right in the Northern Hemisphere (in a clockwise spiral) and to the left in the Southern Hemisphere (in a counter-clockwise spiral). These major spirals of ocean-circling currents are called **gyres** and occur north and south of the Equator.

It is not just surface water that is affected by global winds and the Coriolis Effect — deep water currents are formed this way, too. As surface water molecules are pushed by the force of the wind, they, in turn, drag deeper layers of water below them. Each deeper layer moves more slowly than the layer above it, until about 100 meters deep. Below 100 meters, ocean currents are formed by differences in the density and salinity of the water. These differences are used by Ocean Thermal Energy Conversion systems to generate electricity (see page 21 for more details). As each successively deeper layer of water moves more slowly to the right or left, it creates a spiral effect known as the Ekman Spiral. Because the deeper layers move more slowly than the shallower layers, they tend to twist around and actually end up flowing in the opposite direction of the surface current. In this way, ocean water travels a continuous path all around the Earth.

CORIOLIS EFFECT



Ocean Current Technology

Ocean currents are one of the largest untapped renewable energy resources on Earth. However, they are also the least understood ocean energy resource. Engineers are researching and developing technology designs to harness ocean current energy, but it's still at an early stage of development.

To harness energy from ocean currents economically, and on a commercial scale, there are some major technical challenges to overcome. For example, the logistics of maintenance are likely to be complex and the costs potentially high, so system reliability will be extremely important. The system components will need to be built from materials resistant to corrosion in salt water. Another challenge involves keeping naturally occurring marine growth from building up on the system components.

At this time, there are no commercial, grid-connected systems operating in the open ocean. Only a few small-scale prototypes and demonstration units have been built and tested.

Probably the most promising ocean current technology concept under development is the horizontal axis turbine (which operates similar to wind turbines), but few prototypes have been built or tested. Once concept under development by a U.S. company, Ocean Renewable Power Company, is the OCGen® Power System. It is designed for use in water depths of more than 24 meters (79 feet). Four turbine generator units are stacked together to create a large power generating module. They will be attached to the sea floor by a low-impact mooring system. However, the modules are buoyant, and can hang above the sea floor at a depth that's safe for ships passing by above and for sea life below. Ideally, several dozen modules could be located at the same site, connected to an onshore substation through a single underwater cable. The company expects a module to have a peak generating capacity of 600 kW in a 6-knot water current. The modules produce no emissions of any kind and require no fossil fuels to operate. Ocean Renewable Power Company hopes to test their system in the Gulf Stream on Florida's Outer Continental Shelf someday in the near future.

OCGEN POWER SYSTEM

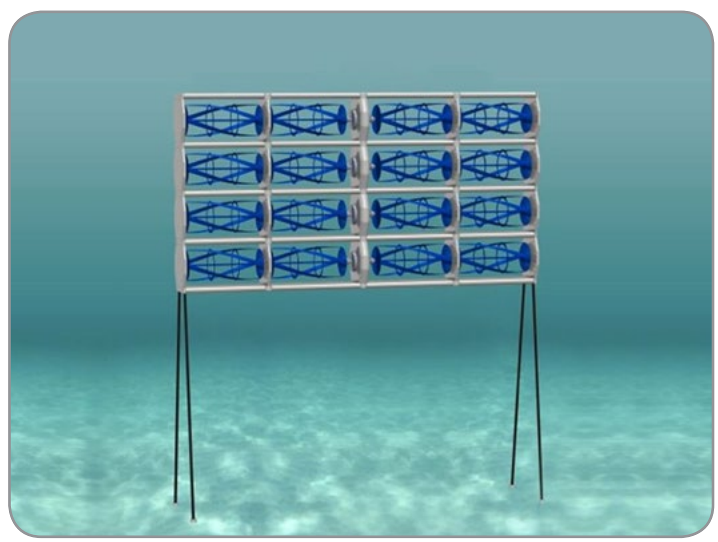


Image courtesy of Ocean Renewable Power Company

Ocean Thermal Energy Conversion (OTEC)

Oceans cover about 70 percent of the Earth's surface. Radiant energy from the sun is absorbed by the ocean's surface and some of it is transformed into heat. Deep ocean water does not receive any sunlight, and stays at a cool, constant temperature year round. The difference in temperature between these ocean layers can be used to generate electricity in an Ocean Thermal Energy Conversion (OTEC) plant.

OTEC Technology

An Ocean Thermal Energy Conversion power plant can be designed as either open-cycle, closed-cycle or as a hybrid system. Each system uses a **heat engine** to capture energy as heat flows naturally from hot to cold.

In an open-cycle system, warm surface water enters a low pressure vacuum chamber, where it boils and turns into steam. The steam spins a turbine connected to an electrical generator. Salt and other contaminants are left behind in this process. In a heat exchanger, the steam is exposed to cold ocean water and condenses back to a liquid. It is now **desalinated** fresh water that may be used for drinking or agriculture.

In a closed-cycle system, warm surface water passes through a heat exchanger to boil a fluid with a low boiling point. The steam created spins a turbine connected to a generator producing electricity. Cold ocean water condenses the steam back into the original fluid and flows back through the system to repeat the cycle. The working fluid and ocean water never mix. Used ocean water is piped back into the ocean fairly near shore.

A hybrid OTEC system produces electricity with a closed-cycle system and fresh water with an open-cycle system all at the same time. Warm ocean water enters a low pressure vacuum chamber, where it boils and turns into steam. The heat of the steam boils ammonia in a separate container. As the ammonia boils and turns into steam, it spins a turbine to generate electricity. Boiling the ocean water removes its salt and other impurities. When this steam condenses in the heat exchanger, it emerges as fresh, pure water for drinking or agriculture.

Benefits of OTEC

There are many possible benefits to using OTEC as a renewable source of energy. OTEC power plants could be a reliable source of baseload power since they can generate electricity 24 hours per day, 365 days per year. They can also produce fresh water as a by-product. Since producing fresh water uses a lot of energy, a remote tropical island, for example, that has to ship in its fuel, would save a lot of energy and money using desalinated water from an OTEC system instead. OTEC plants can also produce hydrogen gas with electrolysis, using electricity generated by the OTEC plant. Hydrogen, an energy carrier, could become a valuable source of energy as the world's fossil fuel resources are depleted.

The cold ocean water moving through an OTEC system provides additional benefits. One involves **aquaculture**, or fish farming. Deep ocean water contains high concentrations of nutrients not found near the surface. In order to farm raise cold water delicacies, nutrient-rich deep water must be pumped up to the surface. Using the deep water pumped by an OTEC system would enhance the growth of numerous seafood products, including shrimp, lobster, oysters, abalone, tilapia, flounder, and salmon, while saving energy and costs for aquaculture companies. Another benefit involves extracting minerals directly from the seawater pumped by OTEC plants. These minerals are used to create materials such as hair and skin care products.

Deep ocean water from an OTEC system can also benefit chilled-soil agriculture. When cold ocean water flows through underground pipes, it chills the surrounding soil. The temperature difference between plant roots in the cool soil and plant leaves in the warm air allows some plants to grow that normally couldn't survive in a hot climate.

Finally, cold ocean water from an OTEC system can provide air conditioning for buildings. This is known as sea water air conditioning, or SWAC (see page 22 for details).

ABALONE FARM

Challenges of OTEC Use

Today's engineers face some major technological challenges involved with using OTEC to generate electricity. Pumping cold ocean water from 1,000 meters below the ocean up to the surface, and then onshore, takes a lot of energy. Engineers must develop OTEC plants that consistently generate more energy than they consume to run the pumping and generation equipment. Also, an OTEC plant must operate reliably in the corrosive ocean environment.

There are physical challenges involved in building an OTEC facility, too. An OTEC power plant must be located where there is a consistent 20°C (40°F) temperature difference between water 20 meters and 1,000 meters deep (65 to 3,280 feet). This generally occurs within latitudes 30° north and south of the Equator. In the U.S., OTEC is limited to tropical regions such as Hawaii or Puerto Rico. To be economically feasible, the OTEC facility needs to be located onshore but near an area with deep ocean depths. But typically, the continental slope gently slopes away from the shoreline. Some companies are experimenting with OTEC plants out in the open ocean, like on an oil production platform.

OTEC Research and Development in Hawaii

The Natural Energy Laboratory of Hawaii runs a research and development center known as the Hawaii Ocean Science & Technology (HOST) Park. It is a unique outdoor demonstration site for emerging renewable and ocean based technologies.

One area of research at the park is OTEC systems. Twenty-four hours a day, three sets of pipelines deliver deep sea water from a 1,000 meter depth as well as warm surface waters. Several OTEC systems, both on and offshore, have been built and tested here since the early 1970s. Research has been conducted by universities, private industries, and the U.S. Navy. One of HOST Park's successes was a 250 kW OTEC plant that operated for six years in the 1990s.

HAWAII OCEAN SCIENCE & TECHNOLOGY (HOST) PARK

Image courtesy of NELHA

OTEC Technology around the World

In June 2013, an OTEC power plant began generating electricity on Kume Island, Japan. The OTEC plant has a 50 kW capacity. It is part of the Okinawa Prefecture Deep Sea Water Research Institute of Japan, and was built as a research and educational tool.

KUME ISLAND OTEC POWER PLANT

Image courtesy of Ocean Renewable Power Company

Sea Water Air Conditioning Systems

There is another way that cool ocean water can be used as a renewable energy resource. Instead of using electricity to power conventional air conditioning systems, it is possible to use cold ocean water to cool air within a special system known as a sea water air conditioning (SWAC) system. The SWAC system is also called district cooling because all the buildings using the system share the same cooled water. In tropical locations that use tremendous amounts of energy to generate the electricity needed to keep their buildings cool, using a sea water air conditioning system may save consumers a lot of money.

In a sea water air conditioning system, cold sea water is pumped from deep below the surface to a cooling station on shore. Inside the cooling station the cold water moves through a heat exchanger and transfers the salt water's coldness to fresh water. The fresh water moves through underground pipes circulating in a closed loop through the district's buildings. Traditional chiller systems use the cold fresh water to cool each building's air. As the water warms, it flows back to the cooling station to be chilled again. The ocean water and fresh water never mix. Warmed sea water is returned to the ocean through another pipe near shore.

The SWAC system is considered a proven technology. It is being used successfully in a few places around the world, including a resort and spa in Bora Bora.

SWAC PIPELINE

Image courtesy of Makai Ocean Engineering

Osmotic Power Plant

In November 2009, the large Norwegian energy company, Statkraft, opened the world's first osmotic power plant. The prototype power plant is based on the natural process of **osmosis**. It is a clean, renewable energy source.

In the osmotic power plant, seawater and freshwater are separated by a special membrane in a large tank. Freshwater can move through the membrane but saltwater cannot. The salt content of the seawater draws freshwater through the membrane to dilute the salinity, increasing pressure on the seawater side of the membrane. The increased pressure is used to spin a turbine to generate electricity.

This osmotic power plant outside Oslo, Norway, only generates about four kilowatts of electricity. Currently, Statkraft is working to improve the efficiency of the membrane to increase power production and hopes to open a two megawatt pilot plant capable of delivering electricity to the grid by 2018. If the pilot plant is successful, a 25 megawatt demonstration plant will be built. Statkraft hopes that by 2030, commercial osmotic power plants will be built to provide reliable, baseload power around the world.

STATKRAFT TOFTE OSMOTIC POWER PROTOTYPE PLANT

Image courtesy of Statkraft

Non-Energy Mineral Resources

In addition to providing us with fossil fuel deposits and renewable sources of energy, the ocean is rich with minerals.

Bureau of Ocean Energy Management (BOEM)

The Bureau of Ocean Energy Management, part of the Department of the Interior, manages the extraction of offshore minerals from our OCS. While the largest component of this is the exploration for and development of oil and gas resources, the bureau is also responsible for what are loosely referred to as non-energy minerals, primarily sand and gravel, obtained from the ocean floor. Non-energy minerals fall under the BOEM Marine Minerals Program. BOEM makes sure the removal of mineral resources is done in a safe and environmentally sound manner, and that any potential adverse impacts to the ocean, coastal, or human environment are avoided or minimized. The OCS contains an underwater treasure trove of resources for the United States. With careful management, these resources can be wisely and economically used and protected.

There are two types of leases for extracting sand and gravel and other non-energy minerals from the OCS. First, there are non-competitive negotiated agreements, used for obtaining sand and gravel for public works projects funded by a federal, state, or local government agency. The second type is a competitive lease sale, where any qualified business may submit a bid. In addition to sand and gravel, BOEM has received non-energy lease requests for salt from the Atlantic OCS and metallic ores from the Pacific Exclusive Economic Zone.

Sand and Gravel Consumption

Because so much sand and gravel is consumed in the U.S., the United States Geological Survey (USGS) keeps track of sand and gravel consumption in two separate categories: construction and industry. Sand and gravel used for construction are used as-is or are mixed with other materials. For example, sand can be combined with other **aggregate** to make concrete. They are used to build homes and schools, businesses and factories, roads and highways, bridges and tunnels, and dams and airports. More than a billion tons of construction sand and gravel are produced each year in the U.S. A small amount is also imported.

Other uses for sand in the construction industry include making concrete for road construction, for mixing with asphalt, as construction fill, and for the production of construction materials like concrete blocks, bricks, and pipes. It is also used to make roofing shingles, railroad beds, put on icy roads in the winter, to filter water during the purification process in water and sewage treatment plants, and for beach restoration along our coastlines.

In industry, high-quality sand and gravel are used to produce another material. For example, making glass. The U.S. leads the world in exporting industrial silica sand.

CONSTRUCTION AGGREGATE

Sand and Gravel from the OCS

Historically, construction aggregate has been produced onshore in the U.S. because land resources have been plentiful and cheap. This situation is changing, however, for several reasons: economical sources are being depleted, lands with resources are more valuable for other uses, environmental concerns preempt use, and available resources are too far from markets. Typically, aggregate is consumed within fifty miles of where it is produced. Not surprisingly, construction sand and gravel are produced in all 50 states.

These minerals are found in large quantities along the seabed of the OCS, too. They are our most abundant and important non-energy mineral resources. The sand and gravel can be mined using several types of dredges that remove it from the ocean floor and deposit it on barges or even pipe it directly to shore. Some dredges use suction to bring the sand and gravel to the surface, while others raise it in large buckets or scoops.

DREDGE SHIP

Economic Considerations

Construction aggregate is a low-cost item. A very small increase in price per ton can add dramatically to the total construction cost of a project. Transportation of the aggregate from the production site to the construction site is the largest cost. Most aggregate is transported by truck. Therefore, to keep transportation costs down, aggregate must be produced locally.

The greatest demand for construction aggregate is in major metropolitan areas, where land prices are high and land use is restricted. Land development has made many of the local deposits unreachable. Also, the land is so valuable that communities don't want to use it for aggregate production. In New York City, for example, aggregate costs are three times the national average. New York is not an isolated case. In the United States, 39 percent of our nation's population lives in a county directly on a shoreline. It is projected that population in coastal areas will increase another eight percent by 2020, which would mean about half the population of the U.S. will live near an ocean. As the population shifts to our coastlines, construction will increase here, too. Where will the construction industry get the materials it needs at reasonable prices?

One answer is from the oceans. The U.S. extracts very little sand and gravel from the OCS right now, but other countries have been doing it for years. Japan is a world leader in mining sand and gravel from the ocean. About 25 percent of the sand and gravel produced in the United Kingdom comes from offshore mining. Several countries have developed sophisticated mining equipment and have conducted numerous studies to determine the impacts of marine mining on the fishing industry and the environment.

The technology is available to recover sand and gravel from the OCS economically, but the United States' sand dredging industry is comparatively small and designed for near-shore work. Federal law requires that any equipment used to mine minerals in the EEZ or transport them must be built in the U.S. Therefore, America's ship builders may have to adapt equipment used in deeper water projects. U.S. companies cannot buy the barges and dredges from countries already well skilled in the business.

Transportation of the aggregate is another consideration. Transportation costs will continue to increase for land-based mines, as production sites are located farther from metropolitan areas. Marine transportation by barge, on the other hand, costs about one-third as much per ton as trucking.

Beach Restoration

One established area in which the United States uses sand from the OCS is in the restoration of beaches. Loss of sand from the nation's beaches, dunes, and barrier islands is a serious problem that affects both the coastal environment and the economy. A substantial portion of the nation's coastline is eroding severely, causing damage to beaches, wetlands, and coastal properties. The traditional approach of building jetties has become very expensive and has often proved ineffective in the long run.

Many coastal communities have been restoring their beaches using sand dredged from the ocean or from nearby navigational channels as part of their maintenance programs. Restoring the beaches with sand from the ocean is a cost effective approach, though studies are showing that sand cannot be dredged too near the shoreline without altering the current and wave patterns, which could intensify erosion.

BOEM's Marine Minerals Program oversees all aspects of removing sand from the OCS for beach restoration. To date, BOEM has conveyed rights to 56 million cubic meters of OCS sand for 38 coastal restoration projects in six states. These projects have resulted in the restoration of 325 kilometers (200 miles) of the nation's coastline, protecting billions of dollars of infrastructure as well as important ecological habitat. The BOEM Marine Minerals Program is involved in more marine mineral leases than ever before. The MMP is seeing an increase in the requests for OCS sand because suitable state resources are becoming depleted.

BEACH RESTORATION IN PROCESS

Crushed Shell Resources

Crushed shell from the OCS is sometimes used as a foundation for roadbeds and in manufacturing fertilizer. Shell is not evenly distributed along the OCS, but in areas where it is abundant, it can be an economical alternative to onshore products.

Environmental Impacts

Of course, the mining and transport of ocean sand, gravel, and shell does have an impact on the environment of the oceans, just as land-based mining does. During active mining, water is disturbed, with an increase in turbidity and noise. Turbidity is the amount of sediment suspended in the water. These disturbances may affect the plant and animal populations near the site.

Effects that should be considered before permitting dredging activity might include changes to the topography of the sea floor and to marine plant and animal communities on the site, as well as broader changes to the composition of the area's ecological systems. Studies are being conducted to determine how quickly the plant and animal communities in dredged areas reestablish themselves.

Sometimes fishermen face problems as discarded mining equipment and rough terrain created can damage their nets. Fish populations can also be disturbed during the time of active mining, and breeding grounds can be affected. Studies have shown that many of the changes to the ocean environment are short-term or can be **mitigated** with careful management.

The ecology of the different areas of the EEZ is varied and complex. Marine mining in some areas will produce completely different effects than in others. Site-by-site environmental impact studies will need to be undertaken to protect the integrity of the EEZ, as is required of land-based mine sites. In many cases, the effects of marine resource recovery will be more economical and less damaging to the environment than the effects of recovering the same resource on land.

Non-Energy Minerals in our EEZ

Other non-energy minerals located within the EEZ may provide a wealth of resources for the United States in the future. They are located in the sediments deep on the ocean floor, on underwater mountain ridges, in muds and oozes, and even dissolved in the seawater itself.

Mineral deposits in U.S. waters (other than sand and gravel) include massive phosphate beds beneath the continental shelf from North Carolina to northern Florida, titanium-rich heavy mineral sands off the east coast from New Jersey to Florida, gold-bearing sand and gravel deposits offshore Alaska, barite deposits offshore southern California, manganese deposits offshore Hawaii and on the Blake Plateau offshore South Carolina and Georgia, and the cobalt and platinum-rich crusts in the Hawaiian EEZ area.

Deep Sea Ocean Resources – Hydrothermal Vents

Deep on the ocean floor, hydrothermal vents located along volcanic ridges contain metallic sulfide deposits that are rich in manganese, cobalt, phosphorite, zinc, iron, lead, and silver. These minerals are used in many products, including batteries, paint, weights, crystal glass, jewelry, photographic and electronic equipment, plastics, and in the construction and transportation industries.

Active vents, called black smokers, produce new mineral deposits whenever they erupt. Deposits form when the elements in hot volcanic water flowing out of a vent meet cold, deep ocean water. The elements **precipitate** to form deposits, or nodules, on the crust around the vent. Most of these deposits are located in extremely deep water and are considered uneconomical to mine at the present time, but their potential is significant.

DEEP OCEAN FLOOR VENT

Manganese Ore

Most of the world's manganese resources are found in South Africa and the Ukraine. At this time, it is more economical for the U.S. to import the manganese we need instead of mining any poor quality resources we have. The manganese we import is used to manufacture dry-cell batteries and in steel production.

The ocean may provide us with manganese resources in the future, should reserves on land be depleted and if economical deep sea mining methods are developed. Nodules of manganese and other metals are found on the Blake Plateau offshore South Carolina and Georgia and offshore Hawaii on the abyssal plains of the Pacific Ocean floor.

Manganese nodules could be collected from the ocean floor and transported to the surface without complicated mining techniques. However, they are located so deep, it is not yet economical to retrieve them. Also, much is unknown about the potential environmental damage from excavating manganese nodules.

MAGANESE

Cobalt

Cobalt is mainly used for industrial applications. Lightweight superalloys containing cobalt can withstand high temperatures. They are used by the aviation industry to make jet engines and to make gas turbine engines used for energy generation. Cobalt is used by industry to make magnets, too. Its signature blue color is used to create deep blue glass and paint pigment.

Cobalt resources in the United States are low grade and production from these deposits is usually not economically feasible. Therefore, the U.S. produces no cobalt. We import 75 percent of our supply and the remaining 25 percent comes from recycled scrap.

Cobalt is another metal found within the nodules created when hot volcanic water flowing out of a hydrothermal vent meets cold, deep ocean water. There may be millions of tons of cobalt in these nodules, in crusts covering volcanic rocks on the ragged, steep slopes of underwater volcanoes. Presently, we do not have the mining technology to retrieve them economically.

Extracting cobalt from the ocean may be important in the future as currently it is only available in a few countries with differing standards for mining on and offshore — the Democratic Republic of the Congo, Russia, Australia, and China. Recovering cobalt from offshore deposits near Hawaii could reduce our nation's dependence on supplies from these countries. However, cobalt crust mining would impact the delicate environment surrounding hydrothermal vents.

Phosphorite

The mineral phosphorite is found within phosphate rock, a type of sedimentary rock. Currently, there are abundant onshore resources of phosphate rock, and the U.S. exports some of its production. However, scientists predict our supply could run out within the next 50 years. As onshore resources become more difficult and costly to extract, and mining land is valued more for other uses, offshore deposits may become an important resource.

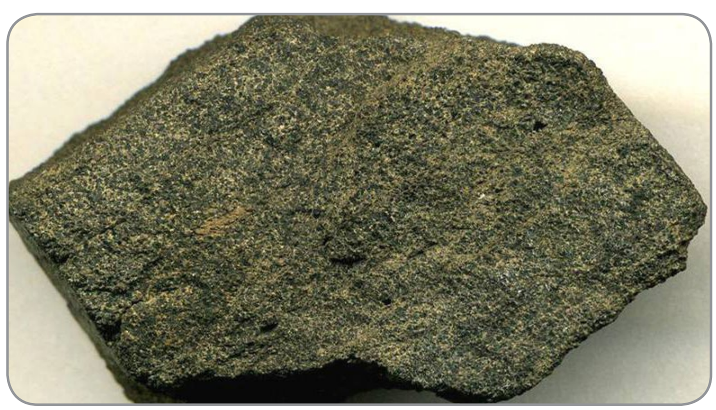
Some phosphate rock mined on land is processed to recover the element phosphorus. It is mainly used in fertilizers, but is also an important ingredient in feed supplements, fireworks, and water treatment.

Phosphate rock is formed in the ocean in the form of calcium phosphate, called phosphorite. Phosphorite is plentiful in deep depressions and sedimentary basins along stable regions of the continental shelf. It is deposited in extensive layers that cover thousands of square miles. Phosphorite deposits have been discovered off the coast of North Carolina and Georgia. Recovering these deposits from the ocean floor, however, is still too expensive, so they remain untouched until a profitable method of deep ocean mining is developed.

REFINED COBALT

COBALT COLORED GLASS

PHOSPHORITE ROCK



Images courtesy of OSU Newark

Other Minerals

Deposits of heavy minerals and other valuable minerals are also located in pockets throughout the OCS. The United States has limited onshore deposits of most of these minerals and must import a significant percentage of its demand.

Titanium is the only important mineral in this group that the U.S. exports in significant amounts, and its supplies are limited. Titanium is an essential mineral in the aerospace industry because of its ability to withstand high temperatures and is widely used as the white pigment in paints, paper, and plastics. There is no substitute for titanium at this time that is effective and economical.

The United States imports almost 100 percent of the platinum we use, mostly from South Africa and Russia. Most people think of jewelry when platinum is mentioned, but 97 percent of its demand is for industrial applications, especially in the auto industry. When the government phased out leaded gasoline, the demand for platinum increased dramatically. Automobiles that run on unleaded gasoline require catalytic converters, which are made with platinum.

Chromium is another mineral essential to the economic welfare of the country. Chromium is used in the manufacture of stainless steel and for other industrial purposes. Chromium is considered a National Defense Stockpile item because of its importance in the production of cars, planes, and trains. At present, the U.S. imports more than 80 percent of the chromium it requires, mostly from South Africa.

Gold is used for many purposes. Jewelry accounts for 70 percent of U.S. use, but gold is also important to the electronics and aerospace industries, as well as to medicine and dentistry. Currently, the U.S. is the second leading producer of gold after South Africa and exports a small amount to other countries. Twenty-four gold mines account for most of the gold production in the U.S. today.

Currently, there is little incentive to recover offshore resources of platinum, chromium, and gold. Considering the limited onshore resources and the political instability of major suppliers, however, they may become important resources for the U.S. in the future.

PLATINUM NUGGET

CHROMIUM ORE

GOLD CRYSTAL

History of Renewable Ocean Energy and Offshore Resources

13th Century	Chinese engineers built machines that used the energy in waves rising and falling with the tides to crush iron ore.
15th Century	Italian inventor Leonardo da Vinci designed a wave machine.
1953	Individual states were given jurisdiction over the lands within 3 miles of their shorelines.
1983	The United States claimed jurisdiction over all the area within the Exclusive Economic Zone (EEZ) and is responsible for protecting and developing its natural resources.
1991	World's first offshore wind farm begins operation in Denmark.
2004	European company Pelamus Wave Energy demonstrates the first commercial-scale offshore wave power machine successfully generating electricity into the Scotland national grid.
2005	The Energy Policy Act of 2005 was passed. It required increased use of renewable fuels for transportation and strengthened incentives for wind and other renewable energy sources.
2008	World's first multiple machine wave farm operated at Aguçadoura Wave Farm located off the northwest coast of Portugal with a total installed capacity of 2.25 MW.
2010	Secretary of the Interior Ken Salazar splits the Minerals Management Service into two separate organizations, the Bureau of Safety and Environmental Enforcement and the Bureau of Ocean Energy Management.
	Secretary of the Interior Ken Salazar launches the "Smart from the Start" initiative to speed offshore wind energy development off the Atlantic coast.
	Cape Wind project is granted the first U.S. commercial offshore wind lease.
2011	Secretary of the Interior Ken Salazar and Secretary of Energy Steven Chu unveil a coordinated strategic plan for expediting commercial-scale wind energy on the federal Outer Continental Shelf, identifying Wind Energy Areas well suited for commercial development with minimal impacts to the environment and other important uses.
2012	Federal Energy Regulatory Commission (FERC) issued a pilot commercial license for Verdant Power's Roosevelt Island Tidal Energy (RITE) Project, being operated in New York City's East River – the first-commercial license for tidal power in the United States.
	Bangor Hydro Electric Company verifies that electricity is being delivered to their power grid from Ocean Renewable Power Company's Cobscook Bay Project. This is the first power from any ocean energy project, including offshore wind, wave, and tidal energy, to be delivered to an electric utility grid in the U.S., and it is the only ocean energy project, other than one using a dam, that delivers power to a utility grid anywhere in the Americas.
2013	The nation's first grid-connected offshore floating wind turbine prototype is built off the coast of Castine, Maine, rising 18 meters (60 feet) in the air and featuring a 20-kilowatt capacity – enough to power a few homes. This project represents the first concrete-composite floating platform wind turbine to be deployed in the world.
	As part of President Obama's comprehensive plan to move our economy toward domestic clean energy sources and cut carbon pollution, Secretary of the Interior Sally Jewell and Bureau of Ocean Energy Management Director Tommy P. Beaudreau, held the nation's first-ever competitive lease sale for renewable energy in federal waters. Deepwater Wind New England, LLC won two leases covering a Wind Energy Area of 164,750 acres offshore Rhode Island and Massachusetts for wind energy development. When built, these areas could generate enough combined energy to power more than one million homes.
	A second competitive lease sale for renewable energy in federal waters was held, auctioning nearly 112,800 acres offshore Virginia.
2013-2014	A series of competitive lease sales for renewable energy in federal waters were held. Auctions for Wind Energy Areas offshore Massachusetts, Maryland, and New Jersey took place.
2016	Deepwater Wind, off the coast of Block Island, Rhode Island, completed construction as the nation's first offshore wind farm.

History of Offshore Oil and Gas Resources

1897	The first offshore well was drilled from a wooden pier in Summerland, California.
1930s	Methane hydrate was observed (outside of a laboratory) in natural gas pipelines, for the first time, blocking the flow of gas.
1937	The first Gulf of Mexico exploration occurred on a state lease offshore Louisiana from a 33,000 square foot wooden fixed platform, in 4.3 meters of water, less than one mile from shore. It became the Creole Field and produced liquids for more than 30 years.
1945	President Truman asserted federal jurisdiction over all the area of the Outer Continental Shelf.
1947	The first well was drilled out of sight of land, at the Ship Shoal block 32 discovery in the Gulf of Mexico. This project spawned other industry firsts, including the first offshore piled platform, the first use of a drilling **tender**, rig, and helicopter in support of offshore exploration and production.
1948	Bell Helicopters developed the three-person helicopter (Model 47) that was first used to transport workers to offshore facilities.
1949	The first submersible drilling rig combined a barge and a piled platform so only the columns connecting the submerged barge were exposed to wave forces.
1953	Individual states were given jurisdiction over the lands within 3 miles of their shorelines.
1954	100 offshore wells were drilled in the U.S.
	The first self-elevating jackup drilling rig was put in use. The rig had 10 legs, each 1.8 meters in diameter and 48.8 meters long.
	The first offshore natural gas pipeline in the Gulf of Mexico was used to transport oil from the Creole platform to shore about a mile away.
1956	A patent filed in 1950 was granted in 1956 for three-dimensional (3D) seismic surveys that resulted in recordings taken from multiple points, increasing clarity of subsurface structures and significantly improved seismic images.
1959	The first offshore exploration activity occurred in Cook Inlet, Alaska.
1960s	The first discovery of methane hydrate in natural world was found in subsurface sediments of a gas field in the Western Siberian Basin.
1960	Subsea wellheads as they are used today were first tested in the Gulf of Mexico.
1961	The first semisubmersible drilling rig, the Bluewater I, began operating.
1970s	Methane hydrate was found in samples from the North Slope of Alaska and in seafloor sediments collected from the bottom of the Black Sea.
1971	The first mobile production unit in use produced the Ekofisk field, the first oilfield in the North Sea.
1974	The first oil embargo occurred.
1975	The first floating production unit is put in use.
1978	More than 1,200 new wells were drilled.
1980s	Major methane hydrate discovery off the coast of Guatemala.
1982	Oil and gas prices began to decline.
	The U.S. launched a national research and development program dedicated to the study of naturally occurring methane hydrate.
1983	The U.S. claimed jurisdiction over all the area within the EEZ and is responsible for protecting and developing its natural resources.
1984	The first tension leg platform was installed in the North Sea Hutton Field.
1988	The deepest fixed platform, Shell's Bullwinkle platform in the Gulf of Mexico, operating in 411.5 meters of water. It is the world's tallest pile-supported, fixed steel platform with a total height of 529.1 meters.
1989	The Exxon Valdez oil spill off the coast of Alaska raised public concern over offshore production.

1990	President George H.W. Bush excluded the Pacific OCS, the North Atlantic and North Aleutian areas, and parts of the Eastern Gulf of Mexico from drilling until the year 2000. President Bush issued an Executive Order canceling lease sales and prohibiting future lease sales off the east and west coasts, too.
1993	Increased use of natural gas changed the energy picture and spurred the development of 800 new wells.
1995	The first dedicated scientific effort to investigate offshore methane hydrate, by the Ocean Drilling Program, with an expedition to the Blake Ridge area off the coast of South Carolina. Scientists found lower concentrations of methane hydrate here than they expected.
1996	The first Spar production facility was installed in 588 meters of water. The economics of the Spar were quickly realized, and the concept soon became a production facility of choice in the Gulf of Mexico.
1997	President Clinton extended the moratorium on drilling for another 10 years. The oil and gas basins with the highest potential for development were included in this moratorium.
1998	President Clinton withdrew from leasing through June 30, 2012, those areas of the OCS under moratoria.
	Methane hydrate research wells drilled in Canadian Arctic, and off the coast of Japan. High concentrations of hydrate found in both locations.
1999	Discovery of the Thunder Horse field, the largest Gulf of Mexico discovery in 1,829 meters of water, with estimated recoverable reserves of 1 billion barrels of oil.
2000	The Methane Hydrate Research and Development Act of 2000 mandated that the DOE lead the national methane hydrate R&D program and utilize the talents of federal, private, and academic organizations to carry out program goals. The program was extended under the Energy Policy Act of 2005.
2002	Methane hydrate production successfully demonstrated for the first time in the Mallik test well in the Canadian Arctic, by an international group that included Japan, Canada, and the U.S.
	Ocean Drilling Program found high concentrations of methane hydrate in an area known today as Hydrate Ridge off the Oregon coast.
2003	World record for ultra-deepwater depth reached in 3,051 meters of water in the Gulf of Mexico with the drillship Discoverer Deep Seas.
2005	International Ocean Drilling Program used conventional coring and pressure-coring methods at four methane hydrate sites off the coast of Vancouver Island.
	The record-setting hurricane season of 2005 caused massive damage to the U.S. petroleum and natural gas infrastructure. The Gulf of Mexico, one of the nation's largest sources of oil and gas production, was dealt a one-two punch by Hurricanes Katrina and Rita during August and September.
	The Energy Policy Act of 2005 was passed. It required increased use of renewable fuels for transportation and strengthened incentives for wind and other renewable energy sources.
	Gasoline prices broke $3.00 per gallon for the first time.
2007-2008	Mallik test well in the Canadian Arctic produced sustained, stable gas flow from methane hydrate during a longer-duration production test. The success of this production test was a major step forward in verifying the producibility of methane from hydrate.
2008	Congress allowed the federal ban on offshore drilling to expire.
	For the first time, crude oil prices broke $100 per barrel and gasoline prices broke $4.00 per gallon.
2010	An explosion and fire occurred on the offshore drilling rig Deepwater Horizon, which had been drilling an exploratory well in the Gulf of Mexico. The accident killed 11 crew members and left oil leaking from the unfinished Macondo well prospect into the ocean for months.
	Secretary of the Interior Salazar announced a 6-month moratorium on deepwater drilling.
	President Obama and Secretary of the Interior Salazar announce a comprehensive plan to expand oil and gas production on the OCS.
	Secretary of the Interior Ken Salazar splits the Minerals Management Service into two separate organizations, the Bureau of Safety and Environmental Enforcement and the Bureau of Ocean Energy Management.
2012	The first ever field trial of a methane hydrate production methodology is conducted, whereby CO_2 was exchanged in situ with methane molecules within a methane hydrate structure. Also the longest depressurization field test ever conducted on the North Slope of Alaska, lasting for 30 days.
2016	There are over 2,000 active oil and natural gas production platforms in the OCS. Exploration drilling dropped due to a hike in oil prices.

Creating an Ocean Energy Expo Exhibit

Research topic: ______________________________

Step 1: Research and Learn

1. Read the informational text related to your assigned ocean energy resource. Underline or highlight the main ideas. Put a star by the most important facts. 5 points
2. Do additional research on your topic. Are there current stories in the news about your ocean energy resource? What areas of the country use this energy resource? How much electricity can this energy resource generate – a lot or very little? 5 points
3. As a group, make a list of the facts you want to teach others. Use the research questions below to guide the preparation of your group presentation. Your presentation should highlight this information and other relevant information. 10 points

Research Questions

1. Is the resource considered a renewable or nonrenewable resource?
2. Explain how this resource is used as an energy source.
3. What are the advantages and disadvantages of using the resource?
4. Are there environmental benefits or hazards involved in using the resource?
5. What are the general political and public opinions of using the resource?
6. Cite examples of technology in use to produce/mine/use this resource.
7. Cite examples of careers in this industry.

Step 2: Plan Your Exhibit

As a group, decide on the type of display(s) you will use to make your exhibit interesting. Create or draw a plan or outline for your display. 5 points

Step 3: Use Your Talent

As a group, decide who will do which jobs. Write down the name of each person in the group. Next to each name, write the person's jobs. You can have more than one person helping on each job.
Who will write the script?

- Who will make the display(s)?
- Who will collect the materials we need?
- Who will learn the script and teach others?

Step 4: Write Your Script and Create Your Exhibit

1. Write a two minute script using the research questions and facts you listed. The script should keep listeners engaged during your presentation by adding interesting facts and sharing information that is relevant to their lives 15 points
2. Cite references used in your research and presentation. 5 points
3. Create an interesting display that includes visuals and/or hands-on items. Visuals can include dioramas, diagrams, pictures, video clips, and more. Make sure the display and the script cover the same information. 15 points
4. Practice the script so that you do not have to read it. Use note cards with the important facts listed on them, if needed.

Step 5: Teach Others

Give a presentation of your exhibit to others. 15 points

Total Points: __________

Exploring Oil Seeps

Question

How do you think natural seeps affect the ocean environment?

Materials

- 1 Clear cup or beaker
- Graduated cylinder
- Plastic spoon
- 50-60 cm^3 of Sand (3 spoonfuls)
- 2 mL of Vegetable oil (several drops)
- 1 Small mixing bowl
- 20-30 cm^3 of Top soil (1-2 spoonfuls)
- 1 Piece of modeling clay
- Timer or watch
- Water

Procedure

1. Pour the sand into the bottom of the container.
2. Pour the oil onto the sand and add 1 mL of water.
3. In the mixing bowl, mix the soil with water until it is wet but not saturated.
4. Pack the soil tightly in the container.
5. Flatten the clay into a thin circle as large as the opening of the container.
6. Place the clay circle on top of the soil to make a seal over the soil with the clay.
7. Fill the container with water.
8. Observe the surface of the water to see how long it takes the oil to seep through the layers of the model to the surface of the water.
9. If seeping does not occur after several minutes, agitate the sides of the container to accelerate the seeping.

Observations and Data

Time Elapsed	Estimated Coverage of Oil at Surface	Observations

Conclusions

1. How long did it take for the oil to begin seeping to the surface of the water?
2. How long did it take to build a layer of oil on the surface of the water?
3. This activity models the way petroleum and natural gas seep in the world's oceans. How do you think natural seeps affect the ocean environment?

Research Questions

- How long do you think it would take for all the oil to seep to the top? How would you design an experiment to test this?
- What actions or materials would affect the rate of oil seeping to the surface?
- What effect would salt water have on the system? How salty should the water be?
- What effect would a taller container with more water have on the system? What about a wider container with more surface area?
- How does the shape, size, and condition of the clay seal affect the rate of oil seeping to the surface?
- How does the composition of the sea floor affect the rate of oil seeping to the surface?
- How does the placement of the oil in the sea floor affect the rate of oil seeping to the surface?

Additional Investigations

Select one of the research questions from the list above or create your own. Use the chart below to plot out the variables related to the question. Explore the question further by creating an experiment to test it out. Use page 34 for your work.

Investigation Question:		
Independent Variable	**Dependent Variables**	**Controlled Variables**

Exploring Oil Seeps Inquiry Investigation

Question: ______________________________

Identify the independent variable:

Identify dependent variables:

Identify controlled variables:

Hypothesis

Materials

✔ Procedure

Observations and Data

Conclusions:

1. How do your experimental results compare with the experimental results of the other groups that investigated the same question?

2. Explain the modifications to the materials and procedure of your experiment to accurately test your hypothesis.

Additional information or questions:

Final Notice of Sale 208 Package

DEPARTMENT OF THE INTERIOR

Bureau of Ocean Energy Management (BOEM)

Outer Continental Shelf (OCS) Central Planning Area (CPA) Gulf of Mexico (GOM)

Oil and Gas Lease Sale 208

AGENCY: Bureau of Ocean Energy Management, Department of the Interior

ACTION: Final Notice of Sale (NOS) 208

SUMMARY: On ______________________________, the BOEM will open and publicly announce bids received for blocks offered in CPA Oil and Gas Lease Sale 208. The Final Notice of Sale 208 Package contains information essential to bidders, and bidders are charged with the knowledge of the documents contained in the Package.

Information to Lessees

Lease Terms

Initial Periods:

- 5 years for blocks in water depths of less than 400 meters;
- 8 years for blocks in water depths of 400 to less than 800 meters (an exploratory well is required within the first 5 years of the initial 8-year term to avoid lease cancellation); and
- 10 years for blocks in water depths of 800 meters or deeper.

Minimum Bonus Bid Amounts: A bonus bid will not be considered for acceptance unless it provides for a cash bonus in the amount of $25 or more per acre for blocks in water depths of less than 400 meters, or $37.50 or more per acre for blocks in water depths of 400 meters or deeper.

Rental Rates Per Acre:

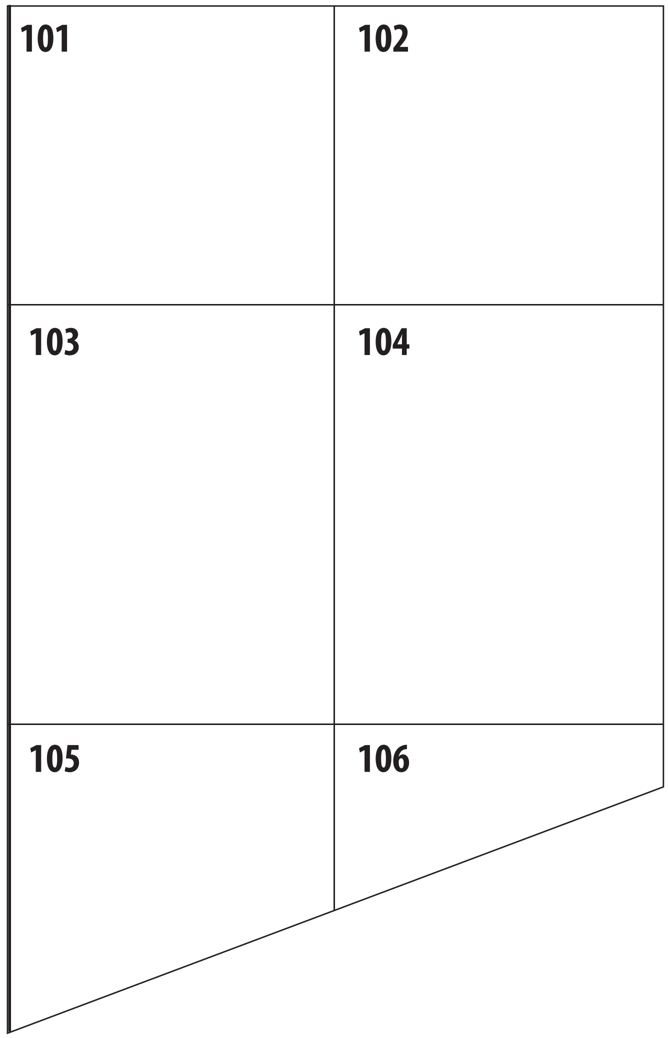
Sale 208 Rental Rates per Acre			
Water Depth in meters	**Years 1-5**	**Years 6, 7 & 8**	**Years 9-10**
0 to <200	$7.00	$14.00, $21.00 & $28.00 (if a lease extension is approved)	N/A
200 to <400	$11.00	$22.00, $33.00 & $44.00 (if a lease extension is approved)	N/A
400 to <800	$11.00	$16.00 (if exploratory well drilled)	N/A
800+	$11.00	$16.00	$16.00

Royalty Rate

18-3/4 percent royalty rate for blocks in all water depths. Royalty payments begin the first day of the month after production begins.

List of Blocks Available for Leasing

LEASE SALE 208



Water Depth	Map Name	Block Number	Available Acreage	Minimum Bid Per Acre	Lease Term	Minimum Bid Per Block	Rent Per Acre
190 meters	Dolphin Shoal Area	101	5,000	$25.00	5 yr	$125,000	$7.00
190 meters	Dolphin Shoal Area	102	5,000	$25.00	5 yr	$125,000	$7.00
650 meters	Brown Canyon	103	5,760	$37.50	10 yr	$216,000	$11.00
650 meters	Brown Canyon	104	5,760	$37.50	10 yr	$216,000	$11.00
900 meters	Riley Ridge	105	4,085	$37.50	10 yr	$153,188	$11.00
900 meters	Riley Ridge	106	1,784	$37.50	10 yr	$66,900	$11.00

Budget Calculations & Planning Form

Block Number: ____________________

Company Name: ______________________________ **Investment Amount: $**_________________________	**Company Name:** ______________________________ **Investment Amount: $**_________________________
Company Name: ______________________________ **Investment Amount: $**_________________________	**Company Name:** ______________________________ **Investment Amount: $**_________________________

Total Investment Funds Available: $____

Bid Amount

Minimum Bid: $________________________ Planned Bid: $_________________________

Monthly Rental Fees

Years 1-5

Monthly Rental Fee = _________________ acres X $________________ = $_________________ /month

Years 1-5 Rental Fee = $_________________ /month X 60 months = $_____________________

Years 6-10

Monthly Rental Fee = ________________ acres X $________________ = $_________________ /month

Years 6-8 Rental Fee = $_______________ /month X 36 months = $__________________

Years 9-10 Rental Fee = $_______________ /month X 24 months = $__________________

Total rent to be paid: $____

Exploratory Well Costs

How many wells do you plan to drill? ____________________________

BOEM Permit Costs

_____________________ X $ 10,000 = $______________________

Number of wells X cost per well permit = total permit costs

Exploratory Well Drilling Costs

________________________ X $ 40,000,000 = $__________________________

Number of wells X exploratory well drilling costs = total exploratory well drilling costs

$______________________ + $______________________ = $_________________________

Total permit costs + total exploratory drilling costs = total exploratory well costs

Budget

Actual Bid		$ ___________________________
Total Rent		$ ___________________________
Total Exploratory Well Costs	+	$ ___________________________
Total Budget		$ ___________________________

Bid Form

Regional Director
Bureau of Ocean Energy Management
Gulf of Mexico OCS Region
1201 Elmwood Park Boulevard
New Orleans, Louisiana 70123

Oil and Gas Lease Sale ____________208____________
Date of Lease Sale: ______________________________
Company Submitting Bid:________________________
GOM Company Number: ________________________

Oil and Gas Lease Bid

It is understood that this bid legally binds the bidder(s) to comply with all applicable regulations, including paying the 1/5th bonus on all high bids, as provided in the Final Notice of Sale.

The following bid is submitted for an oil and gas lease on the area and block of the Outer Continental Shelf specified below:

Map Name	Block Number	Amount Bid
_______________________	__________	$_______________________

GOM Company Number	Percent Interest	Company Name(s), and Signature(s)
__________	__________	_______________________
		By: _______________________
__________	__________	_______________________
		By: _______________________
__________	__________	_______________________
		By: _______________________
TOTAL:	100.00	

Bid Record

Oil and Gas Lease Sale 208

Instructions

Use this form to record each bid as it is read aloud. After the auction, rank the bids within each block to determine the winners.

Block Number	Company Name	Amount Bid/Acre	Total Bonus	Rank
101				
102				
103				
104				
105				
106				

Drilling Rig Model

✪Objectives

Design and build a basic model of either a drillship or a semisubmersible drilling rig. The model can be made out of recycled materials and found objects. Your model must meet the following design specifications:

When placed in a tub of water, the model must float for 2 minutes, keeping the drilling platform at least 5 cm above the water's surface.

Design

Drilling rig model description:

Team members:

What I know about this offshore drilling rig:

Research citations:

Individual design sketches:

Team Design

Meet as a team and review individual designs for strengths and weaknesses. As a team, decide on the best sketch or develop a hybrid that incorporates several strengths from multiple designs. Sketch the design, make a list of supplies, and test the design.

Team design sketch:

Supplies:

Testing Phase

Observations and data:

Structural evaluation:

What worked?

What didn't work?

Re-engineering the Model

As a team, consider your first design and the structural strengths and weaknesses. Did your model meet any of the required design specifications? Brainstorm solutions as a team and redeisgn and test the model.

New design ideas:

Team design sketch:

Supplies:

Re-testing Phase

Observations and data:

Structural evaluation:

What worked?

What didn't work?

What improvements or changes would you consider making to this model if you had additional time and resources?

North America Map

Getting the Oil Out

Activity courtesy of SPE

Background

In the offshore environment, artificial lifting systems, or pumps, along with injections of gases, are used to help pull the oil out of the reservoir rock and pump it up the well after natural pressure in the reservoir declines. These pumping units consist of a vertically aligned motor, power cable, seal-chamber, and surface control unit. This system uses centrifugal force to lift the hydrocarbons to the surface. Gas lift can also be used to bring fluids to the surface. This procedure pumps gas at a high pressure into the well, reducing the density of the fluids to create a bubbling effect, that increases pressure and pushes fluids to the surface.

Question

Will it be easier to bring up liquid with a long tubing system, or a short tubing system?

Hypothesis

Draft a hypothesis to answer the question using an "If...then...because..." format.

Materials *FOR EACH STUDENT OR PAIR*

- 8-10 Drinking straws
- Masking tape
- Scissors
- Ruler
- Carton of chocolate milk or dark-colored beverage (so it can be seen through the straw)

Procedure

1. Using the scissors, cut a 1 cm slit at one end of each straw.
2. Join the straws end to end to form one long tube. Place the slit end of the straw into the inside of the adjoining straw.
3. Place masking tape over each connected end to secure the joint and create an air tight seal.
4. Place the carton of chocolate milk (or other beverage) on the floor. One member of the group stands up and inserts the extended straw "tubing" into the beverage trying to bring the liquid to the top of the "tubing" using his/her suction.
5. Now, decrease the number of straws used for the "tubing" by cutting off one straw. The same student tries to bring the liquid to the top.
6. Continue cutting off one straw at a time. After each cut try to bring the liquid to the top of the tubing.

Conclusions

1. Which length of straw required the most effort to bring the liquid to the top? Which length of straw required the least effort to bring the liquid to the top? Explain why.

Extensions

- Try to pull up liquids of different viscosities and densities.
- Try using straws of different diameters to make your tubing.
- What could you add to this activity to better simulate the deep water drilling environment?
- On land, a horsehead pump is often used for artificial lift. Why is it not used for deep water?

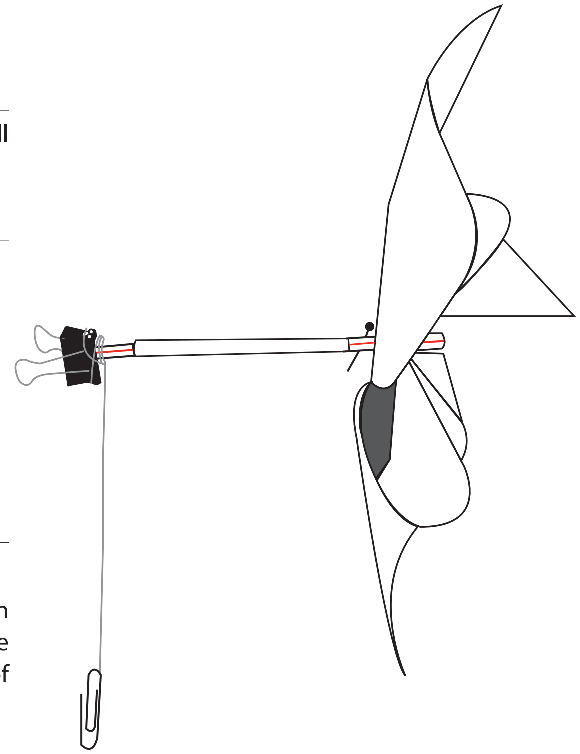
Wind Can Do Work

Question

- What is the maximum load that can be lifted all of the way to the top of the windmill shaft?

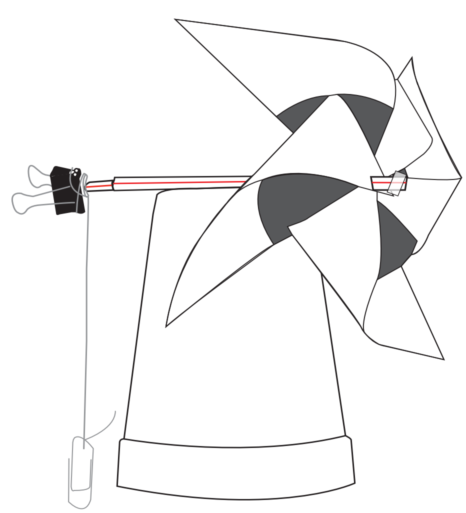
Materials

- *4-Blade Windmill Template*
- 1 Extra-long straw
- 1 Small straw
- Masking tape
- 50 cm String or thread
- Paper clips
- Large foam cup
- 2 Straight pins
- Binder clip
- Fan
- Ruler
- Hole punch
- Marker
- Scissors



✔ Procedure

1. Turn the cup upside down.
2. Cut the longer straw so that you have an 8 cm length. Share the other portion with another student or group, or discard it. Tape this straw horizontally to the bottom of the cup (which is now the top) so that there is an equal amount of straw on both ends. Set this aside.
3. Prepare the windmill blades using the *4-Blade Windmill Template*.
4. Measure 1.0 cm from the end of the small straw and make a mark. Insert a pin through the small straw at this mark. This is the front of the straw.
5. Slide the small straw through the windmill blades until the back of the blades rest against the pin. Gently slide each blade over the end of the straw. Secure the blades to the straw using tape.
6. Insert the small straw into the larger straw on the cup.
7. Tape the string to the end of the small straw. Tie the other end of the string to a paper clip. Make sure you have 30 cm of string from the straw to the top of the paper clip.
8. On the very end of the small straw near where the string is attached, fasten a binder clip in place for balance and to keep the string winding around the straw.
9. Slide the small straw forward to bring the binder clip next to the larger straw. Place a second straight pin through the small straw at the other end of the larger straw. This will keep the blades away from the cup while still allowing them to move and spin.
10. Place your windmill in front of the fan and observe. Record observations in your science notebooks.
11. Investigate: Keep adding paper clips one at a time to determine the maximum load that can be lifted all of the way to the top. Record your data.



Conclusion

Draw a diagram of the system. Label the energy transformations that occurred in order for work to take place.

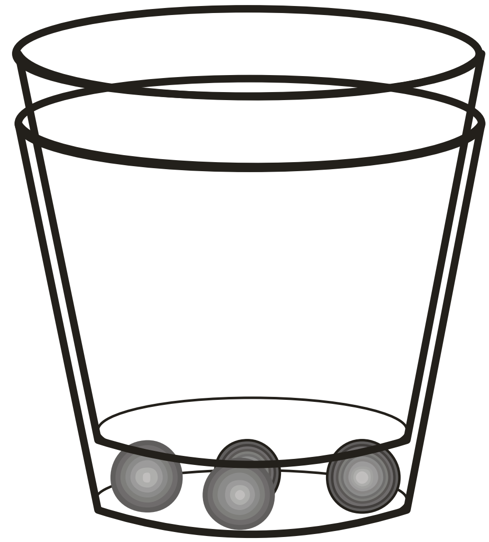
Extensions

- How could you change the design of your windmill to produce more work from the system?
- What variables can you change in this investigation? Create a new investigation changing one variable at a time.

Science of Electricity Model

Observe the science of electricity model. Draw and label the parts of this model. On the lines below, explain how electricity is generated.

Exploring Convection Currents



Question

How does thermal energy move through the oceans?

Hypothesis

Draft a hypothesis to answer the question using an "If...then...because..." format.

Materials

- 2 Clear plastic cups
- 4 Marbles
- Hot water
- Ice water
- Food coloring

✔ Procedure

1. Place the marbles in the bottom of one cup so they are evenly spaced around the cup's edge. Pour hot water in the cup until the water just covers the marbles.
2. Place the second cup inside the first one, resting on the marbles. The hot water in the first cup should touch the bottom of the second cup.
3. Fill the second cup almost to the top with ice water.
4. **Wait 15 seconds**. Carefully put one small drop of food coloring on top of the water.

Observations

Record your observations. Draw a diagram of the food coloring in the water. Use arrows to show the direction of movement.

Conclusions

1. Use your diagram and observations to explain how convection works.
2. How do you think this experiment would change if you were using salt water? Does the salt in the ocean water freeze?
3. Which do you think would be a more efficient use of ocean temperature differences: an OTEC system using warm surface waters to create steam, or a SWAC system that uses cold deep waters to cool a building? Explain your choice.

Offshore Ocean Resource Presentation Planner

Research topic: ______________________________

Group members:
-
-
-
-

Mapping team member: ______________________________

✔ Procedure

1. Read the informational text about your assigned offshore resource.
2. Use the research questions below to guide the preparation of your group presentation.
3. Split up the work. Decide who will be responsible for preparing and presenting the information for each research question.
4. Who will find pictures or visual aids?
5. If time allows, do additional research on your topic.
6. Make a list of the facts you want to teach others.
7. Cite references used in your research and presentation.
8. As a group, practice the entire presentation until everyone is comfortable sharing their facts.

? Research Questions

1. Where is this offshore resource found? Give this information to the mapping team member so he/she can add your offshore resource to the class map.
2. How was this offshore resource formed?
3. How is this offshore resource recovered?
4. Explain how this offshore resource is used.
5. Are there economic benefits to using this offshore resource?
6. Are there environmental impacts associated with the recovery of this offshore resource?
7. What are the advantages and disadvantages of using the offshore resource?
8. What are the general political and public opinions of using the offshore resource?
9. Cite examples of technology in use to produce/mine/use this offshore resource.
10. Give examples of specific careers or industries associated with this offshore resource.

Island Resort Design Project

You work for a design firm that was hired by a multibillionaire to build a small resort home on a deserted tropical island. All sources of energy, food, and building materials have to be brought to the island on barges. Generating electricity by burning diesel fuel is currently the only option on the island, but the home owner wants to add ocean energy resources to make his home unique. The design already includes solar panels on the roof that will generate electricity during the day, and a solar hot water heating system to heat the home's water.

Your job is to compile several more ideas to present to your client, with supporting evidence as to why you believe each will work as a source of energy for his home. Cost is not a factor in your design since he's a multibillionaire!

Below, draw a map of the island, where you propose to build the home, and mark the locations of your sources of energy. Use an additional sheet of paper to write a one page report for your client, detailing your sources of energy and supporting evidence.

ISLAND MAP

Exploring Ocean Energy and Resources
Glossary

abyssal plain	large area of extremely flat or gently sloping ocean floor just offshore from a continent, at depths of 13,000-20,000 feet
aggregate	loosely compacted sediment, fragments of rock that have been broken apart
airfoil	term describing the shape of an object that allows air to flow above and below creating lift
aquaculture	cultivating aquatic animals and plants, especially fish, shellfish, and seaweed, in natural or controlled marine or freshwater environments
attenuator	wave energy collection device that is situated parallel to the force and direction of the wave
bid	an offer for an OCS lease submitted by a potential lessee in the form of a cash bonus dollar amount or other commitments, as specified in the final notice of sale
bonus	a payment equal to the high bid submitted by the successful bidder for the right to be awarded an oil and gas lease
carbon cycle	the natural exchange of carbon between the spheres of the Earth
continental rise	the gently sloping transition between the continental slope and the deep ocean floor
continental shelf	a gently sloping submerged marginal zone of the continents extending from the shore outward through shallow waters to the continental slope
continental slope	a relatively steep, narrow feature paralleling the continental shelf--the region in which the steepest descent to the ocean bottom occurs
Coriolis Effect	the deflection of moving objects due to the rotation of the Earth
crest	the highest point on a wave
crude oil	term used for petroleum, an energy-rich hydrocarbon mixture formed from fossilized remains of ancient sea life
desalinate	the process of removing salt from seawater
dissociate	to separate into smaller parts or individual molecules
dynamic positioning systems	computer-controlled systems that allow ships or rigs to maintain their position with items such as thrusters or propellors
electronic service platform	a transformer substation that connects the electrical outputs of the turbines in the wind farm and transmits voltage onshore/to the grid
estuary	the area of water at the mouth of a river
Exclusive Economic Zone (EEZ)	the maritime region adjacent to the territorial sea, extending 200 nautical miles from the baselines of the territorial sea, in which the United States has exclusive rights and jurisdiction over living and nonliving natural resources
fetch	wind duration, the distance over which wind blows or travels
final sale notice	provides the final terms and conditions for a lease sale, including the date, time, and location for the sale itself; also includes a list of the companies that have legally, technically, and financially qualified to participate in the lease sale
fossil fuels	nonrenewable energy sources formed from the remains of ancient life
gas hydrate	ice like structures of gas and water in which gas molecules are trapped within a framework or cage of water molecules
gear box	device used in wind turbines to convert the slow rotation of the blades and rotor to a faster rotation in order to produce electricity
generator	a device that produces electricity by converting motion energy into electrical energy with spinning coils of wire and magnets

geohazard	geological or environmental condition that can lead to risks or damages
gigawatt	one billion watts
gyre	spiral or vortex
heat engine	mechanical device that transforms part of the heat entering it into work
hub	part that holds or attaches blades together on a wind turbine
hydrocarbon	any organic compound that contains only hydrogen and carbon
hydrokinetic energy system	a system that converts the energy in moving water into mechanical and electrical energy
hydrophone	underwater microphone or listening device
hydrothermal vents	underwater geysers
jurisdiction	having authority or control
lease	contract authorizing exploration for and development and production of minerals for a specified period of time over a given area
methane	naturally occurring gaseous compound consisting of one carbon and four hydrogens; greenhouse gas; major component of natural gas
methane hydrate	methane trapped within a crystallized structure of water forming a solid similar to ice
mitigate	to make less severe
momentum	the product of the mass and velocity of an item
monopile	large steel tube driven into the seabed to support the tower of a wind turbine
mooring	a permanent structure anchored to the ocean floor that allows vessels or objects to temporarily or permanently be secured by attachment
moratorium	an authorized period of delay
nacelle	box that houses the major mechanical components of a wind turbine, including the drive shaft, gear box, and generator
nautical mile	unit of length used in air and sea navigation, equal to a minute of latitude
nonrenewable	a source of energy that cannot be replenished readily through natural processes
offshore	describing a region off the coast
organic material	material that was derived from a once living organism; contains carbon
osmosis	the movement of an item through a membrane to an area of higher concentration
Outer Continental Shelf (OCS)	all submerged lands lying seaward of state coastal waters (3 miles offshore) which are under U.S. jurisdiction
Outer Continental Shelf Lands Act	created on August 7, 1953, defines the OCS as all submerged lands lying seaward of state coastal waters (3 miles offshore) which are under U.S. jurisdiction
overtopping device	a wave energy generation device that focuses waves in the direction of a catch basin or reservoir to generate electricity
period	the time for the wave to make one complete cycle; the time for two crests to pass a point
permeability	the ability of an item to allow fluids to pass through it
point absorber	floating structure that absorbs wave energy from all directions
porous	having pores or tiny cavities that can trap fluids
porosity	a measure of the open space in a rock, the number of pores

power grid	also the electrical grid, network of power stations, power lines, and transformers used to deliver electricity from generation to consumers
precipitate	the solid material separated out of a solution during a chemical reaction
prototype	a preliminary model that has not undergone thorough testing
pumped storage hydropower	electrical energy storage method where water is pumped from a reservoir at a lower elevation and is stored at a higher elevation in the form of gravitational potential energy until needed, when needed water flows downhill and turns a turbine to generate electricity
renewable	sources of energy with a more constant supply because they are replenished in a short amount of time
royalty	share of the minerals (oil and gas) produced from a lease; the percentage of oil and gas production, usually fixed at 12 1/2 percent or 26 2/3 percent, either in money or in kind, which a lessee is required to pay the Treasury Department
sedimentary rock	rock formed from the compaction of sediments and aggregates over time
seismic technology	technologies used in exploration of oil and natural gas that utilize shock waves to interpret rock layers
sluice	a gate used for the control of water flow
surge converter	a wave energy generation device that uses wave motion and a floating device to generate electricity
swell	a series of waves created by motion of water and gravity; surface gravity waves
tender	a boat or small vessel
terminator	a wave energy device that is positioned perpendicular to the wave and captures or reflects the energy
tidal barrage	a facility built like a dam that allows the tides to power turbines and generate electricity
tide	rise and fall of sea levels caused by the moon, sun, and rotation of the Earth
trough	the bottom of a wave
turbidity	the clarity of water due to particulate matter
wavelength	the distance from crest to crest on a wave
wellbore	the hole that forms the well when drilling for oil or natural gas
wind farm	a group of wind turbines in a similar location

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