NOAA Ship *Okeanos Explorer:* America's Ship for Ocean Exploration. Image credit: NOAA. For more information, see the following Web site: *http://oceanexplorer.noaa.gov/okeanos/welcome.html*

Section 4: Key Topic – Energy

What's the Big Deal?

[adapted from the 2003 Windows to the Deep Exploration]

Focus

Significance of methane hydrates

Grade Level

9-12 (Earth Science)

Focus Question

Why should a NOAA Ocean Exploration expedition focus investigations on methane hydrates?

Learning Objectives

- Students will define methane hydrates, describe where these substances are typically found, and explain how they are believed to be formed.
- Students will describe at least three ways in which methane hydrates could have a direct impact on their own lives.
- Students will describe how additional knowledge of methane hydrates expected to be found during Ocean Exploration and Research expeditions could provide human benefits.

Materials

- Copies of *Methane Hydrate Investigation Guide*, one for each student group
- Copies of the *Methane Hydrate Model Construction Guide*, one for each student group
- Materials for constructing a methane hydrate model:

  For constructing a pentagon:
  - Paper, unlined 8-1/2" X 11"
  - Pencil
  - Protractor or compass

  For constructing the half dodecahedron, clathrate cage, methane molecule and methane hydrate model:
  - Scissors
  - Cardboard or card stock (enough to make 7 pentagons)
  - Ruler, 12-inch
  - 11 - Bamboo skewers, 12" long
  - 20 - Styrofoam balls, 1/2" to 1" diameter
  - 4 - Styrofoam balls, 1" diameter
  - 1 - Styrofoam ball, 1-1/2" diameter
  - Tape, wrapping or strapping

Ocean Exploration and Research

- Spray paint, water-based latex; dark blue, light blue, red, and black
- Fishing line, 8 lb test; or light colored thread

Audiovisual Materials

- None

Teaching Time

One or two 45-minute class periods plus time for student research

Seating Arrangement

Five groups of 3-6 students

Maximum Number of Students

32

Key Words and Concepts

Cold seeps
Methane hydrate
Methanogenic Archaea
Clathrate
Greenhouse gas
Greenhouse effect
Paleocene extinction
Cambrian explosion
Alternative energy
Natural hazards

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

> ***For kicks, oceanographer William P. Dillon likes to surprise visitors to his lab by taking ordinary-looking ice balls and setting them on fire. 'They're easy to light. You just put a match to them and they will go,' says Dillon, a researcher with the U.S. Geological Survey (USGS) in Woods Hole, Mass. If the truth be told, this is not typical ice. The prop in Dillon's show is a curious and poorly known structure called methane hydrate.***
>
> *from "The Mother Lode of Natural Gas"*
> *by Rich Monastersky,*
> *www.sciencenews.org/pages/pdfs/data/1996/150-19/15019-12.pdf*


Methane hydrate looks like ice, but as the "ice" melts it releases methane gas which can be a fuel source. Image credit: Gary Klinkhammer, OSU-COAS

Methane hydrate is a type of clathrate, a chemical substance in which the molecules of one material (water, in this case) form an open lattice that encloses molecules of another material (methane) without actually forming chemical bonds between the two materials. Methane is produced in many environments by a group of Archaea known as methanogenic Archaea. These Archaea obtain energy by anaerobic metabolism through which they break down the organic material contained in once-living plants and animals. When this process takes place in deep ocean sediments, methane molecules are surrounded by water molecules, and conditions of low temperature and high pressure allow stable ice-like methane hydrates to form. Besides providing entertainment for oceanographers, methane hydrate deposits are significant for several other reasons. A major interest is the possibility of methane hydrates as an energy source. The U.S. Geological Survey has estimated that on a global scale, methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined. In addition to their potential importance as an energy source, scientists have found that methane hydrates are associated with unusual and possibly unique biological communities. In September, 2001, the Ocean Exploration Deep East Expedition explored the crest of the Blake Ridge at a depth of 2,154 m, and found methane hydrate-associated communities containing previously-unknown species that may be sources of beneficial pharmaceutical materials.

While such potential benefits are exciting, methane hydrates may also cause big problems. Although methane hydrates remain stable in deep-sea sediments for long periods of time, as the sediments become deeper and deeper they are heated by the Earth's core. Eventually, temperature within the sediments rises to a point at which the clathrates are no longer stable and free methane gas is released (at a water depth of 2 km, this point is reached at a sediment depth of about 500 m). The pressurized gas remains trapped beneath hundreds of meters of sediments that are cemented together by still-frozen methane hydrates. If the overlying sediments are disrupted by an earthquake or underwater landslide, the pressurized methane can escape suddenly, producing a violent underwater explosion that may result in disastrous tsunamis.

The release of large quantities of methane gas can have other consequences as well. Methane is one of the greenhouse gases. In the atmosphere, these gases allow solar radiation to pass through to the surface of the Earth, but absorb heat radiation that is reflected back from the Earth's surface, thus warming the atmosphere. A sudden release of methane from deep-sea sediments could increase this effect, since methane has more than 30 times the heat-trapping ability of carbon dioxide.

In 1995, Australian paleoceanographer Gerald Dickens suggested that a sudden release of methane from submarine sediments during the Paleocene Epoch (at the end of the Tertiary Period, about 55 million years ago) caused a greenhouse effect that raised the temperatures in the deep ocean by about 6° C. The result was the extinction of many deep-sea organisms known as the Paleocene extinction event. More recently, other scientists (*e.g.*, Kirschvink and Raub, 2003; Simpson, 2000) have suggested that similar events could have contributed to mass extinctions during the Jurassic Period (183 million years ago), as well as to the sudden appearance of many new animal phyla during the Cambrian Period (the Cambrian Explosion, about 520 million years ago).

This lesson guides a student investigation into the significance of methane hydrates.

Iceworms *(Hesiocaeca methanicola)* infest a piece of orange methane hydrate at 540 m depth in the Gulf of Mexico. During the Paleocene epoch, lower sea levels could have led to huge releases of methane from frozen hydrates and contributed to global warming. Today, methane hydrates may be growing unstable due to warmer ocean temperatures. Image credit: Ian MacDonald. *http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/iceworms_600.jpg*

Learning Procedure

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go*….
   - Visit *http://oceanexplorer.noaa.gov/explorations/deepeast01/logs/oct1/oct1.html* and *http://oceanexplorer.noaa.gov/explorations/03windows/welcome.html* for background on the 2001 Deep East Expedition to the Blake Ridge and

the 2003 Windows on the Deep Expedition.
- Review questions on the *Methane Hydrates Investigation Guide.*
- Review procedures on the *Methane Hydrate Model Construction Guide*, and gather necessary materials. This activity may be done as a cross-curricular mathematics lesson using student-constructed pentagons and dodecahedrons. Correlations with Common Core State Standards for Mathematics are provided in Appendix A on page 159.

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, which should include further understanding of energy resources in the ocean.

   Lead an introductory discussion about the 2001 Deep East Expedition to the Blake Ridge and the 2003 Windows on the Deep Expedition. Briefly describe methane hydrates and why these substances are potentially important to human populations. You may also want to visit *http://www.pmel.noaa.gov/vents/* for more information and activities on hydrothermal vent communities.

3. Provide each student group with a copy of the *Methane Hydrates Investigation Guide* and the *Methane Hydrate Model Construction Guide*. Tell students that they will be expected to present a group report, including a model of a methane hydrate, that addresses these questions, and participate in a class discussion of their results.

4. Lead a discussion of students' research results. Referring to students' models, begin with a discussion of what methane hydrates are, where they are found, and how they are formed. Next, ask for a group that can explain one way in which methane hydrates are significant to humans. Continue this process until all five groups have had a chance to present one piece of the whole story. Now, ask students what scientific research priorities and public policies should be established concerning methane hydrates. Encourage students to comment on the potential significance of global warming, alternative energy sources, useful biological products, and natural hazards.

   Be sure the following points are included in the discussion:
   - A clathrate is a chemical substance in which molecules of one material (*e.g.*, water) form an open solid lattice that encloses, without chemical bonding, molecules of another material (*e.g.*, methane).

   - Methane hydrate is a clathrate in which a lattice of water molecules encloses a molecule of methane.

   - In general, methane hydrates formed under conditions of low temperature and high pressure, such as are found in deep ocean environments. See *http://oceanexplorer.noaa.gov/explorations/03windows/background/hydrates/media/fig1_phase_diagram.html* for a phase diagram illustrating combinations of pressure and temperature that are suitable for methane hydrate formation.

- Clathrates have been known as a type of chemical substance since the 1800's, but methane hydrates first received serious attention when they were found to be plugging natural gas pipelines, particularly pipelines located in cold environments. In the late 1960s, naturally-occurring methane hydrate was observed in subsurface sediments in Western Siberia and Alaska. Marine methane hydrate deposits were first found in the Black Sea and subsequently in cores of ocean bottom sediments collected by the R/V *Glomar Challenger* from many areas of Earth's ocean.

- Methane is a greenhouse gas that is ten times more effective than carbon dioxide in causing climate warming. Carbon isotope variations in carbonate rocks and sediments indicate that large-scale releases of methane from ocean hydrates could have occurred at various times in Earth's history, including the Pre-cambrian and Cretaceous Periods. Such releases could have caused significant climate change that may be related to extinction events, as well as to the rapid evolution of new species during the Cambrian Period.

- Methane can be released from methane hydrates when deposits are disrupted by earthquakes or landslides; or when pressure on hydrates is reduced due to a sea-level drop, such as occurred during glacial periods; or when clathrates become unstable due to warming.

- Methane is a fossil fuel that could be used in many of the same ways that other fossil fuels (*e.g.*, coal and petroleum) are used. According to the U.S. Department of Energy, the quantity of methane potentially available is enormous. For example, the U.S. domestic natural gas recoverable resource is roughly 2,300 trillion cubic feet (Tcf). In the case of methane hydrates, the potentially-recoverable domestic resource base could be on the order of 5,000 Tcf.

- Oil and gas drilling and production activities may disturb methane hydrate deposits that are near the seafloor surface, and such disruption poses hazards to personnel and equipment. Ongoing natural phenomena (*e.g.*, subsidence and uplift of the seafloor, global climatic cycles, changes in ocean circulation patterns, changes in global sea level) continually alter the temperature and pressure conditions in sea-bottom sediments. These processes affect the stability of natural methane hydrates, and can result in potentially massive destabilization of these hydrates. If a large quantity of methane enters the atmosphere, it will reside there for roughly 10-20 years, during which it will act as a very efficient greenhouse gas. Over the longer term, the atmospheric impact of methane will continue at lesser levels as the methane slowly dissipates through oxidation into water and carbon dioxide.

- In September, 2001, the Deep East Expedition explored the crest of the Blake Ridge at a depth of 2,154 m, and found methane hydrate-associated communities containing previously-unknown species that may be sources of beneficial pharmaceutical materials.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics," then click "Habitats," the "Deep Sea" for links to resources about hydrothermal vents and chemosynthetic communities.

The "Me" Connection

Have students write an essay describing why ocean exploration expeditions are, or are not, personally relevant and important.

Connections to Other Subjects

English/Language Arts, Biology, Chemistry, Mathematics

Assessment

Students' responses to *Investigation Guide* questions and class discussions provide opportunities for assessment.

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. Have students investigate events in Earth's history that may have been influenced in some way by methane hydrates. The next-to-last paragraph in the Background section refers to some of these.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 5, 11, and 12 for interactive multimedia presentations and Learning Activities on Chemosynthesis and Hydrothermal Vent Life, Energy from the Oceans, and Food, Water, and Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

(All of the following Lesson Plans are targeted toward grades 9-12)

This Life Stinks (from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_stinks.pdf

Focus: Methane-based chemosynthetic processes (Physical Science)

Students will define the process of chemosynthesis, and contrast this process with photosynthesis. Students will also explain the process of methane-based chemosynthesis and explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

The Big Burp: Where's the Proof?
(from the 2007 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/burp.pdf

Focus: Potential role of methane hydrates in global warming (Earth Science)

Students will describe the overall events that occurred during the Cambrian Explosion and Paleocene Extinction events and will define methane hydrates and hypothesize how these substances could contribute to global warming. Students will also describe and explain evidence to support the hypothesis that methane hydrates contributed to the Cambrian Explosion and Paleocene Extinction events.

The Benthic Drugstore
(from the Cayman Islands Twilight Zone 2007 Expedition)
http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/drugstore.pdf
Focus: Pharmacologically-active chemicals derived from marine invertebrates (Life Science/Chemistry)
Students will identify at least three pharmacologically-active chemicals derived from marine invertebrates, describe the disease-fighting action of at least three pharmacologically-active chemicals derived from marine invertebrates, and infer why sessile marine invertebrates appear to be promising sources of new drugs.

Chemosynthesis for the Classroom
(from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_chemo.pdf
Focus: Chemosynthetic bacteria and succession in chemosynthetic communities (Chemistry/Biology)
Students will observe the development of chemosynthetic bacterial communities and will recognize that organisms modify their environment in ways that create opportunities for other organisms to thrive. Students will also explain the process of chemosynthesis and the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings. Please send your comments to:
oceanexeducation@noaa.gov

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818 843.762.8737 (fax)
paula.keener-chavis@noaa.gov

Acknowledgments

Produced by Mel Goodwin, PhD, Marine Biologist and Science Writer, Charleston, SC for NOAA. Design/layout: Coastal Images Graphic Design, Charleston, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: *http://oceanexplorer.noaa.gov*

Methane Hydrate Investigation Guide

Research Questions

1. What is a clathrate?

Methane hydrate looks like ice, but as the "ice" melts it releases methane gas which can be a fuel source. Image credit: Gary Klinkhammer, OSU-COAS

2. What is methane hydrate? Include a model of a methane hydrate with your written report (refer to the *Methane Hydrate Model Construction Guide*).

3. How are methane hydrates formed?

4. Where are methane hydrates found?

5. What is the effect of methane in the atmosphere? Is there any evidence of a direct effect on life on Earth in geological time?

6. In what ways can methane be released from methane hydrates?

7. Is there any practical use for methane hydrates?

8. Do methane hydrates pose any immediate danger to coastal areas?

9. Are any unusual biological organisms or communities associated with methane hydrates? If so, do these communities have any known or potential significance to humans?

Research Tips

1. Try a keyword search using the following terms, alone or in combination:
   Cold seeps, Methane hydrate, Clathrate, Methanogenic Archaea
   Paleocene extinction, Energy hazard
   Note: Use quotation marks or underlined spaces to tell your search engine to look for two-word phrases as a single term

2. Explore the following Web sites:
   http://oceanexplorer.noaa.gov
   http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/maincontent.htm
   http://marine.usgs.gov/fact-sheets/gas-hydrates/title.html

Methane Hydrate Model Construction Guide

Materials

Materials for constructing a methane hydrate model:

For constructing a pentagon:

- Paper, unlined 8-1/2" X 11"
- Pencil
- Protractor or compass

For constructing the dodecahedron half, clathrate cage, methane molecule and methane hydrate model:

- Scissors
- Cardboard or card stock (enough to make 7 pentagons)
- Ruler, 12-inch
- 11 - Bamboo skewers, 12" long
- 20 - Styrofoam balls, 1/2" to 1" diameter
- 4 - Styrofoam balls, 1-1/2" diameter
- 1 - Styrofoam ball, 1" diameter
- Tape, wrapping or strapping
- Spray paint, water-based latex; dark blue, light blue, red, and black
- Fishing line, 8 lb test; or light colored thread

Procedure

1. General Notes:
   - Use a good quality latex spray paint; oil-based paints containing organic solvents tend to melt the Styrofoam.
   - Be sure the skewers are inserted into the middle of the Styrofoam balls.

Part 1 – Build a pentagonal dodecahedron

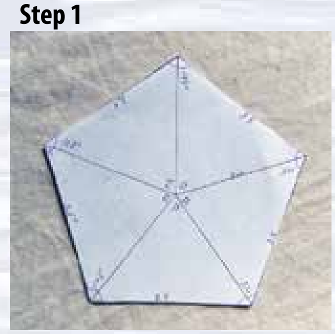
1. Draw a pentagon on paper and cut it out. Each side of the pentagon should be four inches long.

2. Trace the paper pentagon onto cardboard or card stock and cut it out. Each group will cut out 13 pentagons.

3. Lay one pentagon on a flat surface and surround it with five more pentagons matched side to side. Tape the five outside pentagons to the center pentagon.

4. Carefully pull up one pair of pentagons and tape their common sides together. Repeat until the five pentagons have been taped together, forming a five-sided bowl. This is one half of a pentagonal dodecahedron.

Step 1



Step 2

Step 3

Part 2 – Build the Model Molecules

1. Spray paint skewers and Styrofoam balls:
   a. Paint ten skewers light blue to represent hydrogen bonds between water molecules
   b. Paint one skewer red to represent the covalent bonds in the methane molecule
   c. Paint twenty 1/2" Styrofoam balls dark blue to represent water molecules
   d. Paint one 1" Styrofoam ball black to represent the carbon atom
   e. Note: the 4 1-1/2" Styrofoam balls remain white to represent hydrogen atoms

2. Cut light blue skewer sticks into thirty 3-3/4" lengths. Cut the red skewer stick into four 2" lengths. Cut them at an angle so the ends are sharp.

Build the clathrate cage:

3. Place the 7th pentagon on a flat surface. Place a blue stick on one side and two blue balls at each end. Carefully insert the end of the blue stick into the middle of each ball. Repeat with three more balls and four more sticks to form a ball-and-stick pentagon.

Step 3a

Step 3b

Step 3c

Step 3d

Step 3e

Step 4

4. Place the ball-and-stick pentagon in the dodecahedron half—be careful, it will lay approximately an inch up from the bottom. The dodecahedron half (bowl) is used as a template to build the ball and stick dodecahedron with the correct stick angle.

Step 5

5. Place five light blue sticks inside the center of each of the dark blue balls using the dodecahedron half as a guide for the correct stick angle. It's very important to insert the sticks into the center of the ball at the same angle as the side of the dodecahedron half.

Step 6

6. Insert a dark blue ball on top of each light blue stick. Carefully remove the incomplete cage from the bowl and place it on a flat surface.

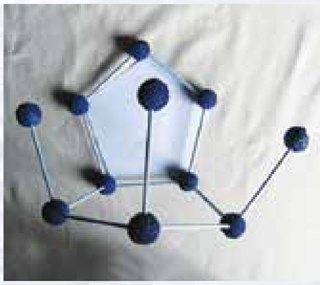
7. Use the 7th pentagon to complete the bottom half of the cage. Turn the ball-and-stick model onto one side and, using the pentagon to determine the correct angle, insert a light blue stick into the center of the two dark blue balls. Then, attach another dark blue ball to connect the two light blue sticks you've just attached. This makes the second face and second pentagon of the cage. The first face was the bottom.

8. Repeat Step 7 four more times to form the remaining faces for the bottom half of the cage.

9. Repeat Steps 3, 4, and 5 to construct the top half of the cage.

10. Carefully place the bottom half of the cage into the bottom of the cardboard bowl. Attach the two halves of the cage together: Working together with your partners, hold the top half of the cage over the bottom half. The two halves will only fit together one way. Rotate the top half until all of the unattached sticks line-up with a ball. Insert each light blue stick into the center of the corresponding dark blue ball.

Step 7

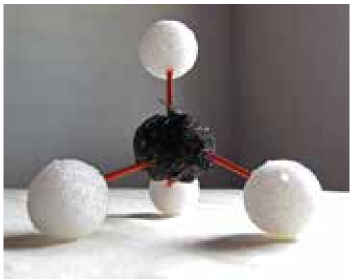


Step 8

Build the Methane Molecule:

11. Insert four red sticks into the black Styrofoam ball so that they are evenly spaced (when the model is placed on a flat surface, three of the sticks and the black ball should look like a tripod with the fourth stick pointing straight up). Attach a white Styrofoam ball to the other end of each of the red sticks.

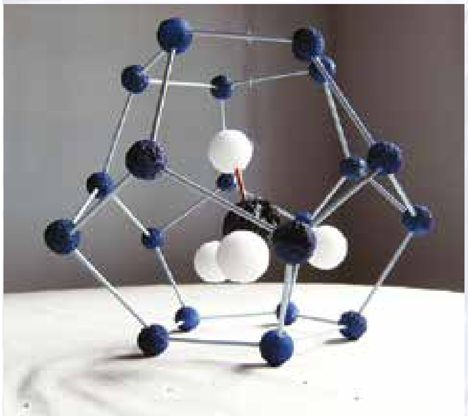
Step 11



Assemble the Methane Hydrate Model

12. Suspend the methane molecule in the middle of the clathrate cage by attaching fishing line from one of its covalent bonds (red sticks) to two opposing hydrogen bonds (light blue sticks) at the top of the cage. Your Methane Hydrate Model is finished!

Step 12



Note: Each of the dark blue Styrofoam balls represents a water molecule consisting of two hydrogen atoms and one oxygen atom. To keep the model simple, we don't show all of these atoms separately.

All photographs by Mellie Lewis, Teacher Facilitator, The College of Exploration.

Appendix A

Adapting the Methane Hydrate Model Construction Activity as a Cross-curricular Mathematics Lesson

Learning Objectives

- Students will demonstrate geometric properties through hands on manipulation of geometric shapes.
- Students will be able to construct a pentagonal dodecahedron.
- Students will be able to construct a model of a methane hydrate.

Teaching Time

Three or four 50-minute class periods or may be sent home as an enrichment activity

Definitions

- Polygon – a geometric shape made up of vertices that are connected with line segments
- Vertex – a point where the sides of an angle meet
- Pentagon – a geometric shape with five equal sides and five 108° angles
- Dodecahedron – a three-dimensional geometric shape that has 12 faces (regular pentagons), 20 vertices, and 30 edges

Prerequisite Skills

Students should have basic knowledge of geometric shapes and know how to draw a pentagon. If not, directions for drawing a pentagon using a compass or protractor may be found in middle school mathematics textbooks or in the links below.

Procedure

1. Lead an introductory discussion of how mathematical models help us understand science concepts.
2. Tell students that they will be using concepts and skills they have learned in mathematics class to build a pentagonal dodecahedron, a clathrate cage, and methane hydrate model.
3. Provide students with copies of the *Methane Hydrate Construction Guide* and required materials.

Resources

http://wiki.answers.com/Q/How_would_you_draw_a_regular_pentagon
http://www.barryscientific.com/lessons/polygon.html

Common Core State Standards for Mathematics

High School:

HSG.MG.A.1. Use geometric shapes, their measures, and their properties to describe objects.

Notes: