CO_2 and the Carbon Cycle

INTRODUCTION

In this three-part lesson, students explore carbon in a progressively complex manner and connect the carbon cycle both to relevant global concerns as well as their own personal behavior. The content in this lesson connects to both Grade 7, Unit A: Interactions and Ecosystems (in particular the impact of humans on ecosystems as well as the cycling of carbon through an ecosystem) as well as Grade 9, Unit C: Environmental Chemistry (in particular monitoring air quality, how CO2 in the environment can affect that environment, methods by which CO2 is released into the environment and how to monitor its levels).

Part 1 asks students to consider what carbon is, as well as the carbon cycle (considering both the natural carbon cycle as well as human influences). Students explore carbon's locations within Earth's systems (i.e., geosphere, hydrosphere, atmosphere, and biosphere) as well as the various forms that carbon can take (i.e., solid, liquid, dissolved, gas). Furthermore, students should recall carbon's role in natural processes such as photosynthesis and respiration (introduced in Grade 4, Topic E: Plant Growth and Changes and Grade 6, Topic E: Trees and Forests) and be able to incorporate these into an initial model of the carbon cycle, before building on this knowledge through exploratory activities.

In Part 2 of this lesson, students consider why it is important and relevant to study carbon and the carbon cycle. Connecting their scientific understanding to current events (specifically, carbon dioxide as a greenhouse gas, and climate change) provides a framework to engage students in a bigger, complex global issue.

The third and final part of the lesson connects students' personal actions to these current events, positioning themselves as empowered actors within an international community. Using the United Nations' Sustainable Development Goals (specifically, SDG 13: Climate Action), students will explore both international agreements and the associated goals for 2030 as well as what shifts they can make in their day-to-day lives to support these initiatives. Students will be challenged to select a single behavior that they can personally change and track; collect data on their behavior in order to create a "before" and "after" carbon footprint report; and present their findings to the community. In this way, learning is made both relevant and authentic, allowing themselves to see the significance of these issues in today's world.

CURRICULUM CONNECTIONS

Grade 7, Unit A: Interactions and Ecosystems

Focusing Questions:

- How do human activities affect ecosystems?
- What methods can we use to observe and monitor changes in ecosystems, and assess the impacts of our actions?

Knowledge Outcomes:

(1) Students will investigate and describe relationships between humans and their environments, and identify related issues and scientific questions

- identify examples of human impacts on ecosystems, and investigate and analyze the link between these impacts and the human wants and needs that give rise to them
- analyze personal and public decisions that involve consideration of environmental impacts, and identify needs for scientific knowledge that can inform those decisions

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

(2) Students will trace and interpret the flow of energy and materials within an ecosystem

- Describe the process of cycling carbon and water through an ecosystem

4) Students will describe the relationships among knowledge, decisions and actions in maintaining life-supporting environments

- Identify intended and unintended consequences of human activities within local and global environments

Grade 9, Unit C: Environmental Chemistry

Focusing Questions:

- What substances do we find in local and global environments?
- What role do they play, and how do changes in their concentration and distribution affect living things?

Knowledge Outcomes:

(3) Students will analyze and evaluate mechanisms affecting the distribution of potentially harmful substances within an environment

- Describe mechanisms for the transfer of materials through air, water and soil; and identify factors that may accelerate or retard distribution
- Investigate and evaluate potential risks from consumer practices and industrial processes, and identify processes used in providing information and setting standards to manage these risks
- Identify and evaluate information and evidence related to an issue in which environmental chemistry plays a major role

KEYWORDS

Carbon, carbon dioxide, carbon cycle, greenhouse gas, carbon capture, carbon storage, global warming, climate, climate change

TIME

10 days

MATERIALS

- **Appendix A: Carbon Images**
- **Appendix B: Student Readings**
- **Appendix C: CO_2 & the Carbon Cycle Student Workbook**
- **Appendix D: CO_2 & the Carbon Cycle Student Workbook Answer Key**
- **Appendix E: CO_2 & the Carbon Cycle Rubric**
- Wonderville.org resources:
  - **What is Carbon Dioxide?** (Lesson Part 1)
  - Do You Know what Carbon Capture and Storage is?

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

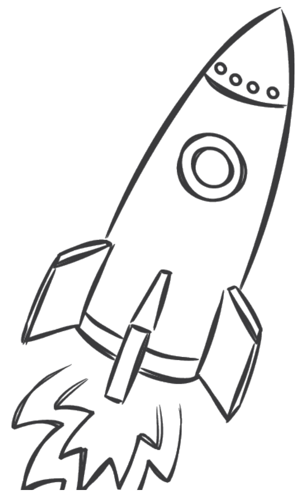
- Web resources:
  - **Earth System Research Laboratory** website and ESRL **History of Atmospheric Carbon Dioxide** movie.
  - **What is Climate Change?** from the David Suzuki Foundation.
  - **What is in the Paris Climate Agreement?** from BBC World News
  - **SDGs in Action App**
  - **Climate Neutral Now website:** Calculate **your carbon footprint**
  - Optional: **UN Climate Change videos**; **The World's Largest Lesson**
  - Optional: Article on **What the World Will Look Like 4°C Warmer**

MindFuel™

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

wonderville™

HOW TO DIFFERENTIATE AND ENRICH LEARNING



Knowledge is accessed and built by:

- Watching and listening to videos and presentations
- Discussing and interviewing
- Reading text, articles, and research papers
- Viewing and interpreting images, photos and graphs
- Note taking by writing or voice recording (audio workbook)
- Mind-mapping
- Collecting and tracking real-world data

Knowledge is applied/contextualized, practiced, and understood by:

- Sharing personal stories
- Game play with flexibility for reinforcing/repeat
- Choosing personally relevant research topics or projects
- Testing ideas through building, experimenting, and prototyping
- Answering formative (check-in) assessment questions
- Drawing and creating storyboards and diagrams
- Evaluating and incorporating feedback

Knowledge and understanding are demonstrated by:

- Thoughtful reflections and accurate answers in writing or otherwise (journal, test etc)
- Final product uses choice of multi-media (video, website, poster, podcast)
- Creating a product with real-world relevance/applicability
- Creating a product for users/audiences beyond the classroom
- Final product meeting rubric indicators – with student choice for what should be assessed
- Formal oral presentations; participation in campaigns and model displays
- Building model representations for visualizing things that are too small to see
- Collaborating and providing useful/correct feedback to others

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

PART 1 - WHAT IS THE GLOBAL CARBON CYCLE

Through a series of questions and brainstorming, students will discover that there is a natural carbon cycle, similar to the existence of a water cycle, involving various carbon reservoirs and conversions between different forms through processes such as respiration and photosynthesis. As these processes are natural processes, students will visualize atmospheric data and discover that atmospheric concentrations of carbon dioxide are **Earth System Research Laboratory** seasonally influenced and also have an annual increasing trend.

Students will then go on to discover that human activity has increasingly impacted on this cycle since the industrial revolution, leading to increased carbon dioxide concentrations in the atmosphere. Connecting variables and understanding how actions have consequences in a correlational or causational manner is important as students come to understand the carbon cycle as a dynamic system. Throughout the lesson, students will develop their own global carbon cycle model, adding to its complexity as the lesson progresses.

Components for Day 1-2:

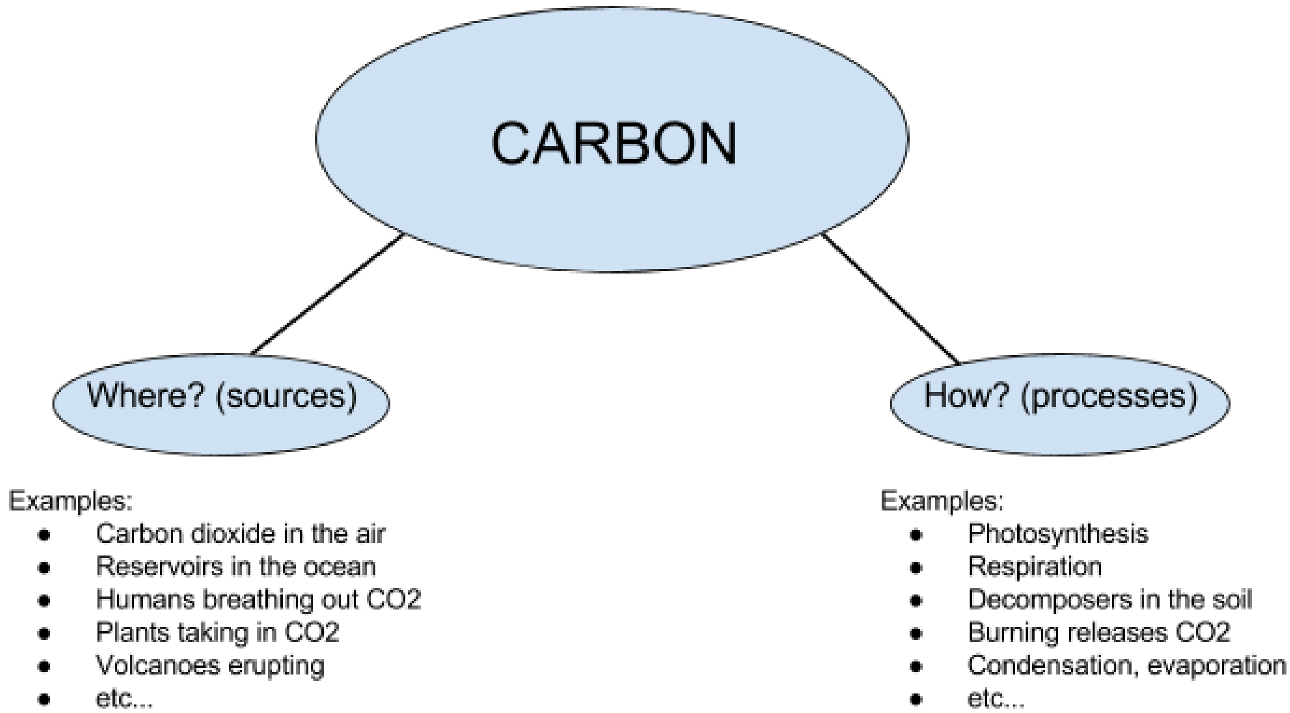
- **Appendix A: Carbon Images**
- **Appendix B: Student Readings**
- **Appendix C: CO_2 and the Carbon Cycle Student Workbook**
- **Appendix D: CO_2 and the Carbon Cycle Rubric**
- **Earth System Research Laboratory** website

Outline

1. Begin the class with **Appendix A: Carbon Images**. Depending on the size of the class, these can be copied into sets for students to use solo, or in small groups of 2-4 (preference is for collaborative group work on this activity). As another alternative, these images can be enlarged into small posters for display around the classroom - and can endure throughout the entire lesson to focus students on recurring ideas throughout the lesson progression.

   Challenge students to organize these images into groups based on commonalities - i.e., can they cluster the ten images into a set or multiple sets because of something that the items have in common? Once students have had a chance to categorize the images, ask them to share their ideas with the larger class. Note that at this phase there are no wrong answers, but the ultimate goal (i.e., by the end of Part 1) students should all understand that all ten images are part of one common group - that they contain carbon and are part of the carbon cycle.
2. Reminding students of what they may have learned previously about carbon (i.e., the various forms it can take as solid, liquid, dissolved, and gas; the role it plays in photosynthesis and respiration), ask students as a class to respond to the following two ideas and collect responses in a class-wide mind map:
   A. Where is carbon found in nature?
   B. What natural processes transform carbon? (note: support may be needed to explain and define both "natural processes" and "transform".
3. Ask students to draw a two-dimensional model to represent their understanding of carbon and the

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.



carbon cycle (i.e., taking the concepts generated in the class-wide mind map from the previous step, and connecting ideas into a cyclical model). Encourage students to use both pictures and words to represent their understanding in the model. Note that there may be misconceptions present in students' models at this phase; further iterations and feedback will refine these models in later steps.

4. Have the students read **Appendix B: Student Readings (Carbon and the Carbon Cycle)**. In particular, challenge students to highlight within the reading where carbon stores and carbon transformations are discussed. Based on their reading, they should return to their models to add more information and correct any misconceptions. Peer feedback at this phase is also encouraged to improve students' models.
5. Return to the class-wide mind map to further add to the collective knowledge represented.
6. Introduce the students to the term carbon reservoir. Let them know it is any part of the environment where carbon may reside for a period of time. Possible carbon reservoirs include: organisms, atmosphere, organic matter in soil, water (as dissolved carbon dioxide), minerals.
7. Allow some time for the students to explore the **Earth System Research Laboratory** website, in particular the mean atmospheric carbon dioxide concentrations for **Mauna Loa, Hawaii (MLO)** and the **South Pole, Antarctica (SPO)**, which are among ESRL's longest operating air quality monitoring sites. Have the students visualize the data through the website by following the instructions in the student workbook.

> Teacher tip: Wherever possible, encourage students to recognise the form of carbon (e.g. carbon dioxide gas versus mineral carbon and organic carbon) and the location within Earth's systems (i.e. geosphere, hydrosphere, atmosphere, biosphere).
> Also encourage students to think of the range of possible reactions - physical, chemical and biological (e.g. photosynthesis, respiration, mineralisation, dissolution, evaporation).

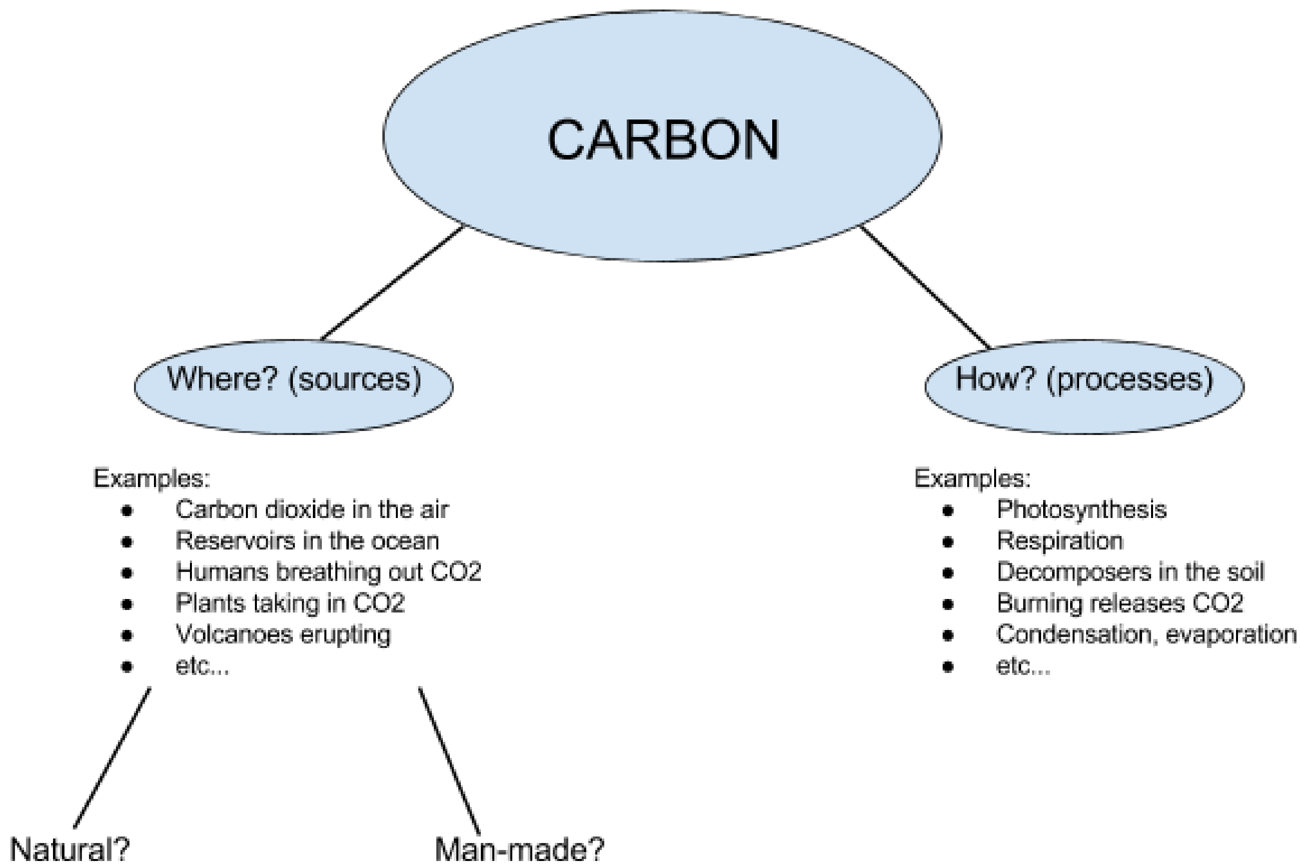
8. Working solo or in small groups of 2-3, have students respond to the questions in **Appendix C: CO_2 & the Carbon Cycle Student Workbook** relating to the ESRL data. Once the students have completed the questions, discuss the answers as a class and address any misconceptions before moving forward.
9. Ask the class if, based on the data they just viewed, the global carbon cycle models they have constructed

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

are an accurate reflection of the carbon cycle on Earth as it exists today. If not, then why not? (Suggested response: No, as the impacts from humans have not been included.)

10. Add two additional questions to the class mind map:
    A. Where are man-made forms of carbon found?
    B. What human processes transform carbon?

    Have the class brainstorm answers to these questions and add them to the class mind map as illustrated below.
11. Refining understanding: Challenge students to return to their models for a third time, using two different



colors to now distinguish between what components of the carbon cycle are natural, and what components result from human activities. Have the students read **Appendix B: Student Readings (Human Impact on the Carbon Cycle)** and continue to add to their models as well as the class-wide mind map.
12. Use internet research to quantify these carbon reservoirs and conversion processes. If any major reservoirs or conversion processes are discovered during the research, have the students add these to their models in the appropriate color.
13. Have the students present their quantified global carbon cycles to the class. Have a class discussion

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

regarding the differences between the different models. Why might they different? Suggested responses include:

A. different data sources (reputable vs non-reputable; data timescale, location, averages)
B. missed processes or reservoirs
C. other reasons (e.g. seasonal influences)

14. To conclude Part 1, revisit **Appendix A: Carbon Images** (first shown to the students at the start of the class), and repeat the initial question: "What do all these images have in common?" By now, it should be obvious to students that these images connect to the carbon cycle - although some of the components may still need further investigation (e.g., melting glacier) and will be researched in Parts 2 & 3 of this lesson.

Teacher tip: Unsure where to start? Here are a few suggested websites for students to begin their research:

NASA Earth Observatory

Earth System Research Laboratory

Woods Hole Research Center

The Global Carbon Project

Image	How it Involves carbon/Carbon Dioxide
Leaf	Carbon stored as biological matter, also conducts photosynthesis and respiration.
Melting glacier	At this point, a glacier can be considered as long term storage of carbon dioxide. Later it will also link to global climate change.
Deforestation	Human impact; changing the carbon storage and photosynthesis rates.
Cattle herd	Carbon stored as biological life, respiration and methane production. Large scale animal agriculture is a human activity, hence this image represents a human impact on the global carbon cycle.
Worms in earth	Breaks down organic matter into soil, releasing carbon.
Human breathing	Respiration releases carbon dioxide.
Shellfish underwater	Carbon stored as shells, ocean as a carbon storage location.
Volcano	Emits carbon dioxide into the atmosphere during an eruption.
Industrial smokestacks	Emits carbon dioxide into the atmosphere.
Gasoline for car	Gasoline is a man made carbon storage component. It is then burned to emit carbon dioxide.

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

PART 2 - HOW DOES THE GLOBAL CARBON CYCLE AFFECT US?

In this part of the lesson, students make the connection between the global carbon cycle, discussed in Part 1, to climate change and it's predicted associated impacts. Students begin the lesson by watching a short video on carbon dioxide, reminding them of its role in the global carbon cycle and also connecting concepts to climate change. Through answering questions, then reading an article on climate change, any misunderstandings can be addressed.

Students are asked to consider how they and their family may be impacted by climate change in the future and whether or not humans need to address climate change given its potential impacts.

The Paris Climate Agreement, the general worldwide agreement to reduce global greenhouse gas emissions to combat climate change, is the introduced and sets the stage for the discussion of specific techniques to reduce greenhouse gas emissions and even remove them from the atmosphere. The positives and negatives of these techniques are also discussed and whether there is "one" technique required or a range of methods.

Components for Day 3-4:

- Wonderville: **What is Carbon Dioxide?**
- Appendix B: Student Readings (**"What is Climate Change?"**, **"What is the Paris Climate Agreement?"**)
- **Appendix C: CO_2 & the Carbon Cycle Student Workbook**
- Optional: **Article What the World Will Look Like 4°C Warmer**
- Optional: **History of Atmospheric Carbon Dioxide** movie from the Earth System Research Laboratory
- Optional: **Do You Know what Carbon Capture and Storage is?**

OUTLINE

1. Commence the lesson by showing the class the Wonderville.org video, **What is Carbon Dioxide?**. Ask students how this movie relates to the global carbon cycle model developed in the previous class.
2. Have students complete the appropriate questions in **Appendix C: CO_2 & the Carbon Cycle Student Workbook**, either solo or in small groups of 2-3. Once students have had a chance to reflect on their answers to these questions, discuss as a class to correct any misconceptions.
   - What is a greenhouse gas?
   - What is the main greenhouse gas of concern?
   - Give some examples of other greenhouse gases.
   - Why are greenhouse gases important?
   - How have humans changed the amount of greenhouse gases in the atmosphere?
   - How are these changes in greenhouse gas concentration affecting the planet?

Optional supplementary videos:

- ESRL: **History of Atmospheric Carbon Dioxide**
- Wonderville.org: **Do You Know what Carbon Capture and Storage is?**
- Wonderville.org: **What to do with CO_2?**

Optional supplementary readings:

- NASA: **What are Climate and Climate Change?**
- Big Think: **What the World Will Look Like 4c Warmer**

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

3. Give the students some time to read this article "**What is Climate Change?" found in Appendix B: Student Readings**, then allow the students some time to correct and misunderstandings in their workbook. Either in small groups or as a class, have students record their initial ideas on how climate change can impact themselves directly, their communities/city, their country, and ultimately the world.
4. Divide the class into two groups - with one group assigned to "climate change should be addressed" and the other assigned to "climate change should not be addressed". In one of the suggested ways, encourage students to explore the relevance of studying climate change:
   A. Small- or large-group debate
   B. Creating pro/con lists
   C. Online research (e.g., social media) - who is arguing what?

   Responses to why climate change study is important (pro) may include: preventing sea level rise (and associated infrastructure damage and mass migration); preserving biodiversity; limiting the spread of disease; keeping agricultural regions with the appropriate climate for current crops; keeping cultural icons such as the Great Barrier Reef (Australia) and other coral reefs.

   Responses to why climate change study is not important (con) may include: change to the status quo required; fossil fuels currently readily available and technology already developed; technology for other forms of energy not as well developed and tested; climate change isn't 100% guaranteed to happen.
5. Give this students the article **"What is the Paris Climate Agreement?" (found in Appendix B: Student Readings)** and give them time to read it, then respond to the following questions in their workbook:
   - What is the targeted maximum temperature change agreed to in the Agreement?
   - The Agreement aims to eventually limit greenhouse gas emissions from human activity to the same level as what?
   - How often will each country's contribution be reviewed?
   - What will the role of rich nations be, compared to less developed nations?
6. Have the class brainstorm various methods of limiting climate change. Use a class mind map to assist with this. In the middle put the words "limit climate change" and off this put "ways to reduce inputs of GHG (greenhouse gases) to the atmosphere" and "ways to increase removal of GHG from atmosphere". For each method the class suggests, have them determine which category it belongs to or, if there may be a third category.

   As a class discuss:
   A. Whether there is any one particular greenhouse gas reduction method that will provide a solution? (No)
   B. Could a range of methods be required? (Yes)
   C. Why might this be a better option? (Different methods work better for point or diffuse sources of carbon dioxide and also it means that if one method under performs, or even fails, then there are other methods as backup).
7. Circle back to the images shown in Part 1 (**Appendix A: Carbon Images)**. Once again, ask the question "what do all these images have in common?" Students should recognise that these images are all related to the global carbon cycle and the impacts resulting from changing the balance of this cycle, climate change.

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

PART 3 - APPLICATION - HOW ARE STUDENTS CONNECTED TO THIS GLOBAL ISSUE?

Days 5-10 (approx): Project Work & Presentations

The third and final part of this lesson challenges students to connect their knowledge of carbon and the carbon cycle (Part 1) to their personal carbon footprint. Building on Part 2, in which students explored the significance of studying the carbon cycle and connected carbon (specifically, carbon dioxide) to global issues such as climate change, Part 3 now asks students to reflect on how their personal decisions contribute to global impact via project-based learning.

The purpose of the project is for students to address the following question: What impact can one behavioral shift have on your carbon footprint?

To address this guiding question, students will start by analyzing their current behavior and understanding how it contributes to their starting carbon footprint. They will then select one behavior to change, in an effort to reduce their carbon footprint. After acting on this behavioral shift, they will need to report both qualitative and quantitative data about the experience and the impact on their carbon footprint.

To make this activity meaningful, students need an understanding of why it is important to minimize their carbon footprint. To this end, the United Nations' Sustainable Development Goals (SDGs) can be used as a framework for engagement; specifically, Goal 13: Take urgent action to combat climate change and its impacts fits well with these lesson outcomes. By connecting their personal actions to a larger global movement, students can be increasingly engaged as global citizens and empowered to help create change. Before commencing project work, it is encouraged that students explore the 17 SDGs set by the UN and identify for themselves the significance of collaboration to achieve these goals.

Components for Day 5-10:

- **SDGs in Action App**
- **Climate Neutral Now** website: Calculate **your carbon footprint**
- **Appendix C: CO_2 and the Carbon Cycle Student Workbook**
- **Appendix E: CO_2 & the Carbon Cycle Rubrics**
- Optional: **UN Climate Change videos**; **The World's Largest Lesson**

OUTLINE

1. Introduce students to the UN's Sustainable Development Goals:
   - Recommended: **SDGs in Action App**
   - Alternatives: U**UN Climate Change videos**; **The World's Largest Lesson**

   Working in pairs or small groups, give students time to explore the sustainable development goals, focusing specifically on responding to the following questions (answers can be recorded in **Appendix C: Carbon Cycle Student Workbook**):
   - Which sustainable development goal (1-17) best connects to carbon and the carbon cycle?
   - Do you think the SDGs are important? Why/why not?
   - Do you think the SDGs are achievable? Why/why not?

   Following this small group work, encourage students to share their responses with the class. Students

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

should realize that the best-aligned SDG for this lesson is Goal 13: Climate Action. There are no right or wrong answers about whether students think the SDGs are important and/or achievable; the purpose of the discussion is to encourage student reflection on why world leaders would have come together to set these goals, what changes need to happen (both on an individual, national, and international scale) in order for goals to be met, and use evidence to support their arguments and beliefs about the SDGs by challenging students to explain (i.e., why/why not).

2. Present to students the project challenge: What impact can one behavioral shift have on your carbon footprint? The purpose of participating in this challenge is to join the international action for the sustainable development goals. Students will use **Appendix C: Carbon Cycle Student Workbook** to work through the project. In advance of beginning the project, the class should also review **Appendix E: CO_2 & the Carbon Cycle Rubrics** for evaluation criteria.

   Note: *As an option, classes can choose to participate in The World's Largest Lesson for this project work. For more information about this, visit* **http://worldslargestlesson.globalgoals.org/**

3. **Brainstorm/Research:** In Part 2, students worked collaboratively to generate some hypothetical ways to tackle global climate change. They will now need to think about what specific actions they can personally take to mitigate climate change. Students will:
   - Calculate their carbon footprint (see table for suggested links below).
   - Use the SDG app, other online resources, and the ideas generated in lesson Part 2 to select one single behavioral change they will take for this action project.

Carbon Footprint Calculators

Ultimately the more information students have, the more accurately they can calculate their own footprint. In particular, car mileage and efficiency of cars they normally travel in and information about energy and water use in the home This information would be likely be available from their parents and utility bills.

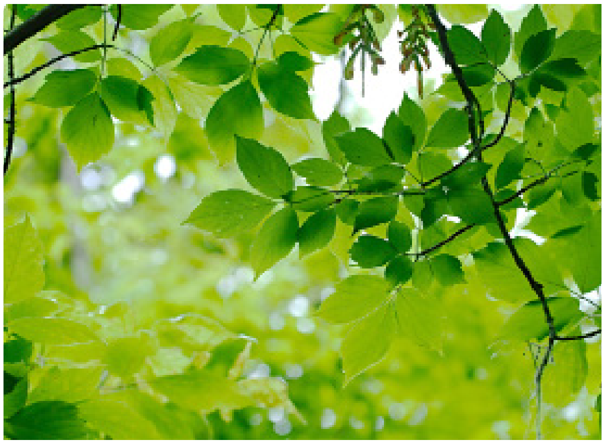
Calculator	Appropriate For	Comments
Earthday	Worldwide	Student and adult version with simple or complex questions in each. Gives results as an area only but allows visualization of how many "Earths" would be required if everyone lived as they did.
Stanford	Worldwide	This calculator is targeted specifically at high school students.
Berkeley Cool Climate	USA only	Students would likely need parents help or choose the "average" option for questions they are unsure about.
Climate Neutral Now	Worldwide	A good student calculator.

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

4. **Refine a Solution**: Students can work either solo or in small groups of 2-3 where the entire group undertakes the same action to mitigate climate change. The action (solution) selected must be carried out by students (suggested: one week) and be promoted in a campaign:
    - Creating a poster, website, video, podcast, or other medium to educate peers/community about the problem, as well as the proposed actionable solution. Both images and words (incorporating persuasive language to encourage people to participate in the solution) should be included.
    - Students will need to present a "before" and "after" carbon footprint calculation as a way of collecting data as evidence as to how successful their action was at creating change. The data collection and analysis should be a part of the class presentations/debrief.
5. **Presentations & Debrief:** Following students' action campaigns, the class should regroup to present their before/after carbon footprints and final results. Encourage students to include qualitative feedback about the challenges they may have faced while trying to implement change in their lives, and recommendations for other individuals who may wish to take similar action.

6. **Discuss:**
    - Were any actions more (or less) impactful at creating change (i.e., creating a difference from start to finish re. carbon footprint?).
    - How likely do you think other students would be to take the action - how easy or hard was it to implement and create behavioral change?
    - What could be done differently next time to achieve different (or better) results? Have students submit their student workbooks (along with the before/after carbon footprint data) and their presentation materials for assessment against the project rubric.

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.



LEAF

MELTING GLACIER

DEFORESTATION

CATTLE HERD

WORMS IN EARTH

HUMAN BREATING

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

SHELLFISH UNDERWATER

VOLCANO

INDUSTRIAL SMOKESTACKS

GASOLINE FOR CAR

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

CARBON AND THE CARBON CYCLE

Part 1: The Global Carbon Cycle

The global carbon cycle involves the movement of carbon between the biosphere, geosphere, hydrosphere and atmosphere through various pathways. The existence of this cycle makes it possible for life to exist on Earth.

There are four major carbon reservoirs on Earth:

1. Atmosphere

   Carbon mostly takes the form of carbon dioxide (CO_2), however significant amounts of methane (CH4) also exist in the atmosphere. Both of these compounds are greenhouse gases. All biological life (plants and animals) releases carbon dioxide through respiration, which plants absorb during photosynthesis, producing more oxygen for humans and animals to inhale. Carbon dioxide is also removed by dissolving into water.

2. Biosphere

   This reservoir includes both alive and dead organisms, and soils. It is mostly made up of organic carbon (molecules involving multiple carbon atoms, hydrogen and oxygen) and some inorganic forms such as calcium carbonate (which is the compound shells are made of). As this reservoir is dependent on biological processes, it follows daily and seasonal cycles. Carbon can enter this reservoir through photosynthesis in plants. It leaves through the processes of respiration, combustion, including the breakdown of organic matter in the soil, all of which releases carbon dioxide to the atmosphere. Over the longer term, sequestration and mineralisation in soils and sediments into rocks and minerals.

   It is worth noting that respiration is carried out by all biological life (animals and plants) and is the conversion of organic carbon to carbon dioxide and organic matter and/or energy. Photosynthesis is only carried out by plants and is the conversion of carbon dioxide and energy (from the sun) to organic matter.

3. Hydrosphere

   Oceans contain a large reservoir of carbon, which mainly enters through the dissolution of carbon dioxide in the atmosphere. This dissolved carbon dioxide can then be used photosynthesis or converted to calcium carbonate (shell material) where it can precipitate as a solid. Organic carbon and mineral carbon forms can also be removed from this reservoir by being deposited in the sediment.

4. Geosphere - Earth's interior, crust and mantle (including fossil fuels)

   Most of the Earth's carbon is stored in the crust and upper mantle, the majority as limestone, but also as fossil fuels. It can remain in this reservoir for millions of years as this is the slowest part of the global carbon cycle. It can be naturally released from this reservoir as carbon dioxide through volcanoes and hot spots.

Part 2: Human impact on the Carbon Cycle

Humans have had an increasing impact on the global carbon cycle since the industrial revolution during the late 1700s. The main human activities impacting the global carbon cycle include:

- Burning of fossil fuels

  The digging up of fossil fuels and combustion for energy has resulted in the release of carbon to the atmosphere at a rate much greater than would naturally occur.

- Land use changes

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

Deforestation to allow the creation of agriculture and urban areas has resulted in the replacement of areas with relatively high carbon storage with areas of relatively low carbon storage.

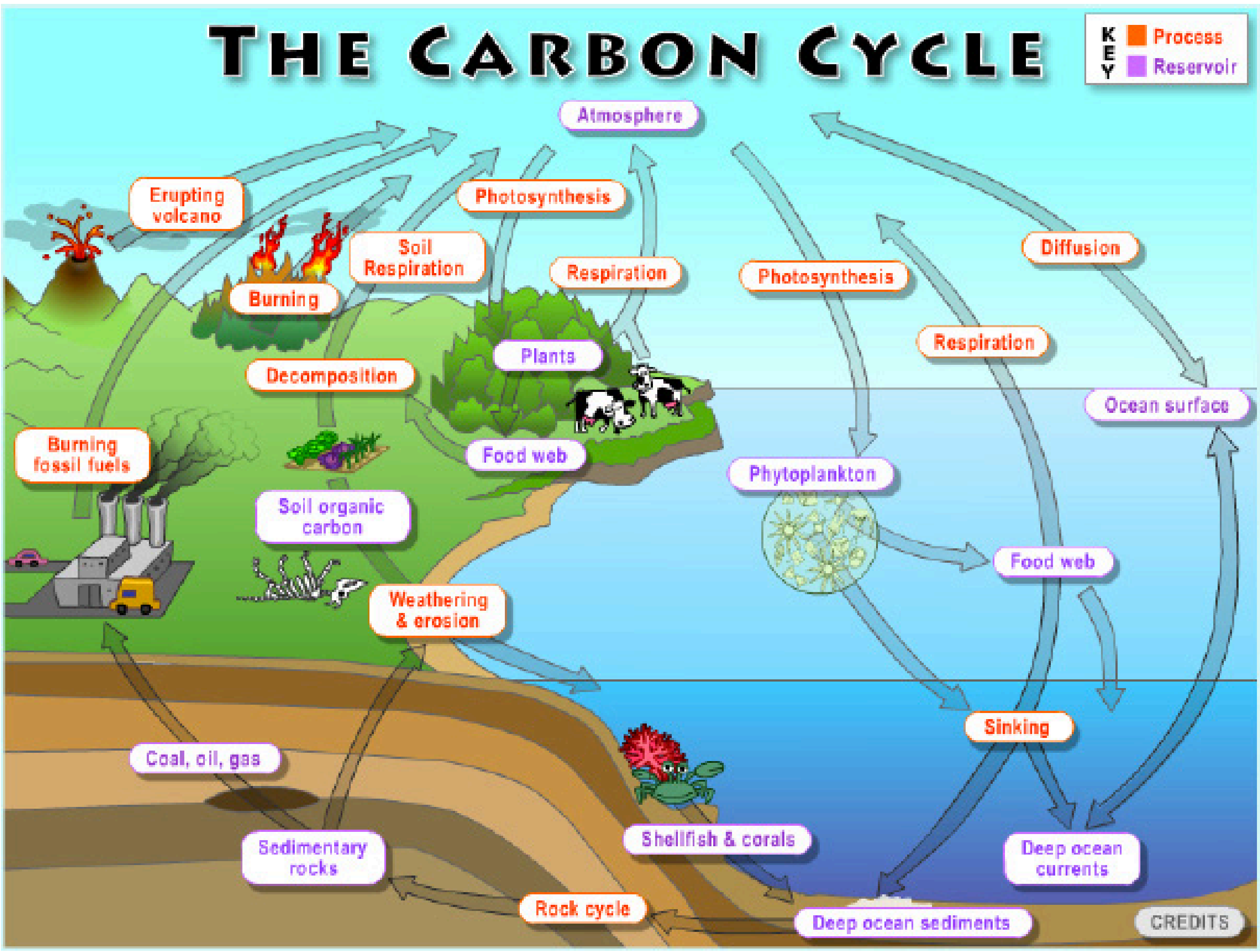
- Cement production and other industry

  Various industrial processes result in the release of carbon dioxide directly to the atmosphere.

Regardless of its source, carbon dioxide is considered a greenhouse gas; it helps to control Earth's temperature by keeping the thermal energy from the sun in the atmosphere. This is a good thing, because under normal

Greenhouse Gases:

Types of gas molecules that exist in the atmosphere around Earth. They allow sunlight through to warm Earth, but trap the reflected heat and prevent it from escaping back into space.



Source: **Carleton College, Earth Labs**

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

WHAT IS CLIMATE CHANGE?

There's a lot of information floating around about climate change. Most people know it has something to do with industrial pollution, changing weather and car exhaust, and they kind of get what Al Gore was trying to say in **An Inconvenient Truth**.

In a nutshell, climate change occurs when long-term weather patterns are altered — for example, through human activity. Global warming is one measure of climate change, and is a rise in the average global temperature.

How does it happen?

- Life on Earth is possible because of the warmth of the sun. While some of this incoming solar radiation bounces back into space, a small portion of it is trapped by the delicate balance of gases that make up our atmosphere. Without this layer of insulation, Earth would simply be another frozen rock hurtling through space. Carbon dioxide (CO_2) is the most important gas in this layer of insulation.
- Carbon is stored all over the planet — in plants, soil, the ocean, and even us. We release it into the atmosphere as carbon dioxide through activities such as burning fossil fuels (coal, oil and gas) and cutting down trees. As a result, today's atmosphere contains 42 per cent more carbon dioxide than it did before the industrial era.
- We have released so much carbon dioxide and other **greenhouse gases** that our planet's atmosphere is now like a thick, heat-trapping blanket. By disrupting the atmospheric balance that keeps the climate stable, we are now seeing extreme effects around the globe. It's like a thermostat that's gone haywire — it just doesn't work the way it should. The result: the climate changes, and it gets warmer. Extreme weather events also become more common.
- Global warming has already begun. Since 1900, the global average temperature has risen by 0.7 degrees Celsius, and the northern hemisphere is substantially warmer than at any point during the past 1,000 years.

Who keeps tab on climate change?

Our understanding of climate change is largely the result of the **Intergovernmental Panel on Climate Change** (IPCC), the world's most authoritative voice on the topic. Established by the United Nations, the IPCC assesses the scientific and socio-economic information relevant to climate change. The IPCC also looks at the potential impacts of climate change, and options for slowing it down or adapting to it.

The IPCC has released several **assessment reports** over the years. More than 2,500 scientific expert reviewers, 800 contributing authors and 450 lead authors from over 130 countries contributed to the last one, the Fourth Assessment Report. The Fifth Assessment Report's Working Group I report is expected to be released in 2013.

Despite the international scientific community's consensus on climate change, a small number of climate change **deniers** continue to deny that climate change exists or that humans are causing it. However, these individuals are generally not climate scientists, and their arguments have been discredited by the scientific community at large. The debate is over about whether or not climate change is real; it is now time to act to solve the problem.

Published online by the David Suzuki Foundation, 2014

http://www.davidsuzuki.org/issues/climate-change/science/climate-change-basics/climate-change-101-1/

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

WHAT IS IN THE PARIS CLIMATE AGREEMENT?

By Helen Briggs BBC News

What was agreed as part of the Paris climate deal?

Overview

The deal unites all the world's nations in a single agreement on tackling climate change for the first time in history.

Coming to a consensus among nearly 200 countries on the need to cut greenhouse gas emissions is regarded by many observers as an achievement in itself and has been hailed as "historic".

The Kyoto Protocol of 1997 set emission cutting targets for a handful of developed countries, but the US pulled out and others failed to comply.

However, scientists point out that the Paris accord must be stepped up if it is to have any chance of curbing dangerous climate change.

Pledges thus far could see global temperatures rise by as much as 2.7C, but the agreement lays out a roadmap for speeding up progress.

What are the key elements?

- To keep global temperatures "well below" 2.0C (3.6F) above pre-industrial times and "endeavour to limit" them even more, to 1.5C
- To limit the amount of greenhouse gases emitted by human activity to the same levels that trees, soil and oceans can absorb naturally, beginning at some point between 2050 and 2100
- To review each country's contribution to cutting emissions every five years so they scale up to the challenge
- For rich countries to help poorer nations by providing "climate finance" to adapt to climate change and switch to renewable energy.

What's in and what has been left out?

The goal of preventing what scientists regard as dangerous and irreversible levels of climate change - judged to be reached at around 2C of warming above pre-industrial times - is central to the agreement.

The world is already nearly halfway there at almost 1C and many countries argued for a tougher target of 1.5C - including leaders of low-lying countries that face unsustainable sea levels rises in a warming world.

The desire for a more ambitious goal has been kept in the agreement - with the promise to "endeavour to limit" global temperatures even more, to 1.5C.

Dr Bill Hare, CEO of Climate Analytics, says the objective is "remarkable".

"It is a victory for the most vulnerable countries, the small islands, the least developed countries and all those with the most to lose, who came to Paris and said they didn't want sympathy, they wanted action."

Meanwhile, for the first time, the accord lays out a longer-term plan for reaching a peak in greenhouse emissions "as soon as possible" and achieving a balance between output of man-made greenhouse gases and absorption - by forests or the oceans - "by the second half of this century".

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

"If agreed and implemented, this means bringing down greenhouse-gas emissions to net zero within a few decades. It is in line with the scientific evidence we presented," says John Schellnhuber, Director of the Potsdam Institute for Climate Impact Research.

Some have described the deal as "woolly" because some of the targets were scaled down during the negotiations.

"The Paris Agreement is only one step on a long road, and there are parts of it that frustrate and disappoint me, but it is progress," says Greenpeace International executive director Kumi Naidoo.

"This deal alone won't dig us out the hole we're in, but it makes the sides less steep."

What about money?

Money has been a sticking point throughout the negotiations.

Developing countries say they need financial and technological help to leapfrog fossil fuels and move straight to renewables.

Currently they have been promised US $100bn (£67bn) a year by 2020 - not as much as many countries would like.

The agreement requires rich nations to maintain a $100bn a year funding pledge beyond 2020, and to use that figure as a "floor" for further support agreed by 2025.

The deal says wealthy countries should continue to provide financial support for poor nations to cope with climate change and encourages other countries to join in on a voluntary basis.

Dr Ilan Kelman of UCL, London, says the lack of time scales is "worrying".

"The starting point of $100bn per year is helpful, but remains under 8% of worldwide declared military spending each year."

What happens next?

Only elements of the Paris pact will be legally binding.

The national pledges by countries to cut emissions are voluntary, and arguments over when to revisit the pledges - with the aim of taking tougher action - have been a stumbling block in the talks.

The pact promises to make an assessment of progress in 2018, with further reviews every five years.

As analysts point out, Paris is only the beginning of a shift towards a low-carbon world, and there is much more to do.

"Paris is just the starting gun for the race towards a low-carbon future," says WWF-UK Chief Executive David Nussbaum.

Prof John Shepherd of the National Oceanography Centre, University of Southampton, says the agreement includes some welcome aspirations but few people realise how difficult it will be to achieve the goals.

"Since the only mechanism remains voluntary national caps on emissions, without even any guidance on how stringent those caps would need to be, it is hard to be optimistic that these goals are likely to be achieved."

Helen Briggs, BBC News, 31 May 2017

http://www.bbc.com/news/science-environment-35073297

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

NAME: ________________ **CLASS**: ________________ **DATE**: ________________

Carbon Cycle

Use the space below to draw your model of the global carbon cycle.

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

NAME: ________________ **CLASS**: ________________ **DATE**: ________________

Part 1: What is the Global Carbon Cycle?

To visualise the data from the Mauna Loa (MLO) and South Pole (SPO) sites, look under the Data heading and choose the Data Visualization link. On the right side, choose Carbon Cycle Gases and then choose Time Series for the plot type. Choose the time range you are interested in, then press Plot.

Questions on ESRL atmospheric data

On first inspection what do you notice about the carbon dioxide concentration at the Mauna Loa and South Pole sites?

____

____

____

Why do you think there are seasonal fluctuations in carbon dioxide concentration? Why are the magnitudes of the fluctuations different for each site?

____

____

____

From viewing this data, do you think the global carbon cycle is currently in balance? Why or why not?

____

____

____

Part 2: How does the Global Carbon Cycle Affect Us?

1. What is a greenhouse gas? ____

   ____

2. What is the main greenhouse gas of concern? ____

   ____

3. Give some examples of other greenhouse gases: _____________________________________

   ____

4. Why are greenhouse gases important? ____

   ____

MindFuel™

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

wonderville™

NAME: ________________ **CLASS**: ________________ **DATE**: ________________

5. How have humans changed the amount of greenhouse gases in the atmosphere?

____

____

____

6. How are these changes in greenhouse gas concentration affecting the planet?

____

____

____

7. How do you think climate change might affect you directly?

____

____

____

8. What is the targeted maximum temperature change agreed to in the Paris Climate Agreement?

____

____

____

9. The Paris Climate Agreement aims to eventually limit greenhouse gas emissions from human activity to the same level as what?

____

____

____

10. How often will each country's contribution be reviewed as part of the Paris Climate Agreement?

____

____

____

11. What will the role of rich nations be as part of the Paris Climate Agreement?

____

____

____

MindFuel™

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

wonderville™

NAME: ________________ **CLASS**: ________________ **DATE**: ________________

Part 3: Project: What impact can one behavioral shift have on your carbon footprint?

What can you personally do to impact carbon dioxide levels in the world? In this project, you will find out.

There's three steps to this work:

1. Start by calculating your carbon footprint now.
2. Pick just one change that you can make in your day-to-day life that will change your carbon footprint. Then, act on that change for at least one week!
3. Create a presentation to share with your peers about the action you take - and calculate your carbon footprint again.

Calculating your carbon footprint:

You can use one of the below websites to calculate your carbon footprint, or your teacher will recommend where to go to get started.

Calculator	Appropriate For
Earthday	Worldwide
Stanford	Worldwide
Berkeley Cool Climate	USA only
Climate Neutral Now	Worldwide

Brainstorm a list of what actions you could take to change your carbon footprint - use the SDG app, online resources, or your peers to help you with this list:

____

____

____

____

____

____

____

____

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

NAME: ________________ **CLASS**: ________________ **DATE**: ________________

From the list you made, select one behavioral shift that you will act on for at least one week, in order to change your carbon footprint. Use the space below to write your commitment, and why you think this is an important/impactful change to make:

____

____

____

____

____

Now you will create a presentation to share your ideas with others. There are two purposes to the presentation:

1. Educate other people about the problem (i.e., the connection between carbon dioxide and climate change, and why climate change is relevant).
2. Convince other people to change their behavior - and follow your recommended action.

You can choose to create your presentation in any way you like - some ideas include:

- Posters to display in the school or community
- A website you can share with others
- A video or podcast that you can publish online
- An interactive display that illustrates the problem and solution(s)
- Other ideas that you can come up with!

Your campaign should be informative and creative. Remember, you are trying to convince people to change their behavior!

MindFuel™

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

wonderville™

NAME: ________________ **CLASS**: ________________ **DATE**: ________________

As part of your presentation, you will also need to include your "before" and "after" carbon footprint data. You'll want to assess what change happened, and how impactful your actions were. Use the space below to plan what form of presentation you will create, where and how you will share it, how you can make sure your presentation reaches the most number of people, and what sources of data/information you will use to educate others about carbon dioxide and climate change.

Reflection: In what ways was your action campaign successful? Did you change your carbon footprint - why/why not?

____

____

____

In what ways could you do things differently next time, to achieve different/better results?

____

____

____

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

Questions	Suggested Student Responses
1. On first inspection what do you notice about the carbon dioxide concentration at the Mauna Loa and South Pole sites?	There are seasonal fluctuations in the carbon concentration at both sites as well as an increasing trend over time. The seasonal fluctuations are greater in Hawaii than in Antarctica. The fluctuations in carbon dioxide concentration are also 180 degrees out of phase.
2. Why do you think there are seasonal fluctuations in carbon dioxide concentration? Why are the magnitudes of the fluctuations different for each site?	The dips in carbon dioxide concentration coincide with summer and are associated with an increase in photosynthesis (resulting in removal of carbon dioxide from the atmosphere) in the environment surrounding the sampling location. In winter respiration dominates so there is an increase in carbon dioxide in the atmosphere. The carbon dioxide fluctuations are greater in Hawaii as there is more vegetation present therefore a it has a greater influence on the atmospheric carbon dioxide concentration at that point.
3. From viewing this data, do you think the global carbon cycle is currently in balance? Why or why not?	No, the carbon cycle is not currently i balance. If the carbon cycle was in balance then the concentration of carbon in the reservoirs (such as carbon dioxide in the atmosphere) would be relatively stable, excluding seasonal/daily fluctuations.
What is a greenhouse gas?	Greenhouse gases are types of gas molecules that exist in the atmosphere around Earth. They allow sunlight through to warm Earth, but trap the reflected heat and prevent it from escaping back into space.
What is the main greenhouse gas of concern?	Carbon dioxide
Give some examples of other greenhouse gases:	Examples can include: methane (CH4), water vapour (H2O), nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride.
Why are greenhouse gases important?	Without greenhouse gases to maintain Earth's climate at relatively stable temperatures that are suitable for life, then life would not be able to exist on Earth.
How have humans changed the amount of greenhouse gases in the atmosphere?	Since the industrial revolution, the burning of fossil fuels and other human activities have resulted in a large amount of carbon dioxide being released to the atmosphere from other long term storage reservoirs.

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

Questions	Suggested Student Responses
How are these changes in greenhouse gas concentration affecting the planet?	The greatly increased concentration of carbon dioxide in the atmosphere has increased the amount of heat being trapped by the atmosphere and has already resulted in glacier melting, permafrost melting and increased occurrence of extreme weather events.
How do you think climate change might affect you directly?	This will depend on where the student is located.
What is the targeted maximum temperature change agreed to in the Agreement?	2°C, and below 1.5°C if possible.
The Agreement aims to eventually limit greenhouse gas emissions from human activity to the same level as what?	To limit the amount of greenhouse gases emitted by human activity to the same levels that trees, soil and oceans can absorb naturally, beginning at some point between 2050 and 2100.
How often will each country's contribution be reviewed?	Every five years starting in 2018.
What will the role of rich nations be?	To provide "climate finance" to help with climate change and switch to renewable energy sources.

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

Appendix E: CO_2 & the Carbon Cycle Rubric

How to use this rubric:

- Provide this rubric in advance of starting the project - make sure that students understand evaluation - or, if desired, the indicators can be created collaboratively with students for greater ownership over what they are trying to achieve.
- This rubric can be used both for self-reflection and for teacher evaluation.
- Students can choose which four of the six categories they wish to be evaluated on, for a total of 100%. Teacher comments and feedback is encouraged for all categories, regardless of which scoring categories are selected.

OUTCOMES	Indicators (can be demonstrated in different ways)	Comments and Feedback	Score
Research and self-directed learning	• Collects data correctly and completely • Documents information and ideas effectively • Gathers information from a wide variety of sources • Identifies problems and solutions relevant to the data collected • Makes productive use of time		25%
Plan and design the presentation	• Shows correct application of ideas and learnings • Thinks critically to assess impacts and picks one to act on, with justification • Provides complete and well thought-out plan for presentation • Incorporates both qualitative and quantitative data into presentation plan • Implements creative and unique elements into the presentation		25%
Conduct the action & presentation/ campaign	• Uses materials, equipment, class space and time adequately and responsibly • Presentation that follows closely the planned design • Carries out all necessary data collection • Incorporates data into activity		25%
Conclusion	• Analyzes and interprets carbon footprint data fully and correctly • Evaluates results and draws thorough and meaningful conclusions based on the data • Thinks critically to assess success of action and brainstorm solutions to improve the action/ presentation		25%
Collaboration	• Considers and incorporates feedback and suggestions from others • Makes thoughtful contributions to class discussions and debriefs • Has respectful and productive interactions with others		25%
Communication and Presentation	• Communicates in ways that are understandable to others, logical and effective; can back up ideas and have meaningful and constructive dialogue • Shares and justifies ideas and information clearly and thoroughly; uses persuasive language • Incorporates powerful images to support the ideas • Presents in a confident and engaging fashion showing understanding and competence		25%

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.