Carbon and Energy in Ecosystems - Diagnostic Question Clusters
Student Version

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Introduction

Understanding ecological processes requires an understanding of smaller scale processes such as those at the molecular, cellular and organismal scales. The diagnostic question clusters (DQC's) created for this project are designed to help professors unpack their students understanding of ecological processes, identifying smaller scale problems that limit large scale understanding.

The created DQC's include a multiple process "umbrella" question followed by several single process questions that help to gauge student understanding of smaller scale processes that limit their ability to understand the "umbrella" question. Based on preliminary analysis of student responses, we've identified 10 DQC's to include in this project. All 10 of the chosen DQC's are organized around topics commonly found in introductory ecology classes, and less so in introductory biology classes.

DQC's are organized into five main topics, with two DQC's in each topic. The organization is shown in the table below. Most of the DQC's will be improved based on previous student responses, but the primary structure will remain the same.

	DQC Topics				
	Carbon Cycling	**Trophic Levels**	**Energy Flow in Ecosystems**	**Understanding Climate Change**	**Carbon Dynamics in Energy Production**
DQC 1	Forest Carbon	Carbon in Nature	Energy Pyramid	Carbon Balance	Biofuels
DQC 2	Grandma Johnson	Trophic Transfer	Rainforest	Keeling Curve	Gasoline

Carbon Cycling DQC's

Conservation of matter is a principle that must be applied to understand concepts in ecosystem ecology. **Forest Carbon** and **Grandma Johnson** are two parallel diagnostic question clusters (DQC's) designed to diagnose student ability to trace carbon through ecosystems. Each DQC begins with an ecosystem scale question about ecosystem carbon cycling that requires students to apply multiple carbon transformation processes in order to provide a correct answer. Within each DQC, subsequent questions ask students to display knowledge of individual processes that are occurring in the initial multiple process question. This design will allow you, the instructor, to identify what processes students don't understand, which are preventing their understanding of ecosystem carbon cycling. A list of individual process questions are shown in the table below.

Processes	**Forest Carbon**	**Grandma Johnson**
Multiple Process	CARBPOOL (1)	GRANJOHN (1)
Transformation – Plant to Plant	CARBPATHSB (5b)	CARBPATHSB (4b)
Transformation – Plant to Soil	CARBPATHSD (5d)	CARBPATHSD (4d)
Transformation – Plant to Animal	CARBPATHSC (5c)	CARBPATHSC (4c)
Transformation – Animal to Animal		COYOTE (5)
Photosynthesis	PLANTRESP2 (2), PLANTRESP1 (3), MASSCHANGE (6a)	MAPLEMASS (3)
Respiration – Decomposition	SOILRESP (4), MASSCHANGEC (6c)	BREADMOLD (2), POTATOMASS (6)
Respiration – Plants	CARBPATHSA (5a), PLANTRESP2 (2), PLANTRESP1 (3)	CARBPATHSA (4a)
Respiration – Animals	PLANTRESP1 (3), MASSCHANGEB (6b)	

Forest Carbon Balance Diagnostic Question Cluster

Carbon transformations are occurring everywhere in a forest. Plants are photosynthesizing, generating organic carbon from carbon dioxide. Organic carbon is being transformed into other organic sources within plants, and between organisms through processes such as biosynthesis and digestion. All organisms are involved in respiration, converting organic carbon sources into inorganic forms. Students must consider all of these carbon transformation processes to provide a proper rationale for their answer to question one about the balance of carbon in a forest (the multiple process question). Even though question one is asking about a process at the ecosystem scale, knowledge of carbon cycling processes at the molecular and organismal scales are necessary for proper understanding of the ecosystem based question. The individual carbon cycling processes involved are posed to students in questions 2-6, enabling teachers to correctly diagnose carbon cycle misunderstandings that limit correct explanations to question one of this DQC.

Forest Carbon Balance Diagnostic Question Cluster

Please answer the questions below as carefully and completely as you can.

1. In an old growth forest, which of these statements would you expect to be true?
   A) An old growth forest absorbs more carbon dioxide than it releases
   B) An old growth forest releases more carbon dioxide than it absorbs
   C) An old growth forest absorbs and releases about the same amount of carbon dioxide

Please explain your answer.

2. In plants, …
   A) photosynthesis occurs but there is no respiration.
   B) photosynthesis occurs in the light and respiration occurs in the dark.
   C) respiration occurs 24 hours a day and photosynthesis occurs in the light.
   D) photosynthesis and respiration occur but not at the same time.
   E) Responses B. and C. are correct.

3. Considering the cellular processes of photosynthesis and respiration, which statements are true? Circle True (T) or False (F) for each response.

T F Photosynthesis is the process by which plants respire.
T F Both animals and plants respire and release CO_2.
T F During respiration, animals release CO_2 and plants release O_2.
T F During respiration, animals release O_2 and plants release CO_2.

4. Circle all correct answers. In most terrestrial ecosystems, soil respiration ...
   A) happens when rocks break down.
   B) is not linked to decomposition rates.
   C) typically decreases as soil moisture increases.
   D) refers to respiration by organisms living in the soil.
   E) typically decreases as temperatures increase.
   F) Includes gases from plant roots

5. Once carbon enters a plant, it can …

A) exit the plant as CO_2. Circle True or False
Explain

B) become part of the plant cell walls, protein, fat, and DNA. Circle True or False
Explain

C) be consumed by an insect feeding on the plant and become part of the insect's body. Circle True or False
Explain

D) be converted to energy for plant growth. Circle True or False
Explain

E) become part of soil organic matter when parts of the plants die and fall off the plant. Circle True or False
Explain

How do each of the processes below affect the mass of the systems where they are occurring?

6a. When a plant absorbs CO_2 and releases O_2 during photosynthesis:

A) The process increases the mass of the plant
B) The process decreases the mass of the plant
C) The process does not affect the mass of the plant.

Please explain your answer.

6b. When an animal breathes in O_2 and breathes out CO_2:

A) The process increases the mass of the animal
B) The process decreases the mass of the animal
C) The process does not affect the mass of the animal.

Please explain your answer.

6c. When leaves in the soil decay:

A) The process increases the mass of the soil
B) The process decreases the mass of the soil
C) The process does not affect the mass of the soil.

Please explain your answer.

Grandma Johnson Diagnostic Question Cluster

“Grandma Johnson” (Ebert-May et al. 2003) is an excellent multiple process question for diagnosing student reasoning about various dynamics in the carbon cycle. Students must trace carbon from organic sources in Grandma Johnson, through cellular respiration by decomposers and into the atmosphere as carbon dioxide, into plants via photosynthesis and biosynthesis, to herbivores via digestion and biosynthesis that eat the plants and finally to the coyote, which consumes an herbivore. The question specifically asks about multiple organisms, making it an ecosystem level question, but knowledge of organismal and molecular scale processes is required to understand the true pathway that carbon atoms take from Grandma Johnson to the coyote. Questions 2-6 are designed to further diagnose and interpret student reasoning about specific processes in the carbon cycle, which must be properly applied to correctly answer the multiple process, Grandma Johnson question.

Ebert-May, D., J. Batzli and H. Lim (2003). "Disciplinary research strategies for assessment of learning." Bioscience **53**(12): 1221-1228.

Grandma Johnson Diagnostic Question Cluster

Please answer the questions below as carefully and completely as you can.

1. Grandma Johnson had very sentimental feelings toward Johnson Canyon, Utah, where she and her late husband had honeymooned long ago. Because of these feelings, when she died she requested to be buried under a creosote bush in the canyon. Describe below the path of a carbon atom from Grandma Johnson's remains, to inside the leg muscle of a coyote. Be as detailed as you can be about the various molecular forms that the carbon atom might be in as it travels from Grandma Johnson to the coyote. **NOTE:** The coyote does not dig up and consume any part of Grandma Johnson's remains.

2. A loaf of bread was left uncovered for two weeks. Three different kinds of mold grew on it. Assuming that the bread did not dry out, which of the following is a reasonable prediction of the weight of the bread and mold together?

A) The mass has increased, because the mold has grown.
B) The mass remains the same as the mold converts bread into biomass.
C) The mass decreases as the growing mold converts bread into energy.
D) The mass decreases as the mold converts bread into biomass and gases.

Please explain your answer.

3. A mature maple tree can have a mass of 1 ton or more (dry biomass, after removing the water), yet it starts from a seed that weighs less than 1 gram. Which of the following processes contributes the most to this huge increase in biomass? Circle the correct answer.

A) absorption of mineral substances from the soil via the roots
B) absorption of organic substances from the soil via the roots
C) incorporation of CO_2 gas from the atmosphere into molecules by green leaves
D) incorporation of H_2O from the soil into molecules by green leaves
E) absorption of solar radiation into the leaf

4. Once carbon enters a plant, it can …

A) exit the plant as CO_2. Circle True or False
Explain

B) become part of the plant cell walls, protein, fat, and DNA. Circle True or False
Explain

C) be consumed by an insect feeding on the plant and become part of the insect's body. Circle True or False
Explain

D) be converted to energy for plant growth. Circle True or False
Explain

E) become part of soil organic matter when parts of the plants die and fall off the plant. Circle True or False
Explain

5. Coyotes are carnivores. Their bodies include many substances, including proteins in all their cells. What percent of the carbon atoms in a coyote's body were once in the following substances and locations? Fill in the blanks with the appropriate percentages; you may use 0% in your response if you feel it is appropriate. The percentages do not have to add up to 100%.

____% from CO_2 that was used by plants for photosynthesis
____% from animals that the coyote ate
____% from CO_2 that the coyotes inhaled
____% from inhaling O_2
____% from soil nutrients that plants absorbed while growing

Please explain your answer.

6. A potato is left outside and gradually decays. One of the main substances in the potato is the starch amylose ($(C_6H_{10}O_5)_n$). What happens to the atoms in amylose molecules as the potato decays? Choose True (T) or False (F) for each option.

T F Some of the atoms are converted into nitrogen and phosphorous: soil nutrients.
T F Some of the atoms are consumed and used up by decomposers.
T F Some of the atoms are incorporated into carbon dioxide.
T F Some of the atoms are converted into energy by decomposers.

Trophic Levels DQC's

Tracing matter (carbon) is key to understanding how and why mass decreases as trophic levels increase. During each transformation step, matter is converted from organic forms to gaseous forms during cellular respiration. Students who fail to recognize or apply the process of cellular respiration during photosynthesis, herbivory and predation struggle to understand changes in biomass at different trophic levels. **Carbon in Nature** and **Trophic Transfer** are two Diagnostic Question Clusters (DQC's) that can diagnose student understanding of the processes involved mass relationships between trophic levels. Multiple process questions ask students to identify carbon in different trophic levels, and subsequent questions focus on the single processes involved in regulating the mass at different trophic levels. The names of individual questions categorized by process are shown in the table below.

Processes	**Carbon in Nature**	**Trophic Transfer**
Multiple Process	CARBNATOR (1)	TROPMASS (1)
Photosynthesis	FOODMOVE (2), GRASSCO2B (5)	PLANTRESPA (3), FOODMOVE (2)
Transformation – Plant to Plant	FOODMOVE (2)	FOODMOVE (2), CARBPATHSB (7b)
Transformation – Plant to Soil		CARBPATHSD (7d)
Transformation – Plant to Animal	FWFEEDING (4)	FWFEEDING (6), CARBPATHSC (7c)
Transformation – Animal to Animal	FWFEEDING (4)	DEERWOLV (5), FWFEEDING (6)
Respiration – Decomposition	DECDIED (3)	
Respiration – Plants	CO2ATM (6)	PLANTRESPA (3), CARBPATHSA (7a)
Respiration – Animals	CO2ATM (6)	FAT15 (4)
Combustion	CO2ATM (6)	

Carbon in Nature Diagnostic Question Cluster

An important key to understanding trophic level dynamics, which is a major topic in ecology courses, is correctly locating carbon in various trophic levels. In addition, students must be able to understand how carbon moves between organisms and trophic levels. This diagnostic question cluster begins with a multiple part question asking students to locate carbon in different parts of an ecosystem, and describe how the carbon got to the various places asked about. Subsequent questions follow up on the processes by which carbon is transferred between organisms, and between organic and inorganic sources. Most questions explicitly ask students to reason at an organismal or ecosystem scale, but implicitly include an understanding of molecular level processes.

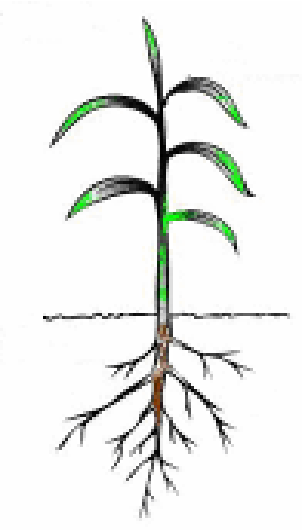
Carbon in Nature Diagnostic Question Cluster

Please answer the questions below as carefully and completely as you can.

1. Carbon exists in different molecules or substances in nature. Please explain where carbon might exist in a forest.

Question:	YES or NO	If YES, what substances in these locations contain the carbon?	If YES, where did the carbon in these substances come from?
Do you think you would find carbon in trees?			
Do you think you would find carbon in the soil?			
Do you think you would find carbon in animals, like deer and wolves?			
Do you think you would find carbon in bacteria in the soil?			
Do you think you would find carbon in the air?			
Where else you might you find carbon?			

2. Draw arrows to explain how food moves through a green plant. Explain what the plant's food is, and where it comes from.



3a. What would happen to the carbon cycle if all decomposers suddenly died and were not replenished? Decide whether each statement is true (T) or false (F).

T F Carbon would accumulate in organic matter.
T F There would be more carbon in the soil for plants to absorb.
T F Carbon would cycle more rapidly without decomposers.
T F Carbon in the atmosphere would increase.

3b. Circle all correct answers. The reason for my responses are that …

A) plants get their carbon from soil through their roots.
B) decomposers serve as a "sink" for carbon and hold it in reserve.
C) with no decomposers the carbon isn't released as CO_2.
D) with one less segment of the food web, carbon would cycle faster.
E) None apply; I wrote my reason to the right of the question.

4. Organisms higher in a food web:

A) eat everything that is lower on the food web.
B) eat organisms directly below them in the food web, but not lower than that.
C) eat only some species directly below them in the food web, but not lower than that.
D) eat only some species directly below them in the food web and some others lower in the food web as well.

Please explain your answer.

5. Explain how increased carbon dioxide in the atmosphere might affect the grasses growing on a soccer field.

6. Carbon exists in the atmosphere, where could it have come from? Circle all correct answers.

A) Photosynthesis by plants
B) Diffusion from the ocean
C) Cellular respiration by plants
D) Cellular respiration by animals
E) Cellular respiration by bacteria
F) Photosynthesis by fungi
G) Burning of biofuels
H) Burning of fossil fuels
I) Depletion of the ozone layer

Trophic Transfer Diagnostic Question Cluster

The Tropic Transfer DQC is parallel to the Carbon in Nature DQC, but takes a slightly different angle. Students are asked in question one to provide a reasonable expectation for the mass at various trophic levels. To correctly answer this question, students need to trace matter during herbivory and predation. Specifically, students must correctly identify that carbon is oxidized during aerobic cellular respiration, therefore resulting in decreasing mass as trophic levels increase. Detailed knowledge of molecular scale processes is necessary to piece together the information required to correctly answer the initial ecosystem level question. Wilson et al. (2006) published a slightly different version of question 3 as part of a project to diagnose student ability to trace matter in cell biology systems.

Wilson, C. D., C. W. Anderson, M. Heidemann, J. E. Merrill, B. W. Merritt, G. Richmond, D. F. Sibley and J. M. Parker (2006). "Assessing students' ability to trace matter in dynamic systems in cell biology." Life Sciences Education **5**: 323-331.

Trophic Transfer Diagnostic Question Cluster

Please answer the questions below as carefully and completely as you can.

1. About how much biomass would you expect to find in the herbivores and carnivores in this ecosystem?

Plants 10,000 kg Herbivores _____ kg Carnivores _____ kg

Please explain your answer.

2. Draw arrows to explain how food moves through a green plant. Explain what the plant's food is, and where it comes from.

3. A potted geranium plant sits in a windowsill, absorbing sunlight. After I put this plant in a dark closet for a few days (but keeping it watered), will it weigh more or less (discounting the weight of the water) than before I put it in the closet?

A) It will weigh less because it is still respiring.
B) It will weigh less because no photosynthesis is occurring.
C) It will weigh more because the Calvin cycle reactions continue.
D) It will weigh the same since no biomass is produced.
E) It will weigh more because it still has access to water and soil nutrients.

4. Your friend lost 15 pounds of fat by dieting. Fat molecules are made from glycerol ($C_3H_5(OH)_3$) and fatty acids such as stearic acid ($C_{17}H_{35}COOH$). What happened to the atoms in the fat molecules when your friend lost weight. Choose True (T) or False (F) for each possibility.

T F Some of the atoms in the fat left your friend's body in carbon dioxide molecules.
T F Some of the atoms in the fat left your friend's body in feces.
T F Some of the atoms in the fat were converted into energy for body heat and exercise.
T F Some of the atoms in the fat left your friend's body in water molecules.
T F Some of the atoms in the fat were burned up when your friend exercised.

5. A remote island in Lake Superior is uninhabited by humans. The primary mammal populations

are white-tailed deer and wolves. The island is left undisturbed for many years. Select the best answer(s) below for what will happen to the average populations of the animals over time.

_____a. On average, there will be a few more deer than wolves.
_____b. On average, there will be a few more wolves than deer.
_____c. On average, there will be many more deer than wolves.
_____d. On average, there will be many more wolves than deer.
_____e. On average, the populations of each would be about equal.
_____f. None of the above. My answer would be: _____
_____
_____

Please explain your answer to what happens to the populations of deer and wolves.

6. Organisms higher in a food web:

A) eat everything that is lower on the food web.
B) eat organisms directly below them in the food web, but not lower than that.
C) eat only some species directly below them in the food web, but not lower than that.
D) eat only some species directly below them in the food web and some others lower in the food web as well.

Please explain your answer.

7. Once carbon enters a plant, it can …

A) exit the plant as CO_2. Circle True or False
Explain

B) become part of the plant cell walls, protein, fat, and DNA. Circle True or False
Explain

C) be consumed by an insect feeding on the plant and become part of the insect's body. Circle True or False
Explain

D) be converted to energy for plant growth. Circle True or False
Explain

E) become part of soil organic matter when parts of the plants die and fall off the plant. Circle True or False
Explain

Energy Flow DQC's

Unlike matter, which cycles within the Earth's ecosystems, energy flows directionally, entering the Earth's ecosystems as sunlight and leaving as reflected sunlight or heat. The biosphere is an "open" system with respect to energy. However, energy and matter are coupled, but are not interchangeable; students struggle to understand this relationship. A common misconception is that matter is converted to energy during transformations of organic material, and is often accentuated by commonly used phrases (e.g. "Cereal at breakfast provides the energy needed for an active day"). Plants capture solar energy and store it as chemical energy within carbon compounds, and most of this chemical energy is converted to heat energy during cellular respiration. Two Diagnostic Question Clusters (DQC's), **Energy Pyramid** and **Rainforest** provide parallel questions to diagnose student reasoning about energy flow through ecosystems. Both DQC's ask students to reason about an ecosystem scale energy flow question, and subsequent questions diagnose their ability to trace energy through individual processes involved in energy flow through ecosystems. The goal is to identify the knowledge gaps, misconceptions and misapplications that prevent students from understanding ecosystem scale questions. The names of individual questions categorized by process are shown in the table below.

Processes	**Energy Pyramid**	**Rainforest**
Multiple Process	ENERPYR1 (1)	TROPFOREST (1)
Photosynthesis	LDTREES(3), CORNGROW (7),	ECOENER1 (2a), WOLVSUN (2b) ENERGYL1 (3), TREEFOREST (6)
Transformation – Plant – Plant	LDTREES (3)	TREEFOREST (6)
Transformation Plant – Animal	GRAPGLUC (4)	ENERGAINA (4a) WOLVSUN (2b)
Transformation – Plant to Decomposer	BREADMOLD (6)	BREADMOLD (5)
Transformation – Energy Loss	ENERPYR3 (2), TROPHERNER (5)	ENERGAINB (4b)
Respiration – Decomposition	BREADMOLD (6), LDTREES (3)	COMPOST (7), BREADMOLD (5)

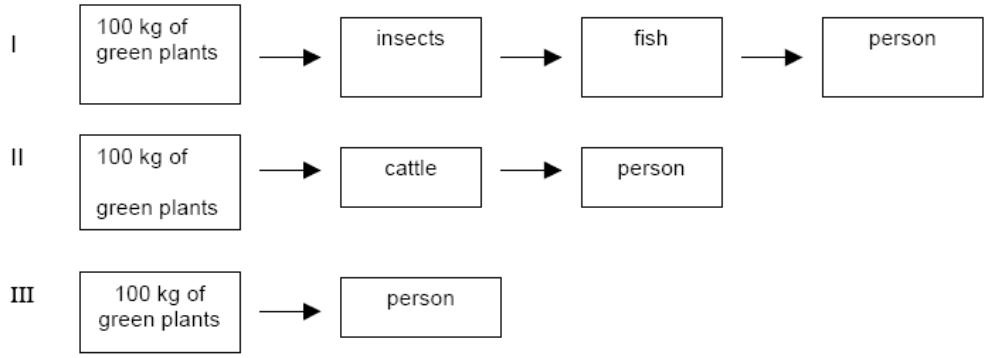
Energy Pyramid Diagnostic Question Cluster

Tracing energy is a necessary principle for understanding ecosystem ecology. Many students incorrectly consider higher trophic levels to contain more energy than lower trophic levels, which is often based on their own experiences consuming vegetables vs. meat products. This DQC specifically asks students to trace energy through trophic levels, and properly identify that energy is lost as heat as matter is transferred within organisms and between trophic levels. Following the initial ecosystem scale, multiple process question, students are asked about processes regarding energy flow, with questions at molecular, organismal and ecosystem scales.

Energy Pyramid Diagnostic Question Cluster

Please answer the questions below as carefully and completely as you can.

1. Consider the three diagrams below. They represent three situations in which 100 kg of green plants serve as the original source of food for each of the food chains. In situation II, for example, cattle eat 100 kg of green plants and then people eat the beef that is produced by the cattle as a result of having eaten the plants.



In which of the three situations is the most energy available to the person?

A) I
B) II
C) III
D) Situations I and II will roughly tie for the most energy.
E) The same amount of energy will be available to the person in all three situations.

Please explain your answer.

2. A land ecosystem contains grass, grasshoppers, sparrows, and hawks. Which population contains the least energy in the ecosystem?

A) grass
B) grasshoppers
C) sparrows
D) hawks
E) this question does not provide enough information

Please explain your answer.

3. Does a living tree have energy? Yes / No
Does a dead tree have energy? Yes / No
Please explain your answers.

4. You eat a grape high in glucose content. How could a glucose molecule from the grape provide energy to move your little finger?

A) The glucose is digested into simpler molecules having more energy.
B) The glucose reacts to become ATP (Adenosine Triphosphate).
C) The glucose is converted into energy.
D) The energy of the glucose is transferred to other molecules.
E) The energy of the glucose is transferred to CO_2.and H2O.

5. The top of a food web:

A) accumulates all of the energy that existed in the consumed organisms that were lower in the food web.
B) has less available energy than trophic levels below it.
C) has the same amount of accumulated energy as each of the trophic levels below it.
D) has available to it all of the energy of the food web.

Please explain your answer.

6. A loaf of bread was left uncovered for two weeks. Three different kinds of mold grew on it. Assuming that the bread did not dry out, which of the following is a reasonable prediction of the weight of the bread and mold together?

A) The mass has increased, because the mold has grown.
B) The mass remains the same as the mold converts bread into biomass.
C) The mass decreases as the growing mold converts bread into energy.
D) The mass decreases as the mold converts bread into biomass and gases.

Please explain your answer.

7. Each Spring, farmers plant about 5-10 kg of seed corn per acre for commercial corn production. By the fall, this same acre of corn will yield approximately 4-5 metric tons (4,000 – 5,000 kg) of dry, harvested corn. What percent of the mass of the harvested corn was once in the following substances and locations? Fill in the blanks with the appropriate percentages; you may use 0% in your response if you feel it is appropriate.

___ % from absorption of mineral substances from the soil via the roots
___ % from absorption of organic substances from the soil via the roots
___ % from incorporation of CO_2 gas from the atmosphere into molecules by green leaves
___ % from incorporation of H_2O from the soil into molecules by green leaves
___ % from absorption of solar radiation into the leaf

Please explain your answer.

Rainforest Diagnostic Question Cluster

A large proportion if general biology students assume that both matter and energy are recycled within ecosystems, indicating that students have more trouble tracing energy in ecosystems than matter. The multiple process question at the beginning of this DQC asks students to decide whether matter and energy are recycled within ecosystems, and provide a detailed explanation of their answer. Subsequent questions 2-7 are designed to further diagnose student reasoning about energy flow within ecosystems, and their ability to identify the relationship between matter and energy. Most questions are posed at the scale of the ecosystem, requiring implicit knowledge of molecular processes. Questions three and six ask questions directed more at the molecular scale.

Rainforest Diagnostic Question Cluster

Please answer the questions below as carefully and completely as you can.

1. A tropical rainforest is an example of an ecosystem. Which of the following statements about matter and energy in a tropical rainforest is the most accurate? Please choose ONE answer that you think is best.

A) Energy is recycled, but matter is not recycled.
B) Matter is recycled, but energy is not recycled.
C) Both matter and energy are recycled.
D) Neither matter nor energy are recycled.

Please explain why you think that the answer you chose is better than the others.

2a. What is the ultimate energy source for ecosystems? Please circle the correct answer.

A) nutrients
B) sunlight
C) water
D) carbon
E) carbohydrates
F) others

2b. Wolves are nocturnal, meaning that they search for food at night. Therefore, could wolves live without sunlight? Circle Yes or No.
Why or why not?

3. Sunlight helps plants to grow. Where does light energy go when it is used by plants? Please choose the ONE answer that you think is best.

A) The light energy is converted into glucose of the plants.
B) The light energy is converted into ATP in the plants.
C) The light energy is used up to power the process of photosynthesis.
D) The light energy becomes chemical bond energy.
E) The light energy does not go into the plants' body.

4a. Of the energy gained by a plant (i.e. producer), what percentage is typically transferred to a rabbit that eats the plant?

A) 90-100%
B) 60-70%
C) 30-40%
D) 10-20%

4b. If you chose B, C or D, what happens to the energy that does not get transferred between the plant and rabbit?

5. A loaf of bread was left uncovered for two weeks. Three different kinds of mold grew on it. Assuming that the bread did not dry out, which of the following is a reasonable prediction of the weight of the bread and mold together?

A) The mass has increased, because the mold has grown.
B) The mass remains the same as the mold converts bread into biomass.
C) The mass decreases as the growing mold converts bread into energy.
D) The mass decreases as the mold converts bread into biomass and gases.

Please explain your answer.

6. The trees in the rain forest contain molecules of chlorophyll a ($C_{55}H_{72}O_5N_4Mg$). Decide whether each of the following statements is true about the atoms in those molecules. Circle True (T) or False (F).

T F Some of the atoms in the chlorophyll came from carbon dioxide in the air.
T F Some of the atoms in the chlorophyll came from sunlight that provided energy for photosynthesis.
T F Some of the atoms in the chlorophyll came from water in the soil.
T F Some of the atoms in the chlorophyll came from nutrients in the soil.
T F Some of the atoms in the chlorophyll came from glucose produced by photosynthesis
T F Some of the atoms in the chlorophyll came from the seed that the tree grew from.

7. When the leaves in a compost pile decay, they lose mass. What do you think happens to the mass of the leaves? Circle True (T) or False (F).

T F The mass goes away when the leaves decompose.
T F The mass is converted to heat energy.
T F The mass is converted into soil minerals.
T F The mass is converted into carbon dioxide and water.

Please explain your answers.

Understanding Climate Change DQC's

What knowledge does a student, or citizen, need in order to understand a scientific document about climate change, such as the reports published by the Intergovernmental Panel on Climate Change? In addition to understanding the scientific method, students must decipher the complex chemical, biological and physical processes involved in the accumulation of atmospheric greenhouse gases and the ability of those gases to absorb infrared radiation reflected from the Earth's surface back towards the atmosphere. At the heart of understanding this complexity is tracing matter, particularly carbon, and tracing energy associated with carbon containing molecules. **Carbon Balance** and **Keeling Curve** are two parallel Diagnostic Question Clusters (DQC's) that are intended to diagnose problems in student reasoning about the processes involved in global climate change. Following an initial multiple process question, students are asked about individual processes contributing to the multiple process question. The names of individual questions categorized by process are shown in the table below.

Processes	**Carbon Balance**	**Keeling Curve**
Multiple Process	ATMBALANCE (1)	KLGSEASON (1)
Photosynthesis	FOODMOVE (3)	CORNGROW (3)
Transformation – Plant to Soil	ORIGFUEL (4), FALEAVEA (5a)	FALEAVEA (4a)
Respiration – Decomposition	FALEAVEA (5a), FALEAVEB (5a)	FALEAVEA (4a), FALEAVEB (4b)
Combustion	COALELEC (6)	QANGASCO (5)
Atmosphere – Greenhouse effect	GLOBWAMC (2)	EARTHWARM (6)
Biogeography		GLOBELAND (2)

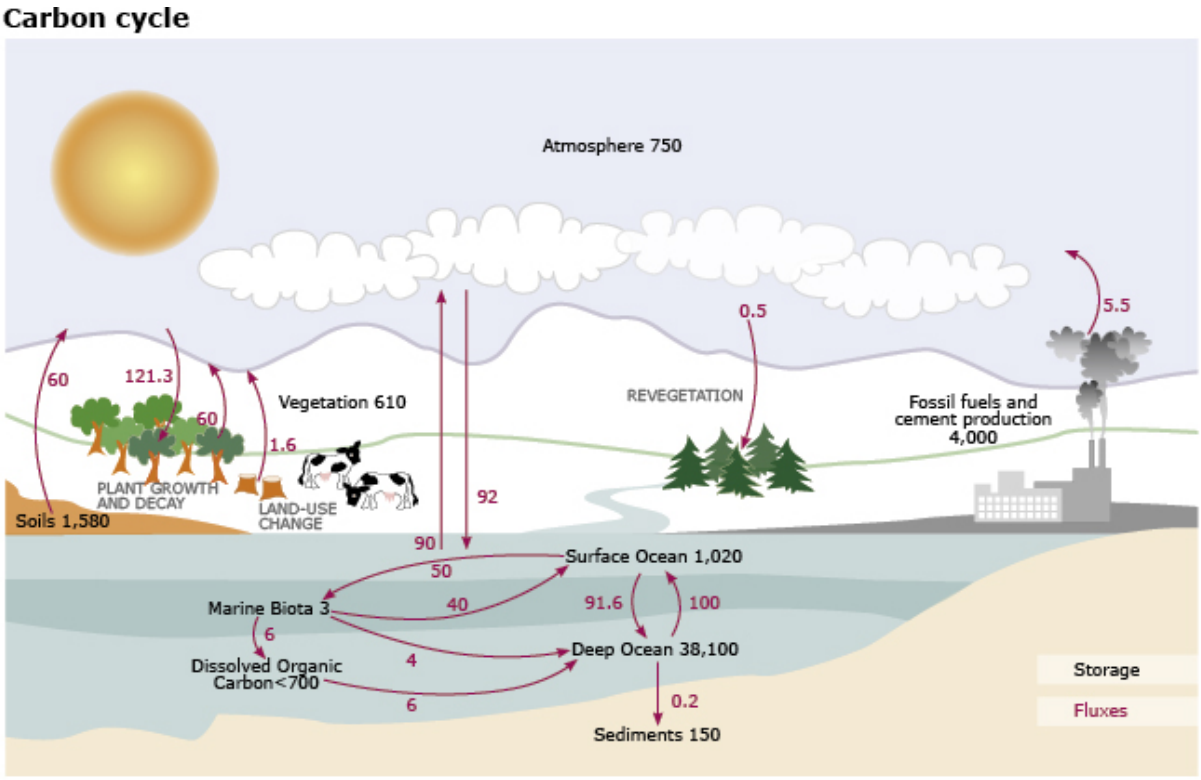
Carbon Balance Diagnostic Question Cluster

Human activities have caused an imbalance in the carbon cycle; most notable is the increase in atmospheric carbon dioxide. However, the rate at which carbon dioxide accumulates in the atmosphere depends on many other carbon transformation processes. In this DQC, students are asked to interpret a carbon cycle diagram that is out of balance; more carbon dioxide is entering the atmosphere than is leaving the atmosphere. Single process questions (2-6) that follow question one require students to individually trace matter through several different carbon transformations. These individual processes are imperative for understanding and explaining the larger imbalance in the global carbon cycle. At the ecosystem scale, students must reconcile human influences to the carbon cycle with ongoing carbon transformation processes occurring with or without human involvement, all the while applying their knowledge of processes that occur at the organismal and molecular levels.

Carbon Balance Diagnostic Question Cluster

Please answer the questions below as carefully and completely as you can.

The carbon cycle diagram shown below indicates the Earth's carbon pools and fluxes. The units used for pools are Pedagrams (10^{15} grams), and the fluxes are in Pedagrams per year.



1. Based on the diagram above, is atmospheric carbon at a steady state? Circle Yes or No. Please explain your answer.

2. Scientists believe that the average temperature of the earth's atmosphere has been increasing during the past 100 years. What is the major cause of this?

A) More heat is released from vehicles and factories into the atmosphere.
B) More particulate pollution (smog) is in the atmosphere.
C) More carbon dioxide is in the atmosphere.
D) Deterioration of the ozone layer
E) None of these causes global warming.

Please explain your answer.

3. Draw arrows to explain how food moves through a green plant. Explain what the plant's food is, and where it comes from.

4. Coal, oil, and gas are called fossil fuels. What were they before they became fossil fuels?

5a. In the fall, the leaves on trees in a deciduous forest fall to the ground. Explain what happens to the leaves once they fall to the ground.

5b. Do the changes in the dead leaves affect atmospheric carbon dioxide levels? Circle Yes or No. Why or why not?

6. Power plants often burn coal to produce electricity. Where do the atoms in the coal go when it is burned? Decide whether each of the statements below is true (T) or false (F).

T F Some of the mass of the coal produces carbon dioxide in the atmosphere.
T F Some of the mass of the coal produces sulfuric acid in the atmosphere.
T F Some of the mass of the coal is converted to heat and electrical energy.
T F Some of the mass of the coal produces oxygen in the atmosphere.
T F Some of the mass of the coal is consumed by the flame when it is burned.

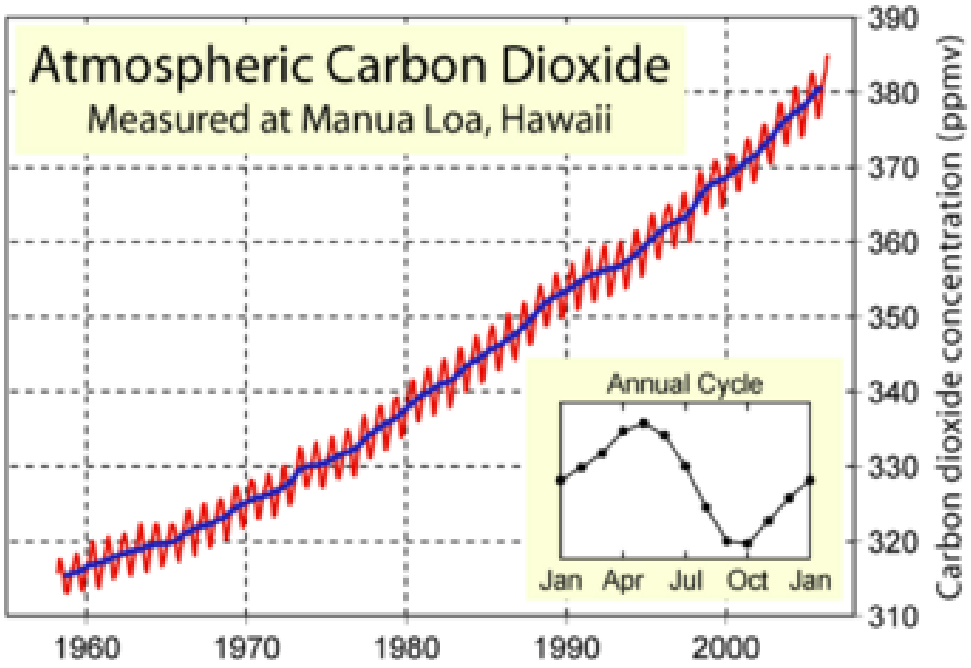
Keeling Curve Diagnostic Question Cluster

The Keeling Curve is a diagram that shows data collected on carbon dioxide levels at Mauna Loa, Hawaii, starting in the 1950's. This diagram shows increasing carbon dioxide levels across years, but fluctuating levels within years due to changes in photosynthesis and respiration across seasons. Students are asked to interpret this diagram, describing both the changing levels over multiple years and changes within a single season. In addition to the carbon transformation processes that must be understood to interpret the Keeling Curve (questions 3-5), students must also have an understanding of biogeography, that the majority of land mass is located in the Northern Hemisphere (question 2). Without hemisphere differences, intra-annual fluctuations would not be evident. This DQC poses questions to students at the ecosystem scale, including questions about human influences, but requires an implicit understanding of smaller scale processes, some of which are asked about in questions two through five.

Keeling Curve Diagnostic Question Cluster

Please answer the questions below as carefully and completely as you can.

1. The graph given below shows changes in concentration of carbon dioxide in the atmosphere over a 47-year span at Mauna Loa observatory at Hawaii.



1a. Why do you think this graph shows atmospheric carbon dioxide levels decreasing in the summer and fall and carbon dioxide levels increasing in the winter and spring?

1b. Why do you think the levels of carbon dioxide have increased from 1960 to present?

2. Would you expect to find more living plant mass in the Northern or Southern Hemisphere of the Earth? Please explain why you chose your answer.

3. Each Spring, farmers plant about 5-10 kg of seed corn per acre for commercial corn production. By the fall, this same acre of corn will yield approximately 4-5 metric tons (4,000 – 5,000 kg) of dry, harvested corn. What percent of the mass of the harvested corn was once in the following substances and locations? Fill in the blanks with the appropriate percentages; you may use 0% in your response if you feel it is appropriate.

___ % from absorption of mineral substances from the soil via the roots
___ % from absorption of organic substances from the soil via the roots
___ % from incorporation of CO_2 gas from the atmosphere into molecules by green leaves
___ % from incorporation of H_2O from the soil into molecules by green leaves
___ % from absorption of solar radiation into the leaf
Please explain your answer.

4a. In the fall, the leaves on trees in a deciduous forest fall to the ground. Explain what happens to the leaves once they fall to the ground.

4b. Do the changes in the dead leaves affect atmospheric carbon dioxide levels? Circle Yes or No.
Why or why not?

5a. Do you think the following statement can be correct? Circle Yes or No.
One gallon of gasoline, which weighs about 6.3 pounds, could produce 20 pounds of carbon dioxide when burned.

5b. Explain your reasoning. How could the carbon dioxide weigh more than the gasoline, or why is this impossible? (Note: Gasoline is a mixture of hydrocarbons such as octane: C_8H_{18}.)

Carbon Dynamics in Energy Production DQC's

Fossil fuel combustion is one of the major causes of increased carbon dioxide levels in the atmosphere. However, the accumulation of atmospheric carbon dioxide due to this combustion process is not as simple as it would appear, as the carbon atoms in gasoline were stored in locations not available for decomposition. Although biofuel combustion is the same process as fossil fuel combustion, biofuel combustion does not theoretically result in increased atmospheric carbon dioxide levels. The carbon transformation processes that lead to the "old" carbon in gasoline and the "new" carbon in biofuels are essential for reasoning about the outcomes of combustion. The two Diagnostic Question Clusters (DQC's) in this topic, **Biofuels** and **Gasoline**, intend to diagnose problematic student thinking about generation and combustion of these two transportation fuels, identifying the important processes involved that students fail to comprehend. The names of individual questions categorized by process are shown in the table below.

Processes	**Biofuels**	**Gasoline**
Multiple Process	BIOFUEL (1)	GASTRACE (1)
Photosynthesis	CARBRESB (3b), CORNGROW (7)	CARBRESB (3b), GASENMATTC (4c)
Transformation – Plant to Soil	SOILCLOSS1 (6a), SOILCLOSS3 (6c), SOILCLOSS4 (6d)	GASENMATTC (4c)
Respiration – Decomposition	SOILCLOSS2 (6b), SOILCLOSS3 (6c)	GASDECOMPA (7a)
Combustion	BIOCOMBUST (5)	OCTANE (2), ENERMTCH (5), GASDECOMPB (7b), GASENMATTA (4a), GASENMATTB (4b), GASENMATTD (4d)
Greenhouse Effect	GLOBWAMC (2)	EARTHWARM (6),
Carbon Residency Time	CARBRESA (3a)	CARBRESA (3a)
Biofuel Production	BIOFUEL2 (4)	

Biofuels Diagnostic Question Cluster

Biofuels are considered to be a source of transportation fuel that can help to reduce the need for fossil fuels, and reduce the rate at which greenhouse gases are accumulating in the atmosphere. In order to understand why biofuels theoretically do not contribute excess carbon dioxide to the atmosphere, students must have a detailed understanding of carbon transformations involved in producing biofuels, particularly the process of photosynthesis. Instead of citing the differences in origin of carbon in biofuels and fossil fuels, students assume that biofuel combustion does not result in the release of carbon dioxide. Question one in this DQC asks students to explain why utilization of biofuels would theoretically reduce the rate of global climate change, while subsequent questions dig deeper into the processes, such as photosynthesis and the greenhouse effect, that are involved in answering the first question. These single process questions aid in pinpointing the knowledge gaps in student understanding about the benefits and consequences of biofuel production and use for transportation.

Biofuels Diagnostic Question Cluster

Please answer the questions below as carefully and completely as you can.

1. Explain why the use of biofuels instead of fossil fuels is a strategy to slow the rate of global climate change. Use as much detail in your answer as you can.

2. Scientists believe that the average temperature of the earth's atmosphere has been increasing during the past 100 years. What is the major cause of this?

A) More heat is released from vehicles and factories into the atmosphere.
B) More particulate pollution (smog) is in the atmosphere.
C) More carbon dioxide is in the atmosphere.
D) Deterioration of the ozone layer
E) None of these causes global warming.

3a. On average, how long do you think a molecule of carbon dioxide remains in the atmosphere after being released by a human being?

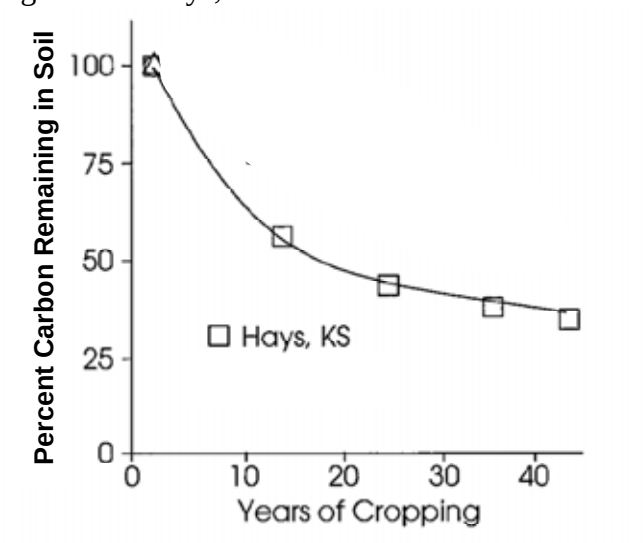
3b. After a period of time, the carbon atom released by a human being will leave the atmosphere. Where does the carbon atom go when it leaves the atmosphere?

4. What are biofuels? How are they different from fossil fuels?

5. Liquid biofuels are mostly a mixture of hydrocarbons, such as ethanol (C_2H_6). Decide whether each of the following statements is true (T) or false (F) about what happens to the atoms in a molecule of ethanol when it burns.

T F Some of the atoms in the ethanol are incorporated into carbon dioxide in the air.
T F Some of the atoms in the ethanol are incorporated into air pollutants such as ozone or nitric oxide.
T F Some of the atoms in the ethanol are converted into energy that moves the car.
T F Some of the atoms in the ethanol are burned up and disappear.
T F Some of the atoms in the ethanol are converted into heat.
T F Some of the atoms in the ethanol are incorporated into water vapor in the atmosphere.

6. The figure below shows the percent of carbon remaining in the soil during the first 40 years of growing crops in a prairie region near Hays, Kansas.



6a. How did carbon get into the soil before crops were grown?

6b. The percent of carbon remaining in soil decreased over time. Where did it go?

6c. If farmers continued to grow crops for more than 40 years, do you think the percent of soil carbon would eventually reach zero? Circle Yes or No. Why or why not?

6d. Scientists would suggest that carbon in the soil would increase if farmers stopped growing crops. Why would this increase in soil carbon occur?

7. Each Spring, farmers plant about 5-10 kg of seed corn per acre for commercial corn production. By the fall, this same acre of corn will yield approximately 4-5 metric tons (4,000 – 5,000 kg) of dry, harvested corn. What percent of the mass of the harvested corn was once in the following substances and locations? Fill in the blanks with the appropriate percentages; you may use 0% in your response if you feel it is appropriate.

___ % from absorption of mineral substances from the soil via the roots
___ % from absorption of organic substances from the soil via the roots
___ % from incorporation of CO_2 gas from the atmosphere into molecules by green leaves
___ % from incorporation of H_2O from the soil into molecules by green leaves
___ % from absorption of solar radiation into the leaf

Gasoline Diagnostic Question Cluster

Millions of years ago, the carbon atoms in gasoline were originally in carbon dioxide molecules in the atmosphere. Carbon dioxide was converted to organic forms during photosynthesis by plants. When the plants died, they were not decomposed, but instead were compressed in the Earth's crust for millions of years, ultimately resulting in the crude oil formation. The oil is refined into gasoline, and burned in internal combustion engines, which provides the energy necessary for movement. However, the carbon atoms once contained deep in the Earth's crust are released to the atmosphere during combustion, which has resulted in sharp increases in global atmospheric carbon dioxide levels. In this DQC, students are asked to trace carbon through the formation of gasoline, combustion and into the atmosphere. Questions one and two ask students to trace carbon through the entire history of gasoline, and subsequent questions are designed to further diagnose student difficulties in understanding the many processes involved in gasoline. Understanding the processes that govern matter transformations allows students to explain the consequences of burning gasoline as a transportation fuel.

Gasoline Diagnostic Question Cluster

Please answer the questions below as carefully and completely as you can.

1. The carbon atoms in gasoline were originally carbon dioxide (CO_2) in the atmosphere. Using words and or drawings, trace the carbon atoms from CO_2 in the atmosphere to octane (C_8H_{18}) in gasoline. Include as many steps and as much detail as you can.

2. Gasoline is mostly a mixture of hydrocarbons such as octane: C_8H_{18}. Decide whether each of the following statements is true (T) or false (F) about what happens to the atoms in a molecule of octane when it burns.

T F Some of the atoms in the octane are incorporated into carbon dioxide in the air.
T F Some of the atoms in the octane are incorporated into air pollutants such as ozone or nitric oxide.
T F Some of the atoms in the octane are converted into energy that moves the car.
T F Some of the atoms in the octane are burned up and disappear.
T F Some of the atoms in the octane are converted into heat.
T F Some of the atoms in the octane are incorporated into water vapor in the atmosphere.

3a. On average, how long do you think a molecule of carbon dioxide remains in the atmosphere after being released by a human being?

3b. After a period of time, the carbon atom released by a human being will leave the atmosphere. Where does the carbon atom go when it leaves the atmosphere?

4a. When you are riding in a car, the car burns gasoline to make it run. Eventually the gasoline tank becomes empty. What happened to the **matter** the gasoline was made of?

4b. When the gasoline tank became empty and the car stopped, where did the **energy** of gasoline go?

4c. What was the ultimate source of energy for the gasoline?

4d. Do cars need air in order to run? Yes / No
Please explain your answer.

5. When a match burns the energy released
A) comes mainly from the match.
B) comes mainly from the air.
C) is created by the fire.
D) comes from the energy that you used to strike the match.
E) none of the above
Please explain your answer.

6. The atmosphere's ability to keep the surface of the earth warm is caused by the ...
A) seasons.
B) greenhouse effect.
C) ozone layer.
D) wind.
E) Responses B. and C. are correct.

7a. Scientists have discovered several microorganisms that are able to decompose gasoline. What happens to the carbon atoms in the gasoline during decomposition?

7b. Do the carbon atoms following decomposition by microorganisms end up in a different location than if the gasoline was burned in a car? Circle Yes or No.
Please explain your answer.

Appendix I. Questions Organized by Process

List of All Multiple Process Questions:

Question Name	DQC	Question Number
ATMBALANCE	Carbon Balance	1
BIOFUEL	Biofuels	1
CARBNATOR	Carbon in Nature	1
CARBPOOL	Forest Carbon	1
ENERPYR1	Energy Pyramid	1
GASTRACE	Gasoline	1
GRANJOHN	Grandma Johnson	1
KLGSEASON	Keeling Curve	1
TROPFOREST	Rainforest	1
TROPMASS	Trophic Transfer	1

List of All Photosynthesis Questions:

Question Name	DQC	Question Number
CARBRESB	Biofuels	3b
	Gasoline	3b
CORNGROW	Energy Pyramid	7
	Keeling Curve	3
	Biofuels	7
ECOENER1	Rainforest	2a
ENERGYL1	Rainforest	3
FOODMOVE	Carbon in Nature	2
	Trophic Transfer	2
	Carbon Balance	3
LDTREES	Energy Pyramid	3
MAPLEMASS	Grandma Johnson	3
PLANTRESP1	Forest Carbon	3
PLANTRESP2	Forest Carbon	2
PLANTRESPA	Trophic Transfer	3
TREEFOREST	Rainforest	6
WOLVSUN	Rainforest	2b
GRASSCO2B	Carbon in Nature	5
GASENMATTC	Gasoline	4c

List of All Transformation Questions:

Plant to Plant

Question Name	DQC	Question Number
TREEFOREST	Rainforest	6
CARBPATHSB	Forest Carbon	5b
	Grandma Johnson	4b
	Trophic Transfer	7b
FOODMOVE	Carbon in Nature	2
	Trophic Transfer	2
LDTREES	Energy Pyramid	3

Plant to Animal

Question Name	DQC	Question Number
CARBPATHSC	Forest Carbon	5c
	Grandma Johnson	4c
	Trophic Transfer	7c
ENERGAINA	Rainforest	4a
FWFEEDING	Carbon in Nature	4
	Trophic Transfer	6
GRAPGLUC	Energy Pyramid	4
WOLVSUN	Rainforest	2b

Plant to Soil

Question Name	DQC	Question Number
CARBPATHSD	Forest Carbon	5d
	Grandma Johnson	4d
	Trophic Transfer	7d
SOILCLOSS1	Biofuels	6a
SOILCLOSS4	Biofuels	6d
FALLEAVEA	Carbon Balance	5a
	Keeling Curve	4a
ORIGFUEL	Carbon Balance	4
SOILCLOSS3	Biofuels	6c
GASENMATTC	Gasoline	4c

Plant to Decomposer

Question Name	DQC	Question Number
BREADMOLD	Energy Pyramid	6
	Rainforest	5
	Grandma Johnson	2

Animal to Animal

Question Name	DQC	Question Number
COYOTE	Grandma Johnson	5
DEERWOLV	Trophic Transfer	5
FWFEEDING	Carbon in Nature	4
	Trophic Transfer	6

Energy Loss

Question Name	DQC	Question Number
ENERGAINB	Rainforest	4b
ENERPYR3	Energy Pyramid	2
TROPHENER	Energy Pyramid	5

List of All Respiration Questions

Plant

Question Name	DQC	Question Number
CARBPATHSA	Forest Carbon	5a
	Grandma Johnson	4a
	Trophic Transfer	7a
PLANTRESPA	Trophic Transfer	3
CO2ATM	Carbon in Nature	6
PLANTRESP2	Forest Carbon	2
PLANTRESP1	Forest Carbon	3
MASSCHANGEA	Forest Carbon	6a

Animal (non decomposer)

Question Name	DQC	Question Number
FAT15	Trophic Transfer	4
CO2ATM	Carbon in Nature	6
PLANTRESP1	Forest Carbon	3
MASSCHANGEB	Forest Carbon	6b

Decomposer

Question Name	DQC	Question Number
BREADMOLD	Grandma Johnson	2
	Energy Pyramid	6
	Rainforest	5
COMPOST	Rainforest	7
DECDIED	Carbon in Nature	3
MASSCHANGEC	Forest Carbon	6c
LDTREES	Energy Pyramid	3
GASDECOMPA	Gasoline	7a
POTATOMASS	Grandma Johnson	6
SOILCLOSS2	Biofuels	6b
SOILCLOSS3	Biofuels	6c
SOILRESP	Forest Carbon	4
FALEAVEA	Carbon Balance	5a
	Keeling Curve	4a
FALEAVEB	Carbon Balance	5b
	Keeling Curve	4b

List of All Combustion Questions

Question Name	DQC	Question Number
BIOCOMBUST	Biofuels	5
COALELEC	Carbon Balance	6
ENERMTCH	Gasoline	5
OCTANE	Gasoline	2
QANGASCO	Keeling Curve	5
CO2ATM	Carbon in Nature	6
GASDECOMPB	Gasoline	7b
GASENMATTB	Gasoline	4b
GASENMATTD	Gasoline	4d
GASENMATTA	Gasoline	4a

List of All carbon Residence Time Questions (could this be transformation instead?)

Question Name	DQC	Question Number
CARBRESA	Biofuels	3a
	Gasoline	3a

List of All Atmospheric/Greenhouse Gas Questions

Question Name	DQC	Question Number
GLOBWAMC	Carbon Balance	2
	Biofuels	2
EARTHWARM	Keeling Curve	6
	Gasoline	6

List of All Biogeograpy Questions

Question Name	DQC	Question Number
GLOBELAND	Keeling Curve	2

List of All Biofuel Production Questions

Question Name	DQC	Question Number
BIOFUEL2	Biofuels	4