Name:________________________________ Hour:______________

# Earth Science

## Final Exam Review Guide

Final Exam Date:_______________

This review guide is not the only resource a student should use to study. This is our best attempt to summarize the entire course but we are human and may have missed something. We strongly urge students to review all of their note packets and video notes to fully prepare for the Final Exam.

### Essential questions for the course:

1. How do the major Earth systems interact? How do the properties and movements of water shape Earth's surface and affect its systems?
2. What regulates weather and climate? How do people model and predict the effects of human activities on Earth's climate?
3. How do people reconstruct and date events in Earth's planetary history? Why do the continents move?
4. What is the universe, and what goes on in stars? What are the predictable patterns caused by Earth's movement in the solar system?

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## **Unit 1:** Space Systems

### Vocabulary:

*Understand and be able to apply each of these terms.*

1. Big Bang theory
2. Black hole
3. Cosmic background radiation
4. Dark Matter/Energy
5. Doppler effect
6. Energy
7. Equilibrium
8. Gluon
9. Gravity
10. Hadron
11. H-R diagram
12. Hubble's Constant
13. Hubble's Law
14. Interstellar Medium
15. Luminosity
16. Main Sequence Star
17. Matter
18. Nebula
19. Neutron
20. Nuclear Fusion
21. Olber's Paradox
22. Proton
23. Protostar
24. Quark
25. Redshift
26. Scientific Theory
27. Singularity
28. Spectroscopy
29. Supernova
30. Universe

### Concepts:

- The Big Bang Theory and the astronomical evidence of light spectra, galaxy motion, and composition of matter that supports it
- Characteristics of stars including their life cycles, nuclear fusion, and element formation
- The formation and structure of solar systems
- The life span of the sun and the role of nuclear fusion it's release of energy
- Incoming solar radiation, where it is absorbed and reflected

# Guiding Questions:

1. How do we know what stars are made of?
2. What fuels our Sun? Will it ever run out of that fuel?
4. What can those motions tell us about the origin of the Universe and our planet?

# Standards:

**ESS1-1.** Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation.

*Components:*

Students use evidence to develop a model in which they identify and describe* the relevant components, including:

- Hydrogen as the sun's fuel;
- Helium and energy as the products of fusion processes in the sun; and
- That the sun, like all stars, has a life span based primarily on its initial mass, and that the sun's lifespan is about 10 billion years.

*Relationships a In the model:*

Students describe the relationships between the components, including a description of the process of radiation, and how energy released by the sun reaches Earth's system.

*Connections:*

Students use the model to qualitatively describe the scale of the energy released by the fusion process as being much larger than the scale of the energy released by chemical processes.

Students use the model to explicitly identify that chemical processes are unable to produce the amount of energy flowing out of the sun over long periods of time, thus requiring fusion processes as the mechanism for energy release in the sun.

**ESS1-2.** Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.

*Articulating the explanation of phenomena:*

Students construct an explanation that includes a description of how astronomical evidence from numerous sources is used collectively to support the Big Bang theory, which states that the universe is expanding and that thus it was hotter and denser in the past, and that the entire visible universe emerged from a very tiny region and expanded.

*Evidence:*

Students identify and describe the evidence to construct the explanation, including:

- The composition (hydrogen, helium and heavier elements) of stars;
- The hydrogen-helium ratio of stars;
- The redshift of the majority of galaxies and the redshift vs. distance relationship; and
- The existence of cosmic background radiation.

Students use a variety of valid and reliable sources for the evidence, which may include students' own investigations, theories, simulations, and peer review.

Students describe the source of the evidence and the technology used to obtain that evidence.

*Reasoning*

Students use reasoning to connect evidence, along with the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future, to construct the explanation for the early universe (the Big Bang theory). Students describe the following chain of reasoning for their explanation:

- Redshifts indicate that an object is moving away from the observer, thus the observed redshift for most galaxies and the redshift vs. distance relationship is evidence that the universe is expanding.
- The observed background cosmic radiation and the ratio of hydrogen to helium have been shown to be consistent with a universe that was very dense and hot a long time ago and

that evolved through different stages as it expanded and cooled (e.g., the formation of nuclei from colliding protons and neutrons predicts the hydrogen-helium ratio [numbers not expected from students], later formation of atoms from nuclei plus electrons, background radiation was a relic from that time).
- An expanding universe must have been smaller in the past and can be extrapolated back in time to a tiny size from which it expanded.

**ESS1-3.** Communicate scientific ideas about the way stars, over their life cycle, produce elements.

*Communication style and format*

Students use at least two different formats (e.g., oral, graphical, textual, and mathematical) to communicate scientific information, and cite the origin of the information as appropriate.

*Connecting the DCIs and the CCCs*

Students identify and communicate the relationships between the life cycle of the stars, the production of elements, and the conservation of the number of protons plus neutrons in stars.

Students identify that atoms are not conserved in nuclear fusion, but the total number of protons plus neutrons is conserved.

Students describe that:

- Helium and a small amount of other light nuclei were formed from high-energy collisions starting from protons and neutrons in the early universe before any stars existed.
- More massive elements, up to iron, are produced in the cores of stars by a chain of processes of nuclear fusion, which also releases energy.

- Supernova explosions of massive stars are the mechanism by which elements more massive than iron are produced.
- There is a correlation between a star's mass and stage of development and the types of elements it can create during its lifetime.
- Electromagnetic emission and absorption spectra are used to determine a star's composition, motion and distance to Earth.

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# **Unit 2:** Earth's place in space

## Vocabulary:

*Understand and be able to apply each of these terms.*

31. Accretion model
32. Biosphere
33. Body Fossil
34. Cast
35. Climate
36. Compositional Model
37. Core dynamics
38. Faunal succession
39. Fossil
40. Gas Giant
41. Geocentric model
42. Geologic Time Scale
43. Geosphere
44. Heliocentric model
45. Igneous Rock
46. Imprint
47. Index Fossil
48. Inference
49. Mantle Convection
50. Metamorphic Rock
51. Mold
52. Replacement Fossils
53. Sedimentary Rock
54. Soft Part Preservation
55. Structural Model
56. Terrestrial Planet
57. Trace Fossil

## Concepts:

- The history of how Earth formed and how it evolved the way it is
- Layers of the Earth and each layer's characteristics
- The age of continental crust versus the age of the seafloor and the differences in rock composition and density
- Understand the cycling of matter by thermal convection
- Changes in our planet's landforms create responses from life (coevolution).
- Mass extinctions on Earth throughout time.

## Guiding Questions:

1. What causes earthquakes and volcanoes?
2. How did the Earth's landscape get to look the way it does today?
3. How do Earth's living things affect non-living things, and vice versa?

## Standards:

**ESS1-6.** Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.

*Articulating the explanation of phenomena*

Students construct an account of Earth's formation and early history that includes that:

Earth formed along with the rest of the solar system 4.6 billion years ago.

The early Earth was bombarded by impacts just as other objects in the solar system were bombarded.

Erosion and plate tectonics on Earth have destroyed much of the evidence of this bombardment, explaining the relative scarcity of impact craters on Earth.

Evidence a Students include and describe the following evidence in their explanatory account:

- The age and composition of Earth's oldest rocks, lunar rocks, and meteorites as determined by radiometric dating;
- The composition of solar system objects;
- Observations of the size and distribution of impact craters on the surface of Earth and on the surfaces of solar system objects (e.g., the moon, Mercury, and Mars); and
- The activity of plate tectonic processes, such as volcanism, and surface processes, such as erosion, operating on Earth.

**ESS2-1.** Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.

*Components of the model*

Students use evidence to develop a model in which they identify and describe the following components:

- Descriptions and locations of specific continental features and specific ocean-floor features;
- A geographic scale, showing the relative sizes/extents of continental and/or ocean floor features;
- Internal processes (such as volcanism and tectonic uplift) and surface processes (such as weathering and erosion); and
- A temporal scale showing the relative times over which processes act to produce continental and/or ocean-floor features.

*Relationships*

In the model, students describe the relationships between components, including:

- Specific internal processes, mainly volcanism, mountain building or tectonic uplift, are identified as causal agents in building up Earth's surface over time.
- Specific surface processes, mainly weathering and erosion, are identified as causal agents in wearing down Earth's surface over time.
- Interactions and feedbacks between processes are identified (e.g., mountain-building changes weather patterns that then change the rate of erosion of mountains).
- The rate at which the features change is related to the time scale on which the processes operate. Features that form or change slowly due to processes that act on long time scales (e.g., continental positions due to plate drift) and features that form or change rapidly due to processes that act on short time scales (e.g., volcanic eruptions) are identified.

*Connections*

Students use the model to illustrate the relationship between

1) the formation of continental and ocean floor features and

2) Earth's internal and surface processes operating on different temporal or spatial scales.

**ESS2-7.** Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth

*Developing the claim*

Students develop a claim, which includes the following idea: that there is simultaneous coevolution of Earth's systems and life on Earth. This claim is supported by generalizing from multiple sources of evidence.

*Identifying scientific evidence*

Students identify and describe evidence supporting the claim, including:

- Scientific explanations about the composition of Earth's atmosphere shortly after its formation;
- Current atmospheric composition;
- Evidence for the emergence of photosynthetic organisms;
- Evidence for the effect of the presence of free oxygen on evolution and processes in other Earth systems;
- In the context of the selected example(s), other evidence that changes in the biosphere affect other Earth systems.

*Evaluating and critiquing*

Students evaluate the evidence and include the following in their evaluation:

- A statement regarding how variation or uncertainty in the data (e.g., limitations, low signal-to-noise ratio, collection bias, etc.) may affect the usefulness of the data as sources of evidence; and
- The ability of the data to be used to determine causal or correlational effects between changes in the biosphere and changes in Earth's other systems.

*Reasoning and synthesis*

Students use at least two examples to construct oral and written logical arguments. The examples:

- Include that the evolution of photosynthetic organisms led to a drastic change in Earth's atmosphere and oceans in which the free oxygen produced caused worldwide deposition of iron oxide formations, increased weathering due to an oxidizing atmosphere and the evolution of animal life that depends on oxygen for respiration; and
- Identify causal links and feedback mechanisms between changes in the biosphere and changes in Earth's other systems.

# **Unit 3:** Earth's Systems

## Vocabulary:

*Understand and be able to apply each of these terms.*

58. Abrasion
59. Absorption
60. Acid Rain
61. Aerobics
62. Air mass
63. Albedo
64. Atmosphere
65. Barometer
66. Bedrock
67. Biosphere
68. Chemical weathering
69. Climate
70. Cold Front
71. Conduction
72. Convection
73. Creep
74. Cryosphere
75. Cyanobacteria
76. Deflation
77. Deposition
78. Differentiation
79. Dune
80. Dune Migration
81. Erosion
82. Exfoliation
83. Front
84. Geosphere
85. Global Atmospheric Circulation
86. Humidity
87. Humus
88. Hydrosphere
89. Ice wedging
90. Isobar
91. Isothermic map
92. Lahar
93. Landslide
94. Leeward
95. Mechanical weathering
96. Mesosphere
97. Mudflow
98. Occluded Front
99. Outgassing
100. Oxidation
101. Parent Material
102. Radiation
103. Regolith
104. Scale
105. Scree
106. Sediment
107. Slump
108. Soil
109. Soil Horizons
110. Stationary Front
111. Stratosphere
112. Subsoil
113. Talus
114. Thermosphere
115. Top soil
116. Troposphere
117. Ventifacts
118. Warm Front
119. Weathering
120. Windward

## Concepts:

- Understanding how severe weather conditions occur and their effects on human activity (ie: hurricanes, floods, droughts, heat waves, etc)

- Earth's dynamic systems (hydrosphere, atmosphere, biosphere, & geosphere) and their relationship with one another
- The chemical and physical properties of water
- Understanding the Water Cycle and the processes that drive it (solar energy, evaporation, transpiration, etc)
- Water's effect on shaping the Earth. Erosion and weathering and stream processes and deposition.
- Formation and classification of igneous, metamorphic, and sedimentary rocks and an examination of the rock cycle and the forces that drive this cycling of matter.
- Understanding the Carbon Cycle and the processes that drive it.

## Guiding Questions:

1. What forces shape the Earth's surface?
2. How do those processes affect humans?
3. What forces shape the Earth's surface?
4. Why do droughts have such a strong impact on Michigan and other parts of the world?

## Standards:

**ESS2-2.** Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

*Organizing data*

Students organize data that represent measurements of changes in hydrosphere, cryosphere, atmosphere, biosphere, or geosphere in response to a change in Earth's surface.

Students describe what each data set represents.

*Identifying relationships*

Students use tools, technologies, and/or models to analyze the data and identify and describe* relationships in the datasets, including:

- The relationships between the changes in one system and changes in another (or within the same) Earth system; and
- Possible feedbacks, including one example of feedback to the climate.

Students analyze data to identify effects of human activity and specific technologies on Earth's systems if present.

*Interpreting data*

Students use the analyzed data to describe a mechanism for the feedbacks between two of Earth's systems and whether the feedback is positive or negative, increasing (destabilizing) or decreasing (stabilizing) the original changes.

Students use the analyzed data to describe a particular unanticipated or unintended effect of a selected technology on Earth's systems if present.

Students include a statement regarding how variation or uncertainty in the data (e.g., limitations, accuracy, any bias in the data resulting from choice of sample, scale, instrumentation, etc.) may affect the interpretation of the data.

**ESS2-3.** Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.

*Components of the model*

Students develop a model (i.e., graphical, verbal, or mathematical) in which they identify and describe the components based on both seismic and magnetic evidence (e.g., the pattern of the geothermal gradient or heat flow measurements) from Earth's interior, including:

- Earth's interior in cross-section and radial layers (crust, mantle, liquid outer core, solid inner core) determined by density;
- The plate activity in the outer part of the geosphere;
- Radioactive decay and residual thermal energy from the formation of the Earth as a source of energy;
- The loss of heat at the surface of the earth as an output of energy; and
- The process of convection that causes hot matter to rise (move away from the center) and cool matter to fall (move toward the center).

*Relationships*

Students describe the relationships between components in the model, including:

- Energy released by radioactive decay in the Earth's crust and mantle and residual thermal energy from the formation of the Earth provide energy that drives the flow of matter in the mantle.
- Thermal energy is released at the surface of the Earth as new crust is formed and cooled.
- The flow of matter by convection in the solid mantle and the sinking of cold, dense crust back into the mantle exert forces on crustal plates that then move, producing tectonic activity.
- The flow of matter by convection in the liquid outer core generates the Earth's magnetic field.

- Matter is cycled between the crust and the mantle at plate boundaries. Where plates are pushed together, cold crustal material sinks back into the mantle, and where plates are pulled apart, mantle material can be integrated into the crust, forming new rock.

*Connections*

Students use the model to describe the cycling of matter by thermal convection in Earth's interior, including:

- The flow of matter in the mantle that causes crustal plates to move;
- The flow of matter in the liquid outer core that generates the Earth's magnetic field, including evidence of polar reversals (e.g., seafloor exploration of changes in the direction of Earth's magnetic field);
- The radial layers determined by density in the interior of Earth; and
- The addition of a significant amount of thermal energy released by radioactive decay in Earth's crust and mantle

**ESS2-4.** Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

*Components of the model:*

From the given model, students identify and describe the components of the model relevant for their mechanistic descriptions. Given models include at least one factor that affects the input of energy, at least one factor that affects the output of energy, and at least one factor that affects the storage and redistribution of energy. Factors are derived from the following list:

- Changes in Earth's orbit and the orientation of its axis;
- Changes in the sun's energy output; iii. Configuration of continents resulting from tectonic activity;
- Ocean circulation;
- Atmospheric composition (including amount of water vapor and CO2);
- Atmospheric circulation;
- Volcanic activity;
- Glaciation;
- Changes in extent or type of vegetation cover; and
- Human activities.

From the given model, students identify the relevant different time scales on which the factors operate.

*Relationships*

Students identify and describe the relationships between components of the given model, and organize the factors from the given model into three groups:

- Those that affect the input of energy;
- Those that affect the output of energy; and
- Those that affect the storage and redistribution of energy

Students describe the relationships between components of the model as either causal or correlational.

*Connections*

Students use the given model to provide a mechanistic account of the relationship between energy flow in Earth's systems and changes in climate, including:

- The specific cause and effect relationships between the factors and the effect on energy flow into and out of Earth's systems; and
- The net effect of all of the competing factors in changing the climate.

**ESS2-5.** Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.

*Identifying the phenomenon to be investigated*

Students describe the phenomenon under investigation, which includes the following idea: a connection between the properties of water and its effects on Earth materials and surface processes.

*Identifying the evidence to answer this question*

Students develop an investigation plan and describe the data that will be collected and the evidence to be derived from the data, including:

- Properties of water, including:
  - a) The heat capacity of water;
  - b) The density of water in its solid and liquid states; and
  - c) The polar nature of the water molecule due to its molecular structure.
- The effect of the properties of water on energy transfer that causes the patterns of temperature, the movement of air, and the movement and availability of water at Earth's surface.
- Mechanical effects of water on Earth materials that can be used to infer the effect of water on Earth's surface processes. Examples can include:
  - a) Stream transportation and deposition using a stream table, which can be used to infer the ability of water to transport and deposit materials;
  - b) Erosion using variations in soil moisture content, which can be used to infer the ability of water to prevent or facilitate movement of Earth materials; and
  - c) The expansion of water as it freezes, which can be used to infer the ability of water to break rocks into smaller pieces.
- Chemical effects of water on Earth materials that can be used to infer the effect of water on Earth's surface processes. Examples can include:
  - a) The solubility of different materials in water, which can be used to infer chemical weathering and recrystallization;
  - b) The reaction of iron to rust in water, which can be used to infer the role of water in chemical weathering;
  - c) Data illustrating that water lowers the melting temperature of most solids, which can be used to infer melt generation; and
  - d) Data illustrating that water decreases the viscosity of melted rock, affecting the movement of magma and volcanic eruptions.

In their investigation plan, students describe how the data collected will be relevant to determining the effect of water on Earth materials and surface processes.

*Planning for the Investigation*

In their investigation plan, students include a means to indicate or measure the predicted effect of water on Earth's materials or surface processes. Examples include:

- The role of the heat capacity of water to affect the temperature, movement of air and movement of water at the Earth's surface;
- The role of flowing water to pick up, move and deposit sediment;
- The role of the polarity of water (through cohesion) to prevent or facilitate erosion;
- The role of the changing density of water (depending on physical state) to facilitate the breakdown of rock;
- The role of the polarity of water in facilitating the dissolution of Earth materials;
- Water as a component in chemical reactions that change Earth materials; and
- The role of the polarity of water in changing the melting temperature and viscosity of rocks.

In the plan, students state whether the investigation will be conducted individually or collaboratively.

*Collecting the data*

Students collect and record measurements or indications of the predicted effect of a property of water on Earth's materials or surface.

*Refining the design*

Students evaluate the accuracy and precision of the collected data.

Students evaluate whether the data can be used to infer the effect of water on processes in the natural world.

If necessary, students refine the plan to produce more accurate and precise data.

**ESS2-6.** Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

*Components of the model*

Students use evidence to develop a model in which they:

- Identify the relative concentrations of carbon present in the hydrosphere, atmosphere, geosphere and biosphere; and
- Represent carbon cycling from one sphere to another.

*Relationships*

In the model, students represent and describe the following relationships between components of the system, including:

- The biogeochemical cycles that occur as carbon flows from one sphere to another;
- The relative amount of and the rate at which carbon is transferred between spheres;
- The capture of carbon dioxide by plants; and
- The increase in carbon dioxide concentration in the atmosphere due to human activity and the effect on climate.

*Connections*

Students use the model to explicitly identify the conservation of matter as carbon cycles through various components of Earth's systems.

Students identify the limitations of the model in accounting for all of Earth's carbon.

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# **Unit 4:** Earth and Human Activity (Human Sustainability)

## Vocabulary:

*Understand and be able to apply each of these terms.*

121. Albedo –
122. Anthropogenic greenhouse gases –
123. Ash Storage Pond -
124. Atmosphere –
125. Biomass –
126. Black Lung Disease –
127. Carbon sink –
128. Coal Seam –
129. Coral Bleaching –
130. Energy Efficiency –
131. Fracking Fluid –
132. Gas Flare –
133. Geoengineering –
134. Geothermal Energy –
135. Greenhouse Effect –
136. Hydraulic Fracturing –
137. Ice Age –
138. Ice Sheets –
139. Nonrenewable Energy -
140. Proxy –
141. Pumped Storage Dam –
142. Reservoir –
143. Sea Ice –
144. Sedimentation –
145. Sunspot –
146. Thermal Expansion –
147. Wind Farm –

## Concepts:

- The difference between renewable and nonrenewable resource
- Resources' effects on human activity
- Human and environmental impact from resource use
- Heat transfer (radiation, convection, conduction)
- Atmosphere: composition, layers, and how temperature and air pressure changes as altitude increases

- The flow of energy into and out of the Earth. Earth's radiation properties (absorption/ reflection/albedo and scattering) of land, water, and atmosphere (cloud cover, ozone)
- Why solar radiation is either absorbed or not in each layer
- Main greenhouse gases, the greenhouse effect, and causes of increase/decrease of greenhouse gases in atmosphere
- Severe weather, such as tornadoes, hurricanes, blizzards, and droughts
- Trends and patterns in climate data and evaluation of climate change graphs
- Global climate change and human influences on Earth's systems

## Guiding Questions:

1. Where do oil and gas come from?
2. How are gas and oil deposits related to carbon cycling?
3. What is the impact of driving cars and using other fossil fuels on the Earth system?
4. How do Earth's natural systems influence our cities and vice versa?
5. What regulates weather and climate?
6. What effects are humans having on the climate?

## Standards:

**ESS3-1.** Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

*Articulating the explanation of phenomena*

Students construct an explanation that includes:

- Specific cause and effect relationships between environmental factors (natural hazards, changes in climate, and the availability of natural resources) and features of human societies including population size and migration patterns; and
- That technology in modern civilization has mitigated some of the effects of natural hazards, climate, and the availability of natural resources on human activity.

*Evidence*

Students identify and describe the evidence to construct their explanation, including:

- Natural hazard occurrences that can affect human activity and have significantly altered the sizes and distributions of human populations in particular regions;
- Changes in climate that affect human activity (e.g., agriculture) and human populations, and that can drive mass migrations;
- Features of human societies that have been affected by the availability of natural resources; and
- Evidence of the dependence of human populations on technological systems to acquire natural resources and to modify physical settings.

Students use a variety of valid and reliable sources for the evidence, potentially including theories, simulations, peer review, or students' own investigations.

*Reasoning*

Students use reasoning that connects the evidence, along with the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future, to describe:

- The effect of natural hazards, changes in climate, and the availability of natural resources on features of human societies, including population size and migration patterns; and
- How technology has changed the cause and effect relationship between the development of human society and natural hazards, climate, and natural resources.

Students describe reasoning for how the evidence allows for the distinction between causal and correlational relationships between environmental factors and human activity.

**ESS3-2.** Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.

*Supported claims*

Students describe the nature of the problem each design solution addresses.

Students identify the solution that has the most preferred cost-benefit ratios.

*Identifying scientific evidence*

Students identify evidence for the design solutions, including:

Societal needs for that energy or mineral resource;

The cost of extracting or developing the energy reserve or mineral resource;

The costs and benefits of the given design solutions; and

The feasibility, costs, and benefits of recycling or reusing the mineral resource, if applicable.

*Evaluation and critique*

Students evaluate the given design solutions, including:

- The relative strengths of the given design solutions, based on associated economic, environmental, and geopolitical costs, risks, and benefits;
- The reliability and validity of the evidence used to evaluate the design solutions; and
- Constraints, including cost, safety, reliability, aesthetics, cultural effects environmental effects.

*Reasoning/synthesis*

Students use logical arguments based on their evaluation of the design solutions, costs and benefits, empirical evidence, and scientific ideas to support one design over the other(s) in their evaluation.

Students describe that a decision on the "best" solution may change over time as engineers and scientists work to increase the benefits of design solutions while decreasing costs and risks.

**ESS3-4.** Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

*Using scientific knowledge to generate the design solution*

Students use scientific information to generate a number of possible refinements to a given technological solution.

Students:

- Describe the system being impacted and how human activity is affecting that system;
- Identify the scientific knowledge and reasoning on which the solution is based;
- Describe how the technological solution functions and may be stabilizing or destabilizing the natural system;
- Refine a given technological solution that reduces human impacts on natural systems; and
- Describe that the solution being refined comes from scientists and engineers in the real world who develop technologies to solve problems of environmental degradation

*Describing criteria and constraints, including quantification when appropriate*

Students describe and quantify (when appropriate):

- Criteria and constraints for the solution to the problem; and
- The tradeoffs in the solution, considering priorities and other kinds of research-driven tradeoffs in explaining why this particular solution is or is not needed.
- Evaluating potential refinements
    - In their evaluation, students describe how the refinement will improve the solution to increase benefits and/or decrease costs or risks to people and the environment.
    - Students evaluate the proposed refinements for:
        - Their effects on the overall stability of and changes in natural systems; and
        - Cost, safety, aesthetics, and reliability, as well as cultural and environmental impacts.

**ESS3-5.** Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

*Organizing data*

Students organize data (e.g., with graphs) from global climate models (e.g., computational simulations) and climate observations over time that relate to the effect of climate change on the physical parameters or chemical composition of the atmosphere, geosphere, hydrosphere, or cryosphere.

Students describe what each data set represents.

*Identifying relationships*

Students analyze the data and identify and describe relationships within the datasets, including:

- Changes over time on multiple scales; and
- Relationships between quantities in the given data.

In their interpretation of the data, students:

- Make a statement regarding how variation or uncertainty in the data (e.g., limitations, accuracy, any bias in the data resulting from choice of sample, scale, instrumentation, etc.) may affect the interpretation of the data; and
- Identify the limitations of the models that provided the simulation data and ranges for their predictions.

**ESS3-6.** Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

*Representation*

Students identify and describe the relevant components of each of the Earth systems modeled in the given computational representation, including system boundaries, initial conditions, inputs and outputs, and relationships that determine the interaction (e.g., the relationship between atmospheric CO2 and production of photosynthetic biomass and ocean acidification).

*Computational modeling*

Students use the given computational representation of Earth systems to illustrate and describe relationships among at least two of Earth's systems, including how the relevant components in each individual Earth system can drive changes in another, interacting Earth system.

*Analysis*

Students use evidence from the computational representation to describe how human activity could affect the relationships between the Earth's systems under consideration.