beetles
Science and Teaching for Field Instructors

Professional Learning Materials

Matter and Energy in Ecosystems

Matter is the "stuff" everything is made of, and energy is what enables everything to happen. Tracking the movement of matter and the flow of energy through ecosystems can be a powerful way of sharing many key ideas in ecology and environmental science. Student activities related to ecosystems, food chains, food webs, food pyramids, decomposition, photosynthesis, and predator–prey relationships are the mainstay of many outdoor science programs. However, for meaningful scientific understanding of these and how they are all interconnected, you need an understanding of how matter and energy move through ecosystems. It's a complex topic, so instructors need opportunities to wrangle with it as adult learners to uncover their own alternative conceptions and build their own more nuanced understanding of this critical idea—both to help them teach more accurately and coherently, as well as to help them build on students' alternative conceptions when they are teaching. During this science content session, participants use the lens of matter and energy to think about an ecosystem in which they teach, about Earth systems in general, and about systems at the level of an individual organism by using living organisms. They co-create diagrams, discuss ideas, come up with questions, learn content, answer some of their questions, and leave with new questions, as well as what will hopefully be an ongoing curiosity about the topic.

Goals for the session:

- **Discuss how matter cycles and energy flows through Earth's systems.**
- **Learn how food provides all organisms with the matter and energy they need to live and grow.**
- **Think about what organisms do with the matter and energy that enters their bodies and the matter and energy they release.**
- **Work in small groups to answer their questions about tracking matter and energy through ecosystems.**
- **Compare matter and energy flows and cycles at the scale levels of organisms, ecosystems, and the planet as a whole.**
- **Discuss the key concepts of the session and learn how these ideas are important for students to make sense of ecosystems.**
- **Learn how addressing this topic can support learning related to the Next Generation Science Standards (NGSS).**
- **Gain an understanding of and appreciation for the interconnectedness of living and nonliving things on our planet.**

THE LAWRENCE HALL OF SCIENCE
UNIVERSITY OF CALIFORNIA, BERKELEY

ABOUT BEETLES™

BEETLES™ (Better Environmental Education Teaching, Learning, and Expertise Sharing) provides environmental education programs nationally with research-based approaches and tools to continually improve their programs.

www.beetlesproject.org

Lawrence Hall of Science is the public science center of the University of California, Berkeley. www.lawrencehallofscience.org

Special Acknowledgments:
We are grateful to former BEETLES team member Lynn Barakos for her insights, perspective, and strong foundational work on this session and write-up.

We would also like to thank Dr. Art Sussman and Dr. Drew Talley for their expertise and knowledge in this topic area and for helping us address our own alternative conceptions around matter and energy in ecosystems.

BEETLES Team: **Craig Strang**, **Kevin Beals**, **Jedda Foreman**, and **Emilie Lygren**
Additional Contributors: **Emily Arnold**, **Lynn Barakos**, **José González**, **Catherine Halversen**, **Valeria Romero**, and **Emily Weiss**
Research Team: **Mathew Cannady**, **Melissa Collins**, **Rena Dorph**, **Aparajita Pande**, **Valeria Romero**, and **Aujanee Young**. Emeritus: **Bernadette Chi**, **Juna Snow**
Project Consultants: **John (Jack) Muir Laws**, **Penny Sirota**, and **Mark Thomas**
Advisory Board: **Nicole Ardoin**, **Kevin Crowley**, **José González**, **Maggie Johnston**, **Celeste Royer**, **Bora Simmons**, and **Art Sussman**. Emeritus: **Kathy DiRanna**, **Kathryn Hayes**, **April Landale**, **John (Jack) Muir Laws**, **Jack Shea**, **Penny Sirota**, **Drew Talley**, and **Mark Thomas**
Editor: **Trudihope Schlomowitz**
Designer: **Barbara Clinton**

The following programs contributed to the development of these materials by field testing and providing invaluable feedback. For a complete list of contributors and additional partners, please see beetlesproject.org/about/partners/

California: YMCA Camp Campbell, Rancho El Chorro Outdoor School, Blue Sky Meadow of Los Angeles County Outdoor Science School, YMCA Point Bonita, Walker Creek Ranch, Santa Cruz County Outdoor Science School, Foothill Horizons Outdoor School, Exploring New Horizons Outdoor Schools, Sierra Nevada Journeys, San Joaquin Outdoor Education, YMCA Camp Arroyo, Shady Creek Outdoor School, San Mateo Outdoor Education, Walden West Outdoor School, Westminster Woods.

Other locations: Balarat Outdoor Education, CO; Barrier Island Environmental Education Center, SC; Chincoteague Bay Field Station, VA; Eagle Bluff Environmental Learning Center, MN; Great Smoky Mountains Institute at Tremont, TN; Wellfleet Bay Wildlife Sanctuary Mass Audubon, MA; Mountain Trail Outdoor School, NC; NatureBridge (CA, WA, VA); Nature's Classroom (CT, MA, ME, NH, NY, RI); North Cascades Institute Mountain School, WA; NorthBay, MD; Outdoor Education Center at Camp Olympia, TX; The Ecology School, ME; UWSP Treehaven, WI; Wolf Ridge Environmental Learning Center, MN; YMCA Camp Mason Outdoor Center, NJ; and YMCA Erdman, HI.

Photos: Pages 1 and 2 by Kevin Beals. Icons: Backpack by Rémy Médard; Growth by Arthur Shlain; Cut by Nathan Thomson; Outside by Petr Holusa; Park by Antar Walker; Time by Wayne Middleton; & Diversity by Cara Foster all from The Noun Project.

Funding from 2012-2021 for BEETLES publications such as this one has been generously provided by the S.D. Bechtel, Jr. Foundation, The Dean Witter Foundation, Pisces Foundation, the Mary A. Crocker Trust.

To contact BEETLES™, email beetles@berkeley.edu

BEETLES™ Professional Learning Materials

Matter and Energy in Ecosystems

Contents

TEACHING ABOUT TEACHING

The presentations in this guide have been designed to practice what we preach. This session reflects a learner-centered approach to instruction as participants experience a version of an effective instructional model while they learn about matter and energy in ecosystems. It's important to maintain the structure of the session so participants have opportunities to access prior knowledge, explore and struggle with concepts and questions before being given new information, and have time to apply new ideas. Resist the temptation to provide a lot of information too early in the session. Simply telling instructors about matter and energy goes against the whole idea—participants will gain more from a meaning-making activity in which they experience, discuss, and process this important topic for themselves.

PRESENTATION OPTION

Want to spend more time outdoors than indoors? This entire session can be done outdoors. Some slides can be skipped when outdoors, but other text is important. You and your co-presenter can take turns writing text from slides onto whiteboards and/or print some slides, using a black font on a white background on the largest sheets of paper possible. You may want to put these in plastic page protectors.

TIMING TIP

Keep things moving. The prompts in the session are purposefully designed to generate productive and interesting conversations, but interesting discussions can make it challenging to stay within the estimated time frame. You may need to gently limit some of the discussion and then pick up on the topic at another time, perhaps after staff has had some experience with applying the teaching strategies.

SESSION OVERVIEW

	Matter and Energy in Ecosystems	Activity Locations	Estimated Time
Invitation	**Introduction and Overview** The topic of how matter and energy move through ecosystems is introduced as participants access their prior knowledge through a Quick-Write. The guiding questions and overall goals for the session are presented.		**10 minutes**
Exploration	**Food Web/Matter and Energy Diagram** Participants work in small groups to draw diagrams, including a food web and the nonliving parts of an ecosystem. They use arrows to show how matter and energy interact and move through the system. As they work, they record any questions about key ideas that come up.		**25 minutes**
Concept Invention	**Earth Ecosystem Diagram** The facilitator leads the whole group to co-create an ecosystems matter/energy diagram that helps make thinking visible and helps participants generalize and extend ideas from their small- group work.	or	**25 minutes**
Application	***Food, Build, Do, Waste* Activity** Participants find and observe an organism and discuss how the organism uses matter from food to build body structures and energy from food to do things. Participants also think about the matter and energy that are emitted by the organism.		**30–50 minutes**
	Break: If you are splitting the session into two shorter sessions, this is a good stopping point. If not, it's a good time for a short break.		
Exploration	**Thought Problems** Small groups discuss and diagram their ideas about one of two thought problems related to matter and energy.		**35 minutes**

SESSION OVERVIEW (continued)

	Matter and Energy in Ecosystems	Activity Locations	Estimated Time
Concept Invention	**Getting Energy (and Matter) from Food** Participants are introduced to more details about cellular respiration, and they compare the process to photosynthesis.	indoors	10 minutes
Concept Invention, Application, and Reflection	**Answering Questions from the Session** Participants discuss posted questions that have been answered and add new ones. They compare their current ideas with their ideas at the beginning of the session. They review matter and energy at the global, ecosystem, and individual organism levels. They describe what's wrong with four inaccurate statements about matter and energy.	indoors	15–20 minutes
Application	**Key Concepts and Connections to the Next Generation Science Standards (NGSS)** The Key Concepts of the session are discussed, and connections are made to the NGSS. BEETLES resources for teaching these concepts are shared.	indoors	10 minutes
Application and Reflection	**Reflecting on the Session** Participants reflect on how they can apply what they have learned to their own instruction with students.	indoors or outdoors	10 minutes
Concept Invention	**OPTIONAL: Exploring Alternative Conceptions** Participants choose common alternative conceptions about the topic to discuss.	indoors or outdoors	30 minutes
	TOTAL:		~3 hrs., 20 minutes–3 hrs., 45 minutes

TEACHING TIPS

Making the session a conversation. As much as possible, this session should feel more like a collaborative conversation and less like merely delivery of content. Throughout the session, it's important to listen to participants' input, making connections between what they say and any relevant concepts. Fold examples participants bring up into points made. Be a co-learner, admitting what you don't know and what you are wondering about. Use staff members as resources and collectively make plans to follow the group's questions and find more information to answer those questions after the session.

This is a science content session. It's main purpose is to help participants struggle with and become more comfortable (and accurate) with matter and energy in ecosystems science content in their instruction. Most BEETLES professional learning sessions are much more focused on pedagogy. This session is more academic and primarily focused on adult-level content discussions and learning. It also takes place almost entirely indoors.

Students, participants,* and *presenter. In this document, we use the word *students* to refer to the learners your instructors work with. We use the word *participants* to refer to the adult learners participating in the professional learning session. The word *presenter* refers to the person(s) who is presenting the session. Feel free to use other terms if you prefer.

MATERIALS

For the group:

- ❏ projection system/computer
- ❏ slides
- ❏ large whiteboard and/or chart paper
- ❏ small whiteboard
- ❏ dry-erase markers: red, blue, purple, black
- ❏ water-based markers (if using chart paper): red, blue, purple, black
- ❏ tape (if using chart paper)
- ❏ optional: equipment for catching and holding organisms (nets, clear plastic cups/containers, hand lenses, etc.)

Optional: for the Hot Pack demonstration:

- ❏ 1 sealed nonporous chemical hot pack
- ❏ 1 letter scale (or any other sensitive scale you have)
- ❏ 1 wet-erase marker

For each group of 4–5 participants:

- ❏ 2 (or more) sheets of chart paper
- ❏ several sentence strips (or large sheets of paper)
- ❏ 1 set of felt-tipped markers, felt-tipped: red, blue, purple, black

PREPARATION

Before the day of the session:

1. **Prepare to present.** Choose who will present each part of the session. (See the Session Overview on pages 4–5 and Step 3 below for the *Food, Build, Do, Waste* activity.) Consider including staff who may have already experienced the session and staff who have a particularly strong background in life science/biology to help deal with the content. Read through the session write-up, sidebars, slides, and handouts to prepare. The more each presenter is able to own the session, the better the presentation. Record notes on a printed version of the session, or however you prefer.
2. **Set up a projection system/review multimedia.** Set up and test the projection system to be sure participants will be able to see items projected during the session.
3. **Read and familiarize yourself with the student activity guide *Food, Build, Do, Waste* and assess your ability to lead the activity.** Choose your staff member most experienced with successfully leading this activity with students to lead this part of the session. An abbreviated version of that write-up is embedded in this *Matter and Energy in Ecosystems* write-up (in blue box on pages 20–21). Use this embedded version if your instructors will not be presenting the activity with students later. If they might be presenting the activity with students, then make time to present the full activity as written in the student activity guide *Food, Build, Do, Waste* (50 minutes).
4. **Gather materials for the *Food, Build, Do, Waste* student activity.** You'll need equipment for collecting organisms to observe. (See the *Food, Build, Do, Waste* activity write-up: http://beetlesproject.org/resources/for-field-instructors/food-build-waste/).
5. **Practice making the Earth Ecosystem Diagram.** It's best to use the bold steps of this write-up (pages 12–19) while making the Earth Ecosystem Diagram rather than follow each line of the script while making the diagram. Practice making the diagram in advance so you can keep things moving
   - **Draw on a large whiteboard, if you have one.** This will allow you to erase and replace arrows as the chart evolves. If you don't have a large whiteboard, use a large piece of chart paper. It'll be messier, but it can work.
6. **Prepare copies of handouts.** Make 1 copy of each handout for each participant. (See Materials list in margin on page 7.)

PREPARATION (continued)

7. **Gather materials for the Food Web/Matter and Energy Diagram activity.** Each group of 4–5 will need the following materials:
   - 1 sheet of chart paper
   - felt-tipped markers: red, blue, black
   - several sentence strips
8. **Identify an outdoor area for the activity.** This should be a nearby area. Pay attention to local hazards, such as fire ants, and make adjustments as needed. Choose a nearby area that the group can get to quickly—one that has organisms that participants can find easily and quickly and that you think will be interesting to investigate.
9. **Make sure participants are prepared.** Make sure participants bring the gear they need to be comfortable indoors and outdoors. Tell them to bring their journals and something to write with.
10. **If the session is too long for the time slots you have available, you can break it into two shorter sessions.** If you have less time available than the 3 hours, 20 minutes–3 hours, 45 minutes needed for this session, we strongly recommend against only doing some of the session; instead, break it up into two parts. Breaking it into two sessions can also help with alleviating brain fatigue from extended wrestling with challenging concepts. If this is your preference, we recommend doing this immediately before or after the *Food, Build, Do, Waste* student activity. Between sessions, you could ask instructors to try applying the concepts to their instruction and to be prepared to report back on how it went. If you're presenting the whole session at once, this is also a good time to take a break.
11. **Optional: Make Session Overview to post on the wall.** You may choose to make a Session Overview to post on the wall during this session. Some presenters and participants prefer having it so they can see the trajectory of the session.

Immediately before the session:

1. **Set out handouts near the front of the room.**
2. **Place the materials for the *Food, Build, Do, Waste* student activity in a pack to carry outdoors.**

MATERIALS (continued)

For each pair:

- ❑ 2 journals (or 2 sheets of paper)
- ❑ 2 pencils
- ❑ a small live organism (that they find outdoors)

Handouts:

For each participant:

- ❑ 1 double-sided copy of *Matter and Energy Thought Problem #1: Evidence (The Tree Question)* and *Matter and Energy Thought Problem #2: Evidence (The Bunny Question)* (pages 40–41)
- ❑ 1 copy of *Matter and Energy at the Global System, Ecosystem, and Individual Organism Levels* (page 42)
- ❑ 1 copy of *NGSS 5th Grade Performance Expectations* (page 43)
- ❑ 1 copy of *Matter and Energy in Ecosystems Resources to Use with Students* (page 44)
- ❑ 1 copy of *Simplified Earth Ecosystem Diagram* (page 45)
- ❑ 1 copy of *Content Information and Alternative Conceptions About Matter and Energy in Ecosystems* (pages 46–52)
- ❑ optional: printed copies of student activity guide: http://beetlesproject.org/resources/for-field-instructors/food-build-waste/

YOU ARE HERE:

10 minutes

TEACHING NOTES

This presentation is layered. It begins with thinking about matter and energy and ecosystems first with a familiar individual ecosystem and then more globally with Earth systems in general. Participants then look at matter and energy in individual organisms through a systems lens during the *Food, Build, Do, Waste* student activity. Thought problems engage participants with two puzzling questions about either a tree or an animal that represent all producers and consumers. Evidence sheets introduce important content that participants use to figure out their thought problems. Finally, participants learn about what is going on at a cellular level.

Traditional Ecological Knowledge (TEK). BEETLES acknowledges and affirms the validity of Traditional Ecological Knowledge (TEK), as well as the many linkages between ecological restoration and cultural resources and values. The strategies and knowledge that were passed down over generations show a detailed understanding of ecological processes and the connection humans have with those processes. While teaching science, we want to hold in our sight the body of knowledge gained from Indigenous peoples who possess detailed knowledge of the organisms and ecosystems of their homelands. Indigenous cultures have a deep history of observing and understanding the natural world that predates science and includes aspects of what we now define as scientific thinking and investigating. Indigenous cultures have knowledge about the natural world and how to investigate it. TEK is an

(continued on next page)

Introduction and Overview

1. **Show Slide 1:** *Matter and Energy in Ecosystems***.**

slide 1

   a. Welcome participants and make sure everyone is ready to begin.
   b. Share that this session is designed for instructors to improve their understanding about matter and energy to more effectively teach students about interactions in ecosystems.

2. **Show Slide 2:** *Quick Write: What do matter and energy have to do with ecosystems?* **Introduce the writing prompt to begin the session. Share:**

slide 2

   a. Take a few minutes to record your ideas on the topic of matter and energy.
   b. You are writing only for yourselves to get your thinking started on this topic.
   c. You have approximately 5 minutes to write.

3. **Show Slide 3:** *Goals for the Session***. Share each point:**

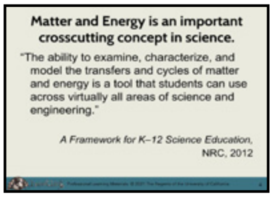
slide 3

   a. *Improve scientific understanding and increase curiosity about this complex topic.* Everyone already has some knowledge about this topic, as well as some questions or confusion. Some questions will be answered, and others will emerge.
   b. *Engage in activities and meaning-making discussions about matter and energy in ecosystems.* The activities and discussions in this session are meant to kick off an ongoing process of thinking deeply about and discussing the topic.
   c. *Model some teaching strategies that can be used with students.* This is not the primary focus of the session, but some of the activities can also be used with students, though they may look very different than they do with adults. The main goal of the session is to focus on you as adult learners.
   d. *Think about how to make effective instructional choices when teaching about the topic.* We'll discuss how and why to make choices about vocabulary and building on students' ideas.

4. **Share that the session will focus on a scientific perspective of understanding ecosystems:**
   a. Science is one extremely useful, evidence-based way of understanding the natural world.
   b. Art, history, and religion are also examples of valuable ways of understanding.
   c. Traditional Ecological Knowledge (TEK) is a way of understanding that includes many overlaps with science about the natural world.
   d. This session will focus on a scientific way of understanding life on Earth.

5. **Share that this topic is important and challenging and that participants should be prepared to change their minds:**
   a. To understand how ecosystems work from a science perspective, you need some understanding about how matter and energy move through ecosystems.
   b. Tracking the transfer of matter and energy can be confusing.
   c. This session is an opportunity to explore the edges of what you do and don't understand scientifically about this topic.
   d. Some of you in the room may have studied these ideas a lot, and others may have never thought about ecosystems in this way.
   e. Don't feel bad if you get confused. That means you are really exploring the edges of your understanding.
   f. This session won't answer all your questions. At the end of the session, hopefully you will have a better scientific understanding. You will also probably have more questions to wonder about.
   g. The ability to change your mind based on evidence is important in science (and in life!). You might choose to go into this session with the intention of finding at least one opportunity to change your mind.

6. **Show Slide 4:** *Matter and Energy is an important crosscutting concept in science.* **Have participants read the quote from the National Research Council.**



slide 4

7. **Share that the topic ties together many life science topics, is key to understanding climate change, and is a useful lens:**
   a. This powerful crosscutting concept underlies and ties together life science concepts such as food chains, food webs, energy pyramids, decomposition, photosynthesis, and predator–prey interactions, as well as ideas taught in physical and Earth science.
   b. The flows and cycles of matter and energy are also key to understanding the carbon cycle, which is foundational to a scientific understanding of climate change and a critically important environmental issue of our era.
   c. During this session, we will build an understanding of how tracking matter and energy can give students a useful lens with which to make sense of interactions between living and nonliving things in ecosystems.

8. **Show Slide 5:** *Guiding Questions for the Session*. **Read the questions out loud.**
   - Share that the activities participants will do together will address the following questions:

     ▶ *How do organisms get the matter and energy they need to live and grow?*

slide 5

TEACHING NOTES

(continued from previous page)

evolving body of knowledge based on many generations of close observations of ecosystems and includes Indigenous views on ecology, spirituality, and human/animal relationships. Some common goals of outdoor and environmental science educators are to teach science ideas and science approaches, related to the outdoors, and to support students to understand and connect with their environment. We wish to honor and show respect to TEK and how it has influenced and continues to influence science, how it overlaps with science, and how it differs from scientific approaches. We encourage educators to respectfully integrate aspects of TEK into outdoor science instruction to help students connect with and understand nature. For more on this topic, see the Background Information for Presenters section of the BEETLES professional learning session *Making Observations.*

Keeping everyone engaged in discussions. Everyone has life experiences, perspectives, and ideas that can contribute to making science discussions interesting and productive. The more broad participation you have, the more productive the conversations will tend to be. There are often participants who know a lot more about science than others; sometimes, they can dominate discussions with higher-level vocabulary, questions, and concepts. This can make others who know less about science become too intimidated to share. Do your best to keep everyone involved and the discussion accessible to all participants. Ask participants to share and define any sophisticated concepts or vocabulary they bring up. If, during discussion of a higher-level question, it looks like part of your group is confused and checking out, you may need to set aside the question to discuss later with one or more participants apart from the group.

- *How do organisms interact with living and nonliving parts of their environment as they use matter and energy?*
- *How do matter and energy stay in and/or leave an ecosystem?*

YOU ARE HERE:

25 minutes

TEACHING NOTES

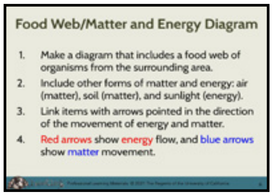
Defining *energy* in the context of ecosystems. The definition of *energy* as something that makes things happen is a useful one when studying ecosystems scientifically. Energy allows organisms to live and grow and reproduce themselves. However, the concept of energy is described and used very differently in other disciplines of science, such as physics and chemistry. It's no wonder that even adult learners can become confused about this concept! This is why we suggest that you make a clear distinction that you are discussing the concept of energy as it relates to understanding the interactions in ecosystems, not in terms of nuclear physics!

There's a difference between food webs and matter/energy diagrams. In this session, participants make matter/energy diagrams that include food webs, but go beyond them. Ecologists use food webs to map out what eats what. Food webs are used as a model of how organisms depend on one another for food and are used primarily to predict the effects of changing food resources in ecosystems. That's why food webs don't include sources of energy such as the sun or nonliving elements such as gases and water. The matter/energy diagrams in this session do include these. For more information on how to lead a food web activity with students, see the BEETLES classroom activity *Food Web* (http://beetlesproject.org/resources/for-field-instructors/food-web/).

Food Web/Matter and Energy Diagram

1. **Share that participants will now dig into the topic and offer them simple definitions for *matter* and *energy*:**
    a. Now you will have a chance to share, explore, discuss, and struggle with ideas about matter and energy in ecosystems.
    b. By matter, we mean the "stuff" everything is made of.
    c. Energy is what makes things happen.

2. **Show Slide 6:** *Food Web/Matter and Energy Diagram*. **Form groups of 4–5 and distribute chart paper and red, blue, and black markers.**
    a. Form groups of 4–5 participants sitting around a table or on the floor.
    b. Give each group a sheet of chart paper and red, blue, and black felt-tipped markers.



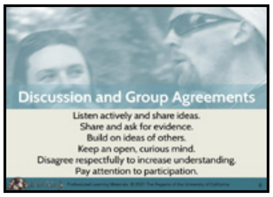
slide 6

3. **Share instructions for the small-group activity:**
    a. You're invited to make a diagram together that includes a food web of organisms from an ecosystem you teach about.
    b. Your diagram should also include a few things that are *not* actually part of a food web but are forms of matter and energy critical for the ecosystem to function: **air (matter)**, **soil (matter)**, and **sunlight (energy)**.
    c. Use the **red** marker to show **energy** movement, and the **blue** marker to show **matter** movement, remembering that in both cases, the arrows should be pointed in the direction of the flow and movement.

4. **Show Slide 7:** *While you are discussing the diagram with your group*.
    - Have participants read the slide.

slide 7

5. **Show Slide 8:** *Discussion and Group Agreements*. **Introduce group agreements about discussion:**
    a. Share: Before we dive into discussion, it's important to review some group agreements for science discussions.
    b. Read aloud the six group agreements.
    c. Ask:
        - *Is anything missing from this list? Does anyone want to talk about any of these group agreements?*
        - *Can we agree to these to keep our discussions respectful and productive?*



slide 8

6. **Share that participants should incorporate everyone's ideas, try to understand others' ideas, and discuss matter and energy in ecosystems:**
   a. Listen to all group members and try to incorporate everyone's ideas into your diagram.
   b. This is a chance to practice trying to understand and learn how other people are thinking about the task.
   c. The goal is not to create a perfect diagram, but to have an in-depth conversation about the transfer of matter and energy in ecosystems.

7. **Share that participants should record their questions about matter and energy as they work:**
   a. Another important part of the task is to write, in large letters on sentence strips, any questions that come up as you discuss your diagrams.
   b. You may also want to identify and circle parts of your diagrams that you can't fully explain or things you find confusing.
   c. If you are struggling/disagreeing, then the activity is successfully raising important issues for you to discuss!
   d. You'll have 15–20 minutes to complete your diagrams.

8. **Distribute sentence strips for group members to record questions.**
   a. As groups begin working on their diagrams, distribute several sentence strips to each group.
   b. Remind participants to write their questions with dark-colored markers in large letters.

9. **Participants post their questions and diagrams.**
   a. When it seems like most groups have completed their diagrams (or when time is up), ask the participants to post their questions on sentence strips on the wall for everyone to see.
   b. Post groups' matter and energy diagrams clustered in a different area of the room.
   c. If there are similar questions, try to cluster them into categories, such as questions about energy or questions about matter.
   d. When all questions are posted, briefly read the questions out loud to the whole group.

10. **Summarize any patterns you notice.**
    - Point out any similarities between the diagrams or the questions with which participants are currently struggling.

11. **Share that participants will build on these ideas and return to the questions later:**
    a. This is just the first step for thinking about matter and energy in ecosystems.
    b. You'll be building on your ideas throughout the session and will revisit your questions near the end.

TEACHING NOTES

Coming up with your own group agreements. Many teams create their own group agreements. If you decide to do that now, give yourself an extra ~30 minutes to complete this session. If you have group agreements your staff uses regularly, you can substitute them or add them here.

Other resources:
- Anti-Oppressive Facilitation for Democratic Process: Making Meetings Awesome for Everyone. Accessed online: http://aorta.coop/portfolio_page/anti-oppressive-facilitation/
- *The Adaptive School: A Sourcebook for Developing Collaborative Groups, 3nd edition.* Accessed online: https://www.thinkingcollaborative.com/product-page/adaptive-schools-3rd-edition-hardcover
- Group Agreements for Workshops and Meetings. Seeds for Change. Accessed online: https://www.seedsforchange.org.uk/groupagree

***Agreements* vs *norms*.** Many books, programs, and schools use the term *discussion norms* to describe group agreements. We intentionally chose not to use the term *norms* because it can send a message that there is one "normal" or accepted way to participate in discussions. This can lead to a marginalization of students of color and other marginalized groups, because the "normal culture" is typically white, if it is unspoken (Solomon, et al., 2005). Group agreements can be a way to shift the culture to be more inclusive, deliberately highlighting different ways of being and acting as acceptable and placing value on hearing and integrating different perspectives.

YOU ARE HERE:

25 minutes

or

TEACHING NOTES

***Matter and Energy Diagram* student activity.** To teach these ideas with students, a student activity write-up very similar to this activity is available under the same title. It works well as a brief introduction to help students unveil their ideas on the topic. Later in a field experience, you can return to it and make adjustments, based on what students have learned (http://beetlesproject.org/resources/for-field-instructors/matter-and-energy-diagrams/).

Making the diagram aquatic-based. If your instructors work primarily with aquatic ecosystems, you'll probably want to make the diagram focused on aquatic ecosystems. To do this, substitute "water" for "soil." Or, include both terrestrial and aquatic ecosystems and add "water" as an additional box.

Drawing arrows. The typical convention used in drawing food webs is to draw the arrows between organisms pointing toward the organism that consumes the food. The arrow shows the direction of the flow of energy and movement of matter.

Earth Ecosystem Diagram

1. **During this activity, guide the framework, use bold steps from the script, draw what participants suggest, ask follow-up questions, and don't stress about the exact content.**
   - **Guide the framework.** Without some structure, this diagram could quickly become a complex mess of confusing lines. The steps listed below help provide a framework for participants' thinking and for the organization of the diagram.
   - **Use the bold steps of this script while making the Earth Ecosystem Diagram and keep things moving.** Although the making of this diagram is carefully laid out in the script below, it can be cumbersome to follow each line of the script while making the diagram, and you may lose your participants' attention if your eyes are on the script too much. Read the script carefully in advance, along with looking at the series of example diagrams. Then when teaching, try to work mostly by using the bold numbered steps, allowing details of the diagram to flow out of participants' suggestions. Keep things moving to keep folks engaged.
   - **Follow participants' lead on what to draw.** Do your best to draw whatever the group suggests, adding any ideas they bring up and briefly discussing each one. If they suggest drawing the water cycle, then you might go ahead and add it to your diagram. If they don't suggest it, you don't need to. If they want to include another group of organisms, such as bacteria or phytoplankton, go ahead and draw them. If participants don't bring these things up, then stay with the more simple representations as suggested in the script. If they bring up inaccuracies, this is not the time to correct them. Be sure to note any alternative conceptions or incomplete ideas so you can come back to them and build on them later in the session.
   - **Ask follow-up questions.** When participants suggest a line or label, ask clarifying questions to help them state clearly what they are thinking so you and others understand. Ask others if they agree; if they disagree, ask why. Once each line or label is drawn, ask if that represents their thinking.
   - **Don't stress about the exact content.** There are many examples included within the steps that represent a lot of content. These are to help you be prepared for what participants may suggest, but they can also appear intimidating if you think you need to bring them all into the conversation. You don't.
   - **Draw on a large whiteboard, if you have one.** This will allow you to erase and replace arrows as the chart evolves. If you don't have a large whiteboard, use a large sheet of chart paper. It'll be messier, but it can work.

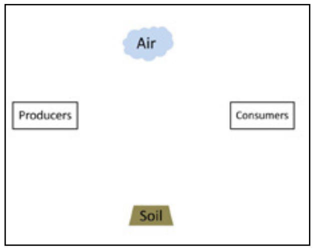
2. **Share Slide 9:** *Earth Ecosystem Diagram*. **Seat participants in a semicircle in front of a large whiteboard and introduce the matter and energy diagram activity. Share:**

slide 9

   a. I'm going to draw a matter and energy diagram for a generalized terrestrial Earth ecosystem (unless you have decided to do an aquatic ecosystem), using input from the whole group.

b. This discussion will focus on adult-level learning, but it's an activity that can also be led with students.

3. **Draw and label "Air," "Soil," "Producers," and "Consumers" on a whiteboard or sheet of chart paper.**



- With black marker, draw and write:
    - *"Air" in a cloud shape, placed a little below the top.*
    - *"Soil" in a box at the bottom.*
    - *"Producers" in a box on the left side.*
    - *"Consumers" in a box on the right side.*

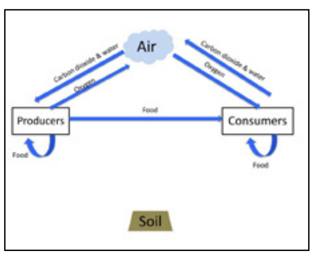
4. **Describe that the diagram will show matter and energy moving through ecosystems on Earth:**

a. These are the living and nonliving parts of ecosystems on Earth that are interconnected through energy and matter.

b. Remember that matter is the "stuff" that things are made of, and energy is the ability to do things or to make things happen.

c. This diagram will be used to show how matter and energy move through the main parts of all ecosystems on Earth.

5. **Begin by diagramming the transfer of matter between organisms and air.**



a. Ask participants to describe some ways that matter moves between consumers or producers and air.

b. As they answer, use the **blue marker** to draw arrows representing their ideas. For example, if they say, "animals breathe air," ask if they want you to draw a blue arrow from the air to the consumers.

c. Ask for specific labels. In the above example, ask what type of gas in the air the consumers need in order to live, and then add the label ("oxygen") above the arrow.

d. Encourage discussion and ask for specificity as you add to the diagram.

e. Examples:

- Consumers take in oxygen: *Draw a blue arrow from air to consumers and label it "oxygen."*
- Consumers release carbon dioxide: *Draw a blue arrow from consumers to air and label it "carbon dioxide & water."*
- Producers take in carbon dioxide: *Draw a blue arrow from air to producers and label it "carbon dioxide & water."*
- Producers release oxygen: *Draw a blue arrow from producers to air and label it "oxygen."*

TEACHING NOTES

About producers. Producers are mainly photosynthetic organisms that transform light energy into the chemical energy in glucose through the process of photosynthesis. Using the light energy from the sun, plants and plant-like organisms, such as algae, make glucose (a simple sugar) by combining carbon dioxide from the air and water. No other type of matter is needed. Organisms that produce their own food are also called autotrophs. There are some producers living in environments without light that use chemical energy to produce their food through a process called chemosynthesis. Chemosynthetic bacteria use chemical reactions to provide the energy to combine carbon dioxide with water to make the sugars they need to live.

About consumers. Consumers can't make their own food, so they get it by eating other organisms. Humans and other animals can't make their own food, so they must get it by consuming plants or algae or other animals that have consumed plants or algae. Fungi and other decomposers are considered consumers because they can't produce their own food. Organisms that can't produce their own food and need to get it from the environment are also called heterotrophs.

***Air* or *atmosphere*.** The more accurate term for *air* is *atmosphere*. Feel free to use it if you'd like to model the scientific vocabulary.

About decomposers. Decomposers transform dead organisms into simpler substances to get the energy they need to live and grow. Some by-products of this process are released into the soil (or water) and the atmosphere and can be used by plants, algae, and other organisms. Since decomposers release carbon dioxide, minerals, and organic matter back into the environment, they are necessary to complete the cycle of matter.

- Decomposers take in oxygen and release carbon dioxide and water: (If decomposers are mentioned at this point, add a box near the soil and label it "Decomposers." Then, *draw a blue arrow from air to decomposers and label it "oxygen." Draw a blue arrow from decomposers to air and label it "carbon dioxide & water."*)

6. Ask for interactions between different groups of organisms—producers and consumers—that involve transferring matter.

7. Diagram interactions between groups of organisms with blue arrows, including circular arrows.

a. Again, draw blue arrows to represent participants' ideas, asking for specific details that will help describe what is actually moving *with* the arrow (e.g., oxygen, food).

b. Circular arrows that start and end with the same category ("nose rings") can be used to show that some consumers eat one another or that producers make and consume their own food.

c. Examples:

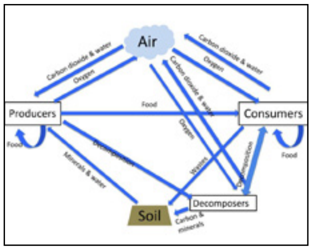
- Producers are eaten by consumers: *Draw a blue arrow from producers to consumers and label it "food."*
- Animals are eaten by other animals: *Draw a circular blue arrow from consumers to consumers and label it "food."*
- Producers make their own food: *Draw a circular blue arrow from producers to producers and label it "food."*

8. Ask for matter interactions between soil and organisms:

a. Describe interactions that involve movement of matter between organisms and soil.

b. What specifically is moving between soil, consumers, producers, and decomposers?

9. Add arrows to represent matter interactions between soil and organisms.



- Examples:
  - *Add a box between Consumers and Soil and write "Decomposers" in the box.*
  - Dead plants decompose into soil: *Draw a blue arrow from producers to decomposers and label it "decomposition."*
  - Decomposers consume dead consumers, and consumers eat decomposers: *Draw a double-headed blue arrow from consumers to decomposers and label it "Decomposition."*
  - Decomposers decompose dead animals into soil: *Draw a blue arrow from decomposers to soil and label it "carbon & minerals."*
  - Plants get minerals and water from soil: *Draw a blue arrow from soil to producers and label it "minerals & water."*
  - Animal poop decomposes into soil: *Draw a blue arrow from consumers to soil and label it "wastes."*

TEACHING NOTES

Terrestrial vs aquatic ecosystems. As drawn in the example, this generalized matter and energy diagram represents terrestrial ecosystems. If you want to add to the diagram to include aquatic ecosystems, you can add the ocean or a lake somewhere near the bottom. Animal waste matter would then be drawn as going into the water, which would also be where aquatic producers get the CO_2 and water they need to photosynthesize and make glucose.

Optional: Hot Pack demonstration. You may want to use a hot pack to demonstrate how to track matter and energy in a closed system. This demo provides a direct experience for participants to observe that matter (or mass) remains the same—and is not lost—when the energy (heat) is released as the pack heats up. Porous hot packs that allow air (matter) to enter and exit the pack will not work for this purpose. The reactant should be contained in a sealed bag, keeping the matter in the closed system. This is evidence that addresses the inaccurate idea that the matter in the bag is consumed or that it changes into energy that's released.

Conducting the demo. Show participants the chemical hot pack. Tell them it contains both matter and energy. Share that you activate it by popping the vial inside that releases a liquid. The chemicals then mix together and react. Let participants know that before you activate the pack, you will weigh it with a letter scale (or any other sensitive scale you have) in order to collect some evidence about the matter inside the pack. Share that you'll also weigh it during and after the chemical reaction. Ask for a volunteer to help you weigh the pack. Record the weight or, if using a letter scale, use a wet-erase marker to mark the starting weight of the pack directly on the scale. Have the volunteer activate the pack and report any changes that happen. They will feel heat coming off it as the chemicals react. Pass the pack around

(continued on next page)

10. Share that there are different cycles of matter within the ecosystem diagram, point out one example, and ask for more:

- **a.** Look at how there's a cycle as matter moves from producer to air, air to consumer, consumer to air, air to producer, etc.
- **b.** What are other cycles you see by following different types of matter?

11. Share that the same matter cycles and isn't created or destroyed:

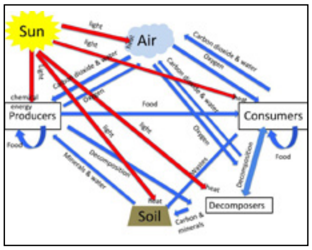
- **a.** As matter moves within Earth's system, new matter isn't being added or lost from the system.
- **b.** The same matter in the system is being recycled between different parts.
- **c.** Earth is mainly a closed system for matter—there are no significant inputs or outputs of matter outside Earth's system.
- **d.** These cycles of different types of matter (carbon cycle, nutrient cycle) show that matter is always conserved—it's neither created nor destroyed.
- **e.** This is why it's accurate to tell students that matter cycles within Earth's system: **Matter cycles!**
- **f.** Matter doesn't leave or enter Earth's overall system, but it does leave and enter ecosystems and moves between ecosystems.

12. Transition to diagramming and discussing energy in Earth's system and how energy constantly enters the system. Share:

- **a.** What happens with matter in Earth's system is very different from what happens with energy.
- **b.** While the same matter is cycling throughout Earth's system, energy from the sun is constantly flowing into and exiting out of Earth's system.

13. Add the sun to the top-left corner.

- *Draw a sun in the top-left corner of the Earth Ecosystem Diagram and label it "Sun."*



14. Add red energy arrows from the sun to producers, consumers, decomposers, and nonliving features of the ecosystem.

- **a.** Ask: Where should we make arrows to show energy coming from the sun as it enters the ecosystem?
- **b.** Listen to participants' responses and then: *Draw red arrows to represent the flow of energy from the sun to all parts of the system. Label these arrows "light."*
- **c.** Share: Energy travels from the sun to Earth as light energy, but some energy is transformed to heat energy or chemical energy when it arrives and interacts with different objects.
- **d.** Ask participants to describe what kind of energy the sunlight is transformed into when it arrives at land, air, water, consumers, and decomposers. [Heat energy.] *Write "heat" at the pointy ends of these arrows.*

TEACHING NOTES

(continued from previous page)

the room so everyone can feel it as it warms up. Ask participants to turn to the person next to them and predict what they think will happen when you weigh it again.

Note: When weighing the hot pack, make sure it rests completely in the center of the scale. If it hangs over the edges, it can be difficult to get an accurate reading. You can use a cup or other container to keep the hot pack centered on the scale. When weighing the hot pack later, there may be a very small, but insignificant, weight change—less than one-tenth of a gram. This is because the accuracy of the scale will most likely not be in the range of hundredths of a gram, and there are several other variables that could potentially interfere with measurements. One way to stay within the margin of error is to record your measurements to one decimal point and not beyond.

Earth is actually not a completely closed system. A little bit of matter enters from space when a meteoroid makes it into our atmosphere. A miniscule amount of matter also leaves Earth's systems when some air molecules dissipate into space or when spacecraft leave.

TEACHING NOTES

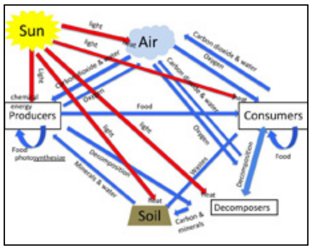
Light energy into kinetic energy. A more advanced understanding is that the light energy is changed to kinetic energy of the molecules. A collection of molecules moving with more energy (faster) is warmer than the same collection of molecules moving with less energy (slower).

Distinguishing sources from types of energy. This can be a good time to address the idea that the sun is the main *source* of energy, but light energy is what actually travels to Earth. You may want to point out to instructors that distinguishing between the source of energy and the energy itself can be confusing for some students. Producers use sunlight, not the actual sun in order to photosynthesize.

Plants can see! Producers also use light and heat from the sun to stay warm and to “see.” Plants have more different kinds of photoreceptors than animals, and they have a lot of complex behaviors based on what they perceive in the light. For more information on this topic, see the book *What a Plant Knows: A Field Guide to the Senses* by Daniel Chamovitz.

e. Examples:
   - Light energy from the sun is transformed to heat when it hits consumers, providing warmth: *Write “heat” at the pointy end of the arrow.*
   - Light energy from the sun is transformed to heat when it hits decomposers, providing warmth: *Write “heat” at the pointy end of the arrow.*
   - Light energy from the sun is transformed to heat when it hits land, air, and water: *Write “heat” at the pointy ends of the arrows.*

15. Focus on flow of energy from the sun to producers: photosynthesis.



a. Ask: What do producers do with light energy from the sun? [Photosynthesize.]

b. *Write “photosynthesize” under the box for producers and underline the* ***synthesize*** *part of the word. Remind participants that* ***synthesis*** *here refers to making glucose/sugar.*

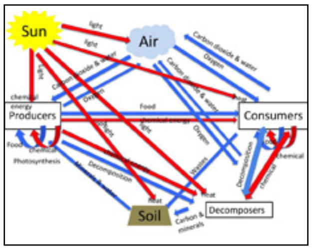
16. Share that producers change light energy into chemical energy, and consumers, decomposers, and producers use light and heat from the sun to see, stay warm, and survive:

a. Producers actually **change** (transform) light energy from the sun into chemical energy that organisms can use to live and grow.

b. Light energy from the sun is transformed to chemical energy through photosynthesis by producers: *Write “chemical energy” at the pointy end of the arrow at producers.*

c. Consumers and decomposers can’t photosynthesize, but they use direct light (to see) and heat energy (to stay warm) from the sun to live and thrive.

17. Producers use some energy from photosynthesis for their own life processes, but they also provide energy to other parts of the ecosystem.



a. Ask: How can we show on the diagram that energy is transferred from producers to other organisms and that energy is used by producers for their own life processes?

b. Listen to participants’ responses and then: *Draw red arrows to represent the flow of energy from producers*

c. Examples:
   - Consumers get energy from eating producers: *Draw a red arrow from producers to consumers.*
   - Decomposers get energy from eating/decomposing dead producers: *Draw a red arrow from producers to decomposers.*

TEACHING NOTES

- There is energy in the food made by producers that is used by producers: *Draw a red circular arrow looping from producers back to producers.*

18. Label the energy arrows from producers to consumers and decomposers.

a. Ask: What kind of energy should we write on the arrows? [Chemical energy.]

b. *Write "chemical energy" on the energy arrows from producers going to consumers and decomposers.*

c. Share: When organisms eat producers, they are getting chemical energy that producers made by using light energy, carbon dioxide, and water.

19. Add more chemical energy arrows.

a. Ask: Where else on the diagram can we add chemical energy arrows?

b. Listen to participants' responses and then: *Draw red arrows to represent the flow of energy between organisms.*

c. Examples:

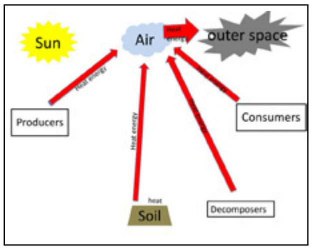
- Consumers get energy from eating other consumers: *Draw a red circular arrow looping from the consumers box back to consumers and label it "chemical energy."*
- Decomposers get energy from eating/decomposing dead consumers: *Draw a red arrow from consumers to decomposers and label it "chemical energy."*
- Consumers can eat decomposers, too: *Add another point (arrowhead) on that same arrow from decomposers to consumers.*

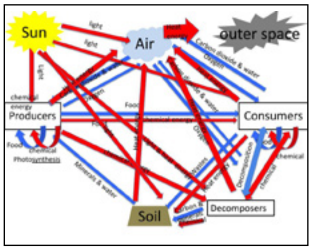
20. Add red arrows for other ideas that participants have about energy transfer.

a. Ask: Are there any other kinds of energy transfers missing from the diagram?

b. Listen to participants' responses and then: *Draw red arrows to represent what they suggest.*

21. Indicate heat energy radiating out into outer space.





a. If you haven't already done so, *draw red arrows showing the flow of heat energy away from organisms and away from Earth.*

b. Share: All organisms also release energy into the environment, and most of this energy eventually flows into outer space.

c. *Draw a burst in the upper-right corner and label it "outer space."* Share that this represents all the places beyond Earth's system where energy can travel. *Draw a red block arrow from air to outer space and label it "heat energy."*

TEACHING NOTES

Referring to heat energy. Physicists prefer to use the term *thermal energy* rather than *heat energy*. We use the term *heat energy* because it's more familiar for students who are beginning to learn the science of energy.

Emphasizing that energy does not cycle; it flows (mostly). It's a very common mistake to talk about energy flow in Earth's system as a cycle, similar to how matter cycles. It's true that energy cannot be created or destroyed (i.e., it is always conserved) just like matter, and it's also true that energy does cycle around a bit, like when it's part of food within an ecosystem. However, the big difference is that energy flows into Earth's system, cycles around some, and then eventually flows out of our atmosphere and is radiated into outer space. On the other hand, matter just cycles through Earth's systems and doesn't leave. Overall, the same amount of energy that enters Earth's system leaves Earth's system in an ongoing flow.

About climate change. When not enough heat energy is able to leave our atmosphere, it upsets the balance of energy flow into and out of Earth's system, and global warming can happen. Earth's climate is changing as a result of the accumulation of heat trapping gases in our atmosphere. These gases prevent some of the heat energy released at the surface of Earth from leaving our planet. This is causing more extreme weather patterns as well as melting of land ice, sea-level rise, and an increase in ocean temperatures worldwide. Increased levels of carbon dioxide are also causing ocean acidification.

d. Examples:

- Producers give off heat energy to air, which flows into outer space: *Draw a red arrow from producers to air and label it "heat energy."*
- Consumers give off heat energy to air, which flows into outer space: *Draw a red arrow from consumers to air and label it "heat energy."*
- Decomposers also release heat energy to air, which flows into outer space: *Draw a red arrow from decomposers to air and label it "heat energy."*
- The land absorbs heat from sunlight and then gives off heat energy to air, which flows into outer space: *Draw a red arrow from soil to air and label it "heat energy."*

22. Trace a pathway on the diagram that shows how energy flows both into and out of Earth's ecosystems.

23. Share how energy flows into, through, and out of Earth's ecosystems and into space:

a. Almost all Earth's energy input comes from the sun. Energy cycles some of it as it moves between organisms through each link in a food chain.

b. As energy flows between organisms, most is released into the environment and isn't available to whatever eats it.

c. Eventually, all energy is transformed into heat and flows into outer space.

24. Share that unlike matter, energy flows out of Earth's systems:

a. What would happen if energy from the sun cycled on Earth like matter does and didn't have a way to flow away from the surface of the planet? [Earth would get unbearably hot!]

b. We can see why it's accurate to tell students that energy flows through Earth's global system: **Energy flows!**

25. Share how producers "package" energy from sunlight with matter from air to produce the energy-rich substances found in food:

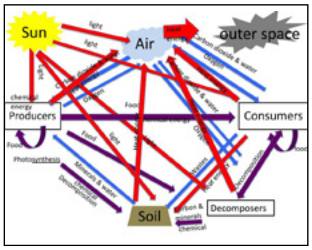
a. Although heat energy is always being lost from ecosystems, energy is also constantly flowing in from the sun and passed on to living things through producers.

b. Producers use photosynthesis to "package" matter they absorb from air and energy from sunlight into food molecules such as glucose.

c. Food is made from energy-rich molecules of matter that can be digested by organisms, providing the energy and matter they need to live and grow.

d. In this way, producers are continually making energy from the sun available to other organisms in ecosystems.

26. Change the food and chemical energy arrows to purple.



a. Share: Since this packaging of matter and energy is transferred together as food, we can show this on the diagram with one combined purple arrow.

b. Go back to the diagram and change any arrows that represent food and chemical energy to **purple** to show that the matter (blue) and energy (red) are combined in food.

c. Share: Food is a specialized package of matter and energy.

d. Examples:

- Consumers eat producers: *Replace the red and blue arrows with a purple arrow from producers to consumers.*
- Producers make their own food: *Replace the red and blue circular arrows with a purple arrow from producers to producers. (If you're drawing on paper, draw with purple over or next to the red and blue arrows.)*
- Consumers eat other animals: *Replace the red and blue circular arrows with a purple arrow from consumers to consumers. (If you're drawing on paper, draw with purple over or next to the red and blue arrows.)*
- Some consumers eat decomposers, and decomposers eat consumers: *Replace the double-headed red and blue arrows with a double-headed purple arrow from decomposers to consumers. (If you're drawing on paper, draw with purple over or next to the red and blue double-headed arrows.)*

27. Pose questions about decomposers to add to the diagram and help participants apply their ideas.

a. Ask participants if they can fill in more details about the role of decomposers in the cycling of matter.

b. Ask the following questions if they have not yet been addressed:

▶ *How do decomposers get energy to live and grow?*

▶ *What happens to the energy that decomposers get from dead things?* [Some energy is used to live and grow. At each link, most is released to the environment as heat.]

▶ *What is the matter released by decomposers that plants and algae can use to make food?* [CO_2, H_2O.]

28. End the discussion and transition to the next activity.

a. Tell participants that they will keep adding more to their scientific understanding of how energy and matter work in ecosystems by looking closely at how individual organisms use energy and matter.

b. Take note of any inaccuracies on the diagram. As you work through the rest of the session, when related content emerges, point it out to the group. Then, ask participants to help you make the diagram more accurate.

TEACHING NOTES

About food. Food molecules provide all living things with chemical energy and matter needed to live and grow. In consumers, food needs to be digestible by the organism to provide both matter and energy in order for the organism to live, build its body parts, and grow. What's digestible food to one organism may not be digestible food to another. Plants and algae use energy from the sun to make their own food molecules—mainly glucose—from carbon dioxide and water. Of course, organisms also need other kinds of matter to survive, such as water, oxygen, CO_2, nutrients, and vitamins, but none of these substances is considered food.

YOU ARE HERE:

30–50 minutes

TEACHING NOTES

Refer to *Food, Build, Do, Waste*. Refer to the BEETLES student activity guide *Food, Build, Do, Waste* (http://beetlesproject.org/resources/for-field-instructors/food-build-waste/),which describes how to present the full activity to students.

How should staff behave during model activities? Some presenters ask participants to behave like children during model activities. We've found that this often leads to exaggerated negative behaviors, and the modeling suffers (and sometimes the experience is ruined). Instead, ask them to participate as adults while imagining how students would respond. There may also be times when participants might get carried away with discussion of adult content to the point that it loses its effectiveness as a model. As the presenter, you may need to point this out and ask them to remember the level of their students and tone down the content of their discussions.

The adapted version of the student activity has been embedded in this professional learning write-up for your convenience. The content shaded in blue (on this page and the next page) differentiates the student activity from the rest of the session.

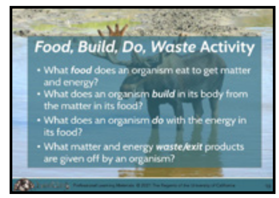
Producers need food, too! Consumers are not the only organisms that need food. Photosynthesizing organisms, such as plants and algae, not only produce sugar molecules that other organisms use, they also use the sugar they produce to live, grow, and reproduce.

Food, Build, Do, Waste

1. **Share that now participants will track energy and matter in an individual organism:**
   a. We've been looking at matter and energy from a broad ecosystem point of view.
   b. Now we'll look at smaller systems within those bigger systems.
   c. We'll take a look at how matter and energy are used by and pass through individual organisms.

2. **Discuss what happens to the matter and energy consumed by an organism in the form of food.**
   a. Ask: Why do organisms need food?
   b. Accept all answers and emphasize that food is the fuel all organisms need to survive, grow, and reproduce.

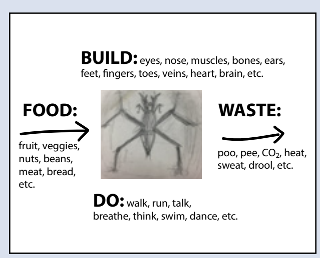
3. **Show Slide 10:** *Food, Build, Do, Waste Activity*. **Share that this will be an abbreviated version of a student activity:**
   a. *Food, Build, Do, Waste* is an activity that can be done outdoors with students to help them answer these questions with real organisms.
   b. We will do an abbreviated version of the activity.



slide 10

4. **Share that this activity helps students think about real organisms: the food they eat, the matter they use to build, the energy they use to do things, and the waste/exit matter and energy that result:**
   a. All organisms are made of matter and need matter to **build** all their body structures.
   b. Organisms use energy they get from food to **do** things needed to live and grow.
   c. All organisms get some matter and some energy from **food** that their bodies can't use. This matter and energy leaves their bodies **(waste/exit)**, and they no longer use it (mostly).

5. **Introduce *Food, Build, Do, Waste* and begin the sample model.**
   a. Share: You will go outside and find an organism to focus on and think about how it uses matter and energy from its food.
   b. Share: Don't take more than a couple of minutes finding and choosing an organism, because we don't have a lot of time.
   c. Write: "food," "build," "do," and "waste/exit" on a whiteboard or a sheet of chart paper, as shown.



6. **Share instructions for doing *Food, Build, Do, Waste*:**
   - You will draw a chart like this in your journals to help you think about and record the following for the organism you've chosen:
     - **food** the organism eats
     - things the organism **builds with matter**
     - things the organism **does with energy**
     - **waste/exit products** it releases in the form of **matter** and **energy**

7. **Quickly model an example for how to use the chart to show how an organism uses matter and energy.**
   - **a.** Choose a familiar organism. (An image of a moose is included on Slide 10, but use whatever you prefer.)
   - **b.** Brainstorm what the organism eats and write it in the "food" area of the chart.
   - **c.** Brainstorm things the organism may build from the food it eats (parts mostly, such as bones, blood, leaves, etc.) and write these in the "build" area.
   - **d.** Brainstorm things the organism may do from the energy it gets and write these in the "do" area.

8. **Brainstorm matter and energy waste/exit products.**
   - **a.** Brainstorm matter and energy waste/exit products from the organism and write these in the "waste" area of the chart.
   - **b.** Share: Heat energy given off by an organism is considered an energy exit because the organism can no longer use it.
   - **c.** Share: All organisms release some gases as waste. (Plants and algae give off oxygen, while animals give off carbon dioxide.)

9. **Group goes outdoors and pairs work on Food, Build, Do, Waste/Exit charts together.**
   - **a.** Participants move outdoors to an area they've chosen nearby where they can find organisms.
   - **b.** Each pair quickly finds an organism.
   - **c.** Pairs record their ideas on their Food, Build, Do, Waste/Exit charts together.

10. **Each pair debriefs their chart with another pair.**
    - **a.** After they have some time to complete their charts, each pair teams up with another pair.
    - **b.** Pairs share their ideas about what their organism builds from matter in its food, what it does with energy from its food, and the wastes/exit products it releases.

TEACHING NOTES

If your instructors will be using this activity with students, model it more fully by using the complete student activity write-up. This activity has been abbreviated quite a bit to keep the length of this session reasonable. Some parts that are important to the student activity are skipped, and others are led less thoroughly than when done with students. If you are planning to have your staff use this activity with students (recommended), make sure you have set aside enough time (50 minutes) to do the activity as it would be led with students, either during this session or afterward. Instructors tend to present an activity with students in the same manner that it was introduced to them, so if it's presented rushed and abbreviated, as written here, they will probably present it that way with students.

Using the term *wastes/exits* instead of *wastes*. We use the term *waste* in this activity because students may have heard it used to describe poop and pee before. But the term *exit* is more accurate. For example, sometimes energy loss from an organism is a form of waste, but often organisms are trying to hold onto their energy, and losing energy (in the form of heat) is more of a loss than a waste. If you think it is appropriate for your group of students, you might choose to use the term *wastes/exits* instead, as we have done here.

Confusion around the word *build*. The word *build* may confuse some people because they may think of things such as nests or anthills that an organism might build that is separate from its body. You may need to emphasize that in this case, the word *build* refers to things that are built from matter the organism got from food. This will mostly be parts of the organism's body, but it may also include things such as spider silk that isn't part of a spider's body but is made from matter it got from food.

TEACHING NOTES

11. Return indoors and add any new questions to the question wall.

a. Gather the group and bring them back indoors.

b. If groups have new questions about matter and energy, have them write their questions on sentence strips and post them near the other questions.

Break

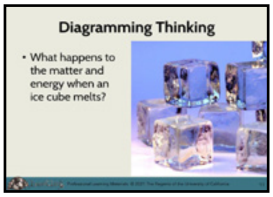
If you are breaking the session into two shorter sessions, this is a good time to stop. Between sessions, you could ask instructors to try implementing what they've learned into their teaching and be prepared to report back on how it went. If you aren't breaking the session into shorter sessions, this is also a good time for a short break.

YOU ARE HERE:

35 minutes

Thought Problems

1. Show Slide 11: ***Diagramming Thinking*****. Introduce the next activity and share:**



slide 11

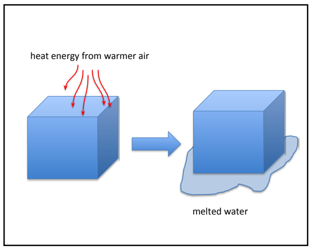
a. The next activity will build on what you just did.

b. You are invited to work on a thought problem related to matter and energy in ecosystems.

c. Together, you can create a detailed visual model of your group's thinking about matter and energy in order to figure out the thought problem.

d. I will demonstrate the process by using the example of a melting ice cube.

2. Model creating a diagram showing the movement of energy and matter in a melting ice cube.



a. Quickly draw a picture of an ice cube and ask:

▶ *How can we show what happens to the matter and energy in an ice cube as it melts?*

b. Begin by drawing red heat energy arrows from the warmer surrounding air toward the ice cube.

c. Ask: What can we add to the diagram to show what you think is happening to the frozen water as it absorbs heat energy? (If suggested, you may want to add an enlarged view of the water molecules.)

d. Draw a block arrow leading to another picture of an ice cube that has partially melted into a puddle and ask what participants think happened to the matter in the ice cube (the water molecules) as energy was added and it melted. Ask:

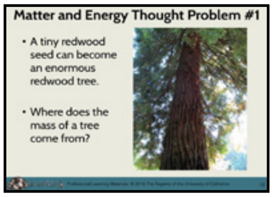
▶ *Did the number of molecules increase? Decrease?*

▶ *Are they moving faster? Slower?*

This is just a demonstration of what participants will be doing. There's no need for you to end up at an accurate conclusion with this demonstration. It's purpose is to show the *process* of making a model based on participants' ideas and how to openly discuss what those ideas are.

e. Share: This is the type of thinking, diagramming, and discussing participants will do with their thought problems.

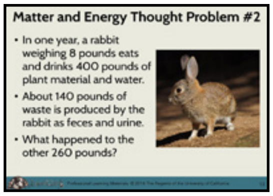
3. **Show Slide 12:** *Matter and Energy Thought Problem #1* **and introduce the problem by reading it out loud.**



slide 12

▶ *A tiny redwood seed can become an enormous redwood tree. Where does the mass of a tree come from?*

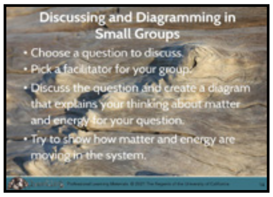
4. **Show Slide 13:** *Matter and Energy Thought Problem #2* **and introduce the problem by reading it out loud.**



slide 13

▶ *In one year, a rabbit weighing 8 pounds eats and drinks 400 pounds of plant material and water. About 140 pounds of waste is produced by the rabbit in feces and urine. What happened to the other 260 pounds?*

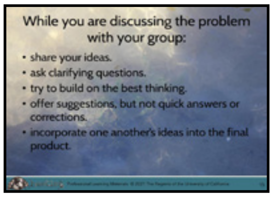
5. **Show Slide 14:** *Discussing and Diagramming in Small Groups*. **Share the discussion procedure:**



slide 14

   a. You should choose one of these two questions to discuss and diagram in your small group.
   b. Pick a facilitator for your group to keep everyone on task and make sure each person contributes to the diagram.
   c. Your group is invited to create a matter and energy diagram that will help you answer and share your question.
   d. You'll have about 15 minutes to complete your diagram.
   e. Form small groups of three to four people.

6. **Show Slide 15:** *While you are discussing the problem with your group*. **Share:**



slide 15

   a. Listen to all group members and try to incorporate everyone's ideas.
   b. When a question is asked by one group member, it shouldn't be quickly answered or corrected by others.
   c. Instead, listen to one another, discuss, and work toward understanding together.

7. **Distribute chart paper and purple markers (unless participants already have them) and have participants begin discussing and working on their diagrams.**

   a. Distribute a sheet of chart paper to each group.

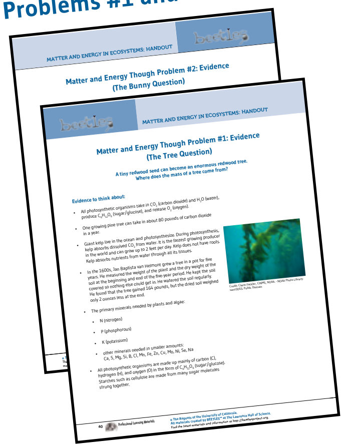
Using materials from earlier. If you are presenting the whole session in one day, participants can use the materials they have from earlier in the session. If you are dividing parts of the session over more than one day, you'll need to redistribute these materials.

TEACHING NOTES

b. Distribute a purple marker to each group. Make sure each group has red, blue, purple, and black felt-tipped markers.

c. Circulate as groups work on their diagrams and answer questions they may have about what they are being asked to do.

Matter and Energy Thought Problems #1 and #2: Handouts



8. After a few minutes, distribute one copy of the double-sided *Matter and Energy Thought Problems #1 and #2: Evidence* sheets to each participant and share:

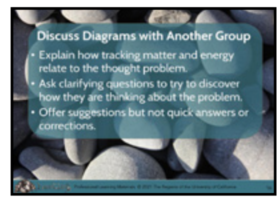
a. I'm distributing a sheet with more evidence to each person.

b. One side of the sheet has evidence for *Matter and Energy Thought Problem #1: Evidence—The Tree Question*; the other side has evidence for *Matter and Energy Thought Problem #2: Evidence—The Bunny Question*.

c. This evidence sheet may help you resolve any questions that may have come up as you were planning your diagram.

d. I'll give you a 5-minute warning before the time is up.

9. Show Slide 16: *Discuss Diagrams with Another Group*. **After about 15 minutes, invite groups to meet and discuss their diagrams. Share:**



slide 16

a. Each group will join with another small group.

b. You'll have about 10 minutes to share your ideas and discuss your diagrams with another group.

c. You should help one another think together by asking clarifying questions.

d. Try to compare and contrast the ideas from your diagrams.

e. I'll give a 2-minute warning before the time is up.

No need to discuss too long or correct inaccuracies yet. Don't spend too much time talking about or correcting participants' diagrams at this point. They will be getting more information in the session that may help them add to their explanations.

10. Debrief participants' learning from this activity with the whole group. Share:

a. Briefly report what you learned about tracking matter and energy from this activity.

b. What are "aha's" about how you were able to deepen or stimulate your thinking through these conversations about matter and energy?

c. On sentence strips, write any new questions you have. (Distribute additional sentence strips to groups, if needed.)

Answers to Thought Problems #1 and #2:

Where does most of the mass of a tree come from?

If you look at the photosynthesis equation, you can see it:

$6CO_2$	+	$12H_2O$	+	light energy	→	$C_6H_{12}O_6$	+	$6O_2$	+	$6H_2O$
carbon dioxide		water				sugar		oxygen		water

(continue on next page)

From this equation, you can see how the carbon (C), hydrogen (H), and oxygen (O) molecules from carbon dioxide and water are all that's needed to make a sugar molecule. The oxygen and carbon atoms in the sugar molecule come directly from carbon dioxide, and the hydrogen atoms in the sugar molecule come from water. The oxygen that is released in photosynthesis comes from water. So the mass of plants is built almost completely from carbon dioxide in the air and the hydrogen in water. It's strange to think that the mass of plants comes from something so seemingly insubstantial as a gas, but it does. A lot of people think that the mass of trees comes from soil, perhaps because educators often focus on the nutrient cycle and because soil seems more substantial than air.

What happened to the other 260 pounds the rabbit ate?

The answer to this question is in the respiration equation:

$C_6H_{12}O_6$	+	$6O_2$	+	$6H_2O$	$\rightarrow$	$6CO_2$	+	$12H_2O$	+	energy
sugar		oxygen		water		carbon dioxide		water		

Although some matter goes toward things such as sweat, babies, shedding fur, etc., the great majority of the mass lost as organisms live and grow is in exhaling the gases that are the result of respiration. As the evidence sheet shows, humans exhale about 2 pounds of carbon dioxide and 1.5 pounds of water vapor per day, and this amount can increase if you are exercising or raising your metabolic rate in other ways. Once again, because gas seems insubstantial, this can be difficult for students (and adults) to understand, but it is a key concept for understanding how matter cycles in ecosystems. The most common alternative conception with this topic is that the matter turns into energy, which *does not* happen in life systems on Earth.

Getting Energy (and Matter) from Food

YOU ARE HERE:

10 minutes

1. **Shift the focus to how living things get energy and matter from their food. Share:**
   - **a.** We have been discussing how energy and matter move through organisms in ecosystems.
   - **b.** But we haven't explored what happens within an organism to get and use energy and matter from food.

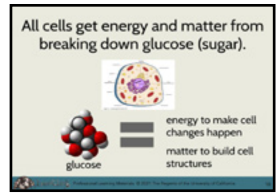
2. **Show Slide 17:** *Getting Energy from Food*. **Ask the following questions for pairs to briefly discuss about how organisms get energy from food:**

slide 17

   - *How do your cells get energy from the food you eat?*
   - *How do plant and algae cells get the energy they need?*
   - *How do the cells of a decomposer get energy to live and grow?*
   - *In other words, what are the mechanisms behind this process?*

TEACHING NOTES

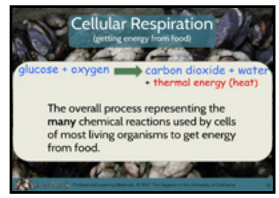
3. **Show Slide 18:** *All cells get energy and matter from breaking down glucose (sugar)*. **Share:**



slide 18

   a. Glucose is the fuel that drives the engine of life (energy).
   b. Glucose also provides the basic materials from which much of life is constructed (matter).
   c. The breakdown of glucose molecules makes energy available to organisms to use to live and grow.
   d. Organisms use matter from glucose to make essential molecules and structures.
   e. Glucose gives organisms fuel (energy) *and* building materials (matter).
   f. This is why it can be useful for students (and us!) to think of food, such as glucose, as a *package of matter and energy.*

4. **Show Slide 19:** *Cellular Respiration*. **Share that blue = matter and red = energy, and then share the blue/matter part:**



slide 19

   a. The blue type on this slide represents what's going on with matter in cellular respiration.
   b. Looking at the blue part of the equation, we can see that sugar and oxygen are converted into carbon dioxide and water.
   c. The red type represents what's going on with energy.

5. **Share that the equation shows how when food is consumed, sugar and oxygen are converted into carbon dioxide and water, and energy is made available for life processes:**
   a. The atoms of the sugar molecules are used by the organism to build structures, while carbon dioxide is released as waste.
   b. When this happens, organisms get the energy they need for life processes. This is a big deal for living things!
   c. Some thermal energy (heat) is released during respiration, but at least half of the energy becomes available for cells to use to make things happen.
   d. This equation is actually a simplification of many complex chemical reactions that happen in order for cells to get energy from food.
   e. The overall process for getting energy from glucose is called cellular respiration.

6. **Share how organisms get energy through cellular respiration:**
   a. Most organisms make energy available for their life processes through cellular respiration.

b. This includes fungi, even though many people are confused by how fungi get energy.

c. This also includes photosynthesizing organisms, such as plants.

d. Plants and algae use cellular respiration at night, and fungi use cellular respiration all the time.

7. **Show Slide 20:** *Photosynthesis*. **Share how this equation represents how photosynthetic organisms (producers) make glucose:**

slide 20

a. Looking at the blue matter part of the photosynthesis equation, we can see that carbon dioxide and water are converted into sugar and oxygen.

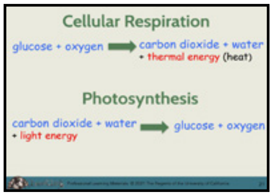
b. If you look at the red part of the equation, you see that energy is needed for this to happen.

c. Photosynthetic organisms use energy from sunlight to make glucose molecules out of carbon dioxide and water.

d. The glucose and resulting carbohydrates that are produced are the food needed by photosynthetic organisms to live.

e. This equation is an oversimplification of the many complicated chemical reactions that happen in the specialized cells of producers where photosynthesis happens.

8. **Show Slide 21:** *Cellular Respiration/Photosynthesis* **and share the circularity of the equations and what this represents:**



slide 21

a. These equations also show that respiration is the exact opposite of photosynthesis.

b. Photosynthesizing organisms make sugars, and all organisms use those sugars to live.

c. Looking at these two processes together, we can see that their reciprocal nature is essential for life on Earth.

d. This is one significant way all living things are connected.

e. By understanding the chemically based cellular connections between all living things, we can appreciate the role of matter and energy in ecosystems.

9. **Address any posted questions related to how organisms get energy from food.**

a. If there are any questions posted about the way organisms get and use energy from food, ask participants whether they now feel like they understand those questions.

b. Invite participants to try answering them, first in pairs and then with the whole group.

TEACHING NOTES

Not all organisms get energy through cellular respiration. Anaerobic organisms don't get energy through cellular respiration. When organisms are breaking down sugars through fermentation, they are also not getting energy through cellular respiration.

TEACHING NOTES

Age-appropriate concepts. Young children are likely to have difficulty studying the concept of energy in depth. It's pretty complex, and everyday language around energy includes a lot of shortcuts that lead to misunderstandings. For this reason, with NGSS, the concept of energy is generally not developed at all in K–2 and only very generally in grades 3–5. Instead, the elementary grades focus on recognition of conservation of matter and the movement of matter into, out of, and within systems under study. The role of energy transfers combined with these cyclings is not introduced until the middle grades and only fully developed in high school.

10. Share that understanding the cycling of CO_2 and O_2 and the flow of energy are useful for upper elementary/middle school students:

a. Focusing students on the gas exchange between producers and consumers can be key to a scientific understanding of the cycling of matter.

b. Students should also understand that energy enters and flows through ecosystems when producers capture and transform light energy from the sun and pass the energy to consumers in the food they eat.

c. With this scientific understanding, they can appreciate how producers provide the fuel for all organisms to live and grow.

11. Share that the chemical mechanisms for the processes of respiration and photosynthesis are often not addressed until high school:

a. We have not included the chemical mechanisms involved in the cycling of matter and flow of energy in ecosystems here.

b. Generally, students don't learn those until they reach high school.

YOU ARE HERE:

15–20 minutes

Answering Questions from the Session

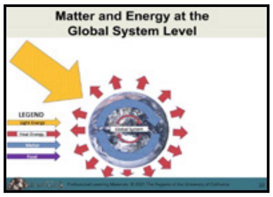
1. **Focus participants on the questions they wrote and posted on the wall. Share:**
   a. Read the remaining posted questions.
   b. Turn to a partner to discuss any questions you still feel the need to address about matter and energy.

2. **After they *Turn & Share*, give participants the opportunity to add any new questions that may have come up.**

3. **Discuss unanswered questions and remove any that have been answered.**
   a. Ask: Are there any questions here that have been answered and that we can remove?
   b. As participants respond, remove those questions and set them aside.
   c. Lead a discussion about the remaining questions:
      - *Are there any questions we still don't have answers to?*
      - *How might we find out more about this topic?*
   d. Address as many of the questions as you have the time or knowledge to tackle in the moment.
   e. Let the discussion unfold at whatever level the participants take it, but make sure to *pay attention to and include those who may not have a lot of science background or understanding.*
   f. If there are questions that you feel can't be easily answered with the group at this time, make a plan with the group for how to address them at a later time.

About leaving some questions unanswered. It's not possible to have everyone leave this session with all their questions answered about matter and energy. This is a complex topic in science, and your instructors may have varying levels of experience in science courses that have prepared them for this topic. It's meant to kick off an ongoing exploration and discussion of this topic among staff. Using the optional activity described at the end of the session, instructors can read and discuss the alternative conceptions in the *Content Information and Alternative Conceptions About Matter and Energy in Ecosystems* handout, which may be helpful to relieve some of their anxiety about not having complete answers.

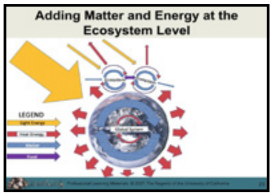
4. **Show Slide 22:** *Matter and Energy at the Global System Level*. **Share:**



slide 22

   a. Distribute one copy of the *Matter and Energy at the Global System, Ecosystem, and Individual Organism Levels* handout to each participant.
   b. Let's step back and review some of the big ideas of this session.
   c. Energy constantly flows into, through, and out of Earth's system.
   d. Energy mostly enters Earth's system as light energy from the sun and leaves as heat energy that eventuallyflows into outer space.
   e. The amount of energy that leaves the system is approximately the same amount that enters, otherwise the global system heats up.
   f. Matter cycles in Earth's systems through food and gas exchanges, with miniscule amounts of matter entering or leaving Earth's system.
   g. Some energy cycles within Earth's system and then eventually leaves.

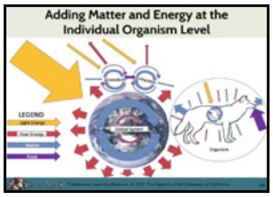
5. **Show Slide 23:** *Adding Matter and Energy at the Ecosystem Level*. **Share:**



slide 23

   a. There are uncountable numbers of overlapping ecosystems on Earth of many different sizes.
   b. Energy constantly flows through Earth's ecosystems.
   c. Energy mostly enters Earth's system as light energy from the sun and leaves as heat energy that eventually flows into outer space.
   d. Matter cycles within ecosystems through food and gas exchanges, but some matter enters and exits ecosystems in the form of gases, organisms, etc.
   e. Some energy cycles within ecosystems and then eventually leaves.

6. **Show Slide 24:** *Adding Matter and Energy at the Individual Organism Level*. **Share:**

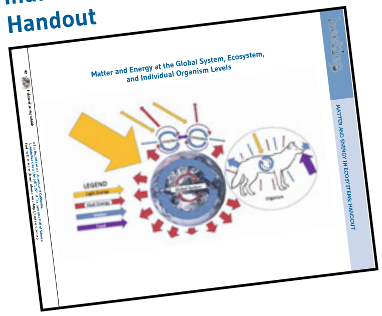


slide 24

   a. Organisms take in most of their matter through food and lose most of their matter through poo, pee, and exhaled carbon dioxide and water. They also lose matter through sweat, skin and hair loss, etc.
   b. Food provides all living things (plants, algae, animals, fungi, etc.) with the matter and energy they need to live and grow.
   c. Cells use oxygen to get energy from food through cellular respiration.
   d. Matter cycles within organisms.
   e. Organisms take in energy through food and through energy from the sun and environment. They lose energy mostly through their skin.
   f. Some energy cycles within organisms and then eventually leaves.

TEACHING NOTES

Matter and Energy at the Global System, Ecosystem, and Individual Organism Levels: Handout



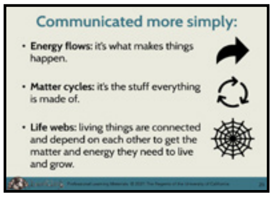
TEACHING NOTES

Energy flows, matter cycles, and life webs from Dr. Art. "Energy flows, matter cycles, and life webs" is from *Dr. Art's Guide to Planet Earth: For Earthlings Ages 12 to 120* by Art Sussman, Ph.D.

The importance of understanding why the wrong answer is wrong. "...critique is an essential element in the process of knowledge construction. In short, knowing why the wrong answer is wrong in academic discourse can be just as important as knowing why the right answer is right." (Henderson, J. B., MacPherson, A., Osborne, J., & Wild, A. (2015). Beyond Construction: Five arguments for the role and value of critique in learning science. *International Journal of Science Education 37*(10): 1669.

7. **Emphasize some main points addressed in the session. Share:**
    - **a.** On the handout, these three models are shown together, simplifications representing vastly complex exchanges of energy and matter.
    - **b.** These review important ideas of this session.
    - **c.** Are there any questions or comments?
    - **d.** Students can benefit greatly from learning these ideas about ecosystems while exploring them firsthand in outdoor science experiences.

8. **Show Slide 25:** *Communicated more simply*. **Share:**

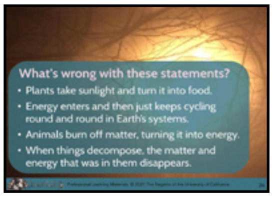


slide 25

    - **a.** A simple and accurate way of describing the nature of matter and energy and how they function in Earth systems is:

        ▶ ***Energy flows, matter cycles, life webs.***
    - **b.** This is a good summary of some of the big ideas of the session.
    - **c.** It's also a useful way of referring to these ideas with students.

9. **Show Slide 26:** *What's wrong with these statements?* **Ask participants to suggest what's wrong with each statement.**

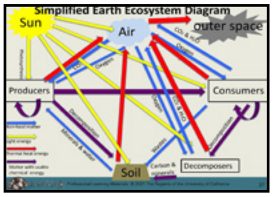


slide 26

    - **a.** These are scientifically inaccurate statements made about matter, energy, and ecosystems commonly made by students and instructors.
    - **b.** What's inaccurate about the first statement? Listen to responses.
    - **c.** Do the same with the other statements.

10. **If participants are confused by any of the inaccurate statements, choose a time to read and discuss the topic.** (See the *Content Information and Alternative Conceptions About Matter and Energy in Ecosystems* handout.)

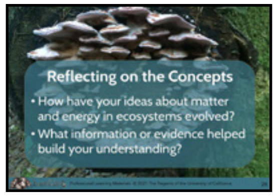
11. **Optional: Show Slide 27:** *Simplified Earth Ecosystem Diagram*, **walk through what each color represents, and compare it with the diagram the group made earlier.**



slide 27

    - **a.** Share that this is a cleaner and clearer version of the diagram they made together earlier in the session, checked for scientific accuracy.
    - **b.** Ask if there are any inaccuracies in the diagram they made earlier that should be adjusted.
    - **c.** Make adjustments to the group diagram, if appropriate.

12. **Show Slide 28:** *Reflecting on the Concepts* **and have participants think back on their initial ideas about matter and energy when you began this session. Share:**



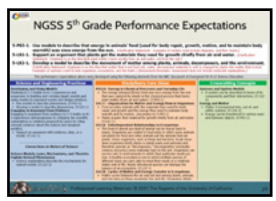
slide 28

   a. Remember that changing your ideas based on new information reflects critical thinking and open-mindedness.
   b. How have your ideas about matter and energy evolved at this point?
   c. What information or evidence helped build your understanding?
   d. Go back to your Quick-Write at the beginning of the session and read what you wrote about matter and energy.
   e. Now, draw a line under your writing (don't erase it—it's useful for learning to see how your ideas have shifted) and spend a few minutes recording (below the line) how your experiences have influenced your understanding about matter and energy.

13. **Ask if anyone would like to share some of what they wrote under the line. Briefly discuss any common themes that emerge.**

Key Concepts and Connections to the Next Generation Science Standards (NGSS)

1. **Show Slide 29:** *NGSS 5th Grade Performance Expectations*. **Share connections between the session topic and the Next Generation Science Standards:**



slide 29

   a. Distribute one copy of the *NGSS 5th Grade Performance Expectations* handout to each participant.
   b. These concepts we've been thinking about are closely aligned with the NGSS.
   c. Read aloud the relevant 5th grade performance expectations in black type in the white box at the top. (5-PS3-1, 5-LS1-1, and 5-LS2-1).
   d. The NGSS are organized as performance expectations.
   e. Performance expectations are examples of what students should be able to do if they learn the grade-level appropriate science practices, disciplinary core ideas, and crosscutting concepts of science.
   f. In the orange box are disciplinary core ideas students should learn that are related to the performance expectations.
   g. In the green box are the relevant crosscutting concepts.

2. **Share science practices related to the 5th grade performance expectations:**
   a. In the blue box are relevant science and engineering practices.
   b. In science, modeling is used to make explanations about natural phenomena more clear.

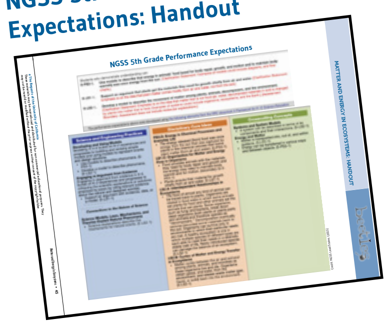
TEACHING NOTES

The *Line of Learning*. This is an adult version of an activity that can be used with students called the *Line of Learning*. Teachers instruct students to write about their prior ideas before the beginning of a lesson and then return to what they wrote at the end of the lesson so they can add to their understanding. This can help learners be more reflective about their learning process and how to become better learners.

YOU ARE HERE:

10 minutes

NGSS 5th Grade Performance Expectations: Handout



TEACHING NOTES

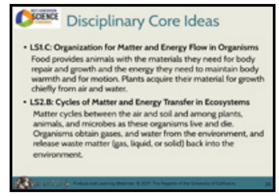
What's the matter? If anyone ever asks you this question, you can always answer, "I am! I am matter, and I am energy!" And you, dear reader, are a glorious bundle of matter and energy for oh so many reasons—especially so for the hard work you are putting into supporting your outdoor science instructors by preparing to present this session. While preparing, don't forget to eat some packages of matter and energy (food) to rebuild your body structures so you can keep doing stuff, such as working (and breathing, etc.). On behalf of outdoor science education, and of all matter and energy in the universe, thank you for your efforts, oh noble outdoor science professional learning presenter!

A Framework for K–12 Science Education. There's more information about the three dimensions of the Next Generation Science Standards in *A Framework for K-12 Science Education*. You may also want to review the standards related to matter and energy for the grade level of the students you work with in your program. Details about how students can come to learn these concepts is also found in the *Framework*.

c. You made models of matter and energy flow in this session. Students can, too, in activities such as *Food, Build, Do, Waste*.

d. You also had multiple experiences with *Engaging in Argument from Evidence* during this session.

3. **Show Slide 30:** *Disciplinary Core Ideas* **(from the orange box on the previous slide) and share that these are science concepts that underlie the fifth grade life science performance expectations:**



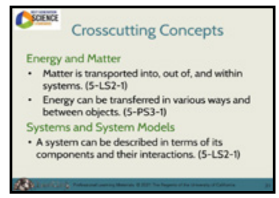
slide 30

a. The performance expectations can seem deceptively simple unless you look at all the parts needed for deep understanding.

b. This is just one part from the orange disciplinary core ideas box on the previous table. Read the slide to yourselves.

c. Activities such as *Food, Build, Do, Waste* can help prepare students for this performance expectation.

4. **Show Slide 31:** *Crosscutting Concepts* **and share how these apply to the standard:**



slide 31

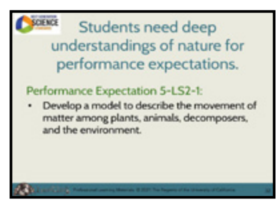
a. Read the slide of the crosscutting concepts related to the fifth grade life science performance expectations.

b. Crosscutting concepts are universal thinking tools used by scientists and engineers to make sense of the world.

c. There are seven crosscutting concepts students learn to use through the grades. One of these is *Energy and Matter*. Another is *Systems and System Models*.

d. You were using both of these crosscutting concepts during this session.

5. **Show Slide 32:** *Students need deep understandings of nature for performance expectations*. **Share that the NGSS require much more of students than being able to recognize equations or repeat definitions:**



slide 32

a. Here's one of those performance expectations again.

b. This is a good example of how the NGSS are designed to help students develop a deeper understanding of how nature works.

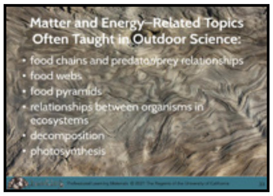
c. Outdoor science experiences are important for helping students with these understandings. The NGSS support outdoor science!

d. For students to be able to create models showing the movement of matter and energy among organisms and the environment, they'll need to understand:

- how matter and energy are transported (disciplinary core ideas)
- how systems work (crosscutting concepts)
- how models are used to make explanations (science practices)

6. **Share limitations of brief outdoor student activities in preparing students for science standards:**
   a. The handout shows what fifth grade students are expected to understand and be able to do on the topic of matter, energy, and ecosystems. Much of it relates to what we have addressed during this session at an adult-learning level.
   b. Activities such as *Food, Build, Do, Waste* were designed to help students build understanding of these important ideas and concepts at their levels.
   c. However, we can't expect students to achieve full understanding through activities experienced in a short amount of time.
   d. For deeper understanding, students need a variety of outdoor science experiences as well as experiences back at school, including the kinds of focused discussions and reflection we have been engaging in during this session.

7. **Show Slide 33:** *Matter and Energy–Related Topics Often Taught in Outdoor Science*. **Share strengths of learning about these topics during outdoor experiences:**



slide 33

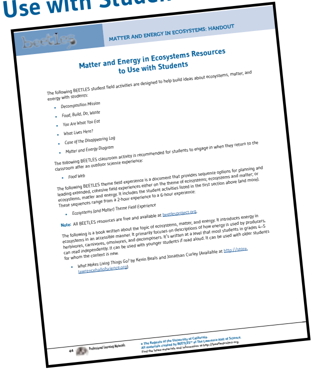
   a. All these topics are commonly taught in outdoor science, and they are all related to matter, energy, and ecosystems.
   b. They can provide an important foundation for students to develop a fuller and more in-depth understanding of ecosystems.
   c. In an outdoor science education environment, students can have the opportunity to apply these ideas to organisms living in a local habitat.
   d. By developing our own adult-level scientific understandings about matter and energy, we can help students see the connections between these, help dispel alternative conceptions, and avoid supporting alternative conceptions.
   e. When instructors integrate accurate ideas about matter and energy as they teach these topics, they can help students develop their fundamental understandings about them.
   f. These ideas are also foundational to understanding climate change.
   g. Students also get the opportunity to develop their scientific perspectives for the understanding of and appreciation for the interconnectedness of living and nonliving things on our planet.

8. **Show Slide 34:** *Matter and Energy in Ecosystems–Related BEETLES Student Activities* **and share:**

slide 34

   a. Distribute one copy of the *Matter and Energy in Ecosystems Resources to Use with Students* handout to each participant.
   b. BEETLES has published free activities to help instructors teach ecosystems, matter, and energy accurately and coherently.

Matter and Energy in Ecosystems Resources to Use with Students: Handout

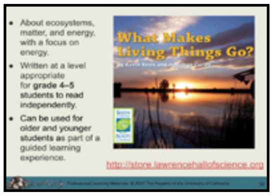


c. The first six activities on the list are individual student activities you can use: *You Are What You Eat*; *Decomposition Mission*; *What Lives Here?*; *Food, Build, Do, Waste*; *Matter and Energy Diagram*; and *Case of the Disappearing Log*.

d. The sixth activity on the list, *Food Web*, is an activity designed for teachers to use back in the classroom after a class has had an outdoor science experience.

e. The seventh "activity," *Ecosystems (and Matter) Theme Field Experiences*, is actually a series of activities. It describes sequence options for planning and leading extended, cohesive field experiences either on the theme of ecosystems; ecosystems and matter; or ecosystems, matter, and energy. It includes the student activities listed above (and more). These sequences range from 2-hour to 6-hour experiences.

9. Show Slide 35: ***What Makes Living Things Go?*** **and share:**



slide 35

a. *What Makes Living Things Go?* is a book written about the topic of ecosystems, matter, and energy.

b. It introduces energy in ecosystems in an accessible manner.

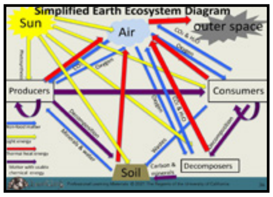
c. It primarily focuses on descriptions of how energy is used by producers, herbivores, carnivores, omnivores, and decomposers.

d. It's written at a level that most students in grades 4–5 can read independently.

e. It can be used with younger students if read out loud.

f. It can be used with older students for whom the content is new.

10. Show Slide 36 (same as Slide 27): ***Simplified Earth Ecosystem Diagram*****:**



slide 36

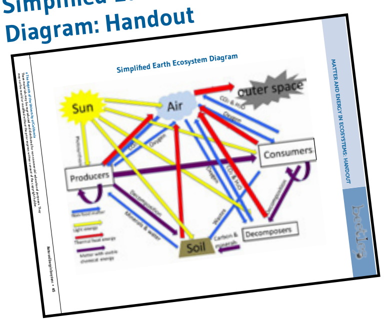
a. Distribute one copy of the *Simplified Earth Ecosystem Diagram* handout to each participant.

b. Share: This diagram may help clarify your understanding and help you remember what we've addressed in the session.

TEACHING NOTES

Give staff more opportunities for reflection and application! Reflection and application are crucial steps in learning. If your staff have scheduled opportunities to discuss what they've learned and plan how to apply it to their instruction, their application to instruction should be much stronger than if they don't have these opportunities. See the Applying Session to Instruction section (beginning on page 36) for ideas on how to do this.

Simplified Earth Ecosystem Diagram: Handout



YOU ARE HERE:

10 minutes

or

Reflecting on the Session

1. Show Slide 37: ***Reflection*** **and share that participants will take some time to reflect on how they can apply what they have learned to their own instruction with students:**

slide 37

a. There has been a lot of learning about concepts during this session.

b. There are BEETLES resources for teaching students about these concepts available for helping students learn (as shown in the previous slide).

c. Take 10 minutes to write about how you can apply content from this session to your instruction with students.

OPTIONAL: Exploring Alternative Conceptions

1. **Post the diagrams from the Food Web/Matter and Energy Diagram activity and the Thought Problems activity.**

2. **Form small groups and distribute one copy of the *Content Background and Alternative Conceptions About Matter and Energy in Ecosystems* handout to each participant.**

3. **Invite participants to sit where they can see the diagrams. Ask them to read the content information on the handout and then read the alternative conceptions. Share:**
   - **a.** Please sit where you can see the diagrams from both the Food Web/ Matter and Energy Diagram activity and the Thought Problems activity.
   - **b.** Take about 5 minutes to silently read the content information for each topic first and then the inaccurate ideas for each topic.

4. **Small groups choose a topic or inaccurate idea to discuss. Share:**
   - **a.** After all participants in your group have read the handout, choose a topic or inaccurate idea that interests you and discuss it as a group.
   - **b.** Discuss specifically *why* you think the inaccurate ideas are not completely accurate and *what may lead students to think this way.*
   - **c.** Also discuss what experiences might help students build on or confront these inaccurate ideas.

5. **Debrief the discussions.**
   - After about 15 minutes of small-group discussions, ask participants the following questions:
     - ▶ *Do any of these ideas and inaccurate ideas surprise you? Which ones? What about them is surprising?*
     - ▶ *Do any of these ideas help with any confusion you had while making the diagrams during the session?*
     - ▶ *What ideas do you have about helping students build on their inaccurate ideas?*

beetles

TEACHING NOTES

YOU ARE HERE:

30 minutes

or

Content Background and Alternative Conceptions About Matter and Energy in Ecosystems: Handout

***Misconceptions, alternative conceptions*, and other such terms.** Students' prior knowledge is often based on their experiences and is intelligent and useful. Students' prior understandings are often called alternative conceptions to give more value to the ideas students have worked out for themselves. Even though alternative conceptions are not fully accurate, these ideas are often based on accurate bits of information, often complex, and part of an extensive mental framework developed over time. Other terms used for this reason include: *naïve ideas*, *preconceptions*, *alternate conceptions*, *incomplete ideas*, and *inaccurate ideas*. Whichever term(s) you choose to use, including *misconceptions*, it's critical that the meaning behind whatever term is used should reflect this respect for students' ideas.

TEACHING NOTES

APPLYING SESSION TO INSTRUCTION

The session is not over! A critical phase of learning anything new is application—when the learner takes new knowledge and applies it. There is some application included in the session, but, as with all professional learning for instructors, the rubber meets the road (or trail) when instructors apply what they've learned to their instruction and when they keep thinking and discussing with their peers. If you want your instructors to keep developing their understandings about ecosystems, matter, and energy and applying it to their instruction, they'll need ongoing support from you. Below are a variety of follow-up activities and discussions to let you dig deeper into the topic and help you facilitate thoughtful implementation.

- **Staff brainstorm about what they and you can do to encourage more accurate and coherent instruction around the topics of ecosystems, matter, and energy.** After the session reflection, your staff will have already recorded ideas they have about implementation into their instruction. You can tap into these, as well as other ideas, through a brainstorm of what they plan to do and how you can support them in doing it.
- **Staff brainstorm about what they and you can do to encourage *less scientifically inaccurate* instruction around the topics of ecosystems, matter, and energy.** These ideas are complex, so it shouldn't be surprising if your instructors have been including scientific inaccuracies in their teaching. The *Content Information and Alternative Conceptions About Matter and Energy in Ecosystems* handout includes a wide variety of commonly held alternative conceptions about the topic. These are inaccurate or partly inaccurate ideas that are common among many students as well as adults, including outdoor science instructors. Reducing the amount of scientifically inaccurate ideas supported by instruction is an important early step in increasing the quality of scientific ecosystem instruction. You might have your staff work in teams to read through the alternative conceptions, making sure they understand what is inaccurate about each one. They can flag those they recognize as being part of current instruction and plan for how they could increase scientific accuracy.
- **Sequencing of activities.** To encourage more coherent instruction around these topics, you might want to set aside some time to support staff in doing some planning of sequencing of activities and conceptual development. This can be done either individually, with at least one other partner, or with a team. The following BEETLES student field activities are designed to help build ideas of ecosystems, matter, and energy with students:
    - *Decomposition Mission*
    - *Food, Build, Do, Waste*
    - *You Are What You Eat*
    - *What Lives Here?*
    - *Case of the Disappearing Log*
    - *Matter and Energy Diagram*

The following BEETLES classroom activity is recommended for students to engage in when they return to the classroom after an outdoor science experience:

- *Food Web*

The following BEETLES theme field experience is a document that provides sequence options for planning and leading extended, cohesive field experiences either on the theme of ecosystems; ecosystems and matter; or ecosystems, matter and energy. It includes the student activities listed on page 36 (and more). These sequences range from a 2-hour experience to a 6-hour experience:

- *Ecosystems (and Matter) Theme Field Experience*

- **Discussion about including energy in instruction.** Energy and matter have often been combined in outdoor science instruction, even in younger grades, which has sometimes led to such confusion as teaching that energy from the sun enters ecosystems and just keeps flowing round and round in a cycle. Understanding energy can be quite confusing. For this reason, with NGSS, the concept of energy is generally not developed at all in grades K–2 and only very generally in grades 3–5. Instead, the elementary grades focus on matter cycles: recognition of conservation of matter and of the movement of matter into, out of, and within systems. The role of energy transfers mixed in with these cyclings is not introduced until the middle grades and only fully developed by high school. You might discuss with your staff how you currently address one or both of these topics and how you would like to address them from now on.

    - **Instructor observations.** If you conduct observations of instructors, discuss how you might incorporate elements from this session into the observations, such as paying attention to how experiences help students build their understandings about ecosystems, matter, and energy.

    - **Continuing a discussion.** If there was a topic that came up during discussion that you had to cut off, and it seems as though your staff is still interested, set aside some time to continue the discussion.

    - **Researching questions.** You might ask volunteers to do deeper research into aspects of ecosystems, matter, and energy that your group found confusing and then have them report back to the group.

    - **Assign your staff a reading that is related to the ideas in this session.** Invite your staff to record notes as they read. Ask them to pair up with someone and compare notes and ideas. Then, bring this discussion into the whole group. Following are some suggested readings (all of which are approachable) in order of sophistication from simple to more complex. Consider the levels of pre-existing knowledge of your staff when choosing the readings.

TEACHING NOTES

- Two highly approachable and friendly guides to science, written by Dr. Art (Dr. Art Sussman) who is a BEETLES advisor and who we were lucky to have do a science review of the content of this session:
  - Sussman, Art. (2000). *Dr. Art's Guide to Planet Earth: For Earthlings Ages 12 to 120*. San Francisco: WestEd.
    - Suggested passages to begin with (although the whole book is valuable and doesn't take that long to read):
      - Chapter 1: Introducing Planet Earth
      - Chapter 2: Matter Cycles: pages 36-41 (The Carbon Cycle, Today's Carbon Cycle)
  - Sussman, Art. (2006). *Dr. Art's Guide to Science: Connecting Atoms, Galaxies, and Everything in Betwee*n. San Francisco: Jossey-Bass.
    - Suggested passages to begin with:
      - Chapter 4: Energy
      - Chapter 9: Life on Earth
- The following book is also written in an approachable way. It's more text-heavy than Dr. Art's books and doesn't include many illustrations.
  - Hazen, Robert M. and Trefil, James. (2009). *Science Matters: Achieving Science Literacy*. New York: Anchor Books.
    - Chapter 19: Ecosystems (Note: The information on impacts of climate change are not up-to-date.)
- Although still written in an approachable manner, the following book goes into more sophisticated content than the preceding books:
  - Hoagland, M., Dodson, B., Hauck, J. (2001). *Exploring the Way Life Works: The Science of Biology*. Burlington, MA: Jones & Bartlett Learning.
    - Suggested pages to choose from depend on what you see as needs for follow-up information of your staff:
      - Chapter 2.9: Life Runs on Sugar, page 57
      - Chapter 2.11: LIfe Recycles Everything it Uses, pages 62–64
      - Chapter 3: Energy—Light to Life, pages 87, 96–99 (Energy Flow and Equilibrium, How a Dog Shares Its Fleas, Chemical Energy Makes Electrical Energy, and Getting Rid of Heat)
        - 3.4: ATP—The Energy Molecule, pages 100–101
        - 3.7: Energy Flow Through Life–A Macro View, pages 104–105

- 3.8: Energy Flow Through Life–A Micro View, pages 108–109
- 3.10: Photosynthesis—Using Sunlight to Make Sugar, pages 112–117
- Doing Science—Van Helmont's Experiment, page 119
- 3.12: Respiration—Breaking Down Sugar to Make ATP, pages 122–127
- In Plant Cells (photosynthesis-respiration), page 131

Matter and Energy Though Problem #1: Evidence (The Tree Question)

A tiny redwood seed can become an enormous redwood tree.
Where does the mass of a tree come from?

Evidence to think about:

- All photosynthetic organisms take in CO_2 (carbon dioxide) and H_2O (water), produce $C_6H_{12}O_6$ (sugar/glucose), and release O_2 (oxygen).
- One growing pine tree can take in about 80 pounds of carbon dioxide in a year.
- Giant kelp live in the ocean and photosynthesize. During photosynthesis, kelp absorbs dissolved CO_2 from water. It is the fastest growing producer in the world and can grow up to 2 feet per day. Kelp does not have roots. Kelp absorbs nutrients from water through all its tissues.

Credit: Claire Fackler, CINMS, NOAA. - NOAA Photo Library: sanc0063, Public Domain

- In the 1600s, Jan Baptista van Helmont grew a tree in a pot for five years. He measured the weight of the plant and the dry weight of the soil at the beginning and end of the five-year period. He kept the soil covered so nothing else could get in. He watered the soil regularly. He found that the tree gained 164 pounds, but the dried soil weighed only 2 ounces less at the end.
- The primary minerals needed by plants and algae:
  - N (nitrogen)
  - P (phosphorous)
  - K (potassium)
  - other minerals needed in smaller amounts: Ca, S, Mg, Si, B, Cl, Mn, Fe, Zn, Cu, Mo, Ni, Se, Na
- All photosynthetic organisms are made up mainly of carbon (C), hydrogen (H), and oxygen (O) in the form of $C_6H_{12}O_6$ (sugar/glucose). Starches such as cellulose are made from many sugar molecules strung together.

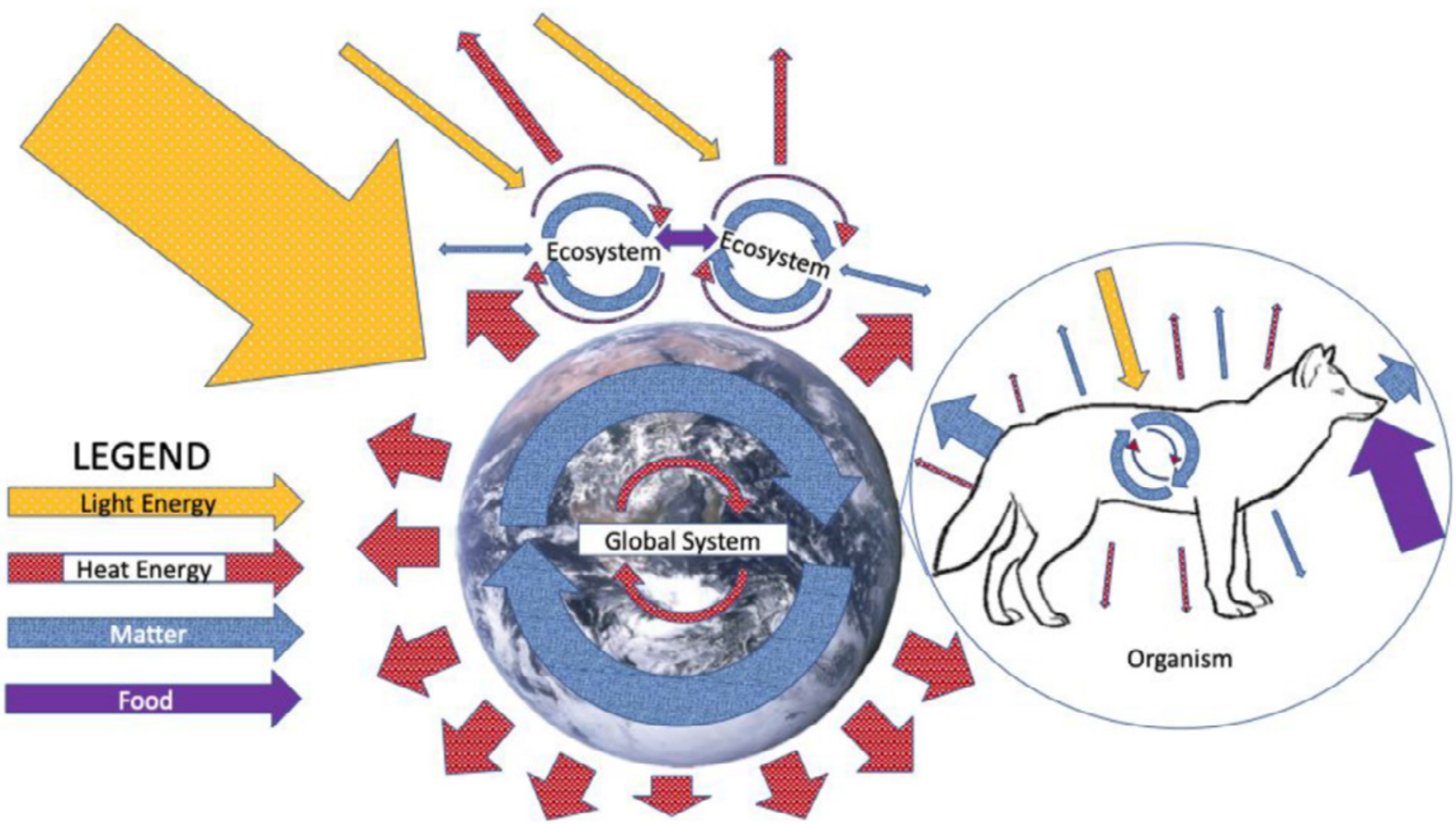
Matter and Energy Though Problem #2: Evidence (The Bunny Question)

In one year, a rabbit weighing 8 pounds eats and drinks 400 pounds of plant material and water. About 140 pounds of waste is produced by the rabbit as feces and urine. What happened to the other 260 pounds?

Evidence to think about:

- The droplets you see when you breathe on a mirror are evidence that you lose water vapor with every breath. Humans release about *1½ pounds* of water per day through breathing and sweating. That's a little less than the weight of a 1 liter bottle of water.
- It's difficult to feel it, but the air around us has mass (weight).
- Just by breathing, each person releases about *2 pounds* of weight every day from the carbon dioxide they breathe out.
- Assuming the average composition of gases, 1 cubic foot of air at standard temperature and pressure (1 Atmosphere) weighs approximately 0.0807 lbs.
- Under the usual circumstances on Earth, matter does not turn into energy.
- $E = mc^2$ is an important idea in physics and the theory of relativity, but it's not useful for describing matter and energy in ecosystems.

Matter and Energy at the Global System, Ecosystem, and Individual Organism Levels



NGSS 5th Grade Performance Expectations

Students who demonstrate understanding can:

5-PS3-1. **Use models to describe that energy in animals' food (used for body repair, growth, and motion and to maintain body warmth) was once energy from the sun.** [Clarification Statement: Examples of models could include diagrams, and flow charts.]

5-LS1-1. **Support an argument that plants get the materials they need for growth chiefly from air and water.** [Clarification Statement: Emphasis is on the idea that plant matter comes mostly from air and water, not from the soil.]

5-LS2-1. **Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment.** [Clarifcation Statement: Emphasis is on the idea that matter that is not food (air, water, decomposed materials in soil) is changed by plants into matter that is food. Examples of systems could include organisms, ecosystems, and the Earth.] [Assessment Boundary: Assessment does not include molecular explanations.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions.
- Use models to describe phenomena. (5-PS3-1)
- Develop a model to describe phenomena. (5-LS2-1)

Engaging in Argument from Evidence
Engaging in argument from evidence in 3–5 builds on K–2 experiences and progresses to critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed world(s).
- Support an argument with evidence, data, or a model. (5-LS1-1)

Connections to the Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
- Science explanations describe the mechanisms for natural events. (5-LS2-1)

Disciplinary Core Ideas

PS3.D: Energy in Chemical Processes and Everyday Life
- The energy released [from] food was once energy from the sun that was captured by plants in the chemical process that forms plant matter (from air and water). (5-PS3-1)

LS1.C: Organization for Matter and Energy Flow in Organisms
- Food provides animals with the materials they need for body repair and growth and the energy they need to maintain body warmth and for motion. *(secondary to 5-PS3-1)*
- Plants acquire their material for growth chiefly from air and water. (5-LS1-1)

LS2.A: Interdependent Relationships in Ecosystems
- The food of almost any kind of animal can be traced back to plants. Organisms are related in food webs in which some animals eat plants for food and other animals eat the animals that eat plants. Some organisms, such as fungi and bacteria, break down dead organisms (both plants or plants parts and animals) and therefore operate as "decomposers." Decomposition eventually restores (recycles) some materials back to the soil. Organisms can survive only in environments in which their particular needs are met. A healthy ecosystem is one in which multiple species of different types are each able to meet their needs in a relatively stable web of life. Newly introduced species can damage the balance of an ecosystem. (5-LS2-1)

LS2.B: Cycles of Matter and Energy Transfer in Ecosystems
- Matter cycles between the air and soil and among plants, animals, and microbes as these organisms live and die. Organisms obtain gases, and water, from the environment, and release waste matter (gas, liquid, or solid) back into the environment. (5-LS2-1)

Crosscutting Concepts

Systems and System Models
- A system can be described in terms of its components and their interactions. (5-LS2-1)

Energy and Matter
- Matter is transported into, out of, and within systems. (5-LS1-1)
- Energy can be transferred in various ways and between objects. (5-PS3-1)

Credit: NGSS Lead States. (2013)

Matter and Energy in Ecosystems Resources to Use with Students

The following BEETLES student field activities are designed to help build ideas about ecosystems, matter, and energy with students:

- *Decomposition Mission*
- *Food, Build, Do, Waste*
- *You Are What You Eat*
- *What Lives Here?*
- *Case of the Disappearing Log*
- *Matter and Energy Diagram*

The following BEETLES classroom activity is recommended for students to engage in when they return to the classroom after an outdoor science experience:

- *Food Web*

The following BEETLES theme field experience is a document that provides sequence options for planning and leading extended, cohesive field experiences either on the theme of ecosystems; ecosystems and matter; or ecosystems, matter and energy. It includes the student activities listed in the first section above (and more). These sequences range from a 2-hour experience to a 6-hour experience:

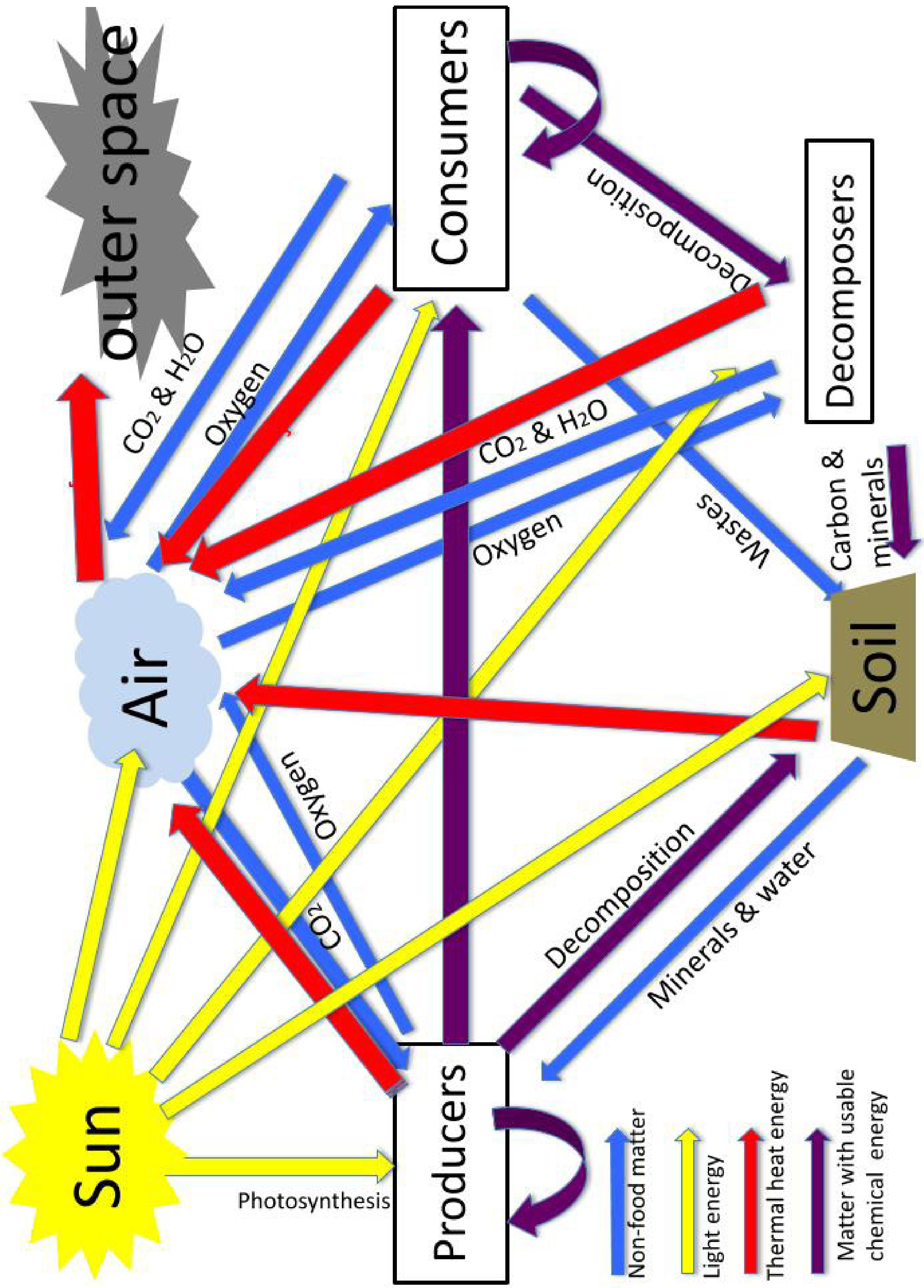
- *Ecosystems (and Matter) Theme Field Experience*

Note: All BEETLES resources are free and available at beetlesproject.org.

The following is a book written about the topic of ecosystems, matter, and energy. It introduces energy in ecosystems in an accessible manner. It primarily focuses on descriptions of how energy is used by producers, herbivores, carnivores, omnivores, and decomposers. It's written at a level that most students in grades 4–5 can read independently. It can be used with younger students if read aloud. It can be used with older students for whom the content is new.

- *What Makes Living Things Go?* by Kevin Beals and Jonathan Curley (Available at http://store.lawrencehallofscience.org)

Simplified Earth Ecosystem Diagram



Content Information and Alternative Conceptions About Matter and Energy in Ecosystems

This handout shares essential concepts and understandings about matter and energy in ecosystems for educators with different levels of background knowledge. It also describes alternative ideas or alternative conceptions people often have about these concepts—ideas that are important to keep in mind when teaching about matter and energy in ecosystems.

Food

Glucose (a simple sugar) provides all living things with the chemical energy and matter they need to live. Photosynthetic organisms make their own glucose molecules (food) from carbon dioxide and water by using energy from sunlight. Chemosynthetic organisms, such as bacteria living in deep sea communities with no access to light energy, produce sugar molecules (food) from carbon dioxide by using small molecules in their environment as the energy source. Consumers and decomposers both break down food into simpler substances (including glucose) that are used to live and grow. The food they eat must be digestible in order to provide both matter and energy for the organism to live, build its body parts, and grow. Organisms also need other kinds of matter to survive, such as water, oxygen, carbon dioxide, nutrients, and vitamins, but these substances are not considered food. The typical convention used in drawing food webs is to draw the arrows between organisms pointing toward the organism that consumes the food. The arrows show the direction of the movement of matter and energy. Food serves as a fuel and also provides the molecules and building materials needed by organisms. This is why it is useful for students to think of food as a *package of matter and energy*.

Inaccurate Ideas About Food

- *Food is converted directly into energy.* OR: *Food is used up immediately to create energy.*
- *Food is needed for growth, but the resulting structures/matter generated by growth come from a different source.*
- *Food is everything that goes into an organism—carbon dioxide, water, sunlight, oxygen, and vitamins.*
- *Plants and animals grow through different processes.*

Producers

Producers are mainly photosynthetic organisms that transform light energy into the chemical energy stored in glucose, through the process of photosynthesis. Using light energy from the sun, plants and plant-like organisms such as algae, make glucose (a simple sugar) by combining carbon dioxide from the air with water. Energy in producers' cells is also used to help fuel the series of complex reactions needed for photosynthesis to happen. No other type of matter is needed. Organisms that produce their own food are also called autotrophs. Chemosynthetic bacteria are also autotrophs.

Inaccurate Ideas About Producers

- *Plants make food from water and air, but food (glucose) is not transformed into the plant's body structures. For example, thinking the mass of a tree comes from water and soil.*
- *Plants and algae take in and use some substances and produce others. These are separate events—the substances that plants take in are not the raw materials for the products they make.*
- *Plants and algae "eat" substances, such as fertilizers, that are used as food.*
- *Roots are feeding organs.* OR: *Plants can get their energy from the soil through their roots.*
- *Plants need only soil, water, and sunlight to live. (i.e., No gases are involved.)*
- *Light is a food for plants and algae.*
- *Light is a facilitating agent—just as it helps us read a book, it helps plants and algae make food.*
- *Energy for photosynthesis comes from the heat of the sun.*
- *Sunlight is only one of many energy sources for plants and algae; others include soil, minerals, water, air, and wind.*
- *Through photosynthesis, plants and algae convert energy from the sun directly into matter (e.g., food or body structures).*

Consumers

Consumers can't make their own food, so they get it by eating other organisms. Humans and other animals are consumers and can't make their own food but must get it by consuming plants, algae, or other consumers. Fungi and other decomposers are also considered consumers because they can't produce their own food. Organisms that get their food from other organisms are also called heterotrophs.

Inaccurate Ideas About Consumers

- *Since carnivores eat only animals, they could survive if no plants or algae existed.*
- *Predation is a specific eating event, not part of a chain—the food in one level of the food chain is not the same thing as the food at the level before or after.*
- *Plants and algae make food because they "want" to feed animals.*

Decomposers

Decomposers transform dead organisms into simpler substances to get the energy they need to live and grow, just as consumers do with the food they eat. Some by-products of this process (carbon dioxide, water, minerals) are released into the soil, water, and atmosphere and can be used by plants, algae, and other organisms. Since they release minerals and other organic matter back into the environment, decomposers are necessary to complete the cycle of matter.

Inaccurate Ideas About Decomposers

- *Decomposition would happen without any decomposers.*
- *Matter is not reused after death. Decomposition leads to a total or partial disappearance of matter or the using up of all the energy.*
- *Dead material enriches soil, but it is not part of the soil.*

Cellular Respiration

All living organisms make energy available for their life processes by using oxygen to break down energy-rich food (such as carbohydrates and fats) into simpler, lower-energy substances (glucose, a simple sugar). After food is broken down into simple sugars, it enters the organism's cells where it goes through a series of chemical reactions that use oxygen. It's through this process of cellular respiration—where cells consume oxygen and release carbon dioxide and water—that cells get and store energy. Some of this energy is released as heat and, more importantly, most is stored as chemical energy. In larger organisms, the gases produced by cellular respiration enter the bloodstream and are released when organisms exhale. Breathing in oxygen and breathing out carbon dioxide and water vapor at the whole-body scale is also referred to as respiration.

Inaccurate Ideas About Cellular Respiration

- *Matter is transformed into energy rather than into simple substances of matter.*
- *Energy from food is used up immediately.*
- *Water is a source of energy.*
- *Food turns into energy in our body.*
- *Energy is a substance.*
- *Sugars are fuel that is used immediately; fat is fuel that is stored.*

Trophic Pyramids

Producers, consumers, and decomposers in an ecosystem can be organized into a trophic pyramid, which is a model that represents feeding relationships between these groups of organisms. The pyramid also shows the distribution and amount of biomass (organic matter that can be eaten as food) among different trophic levels. Most pyramids begin with producers at the bottom, herbivores (primary consumers) as the next trophic level up, carnivores (secondary consumers) next, and ending with carnivores that eat carnivores (tertiary consumers) at the top. Interestingly, most trophic pyramid diagrams leave decomposers off the diagram completely, or they are connected into all three consumer levels by writing them across the side of the pyramid.

At each trophic level, some energy is lost as heat energy, and some energy is used for other life processes. That's why consumers don't get all the energy that was consumed by or stored in the organisms they eat. Since consumers can't get all the energy from the trophic level below them, organisms higher up the chain need more biomass from the producer and consumer levels beneath them. This is the reason why specific food chains are not usually longer than four or five organisms. A food chain or a food web does not represent everything an organism eats. The sun does not belong in food chains or food webs because it is not food.

This continuous release of energy by living organisms (mostly in the form of heat energy and the energy of motion) means that an outside source of energy—the sun—is needed to maintain the flow of energy into ecosystems. That's why ecosystems are not closed systems, as far as energy goes. Energy primarily enters an ecosystem through light energy and leaves on a one-way route out of the ecosystem as heat energy that is released into the surrounding environment and then flows into outer space. Energy is not used up within an ecosystem, but changes forms as it passes through the organisms that eat one another and as it leaves the ecosystem.

Inaccurate Ideas About Trophic Pyramids

- *The flow of energy in an ecosystem is trapped in a closed system.*
- *Food chains are typically very long and include many organisms.*
- *Populations on the top increase as the organisms below decrease.*
- *Organisms do not transfer energy from one to the next.*
- *A top predator gets all the energy from every organism below it in the food pyramid.*
- *Energy accumulates at the top of the pyramid.*
- *Animals' energy does not come from the sun.*

Matter and Energy

Energy is not a substance. It is a property of matter that makes things happen. It's also a measure of how much change can happen in a system—so, it can be represented with a number. Something needs to *happen* for any type of energy to be released or transferred. In other words, energy is released or transferred during *interactions*. As a result of an interaction, energy can transform from one type to another, and the amount of energy associated with an object can change. These *changes* are what are being taken into account as we track the flow of energy through a system. Understanding energy flow and redistribution throughout a system is often a key to understanding the functioning of the system as a whole.

Energy has no physical form, which is why it can't be considered a substance. When we say that energy is transferred from one organism to another, we are not talking about a physical thing being passed from place to place; rather, we're talking about transferring the capacity to do things—for instance, living and growing. When we say that energy is always conserved, we mean that it is neither created nor destroyed.

Energy can be described as being in two different categories: the energy of motion (kinetic energy) and stored energy (potential energy). Light, sound, heat (thermal) energy, as well as the movement of objects, are all examples of kinetic energy. Chemical, gravitational, elastic, and nuclear energy are all examples of types of potential energy. Since potential energy types don't involve detectable movement or even sensation, they are commonly unrecognized. The greater the potential energy, the more capacity there is for something to happen.

Even though chemical energy in matter can be transformed into usable energy by organisms, the *matter* in food does not turn into energy. Remember that energy is not a substance. The energy may change into different forms of energy, and the matter may change into different forms of matter, but the matter doesn't turn into energy. The chemical substances in food are transformed into new substances (through chemical reactions), but there are no new atoms created or destroyed in the process. Under usual circumstances (certainly in all ecosystems and food webs), matter does not turn into energy.

Note: The way energy is described in different disciplines of science can lead to confusion for students and adults. While physics teaches us about the important principle of mass/energy equivalence (i.e., $E = mc^2$), in most cases it makes sense to treat mass and energy as separate concepts. Within Earth's ecosystems, matter doesn't change into energy. During chemical processes, the atoms don't change. In chemical processes, the very inner nucleus of each atom remains the same, and essentially none of the atom's mass changes into energy. In contrast, there are nuclear reactions in which matter changes into energy or energy changes into matter. Examples of this are stars, radioactive decay, and high-energy particle physics experiments. Ecosystem, organism, and cellular interactions are nonnuclear, and we do not need to consider that any matter changed into energy or that energy changed into matter. So, the energy associated with mass is constant and irrelevant to keeping track of changes in energy. However, in particle physics, collisions in which scientists collide and annihilate matter and antimatter at high energies *do* produce new particles and antiparticles with different masses. So, in all nonnuclear cases, it's convenient to treat mass-energy quite separately from other forms of energy and to leave it out of the equations for energy altogether.

A useful way to distinguish energy from matter is to say that, in general, energy flows and matter cycles at a global-systems level. Matter is the substance that all physical things are made of—everything that has mass and takes up space is made of matter. Matter cycles through Earth's systems and does not usually leave (or enter) the planet. On the other hand, a large amount of energy constantly flows to Earth from the sun in the form of light energy, and the same amount must be able to leave our planet in the form of heat energy (or other forms of radiation). If not, Earth's systems would accumulate energy, and we would quickly become a very hot planet. Energy is not "used up" by ecosystems; rather, energy flows into ecosystems, some of it cycles around a bit, and then it flows out of ecosystems. Matter continuously cycles through ecosystems and other Earth systems.

Inaccurate Ideas About Matter and Energy

- *Matter is created from the sun's energy through photosynthesis. Plants and algae convert energy from the sun directly into matter (e.g., food or body structures).*
- *Light energy disappears when plants or algae make sugar.*
- *Things/objects that are not moving do not have energy.*
- *The sun/food/fuel is energy (not the source of energy).*
- *Matter can be created or destroyed (rather than transformed into new types of matter).*
- *Organisms and materials in the environment are very different types of matter and are not transformable into each other.*
- *The sun creates matter.*

Going a Little Deeper on Getting Energy from Food

There is a lot of content in this session for instructors to grapple with. You can certainly go deeper, but that would probably be going too far for most outdoor science instructors and program leaders. However, for those who are interested in going deeper about energy, we've included the information in this section.

Organisms (including plants, animals, and fungi) make energy available for their life processes by using oxygen to break down energy-rich food (such as carbohydrates and fats) into simpler, low-energy substances (glucose). After food is broken down into simple sugars, it enters the organism's cells where it goes through a series of chemical reactions requiring oxygen and resulting in the formation of Adenosine triphosphate (or ATP) through the Krebs cycle, which is able to store and transport chemical energy within cells. It is through this process of cellular respiration—in which cells consume oxygen and release carbon dioxide and water—that cells can get and store energy. Some of this energy is released as heat and, more importantly, most is stored as chemical energy in the form of the tiny but extremely important supermolecule ATP.

Chemical energy is stored and released in all cells by using ATP, which is the primary energy storage and delivery molecule for living things. Cells are constantly making ATP, moving it to where it's needed and partially breaking it down to release the energy they need. The energy needed to break down glucose molecules comes from this ATP. Cellular respiration takes place within the mitochondria of each cell of an organism where sugars are broken down through a series of chemical reactions that need oxygen. This process involves the removal of hydrogens from sugar as new molecules of ATP are formed. When glucose is first broken down in a cell, some energy is immediately made available to the cell. The most important part of processing glucose is how cells store the energy in ATP.

The photosynthesis and cellular respiration formulas included in the session can also go deeper. In cellular respiration, some chemical energy is needed to start the reaction to chemically break down the stable glucose molecule into carbon dioxide and water. The first steps in chemically breaking down glucose use chemical energy that has been stored in the organisms' cells (ATP).

Cellular Respiration

glucose + oxygen → carbon dioxide + water + released energy

There is more chemical energy in the glucose and oxygen on the left side than there is in the carbon dioxide and water on the right side. The extra energy is released during the reaction. Most of the released energy is packaged in little cellular "batteries" (ATP molecules) that the cells use to power chemical reactions, such as making proteins. The big chemical energy concept is that in respiration, the reactants have more chemical energy than the products, so that energy is released. For photosynthesis, the products have more chemical energy, and that energy comes from the sun.

Photosynthesis

carbon dioxide + water + light energy → glucose + oxygen

Basically, cellular respiration releases energy because the chemical energy of 1 glucose molecule + 6 oxygen molecules is greater than the combined chemical energy of 6 water molecules + 6 carbon dioxide molecules. Cells use the energy stored in ATP to enable vital cellular reactions such as making proteins and copying DNA.

BACKGROUND INFORMATION FOR PRESENTERS

To avoid unnecessary duplication of text in this guide, the handout on content information also serves as background information for presenters. See the *Content Information and Alternative Conceptions About Matter and Energy in Ecosystems* handout (pages 46–52) to read up on background content information before presenting this session.

Connections to Other BEETLES Sessions

Matter and Energy in Ecosystems is one of two professional learning sessions focused on participants learning adult instructor-level science content, rather than on how to teach outdoor science. The other science content-focused session is *Adaptation and Evolution.*

REFERENCES

Daehler, K. R., Folsom, J., & Shinohara, M. (2011). *Making Sense of SCIENCE: Energy for Teachers of Grades 6–8, Charts*. San Francisco: WestEd.

Daehler, K. R., Folsom, J., & Shinohara, M. (2012). *Making Sense of SCIENCE: Matter for Teachers of Grades 6–8*. San Francisco: WestEd.

Hazen, R. M., and Trefil, J. (2009). *Science Matters: Achieving Scientific Literacy*. New York: Anchor Books.

Henderson, J. B., MacPherson, A., Osborne, J., & Wild, A. (2015). Beyond Construction: Five arguments for the role and value of critique in learning science. *International Journal of Science Education*, *37*(10): 1668–1697. http://dx.doi.org/10.1080/09500693.2015.1043598

Hoagland, M., Dodson, B., & Hauck, J. (2001). *Exploring the Way Life Works: The Science of Biology*. Burlington, MA: Jones & Bartlett Learning.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.

Sussman, Art. (2000). *Dr. Art's Guide to Planet Earth: For Earthlings Ages 12 to 120*. San Francisco: WestEd.

Sussman, Art. (2006). *Dr. Art's Guide to Science: Connecting Atoms, Galaxies, and Everything in Between*. San Francisco: Jossey-Bass Publishers in partnership with WestEd.