Hydrothermal Vents Lesson Plan: Educators **Dale Stanley**
Expanded Specific Activities /Goals **Nassau Community College**

Hydrothermal Vents

Instructor version with example student answers

Depending on the time allotted for this lesson, it can be done by breaking the specific activities listed below into groups with a summary report at the end or having everyone do all activities, also with a summary report at the end. ***Student version follows.***

***A Must for the Lesson- Visualize the Vent Community*:**
If possible visit a museum with a chimney /black smoker on display. Take pictures of the display and use them in your lesson. Showing a video such as "Volcanoes of the Deep " and "The Deep " from the Blue Planet Series.

Specific Activities

1. Investigate Vents

Questions with sample student answers:

a. Look up what a vent is and where it is found.
A hydrothermal vent is a fissure in a planet's surface from which geothermal heated water issues.

b. Describe the different types of vent. How old and how large are they?
Hydrothermal vents are commonly found near volcanically active places, areas where tectes are moving apart, ocean basins, and hotspots.

c. Look up how and where they were first discovered and how they are found today.
Scientists first discovered hydrothermal vents in 1977 while exploring an oceanic spreading ridge near the Galapagos Islands. Hydrothermal vents are the result of seawater percolating down through fissures in the ocean crust in the vicinity of spreading centers or subduction zones (places on Earth where two tectonic plates move away or towards one another). The cold seawater is heated by hot magma and reemerges to form the vents. Seawater in hydrothermal vents may reach temperatures of over 340°C (700°F). They are found today using a toyo.

Key Concepts - SOME THINGS TO KNOW:
a. Stress the relationship of plate tectonics and the ocean- hydrothermal does mean "hot water". The students should understand that the water is heated from exposure to a fissure or crack in the crust near subduction zones (convergent pates), spreading centers (divergent plates) or hotspots. This super heated water (about 350 °C or 700 °F) can be above the boiling point of water because of the high pressure at depth (like a pressure cooker). The water jets out of the fissure and depending on the content, deposits a mineral and microbe chimney as the water cools. They are similar to geysers and fumaroles on land. Use any diagrams available. Have the students

calculate the pressure in ATM for 3000 m in depth (1 ATM per 10 m). Also have them label a map with the locations of vents, spreading centers and trenches.

b. If the vent water has a high concentration of iron sulfide it is called a "black smoker" because the water/mineral/microbe plume is black in color. It resembles smoke coming from a chimney. If the water/mineral/microbe plume has a high concentration of calcium or silica it is white in color and is called a "white smoker". The chimneys can be small to 60 m high. Students can visualize the size by comparing to nearby buildings or other structures.

c. They were first discovered in 1977 by Robert Ballard investigating the Galapagos RIFT. Video with Bill Nye is short and has Ballard speaking. This is great link to space and extraterrestrial life possibilities and the discovery of the Archaea.

d. Today they are usually found using ocean sensors from research vessels. These sensors include the CTD - Conductivity/Temperature/Depth rosette or array that is lowered vertically into the water. " By lowering the CTD package to near the bottom, then moving the ship while cycling the package up and down only through the bottom few hundred meters, a far greater density of data can be obtained. This technique was dubbed a CTD "Tow-yo" and has proven to be an efficient and effective method for mapping and sampling hydrothermal plumes." (a) Optical sensors for measuring particles and chemical sensors are also used. Also, mapping tools for the vents are available.

   http://www.pmel.noaa.gov/eoi/PlumeStudies/WhatIsACTD/CTDMethods.html

Possible Sources:

1. Current text you are using in class
2. Wikipedia - hydrothermal vents
3. http://oceanservice.noaa.gov/facts/vents.html
4. http://www.pmel.noaa.gov/eoi/PlumeStudies/WhatIsACTD/CTDMethods.html
5. www.amnh.org search "hydrothermal vents"
6. video - Bill Nye and Robert Ballard on you tube - http://www.youtube.com/watch?v=D69hGvCsWgA
7. http://www.nsf.gov/news/overviews/earth-environ/interactive.jspInvestigate organisms living in/around these vents – microbes, mussels, shrimp , worms etc.

2. Investigate organisms - Questions:

a. What is a chemosynthetic microbe, how does it get its food and where is it found?
A type of bacteria, uses energy released by inorganic chemical reaction to produce food , they are found were sunlight doesn't penetrate in total darkness next to or in the hydrothermal vents.

b. Do all vents have the same microbes and the same dominant organisms?
No, different organisms are indiganus to the different parts of the ocean were the vent are located.

c. What are some invertebrate and vertebrate organisms found in the vents and what is their relationship to these microbes?
Vent squat lobsters, vent octopus, pompeii worm, vent barnacle, vent crab, mussels, shrimps, tube worms. All animals feed off of the bacteria in the water in some way.

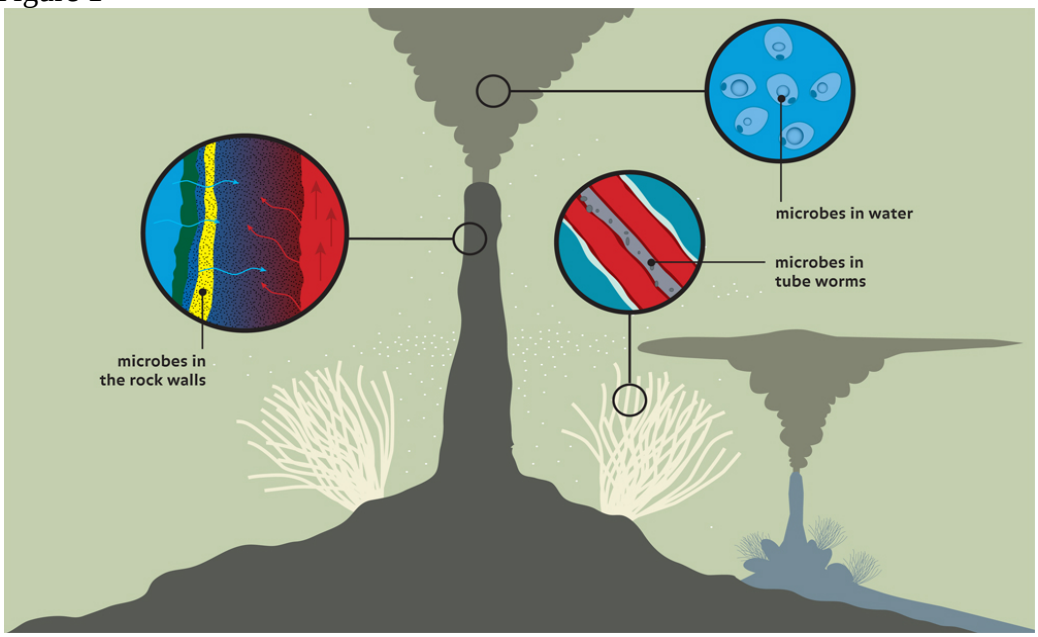
Ex, filter feeding , symbiotic relationship with the bacteria, or eating the bacteria directly.

Key Concepts - SOME THINGS TO KNOW:

a-1) The major importance of these chemosynthetic microbes is that they are life forms that use the **energy of the earth instead of the energy of the sun**. They use the energy from breaking the chemical bonds of small molecules and using this energy to take carbon dioxide from the water and create carbohydrates, lipids and proteins. Like photosynthetic organisms these microbes are the base of the food chain in vent communities. *They may also be the first living organisms on the earth*. Talk about the Archaea.

a-2) Some of these chemosynthetic microbes exist as mutualistic symbionts in other organisms and provide them with food. Other forms live in the water or on the rocks and are consumed as food. Attached is a simple figure from the American Museum of Natural History exhibit - Fig 1 below

Figure 1



Key Concepts continued:

b) Location of the vent determines which organisms are present. Vent ecosystems in the Eastern Pacific are dominated by the giant tubeworm, *Riftia*. These worms are not found in the North Atlantic vents. Deep North Atlantic vents are dominated by a blind shrimp, *Rimimcaris exoculata*, that exists in enormous quantities. Shallower North Atlantic vents have fewer shrimp and a large mussel, *Bathymodiolus.* Skinny tubeworms dominate the vents of the Northeast Pacific, *Ridgeia.* Western Pacific and Indian Ocean vent communities also have different dominant organisms. All locations are dependent on the chemosynthetic bacteria as the primary producer and base of the food web. Most of the information available is on the Eastern Pacific Vent communities.

c -1) Explore the nature of symbiosis and mutualism. Define thermophile. Get a picture of tube worm (Riftia) anatomy. Talk about the lack of a digestive system in the giant

tubeworms and the presence of huge numbers of endosymbiotic sulfur bacteria in their trophosome. The North Atlantic shrimp keep the bacteria on their gills. Mussels and clams trap the suspended bacteria on the mucous of their gills. The tube worm, *Riftia*, keeps the H2S and the O2 separate by binding them to different blood pigments, hence the red color. This separation keeps the oxygen from oxidizing the sulfur before it reaches the bacteria in the trophosome. These pigments are also not too sensitive to temperature changes. The students can talk about possible adaptations to high temperature and toxicity of sulfur. (Tube worms can survive at about 100° C)
c-2) Show pictures or anatomy of any other organisms the students can find. Talk about their relationship to the vent microbes. link to the food web in the next activity section.
Invertebrates: (whatever the students find information on) tube worms (Riftia), clams & mussels (bacteria live in their gills), shrimp, limpets, blind crabs, Galatheid crabs (grow bacteria on their body hairs), are examples
Vertebrates: Eelpout/Zoarcid fish

Note: It is difficult to study these organisms and not much may be known about some of them.

Possible Sources:

1. http://www.darkenergybiosphere.org/ - go to research theme 3 read introduction
2. http://metcalfinstitute.org/c-debi-glossary/ link via www.darkenergybiosphere.org
3. http://www.amnh.org/exhibitions/permanent-exhibitions/rose-center-for-earth-and-space/david-s. -And-ruth-l.-gottesman-hall-of-planet-earth/why-is-the-earth-habitable/life-that-lives-off-the-earth-s-energy/life-at-the-hydrothermal-vents/microbes-around-vents
4. http://oceanexplorer.noaa.gov/explorations/02galapagos/logs/may27/media/tubeworms.html
5. http://www.nsf.gov/news/overviews/earth-environ/interactive.jsp
6. http://www.darkenergybiosphere.org/research/themes.html -Research Theme II. Extent of Life: biomes and the degree of connectivity (biogeography and dispersal).

3. Investigate Chemosynthesis - Questions:

a) How do these organisms break the chemical bonds in small molecules and use this energy to create carbohydrates, proteins and lipids - the biological molecules?

Chemosynthesis, the combination of organic compounds by living organisms like bacteria using energy produced by inorganic chemicals, sunlight is usually not present during this process. Sulfate and methane rise. Bacteria living in and around dark vents extract their energy from hydrogen sulfide (HS) and other molecules that billow out of the seafloor.

Chemosynthesis: CO2 + 4H2S + O2 -> CH20 + 4S + 3H2O

They take the chemical bonds and break them.

Microbes are dispersed, according to where the chemicals they break down are located on the subsea floor.

Key Concepts - SOME THINGS TO KNOW:

a. Different molecules can be used in chemosynthesis. Methane, ammonia and hydrogen were the major gases in the early atmosphere. Recall prior information about the Archaea. See the two figures below and decide what level is best for the students. Most vent organisms use sulfur compounds to create sugars etc.
b. Compare the reactions of photosynthesis to chemosynthesis. Photosynthesis takes solar energy and uses it to turn carbon dioxide and water into sugar and oxygen. 6CO2 +6 H20 -> C6H1206 +6O2. Chemosynthesis breaks chemical bonds and uses this energy to create the molecules necessary for life. The energy of the earth is the source. Sulfur bacteria: 12 H2S + 6 CO2 - > C6H12O6 + 6H20 = 12S OR CO2 +4H2S+ O2 -> CH20(SUGARS) + 4S + 3H2O (This sulfur can precipitate out as yellow globs.)
c. View the Atlas of Marine Microbes. Read the abstracts to gain insight into current research activity. Link through C-DEBI - there are many possible sources of information. Find out the extent of our knowledge and stress the need for basic research.
d. Discuss the Deep Carbon Cycle - what is the fate of carbon dioxide found in the deep ocean? Good overview of role of microbes: Gold's article in PNAS http://www.pnas.org/content/89/13/6045.full.pdf+html

FIGURE 2:

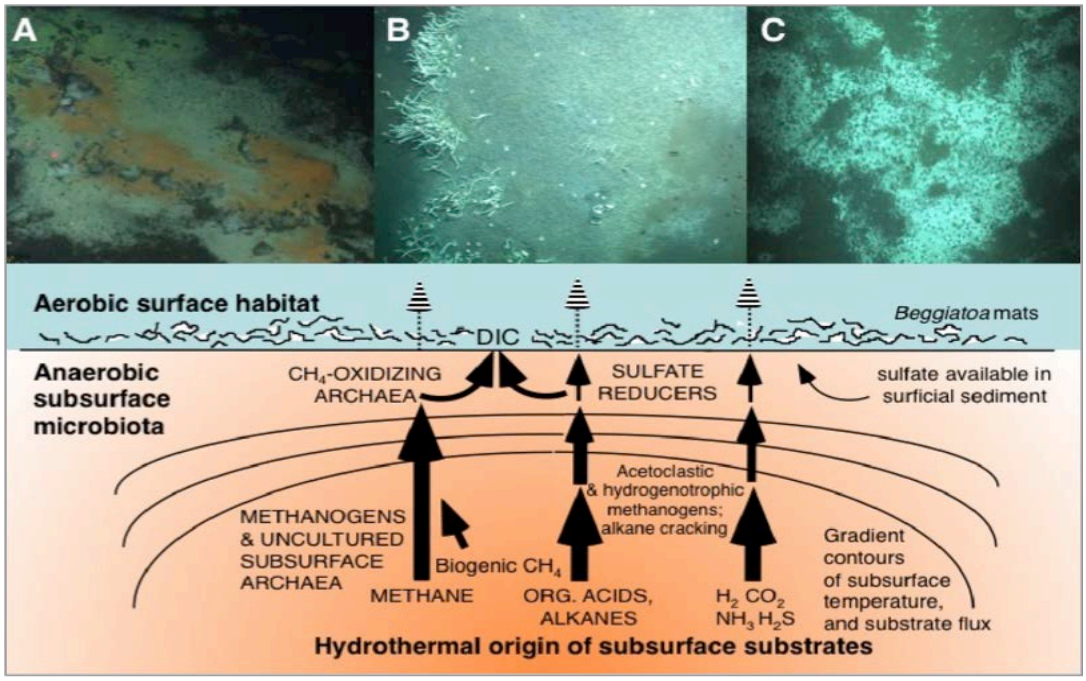
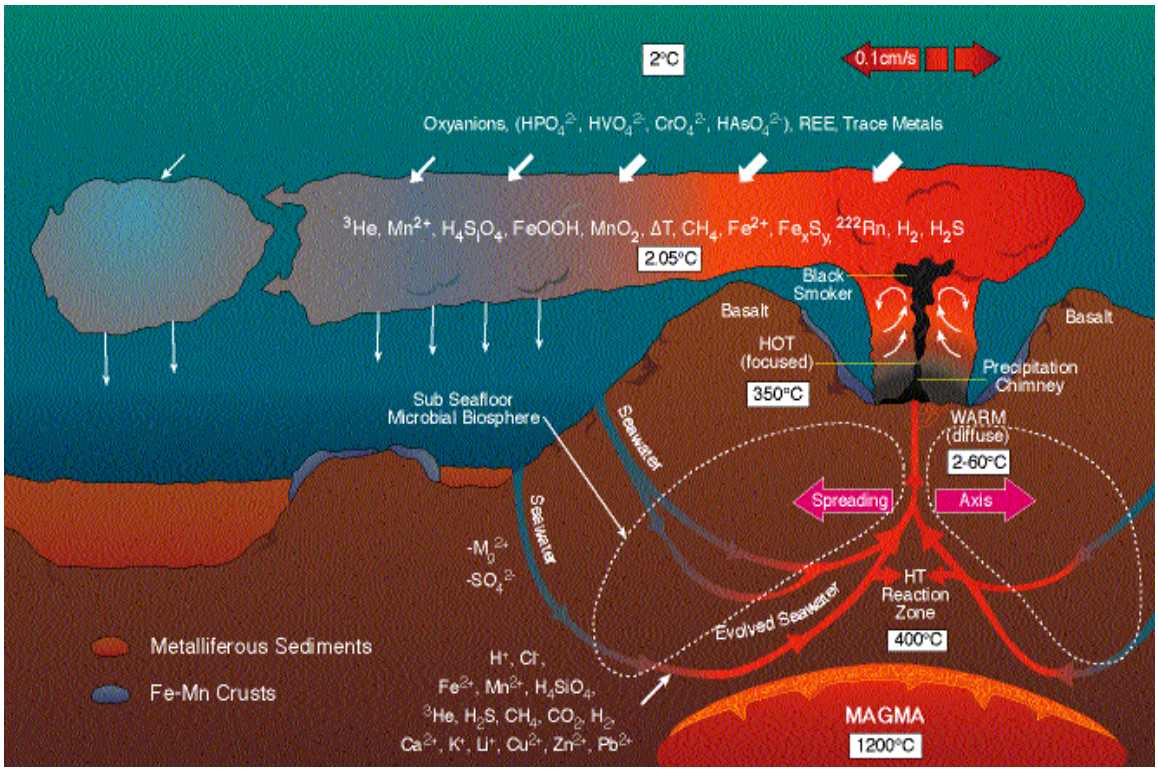


FIGURE 3



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Possible Sources:

1. http://www.pmel.noaa.gov/eoi/nemo/explorer/concepts/chemosynthesis.html = fig 3
2. http://www.pmel.noaa.gov/eoi/chemistry/fluid.html
3. http://www.darkenergybiosphere.org/resources/programs.html - Research Theme II - Extent of life: biomes and degree of connectivity = fig 2
4. http://oceanexplorer.noaa.gov/edu/curriculum/welcome.html
5. http://icomm.mbl.edu/spring2009/booklet.pdf
6. http://www.darkenergybiosphere.org/resources/programs.html
7. https://deepcarbon.net//
8. Good overview of role of microbes: Gold's article in PNAS http://www.pnas.org/content/89/13/6045.full.pdf+html

4. Chemosynthetic Food Web - Questions:

a. Who are the primary producers & compare to a photosynthetic web?

Compared to a photosynthetic food web, the primary producers and first level consumers are unexpectedly different in a Chemosynthetic food web. Vent bacteria and symbiotic bacteria are the primary producers. Vent bacteria have four long tails called flagella that help it propel it through the water. It uses the process of chemosynthesis to produce carbohydrates from the hydrogen sulfide that pours out of the vents. Like plants, vent bacteria form the base of the food web in vents. Symbiotic bacteria oxidize sulfide. The chemicals that bacteria use for energy are carbon dioxide, oxygen, CH4, and H2S.

b. Who are the first level consumers & compare to a photosynthetic web?
Vent zooplankton, vent amphipods, vent shrimp, vent clams, Riftia worms, vent mussels, and pompeii worms are the primary, or first level consumers. Compared to the photosynthetic web, where the first level consumers would eat the plants, these consumers would feed on the bacteria. Vent zooplankton, vent amphipods. and vent shrimp feed on vent bacteria. Vent clams, Riftia worms, vent mussels, and pompeii worms feed on symbiotic bacteria. Unlike the Photosynthetic food web, which depends on the sun for energy, the Chemosynthetic food web depends on the chemicals for energy and the bacteria are the producers.

c. Who are the second level consumers & compare to a photosynthetic web?
The second level consumers are first order carnivores prey on the primary consumers and in turn are eaten by other animals. An example is the lobsters that are small crustaceans that roam about the vent ecosystem feeding on small animals and debris.

d. Who are the third level consumers & compare to a photosynthetic web?
Top order carnivores are the third level consumers. They eat other consumers and carnivores but are rarely hunted by other creatures. Because they are separated from the primary food production by several layers, top order carnivores have the smallest biomass in the food web. The octopus are very active, carnivores mollusks. They capture other animals such as crabs, shrimp and mussels.

Key concepts - SOME THINGS TO KNOW:
Source one below has an interactive food web that can be done by the class as a whole.

a. The primary consumes are the source of food for the ecosystem. They use chemical energy to create the carbohydrates, proteins and lipids needed for life's processes. In a photosynthetic food web these would be the plants or algae. There are more of them than any other organism. Some think that there are more of these microbes than any on earth. These are the vent bacteria and the symbiotic bacteria.
b. The first level consumers are the ones that feed directly on the chemosynthetic microbes. Organisms with symbiotic microbes that feed them fall into this category. In a photosynthetic food web it would be the herbivores. These are the tubeworms, shrimp, amphipods, clams, and mussels.
c. The second level consumers are the ones that feed on the herbivores; they are carnivores. Theses are the Galthheid Crabs, Anemones and Zoarcid fish (eel pout).
d. Third level consumers are carnivores that eat carnivores. They are rarely eaten by other organisms and are the fewest in number. These are the vent octopus, vent ratfish and the blind crabs.

Possible Sources:

1. http://oceanexplorer.noaa.gov/edu/learning/5_chemosynthesis/activities/hydrothermal.html
2. http://www.ridge2000.org/
   via link from http://www.darkenergybiosphere.org/resources/programs.html
3. http://oceanexplorer.noaa.gov/explorations/12fire/logs/sept21/sept21.html
4. marine microbes - via link in
   http://www.darkenergybiosphere.org/resources/programs.html

5. Importance of vent communities: Human uses

This is an effective lesson before a visit too a museum that has a chimney or black smoker on exhibit. You can also view pictures of the exhibit/chimney on the American Museum of Natural History 's web site or another source.

Questions

a. What benefits can humans get from hydrothermal vents? Minerals? Energy Source? Food? Microbes themselves?
Humans benefit from hydrothermal vents because they act as a source of abundant energy. Microbes play an important role because they feed off the energy at the hydrothermal vents, without microbes we might not have any form of life considering they are the base of the food chain. Microbes are the organisms that give us the chance to have many of the different organisms that we know today. The microbes feed off the hydrothermal vents and its hot, mineral-rich fluids. This is the only place on the planet where an energy source renews itself.

Key Concepts - SOME THINGS TO KNOW:

a. Minerals or ore deposits:
What minerals can be found around hydrothermal vents?
Sulfides can be found at both old and young chimneys as well as iron, zinc, and copper-iron sulfide minerals. Present day black smokers, like the ancient black smokers found on land, contain complex mixtures of these crystals of iron and sulfides. The image below is an example. These minerals dissolve in the water as it flows through the rocks. These dissolved minerals precipitate when they mix with cold water forming the chimney. They can also precipitate on the sea floor and be uncovered as the plates move to become land.

Figure 4

b. Energy: There are many possibilities for getting energy from the ocean - thermal and mechanical. Types: waves, tides, currents, offshore wind, salinity gradients, ocean thermal gradients, spreading center/earth core energy. Explore how Iceland has harnessed the thermal energy of the earth. Conservation of these resources and possible consequences should be discussed.
c. Food: imagine how a sulfur- eating organism/ organism with sulfur symbionts would taste! Could these organisms be used on the in hot areas as possible food sources? Could we have farm chambers in our homes where they could provide essential nutrients?
d. Segue into exploration and technological advances required in the next section.

Possible Sources:
1. http://www.amnh.org/exhibitions/permanent-exhibitions/rose-center-for-earth-and-space/david-s.-and-ruth-l.-gottesman-hall-of-planet-earth/why-is-the-earth-habitable/life-that-lives-off-the-earth-s-energy/life-at-the-hydrothermal-vent
2. http://www.darkenergybiosphere.org/resources/programs.html - continental drilling
3. http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_energy.pdf
4. http://www.habitat.noaa.gov/protection/renewable/index.html
5. coastalmanagement.noaa.gov/otec/docs/environmentalfactsheet.pdf

6. Engineering & Ethical Challenges - QUESTIONS:

a. What engineering challenges does exploration in these deep ocean vent communities present?
The pressure underwater in the deep ocean is so extreme that humans cannot go down without man made machines, Like ALVIN. The pressure Increases 1 atmosphere for every 10 meters.

b. What impact will human activities have on this ecosystem? Should we conserve or exploit?
All known threats to deep sea coral communities in alaska are directly or indirectly the result of human activity. Another problem we caused to hurt the environment was the BP oil spill.

KEY CONCEPTS - SOME THINGS TO KNOW:

Class discussion, content will depend on what the class discovered. Any discussion should stress the importance of exploration and basic research in understanding the deep ocean vent ecosystems. C-DEBI research theme 1 looks at the extent of microbial activity in the ocean. The rate of the chemical reactions in the vent communities will play a role in determining what humans should do.

Use the example of ocean gold mining as an example.

Possible Sources:
Engineering Challenges:
1. Videos: http://www.darkenergybiosphere.org/resources/videos.html

2. http://www.darkenergybiosphere.org/resources/programs.html
3. http://www.darkenergybiosphere.org/research/themes.html - research theme

Ethical Challenges:

4. coastalmanagement.noaa.gov/otec/docs/environmentalfactsheet.pdf
5. http://oceanexplorer.noaa.gov/explorations/12lophelia/background/energy/energy.html
6. http://www.theguardian.com/environment/2014/mar/02/underwater-gold-rush-marine-mining-fears-ocean-threat

Activity Discussion and Assessment

After students have researched and answered questions in groups, then do

1. **Class Discussion** - Have each student write one thing they learned from each activity. Read aloud and channel discussion.
2. **Assessment** - Instructor choice: short quiz, short summary page, class position paper, future of the vent ecosystem short story.

TOOLKIT CREDITS:

Developed by Dale Stanley (Nassau Community College, NY) with support by the rest of the C-DEBI Collaborative Toolkit Team.

WEBSITE:

http://www.coexploration.org/C-DEBI/toolkits_biology.html