INCLUSIVE, STRONG AND GREEN

Student Manual
All Hands-on-Deck--You Can Make A Difference!

A Solutions Focused Course or Modular Lessons Using Systems Thinking and Stella Modeling Tools to Address Climate Change with Green Work!

Cloud and Surface Temperature Data combined in image from NASA's Terra Satellite

A 25 Lesson Complete Course Designed for Upward Bound Summer Programs. Individual units or lessons can easily be adapted for use in other contexts by all TRIO Programs

Funded by NSF Grant #1759163

Dear TRIO participants

Each generation is faced with new challenges and new stories that define an era. Our generation is faced with the especially deep challenges of global climate change and equity crises of our times. In additon we have been faced with the global pandemic from which we are recovering. But each challenge is also an opportunity and problem solving is how we move forward.

This course is designed to be a co-learning education experience to foster our increased understanding of how to face challenges generally; and specifically to help us develop the skills to work together to address the serious challenge faced by human-induced global climate change. It's not something that any one of us can solve alone, or anyone solution or state or country can solve. It is a challenge to which each of us working together on all levels (self, family, neighborhood, city, state, country, world) has something to contribute and can make a difference. This challenge also intersects with related issues of poverty, health, inequality, civil rights, and the rights of all species.

This course was originally developed and iteratively pilot tested with over 300 Upward Bound Students over three summers (2019, 2020, 2021) . Following the UB summer program structure it was designed as a 5 week continuous course with 25 lessons that sequentially build skills and knowledge culminating in a student project and community summit hosted by participants. The 2019 course was all in-person and the 2020 and 2021 course was piloted during COVID, with 2020 being all on-line and 2021 being a hybrid course. The course can be used in a fully in-person setting, fully on-line or in a hybrid format.

The lessons or units in this manual may be taken all together in sequence, but your teacher may also select individual lessons that can be done independently or over longer periods of time depending on needs of the program. The course is designed to immerse participants in systems thinking as applied to personal life journey's, and to a participants role in global and local climate issues. In this course, participants study Climate Solutions and are introduced to using Stella Software, a powerful tool for modeling solutions. Participants prepare a systems model presentation to share with the community. Through systems thinking and technology tools we explore together the critical issues and potential solutions that touch each of us wherever we are, whatever our interest in future jobs or careers.

This course was funded by a National Science Foundation (NSF) grant. Throughout its development and piloting over three summers, we asked participants to give us feedback to improve the course and to complete a pre and post-survey. You may or may not be asked to take a pre-and post survey. iStronG is a living curriculum and surveys and other feedback can help us continue to improve the course as a resource for the TRIO community.

Thanks for your help---We hope you enjoy this educational experience!

Kind regards,

The iStronG Team

Student Manual Section 1:

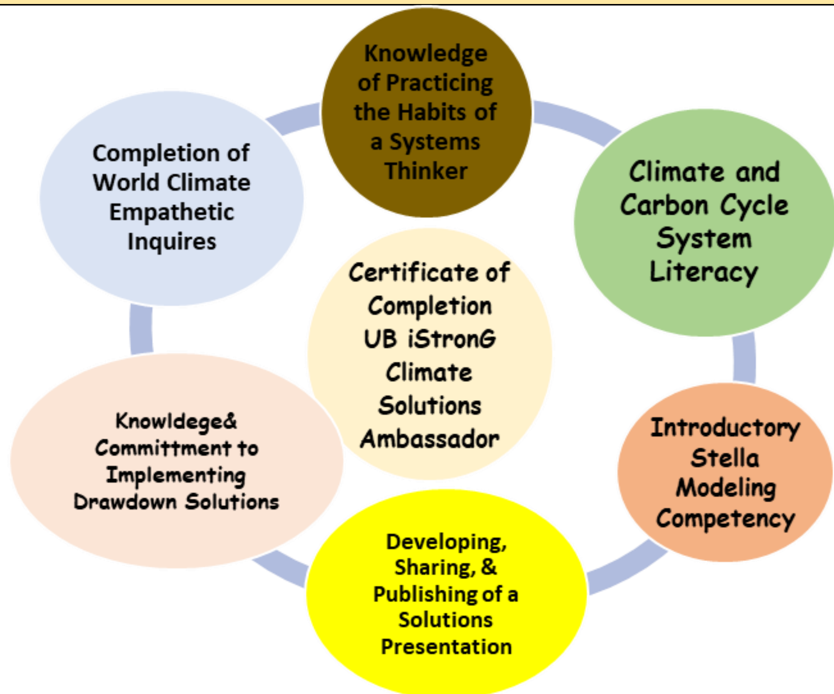
Getting Started with All Hands-On-Deck

This guidebook was originally specifically designed for high school participants in the Upward Bound summer program with 25 scaffolded lessons. However, parts of it or the whole curriculum can be used by anyone who wants to actively learn about and engage in the process of understanding and practicing systems thinking and modeling to help address one of the key problems of our times—that of global and local climate change. Through these integrated lessons, we engage in "empathetic science inquiry" and explore positive possible solutions that can be applied both globally and locally by each person.

iStronG Competency Based Course. This course is specifically designed to be Competency Based. By that we mean it will give you the chance to develop and demonstrate, especially through your projects, a certain set of interrelated skills. The overall student skills that you will be developing by completing this course are:

1. Understanding the concept of Systems and applying the Habits of a Systems Thinker
2. Empathetic Understanding of World Climate Issues
3. Climate and Carbon Cycle System Literacy
4. Introductory Stella Competency
5. Knowledge of Drawdown Solutions at the Global and Local Levels and how relates to Green Work and Lifestyle
6. Demonstrated Preparation and Communication of a Solutions Based Project

Student Manual Exhibit 1: The Six Interrelated Competencies of iStronG



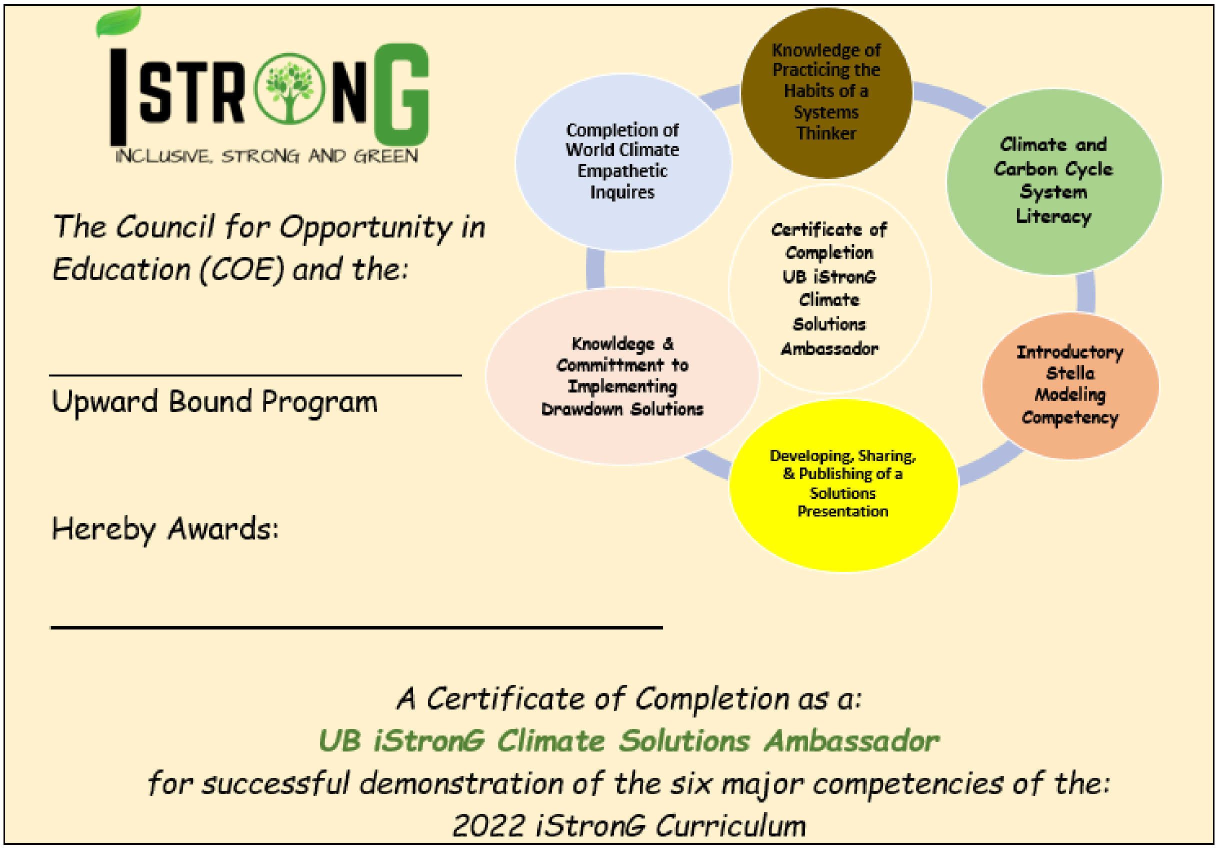
iStronG Course Requirements. The final requirements for this course will be determined by your teacher. The requirements in this manual are designed to enable you to successfully demonstrate your own unique ability to meet the competency-based skills for earning the UB Climate Change Ambassador Certificate. They are listed in Student Manual (SM) Exhibit 2.

Student Manual (SM) Exhibit 2: Course Requirement for Earning a iStronG Climate Solutions Ambassador Certificate

- ✓ Complete both the pre-test at beginning of course and post-test at the end of the course
- ✓ Actively participate in the World Climate Simulation
- ✓ Complete each lesson and formative assessments as your teacher directs
- ✓ Complete all homework assignments made by your teacher
- ✓ Using the pre-loaded Stella carbon cycle models or ones you make yourselves upload your Stella models as directed by your teacher
- ✓ Prepare a solutions-based final presentation with a stella model, and orally present on-line to other UB students and community

Students who successfully complete the course will receive the certificate in SM Exhibit 3. An example for Upward Bound is provided in Student Manual Exhibit 3.

Student Manual (SM) Exhibit 3: Example of Upward Bound Climate Solutions Ambassador Certificate

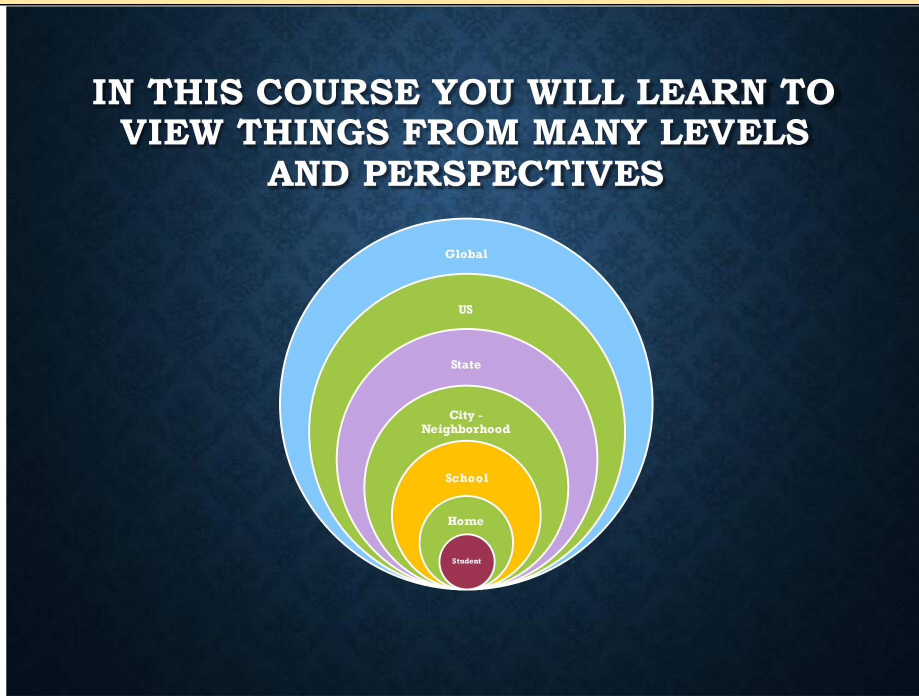


Sections of the Enhanced Student Manual (SM). This manual is intended for student use though out the course as directed by your instructor. It is divided into five sections.

- Section 1: Introduction, Course Requirements, and Overview of the Student Manual (SM)
- Section 2: Curriculum Course Slides (Both Nearpod and Power Point Slides are Provided) Outline with links to slides and PDFs for each Unit
- Section 3: Downloaded copies of Key Information and Lab Sheets Used in the Curriculum Slides
- Section 4: Supplementary Material (Activity Sheets, Information Sheets, and Lab Sheets) from the 2019 Pilot in-person Curriculum

A key goal of this course is developing your knowledge and skills to engage throughout your life in what some have called "empathetic inquiry." Being able to expand your thinking to see interconnections and "take the place of other persons, species and elements in the universe to whom you are in fact intimately related." Exhibit 4 graphically displays the nested interrelated levels each with different perspectives. This is a co-learning project in which; the co-developers of this curriculum, your TRIO teachers, and you as an student are on a shared journey to help address critical issues of our times together!

Student Manual (SM) Exhibit 4: Viewing from Many Levels and Perspectives



iStronG Student Manual
Section 2:
Course Outline and Links

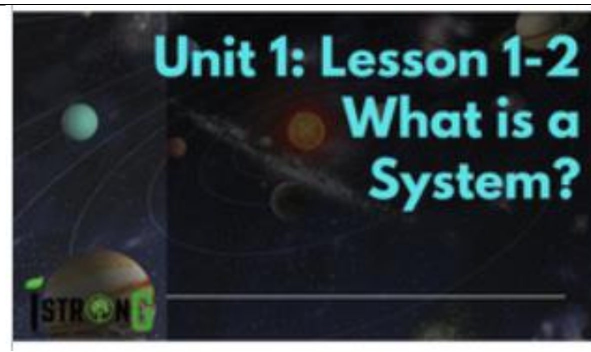
In this section we provide links to NEARPOD slides and for ease of access links to the same slides in Power Point as well as a PDFs of each of the slides in the 5 units of the course. We also provide the links to the Formative Activities and Quiz's embedded in the Nearpod slides as word documents. Links are also provided to certain information and lab sheets as PDF files. Downloaded copies of these are also displayed in Section 3 of this Student Manual (SM).

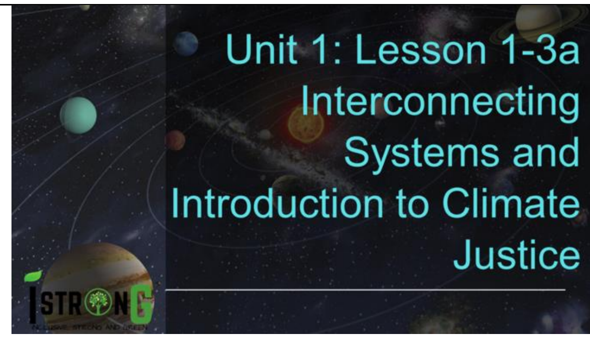
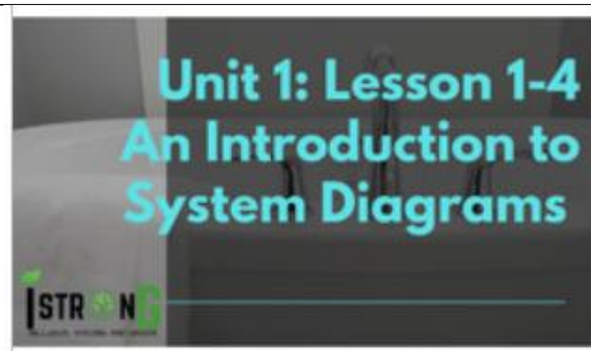
We also provide the links to Stella models that you can download and open in Stella Architect. These links are provided in this Section 2 in the Course Outline and are also listed together in Section 4 of this SM. These are models that your instructor will be going over in class. The links are also provided in the individual lessons. You are invited to use these as examples to help you get started in Stella. You can download them and save them under different names and then you can change and modify them yourselves to see how Stella works. We encourage you to experiment with ideas for making your own models.

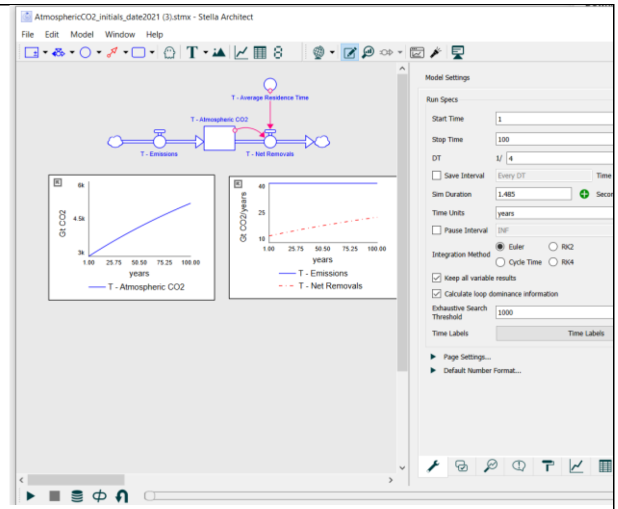
The iStronG course was specifically designed for the Upward Bound (UB) Summer program based on a typical 5 to 6-week program. There are 5 units, each with an average of 4 to 5 lessons. The 5th week is primarily devoted to the project presentations. Each TRIO program has its own schedule and time allocations. Your instructors will be customizing the basic curriculum to fit your individual program's schedule. In this SM, a "generic" curriculum is presented assuming a 5-week course. The Outline provides links to the copies of the curriculum slides and some of the Information Sheets, as well as the Stella example models.

Resources and Links in Student Manual are for Viewing Purposes Only. As with any "text" book, these resources are intended for viewing purposes only and these slides may look different from those you see that are customized for your course by your instructor. ***Any form of interaction or submission of work should be done only through the links your instructor provides.***

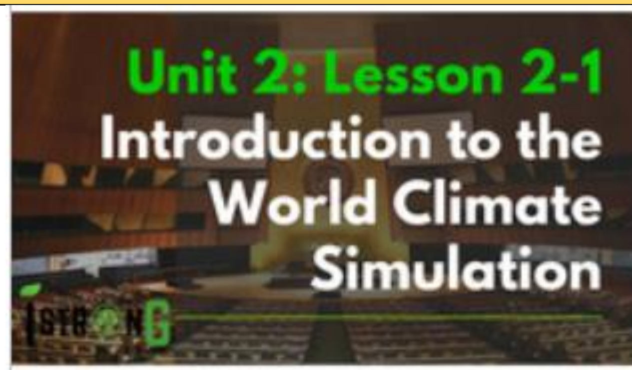
Abbreviations Used in this Course Outline. In addition to referring to the Student Manual as SM, we also use certain abbreviations. These are: FRM= Formative Activity or Quiz; DIS Discussion Guide; PDF Guide; STL = Stella Model; FST = Feedback Survey; MDL= C-Roads Model.

Unit 1: Understanding Systems Click here for a PDF of Unit 1 Slides Click here for a PDF of Unit 1-3a New Climate Justice Lesson	
Lesson 1-1 - Pretest and Course Overview **Preview in Nearpod** FST: Pre survey	
Lesson 1-2 - What is a System? **Preview in Nearpod** Slide 20 - FRM: Systems in Your Life Slide 22 - FRM: Reflection Slide 24 - FRM: Quick Quiz on System Components	
Lesson 1-3 - Habits of a Systems Thinker & Bathtub Thinking **Preview in Nearpod** Slide 21 - DIS: Discussion Opportunity/Alternative Submission Slide 31 - FRM: Drawing Stock Dynamics Practice Slide 33 - FRM: Reflection	

Slide 34 - FRM: Quick Quiz on Stock Flow Dynamics Slide 41 - FRM: Quick Quiz on Habits	
Lesson 1-3a - Interconnecting Systems and Introduction to Climate Justice **Preview in Nearpod**	
Lesson 1-4 - Introduction to System Diagrams **Preview in Nearpod** Slide 22 - FRM: Social Media SFD / Alternative Submission Slide 32 - FRM: Reflection Slide 33 - FRM: Quick Quiz on SFD & Feedback Loops	
Lesson 1-5 – Moving From Diagrams to Models **Preview in Nearpod** Slide 14 - PDF: 1-5-A Guide Sheet with Intro to Stella Terms Slide 15 - PDF: 1-5-E Stella Architect Toolbar Slide 16 - PDF: 1-5-C Lab Sheet for CO2 SFD Slide 17 - PDF: 1-5-D Climate Units Slide 19 - STL: Atmospheric CO2 Model Slide 38 - FRM: Reflection	

Slide 40 - PDF: 1-5-B Lab Sheet Bathtub Model Slide 41 - FST: End of Unit 1 Survey Internet access for a Stella Tutorial at https://www.iseesystems.com/resources/tutorials/	

<table>
<tr><td colspan="2">Unit 2: World Climate Simulation and Role Play Experience
Click here for a PDF of Unit 2 Slides
Click here for a PDF of New Unit 2-4a Climate Justice Lesson</td></tr>
<tr><td>Lesson 2-1 - Introduction to the World Climate Simulation
Preview in Nearpod

Slide 12 – Excel Sheet: World Climate Simulation Teams and Materials</td><td>
</td></tr>
<tr><td>Lesson 2-1a - Get to know your region (Developing Regions)
Preview in Nearpod

Slide 3 - PDF: Glossary of Terms
Slide 6 - MDL: C-ROADS Model
Slide 9 - FRM: 2-1a Historical Cumulative Emissions
Slide 11 - FRM: 2-1a/b Population
Slide 13 - FRM: 2-1a/b Emissions Per Capita
Slide 15 - FRM: 2-1a GDP
Slide 18 - FRM: 2-1a/b Reflection Questions</td><td>
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<tr>
<td>Lesson 2-1b - Get to know your region (Developed Regions)
Preview in Nearpod

Slide 3 - PDF: Glossary of Terms
Slide 6 - MDL: C-ROADS Model
Slide 9 - FRM: 2-1b Regional Emissions
Slide 11 - FRM: 2-1a/b Population *
Slide 13 - FRM: 2-1a/b Emissions Per Capita *
Slide 15 - FRM: 2-1b GDP
Slide 18 - FRM: 2-1a/b Reflection Questions *</td>
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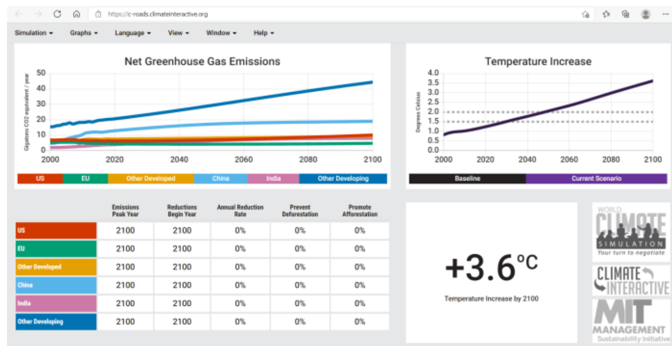
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<td>Lesson 2-1c - Global Impacts
Preview in Nearpod

Slide 4 - MDL: Climate Impact Map
Slide 9 - FRM: Climate Impact Map
Slide 14 - MDL: Surging Seas Map
Slide 17 - DIS: Discussion Opportunity/ Alternative Submission
Slide 19 - DIS: Reflection/ Alternative Submission</td>
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Lesson 2-2 - The World Climate Simulation
[Preview in Nearpod]

Slide 9 – Excel Sheet: World Climate Simulation Teams and Materials

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Lesson 2-3 - Build Your Own Roadmap to Climate Success
Preview in Nearpod

Slide 10 - FRM: Using Systems Thinking to Understand Climate Change
Slide 15 - MDL: C-ROADS Model
Slide 18 - FRM: Simulation 1
Slide 22 - FRM: Simulation 2
Slide 26 - FRM: Part C

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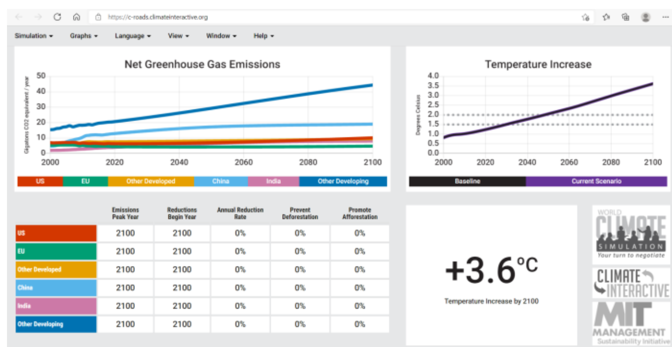

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Lesson 2-4 - World Climate Debrief
Preview in Nearpod

Slide 19 - PDF: Pachamama Alliance
Slide 24 - FST: End of Unit 2 Feedback Survey

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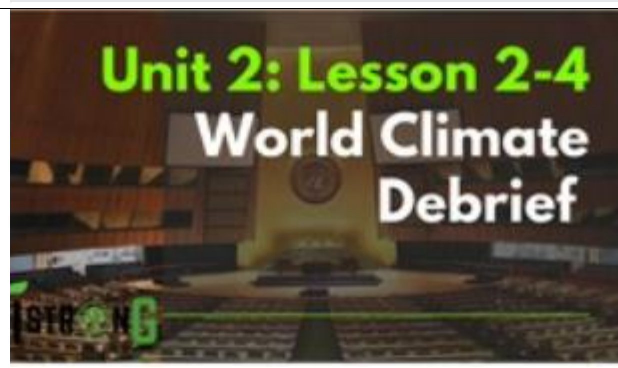

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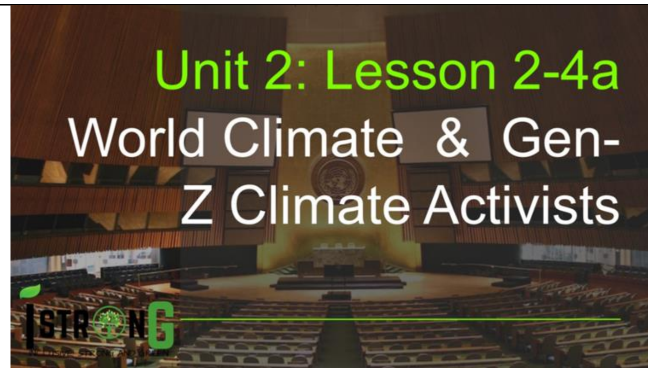
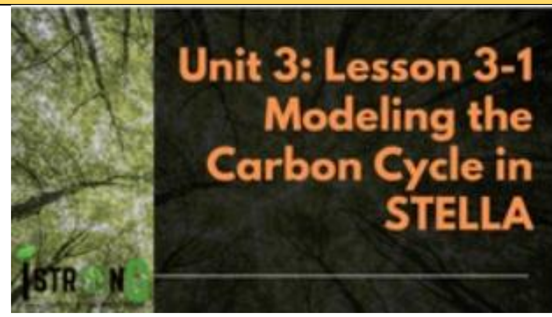
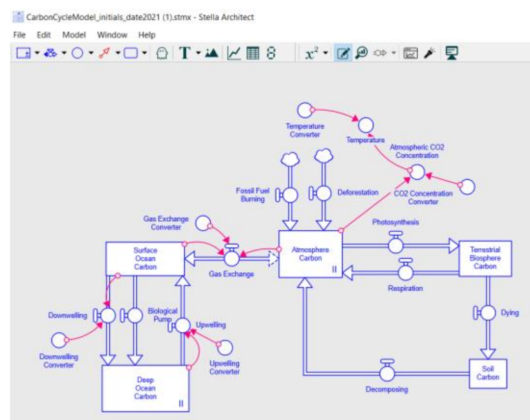
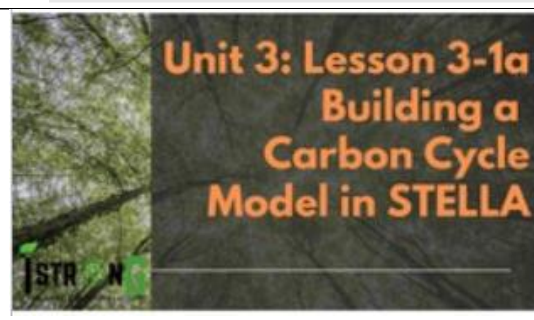
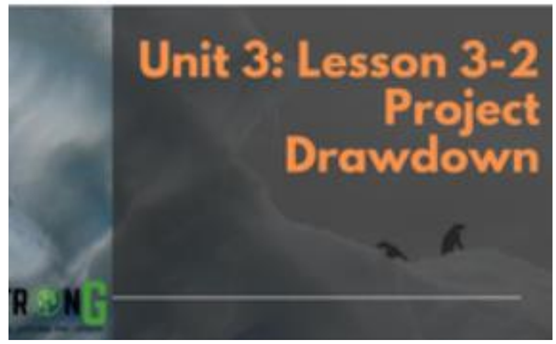
Lesson 2-4a - World Climate & Gen-Z Climate Activists [**Preview in Nearpod**]()	

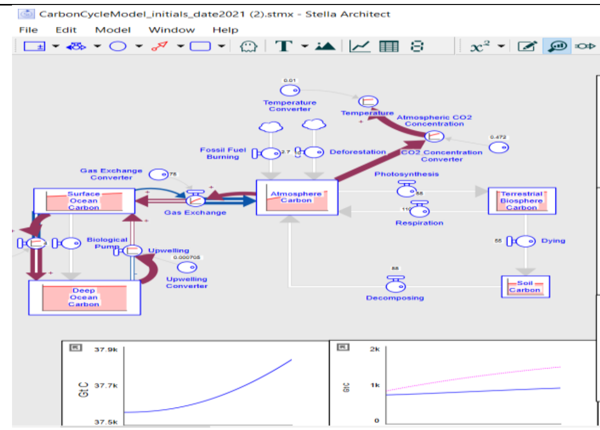
Unit 3: Modeling the Carbon Cycle in Stella; Selecting a Drawdown Solution; and Outlining My Project

[Click here for a PDF of Unit 3 Slides]

[Click here for a PDF of New Unit 3-3a Climate Justice Slides]

Lesson 3-1 - Modeling the Carbon Cycle Stella **Preview in Nearpod** Slide 16 - STL: Carbon Cycle Model Slide 18 - FRM: Model Exploration A Slide 21 - FRM: Model Exploration B Slide 23 - FRM: Model Exploration C Slide 25 - FRM: Reflection Internet access for a Stella Tutorial at https://www.iseesystems.com/resources/tutorials/ ;	 
Lesson 3-1a – Building a Carbon Cycle Model in Stella **Preview in Nearpod** **Building a carbon cycle model in Stella** Slide 19 – PDF: Carbon Cycle Model Handout	

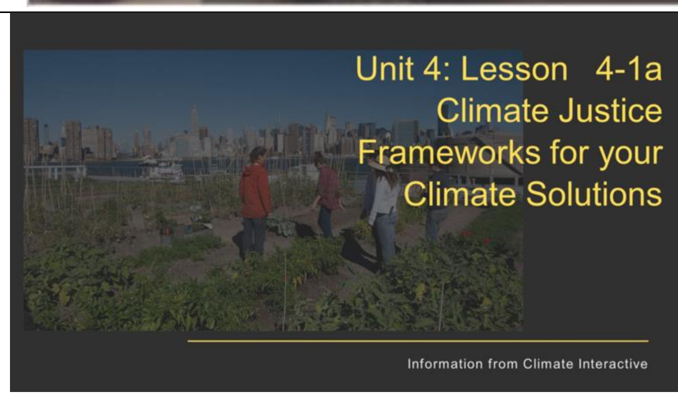
Internet access for a Stella Tutorial at https://www.iseesystems.com/resources/tutorials/ ;	
Lesson 3-2 – Project Drawdown **Preview in Nearpod** Slide 30 – FRM: Drawdown Sectors and Solutions Slide 34 – FRM: Local Action and Pitch Preparation Drawdown Internet access https://drawdown.org/solutions	
Lesson 3-3 – Global to Local **Preview in Nearpod** Slide 10 – STL: Slide 11 – FRM: Connecting Drawdown to the Carbon Cycle Slide 21 – FRM: Reflection Internet access for a Stella Tutorial at https://www.iseesystems.com/resources/tutorials/ ; Drawdown Internet access https://drawdown.org/solutions	

	
Lesson 3-3a - Green New Deals & Your Elevator Pitch **Preview in Nearpod**	
Lesson 3-4 – Mapping Solutions **Preview in Nearpod** Slide 16 - FRM: Polarity Practice Slide 21 - FRM: List of Variables Slide 24 - FRM: Number of Cyclists Connections Slide 26 - FRM: CLD for Bike Surge Slide 28 - FRM: Reflection Slide 29 - FST: End of Unit 3 Feedback Survey	

Unit 4: Answering the Challenge—Preparing My Presentation

[Click here for a PDF of Unit 4 Slides]

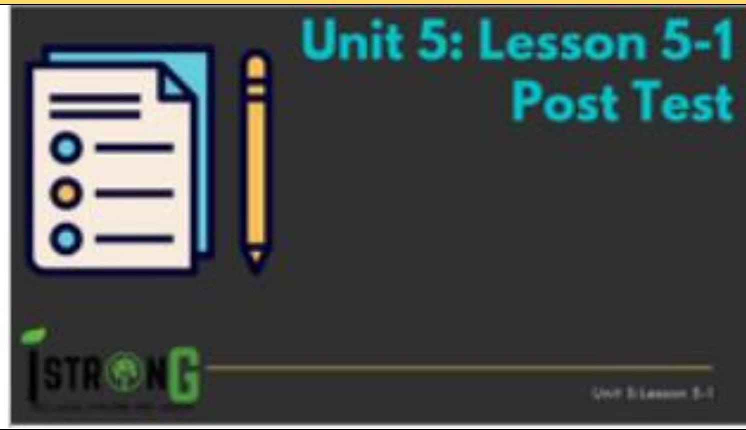
[Click here for a PDF of Unit 4-1a Climate Justice Lesson]

Lesson 4-1 – Multisolving **Preview in Nearpod** Slide 19 - PDF: How to make a FLOWER with Blank Slide 21 - FRM: FLOWER Diagram Internet Access to Multisolving (climateinteractive.org)	
Unit 4: Lesson 4-1a - Climate Justice Frameworks for your Climate Solutions **Preview in Nearpod**	
Lesson 4-2 – Climate Solutions Project **Preview in Nearpod**	

Lesson 4-3 - Research **Preview in Nearpod**	
Lesson 4-4- Green Jobs **Preview in Nearpod** Access Green Job Information on internet Explore green careers | Green Careers | CareerOneStop	

Unit 5: All Hands On-Deck: Sharing Your Model and Your Story with Your Community

Click here for a PDF of Unit 5 Slides

Lesson 5-1 – Post Test **Preview in Nearpod**	
Lesson 5-2 - Bringing It All Together **Preview in Nearpod**	

Student Manual Section 3:

Copies of Selected Information and Lab Sheets Referenced in Curriculum Slides

This section includes copies of selected Information Sheets and Lab Sheets. The Sheets have the same numbers as those listed in the Course Outline.

Unit 1: Lesson 1-5

1-5-A: Guide Sheet with Introduction to Stella Terms

Lesson 1-5 Slide 15 - PDF: [1-5-A Guide Sheet with Intro to Stella Terms]

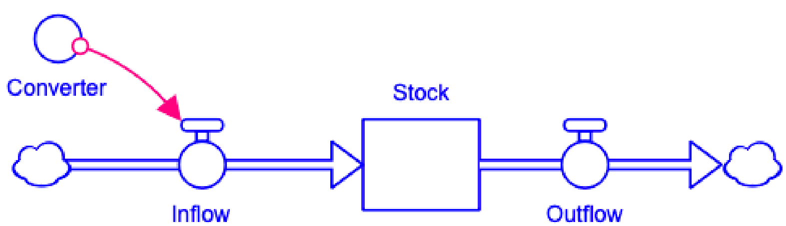
STELLA is a computer program containing numbers, equations, and rules that together form a description of howwe think a system works — it is a kind of simplified mathematical representation of a part of the real world.

The Stella software has two basic modes: map and module. More about this will be explained as we proceed.

Map view - use this view to lay out the model diagram. No indications of model validity will be visible.

x^2 **Model view** - use this view to complete model equations and make your model simulate. Validity indicators will appear on all incomplete variables and a dropdown list of errors or warnings will display on the Run Toolbar.

In STELLA, systems are composed of a few basic parts that can be seen in the example diagram below:



Terms in the Example Model Defined

- A **stock or reservoir** is a model component that stores some quantity. Stocks are system elements that can be measured and that accumulate or decline over time as a result of flows into (inflows) and out of (outflows) them.Stocks usually represent stored amounts, while flows represent rate of movement of material, energy, or information. Stocks are frequently referred to as having 'memory.' In other words, stocks don't disappear or appear instantaneously, but rather accumulate or decline as a result of their inflows and outflows. In fact, it is important to note that **stocks can only change as a result of their flows**. The stock at any instant in time is the result of inflows and outflows integrated over time. If flows are stopped at any time, the stock remains unchanged and, therefore, creates inertia.

- A **flow** adds to or subtracts from a **stock** (or **reservoir).** It can be thought of as a pipe with a valve attached to itthat controls how much material or information is added or removed in a given period of time.
- A **connector** is an arrow that establishes a causal link, or relationship, between different model elements. It shows how different parts of the model influence each other. The connector in our example is the pink arrowbetween the **converter** and the **inflow**. It indicates that that the **inflow** is dependent on the value of the **converter**.
- A **converter** is something that does a conversion or adds information to some other part of the model.

To construct a STELLA model, you first draw the model components in **Map View**. Equations and starting conditions are then added in **Model View**. The time period for the model is also set in order to tell the computer howlong to run the model and how frequently to do the calculations needed to figure out the flow and accumulation of quantities.

When your system map is complete and your equations are entered, you can select the '**Run**' button, sit back, and watch what happens. You may find that you need to correct an error or have new ideas about how to improve your model, and then run it again and again to learn more about how the system changes over time.

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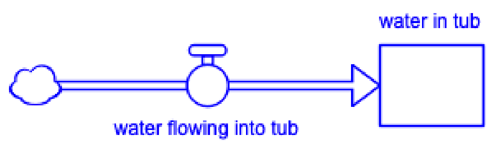
Unit 1 Lesson 1-5

Practice building a bathtub model

1-5-B: Slide 40 - PDF: [1-5-B Lab Sheet Bathtub Model]

- In STELLA, go to **File** > **New Model**. You'll see a panel on the right that shows **Model Settings**. Change the **Time Units** to **Minutes** and leave the other settings at their default values.
- Select the **stock** tool at the top left of the toolbar in STELLA and place the stock in your model by moving your cursor to the white space in your model workbench. Click your mouse to place the stock in the model. Enter the stock name **water in the tub**.

- Select the **flow** tool, which is next to the **stock** tool in the top toolbar. Place it in your model workspace and then drag and drop the flow into your stock, **water in the tub.** STELLA shows you if the flow is successfully connected to the stock by highlighting the stock. Enter the flow name **water flowing into tub**. Your model map should like this:



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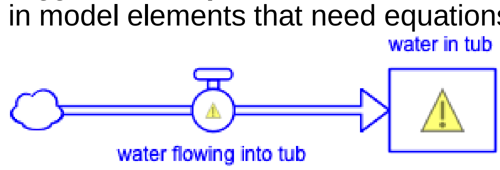
- In order to simulate the model, you next need to enter equations. Switch to **Model View:** x^2. Click on the globe icon to toggle from **Map View** to **Model View.**
- You will now see yellow caution signs in model elements that need equations:



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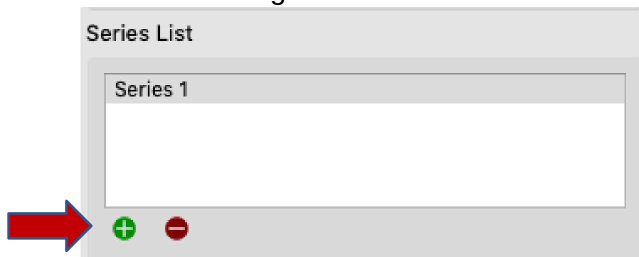
- Enter an intial value and units for the stock, **water in tub**, by clicking on the stock. The equation and **Units** panel will be on the right side of your model map. In the equation box, click on "Enter initial value here" and type **0** to represent that the tub is empty at the beginning of the simulation. In the **Units** dialog box, type **Gallons**.
- Enter a flow rate by clicking on **water flowing into tub** and typing **10**. The **Units** box should show
  Gallons/Minutes. Water is now set to flow into your tub at a rate of 10 gallons/minute.
- Simulate the model by selecting **Model > Run**.
  - What happens? Why?
-

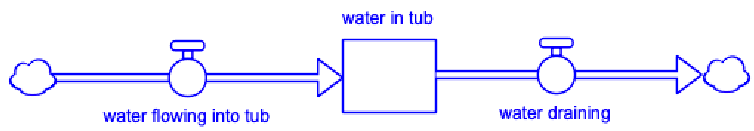
- Add a graph to the model by clicking on the graph icon  in the toolbar and then clicking on the location where you would like the graph to be in your workspace. The panel to the right of your model shows graph settings. Click on the green + sign under the **Series List** and select **water in tub**. The graph will now show the level of water in the tub over time. Simulate the model using **Model > Run**. How much



water is in the tub at the end of the run?

-

- What if you have a tub with a drain that doesn't fully close? You could represent that situation by adding an outflow to your model. Select the flow tool from the toolbar, click on **water in tub** and drag and drop the flow from the stock to the right. Enter the outflow name, **water draining.** In **Model View**, set the outflow rate to 2 gallons/minute by typing **2** in the equation box for **water draining.** Simulate the model using **Model > Run**. How is this model run different from the prior one? What is the level of water in the tub at the end of the run now?



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Unit 1 Lesson 1-5
Lab Sheet for Preparing a Stock-Flow Model of CO_2 Emissions and Removals
1-5-C: Slide 16 - PDF: 1-5-C Lab Sheet for CO2 SFD

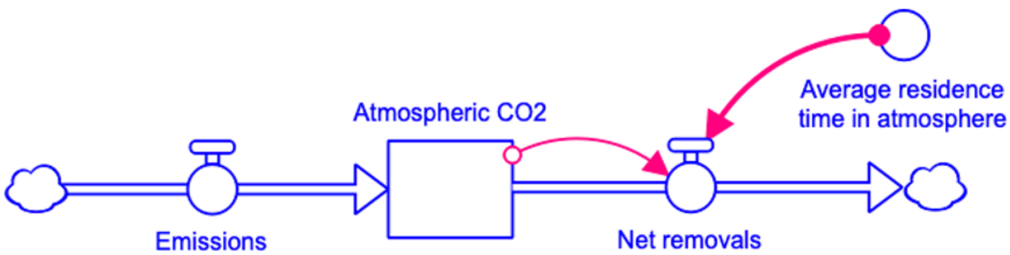


Diagram of a simple atmospheric CO_2 stock-flow system.

Just like water in a tub, the amount of CO2 in the atmosphere accumulates or declines depending on its inflows and outflows. Burning fossil fuels such as coal, oil, and natural gas converts carbon in those fuels into carbon dioxide or CO2, causing **emissions** of CO2 into the atmosphere. The stock of **atmospheric CO2** accumulates as long as **emissions** are greater than **net removals** of CO2.

As you proceed, don't be afraid to frequently refer to the Stella on-line tutorial at this link https://www.iseesystems.com/resources/tutorials/**.** This guide is designed to help you as you follow along with the preparation of the model and make the model on your computer in your practice file.

Divide into partners so you can discuss this lab together. In the directions below names of model elements are given in **bold**.

1. Create a new model by selecting **File > New Model** in STELLA. In the Model Settings panel, set the **Stoptime** to 100 and the **Time Units** to **Years**.
2. In **Map View** place a stock in your model and name it **Atmospheric CO2**. Then add an inflow to **Atmospheric CO2** named **Emissions** and an outflow named **Net removals.** Your model should look like the diagram below.
3. Add initial equations for **Atmospheric CO2, Emissions,** and **Net removals**. In

Model View enter the following values. Note that the initial value for **Atmospheric CO2** roughly represents current conditions as we see in Information Sheet 3-1-C. Be sure to save your element definitions values each time you edit byclicking on the green check mark.

a. **Atmospheric CO2:**
  i. Unit: Gt CO2
  ii. Initial value: 3000

b. **Emissions:**
  i. Unit: Gt CO2/year
  ii. Value: 40

c. **Net Removals:**
  i. i. Unit: Gt CO2/year
  ii. ii. Value: 20

4. **Run Number 1**: Hit Play and watch what happens to the **Atmospheric CO2** stock. How does it changeover time? What is its final value at the end of the run?

5. **Adding Graphs** Once you have gotten your model to run, review the Stella tutorial 2-2 on how to place graphs in your model. https://www.iseesystems.com/resources/tutorials/. We will keep the settings for the time unit to years, and the total time period to 100 years. Place 3 graphs to plot these 3 values over the totaltime period:

Atmospheric CO2
Emissions
Net Removals

Once you have the graphs, run the model again. Take a screen shot of your model results. Write the story ofthe Module 1 down in the documentation section that appears when you are in Map View and you click on an element. Save and verbally discuss the results with your partner. ***What happens to* Atmospheric CO2 *when emissions remain higher than removals for 100 years?***

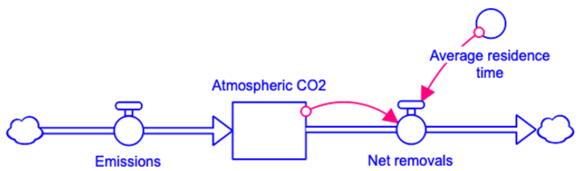
6. We'll now change the model to reflect that the average molecule of CO2 that is emitted from fossil fuel usestays in the atmosphere for about 200 years. This value is called the **average residence time** because it describes the average amount of time that CO2 resides in the atmosphere. Therefore, the outflow of **Net removals** can be expressed as the level of **Atmospheric CO2** divided by the **Average residence time**.

   a. First, click on the **converter** icon ○ in the upper toolbar, move your cursor to a location above

Net removals and click to place the converter. Name the converter **Average residence time**.

b. In **Model View**, click on **average residence time** and enter:
   - **i.** Unit: **Years**
   - **ii.** Equation: **200**

7. Click on the **connector** icon in the toolbar and then click on **Average residence time** and drag and drop a connector from **Average residence time** to **Net removals.** Add another **connector** from **Atmospheric CO2** to **Net removals**. The connectors tell STELLA that the value of **Net removals** is dependent on both **Average residence time** and **Atmospheric CO2.** Your model should now look like this:



8. In **Model View** you now need to enter an equation for **Net removals:**
   - ***a.*** Unit: Gtons CO2/Year
   - ***b.*** Equation: **Atmospheric CO2/Average residence time**

Once you have made the modification, and saved it, hit the Run button and watch the graphs and model change. Take a screen shot of the second model Run. Discuss this model with your partner and the group. ***How do the graphs change over time?***

9. Because atmospheric CO2 is the primary heat-trapping gas in Earth's atmosphere, the climate will continue to warm as long as its level continues to increase.
   - ***a.*** **How could you change the values in your model in order to ensure that Atmospheric CO2 does not grow over time**? You might find it useful to think back to the system of water in a tub –i.e., in order to stop the level of water from increasing, what needs to be true about water flowing into the tub relative to water draining from it? Note that you can change values of **Emissions** and **Average residence time** on the fly during a model run by adjusting the 'dial' on each variable. You can slow the run down by going to **Model > Run Specs** and changing the **Sim Duration** to 10 seconds (or more).

Unit 1 Lesson 1-5
References Sheet for Understanding Units and Terms We Are Using, and Relationship to Common Measures of Discussion of Climate
1-5-D: Slide 17 - PDF: 1-5-D Climate Units

The different terms and units involving carbon and carbon dioxide (CO_2) in the atmosphere can be confusing. The information below is for reference and use throughout the course. For reference here are a few unit descriptions andhow they relate to each other and our discussion of climate. This sheet will prove handy as we proceed through the course.

1. Carbon and carbon dioxide (CO_2) are related but not the same. Each molecule of CO_2 contains one atom of carbon (C) and two atoms of oxygen (O). As carbon moves between different components of the global carbon cycle, it is found in different forms. For example, living organisms contain carbon in complex organic molecules that include sugars, starches, proteins, DNA, and other biomolecules. Carbon in fossil fuels is in the form of hydrocarbons, or molecules in which carbon is bound to other carbon atoms, oxygen,and hydrogen. Most of the carbon in the atmosphere is in the form of CO_2. So, in order to follow an atom ofcarbon around the global carbon cycle, it is more consistent to refer to units of carbon, even if that carbon might be bound to many other atoms. In contrast, scientists often refer to carbon flowing into and out of theatmosphere as CO_2. This difference is important because every 44 grams (g) of CO_2 has only 12 grams of carbon and 32 grams of oxygen. In order to convert the mass of carbon in CO_2 to the mass of CO_2, we multiply by 3.66 because:

$$\frac{44\ g\ CO_2}{12\ g\ C} = 3.66$$

2. In preparing our equations for Stella we need to always check whether we are referring to CO_2 or carbon. Note also that when we are describing the global carbon cycle, we typically refer to gigatons (Gt) which isdefined as 1 billion metric tons.
3. Carbon dioxide (CO_2) currently constitutes about 0.041% by volume of the atmosphere, which is equal to aconcentration of approximately 410

ppm by volume. We know that **1 ppm = 7.81 Gt of CO_2.** Therefore, 410 ppm corresponds to approximately 3202 Gt of CO_2, which you can calculate by multiplying 410 ppm by 7.81 Gt/ppm. You will see that in Lesson 3-1 we use 3000 Gt of CO_2 for our initial value of atmospheric CO_2 in our practice model. In the next Lesson 3-2 of the carbon cycle, you will use a carbon measure rather than a CO_2 measure.

4. The carbon content in CO_2 is approximately (3202 Gt CO_2)/(3.66 Gt CO_2/Gt C), which equals approximately **870 Gt** carbon. Note: Dividing by 3.66 is the same as multiplying by 0.27 so the carbon content is 27% of the CO_2.
5. You have also seen CO_2 concentration expressed in parts per million (ppm) or parts per million by volume (ppmv). Each 1 ppmv (part per million by volume) of the atmosphere weighs approximately 2.1357 Gt. of CO_2.
6. As we learned in Unit 2, 2019 CO_2 levels have reached the dangerously high 410 ppm. April 2020 readings were 416 ppm.
7. The chart below displays the growth of CO_2 from about 280 ppm in 1750 to the current levels of approximately 410 ppm in early 2019.
8. Prior to 1750, global annual mean CO_2 concentration remained within 20% of 280 ppm during the entire 10,000 years since agriculture began. Then from 1750 onwards up to the current century, the increase to 410 ppm as of early 2019 represents more than a 46% increase! (410 – 280)/280. This is a very large increase to happen so rapidly!
9. The present concentration is the highest in the last 800,000 and possibly even the last 20 million years.
10. The increase has been caused by human activities particularly the burning of fossil fuels and deforestation.
11. This increase of CO_2 and other long-lived greenhouse gases in Earth's atmosphere has produced the current episode of global warming. About 30–40% of the CO_2 released by humans into the atmosphere dissolves into oceans, rivers and lakes, which has also produced ocean acidification.

Review: https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide
Review: http://www.grisanik.com/blog/how-much-carbon-is-in-the-atmosphere/

ISTRONG
INCLUSIVE, STRONG AND GREEN

Unit 1 Lesson 1-5
Reference Sheet: Quick Walkthrough of the Stella Architect Tool Bar
1-5-E: Slide 15 - PDF: 1-5-E Stella Architect Toolbar

Model Window Mode Toolbar

Use the Mode toolbar in the Model window to move between Edit and Explore mode, switch between Map and Model views, Navigate modules, and zoom in and out.

x^2 Map and Model View

Click on the ▾ next to the icon to select which view you want to use.

Use **Map view** to lay out model diagrams and build models if you haven't yet, or even won't, add equations. The Properties panel will display only the Documentation and Style tabs. In addition, there will be no markers indicating validity placed on the model, and the dropdown on the Run toolbar displaying a list of errors or warnings won't be visible.

Use **Model view** x^2 to work on the equations and the simulation characteristics of the model. The Properties panel will display the full set of tabs. Any invalid equations will be marked on the diagram and displayed in the Run toolbar.

Edit mode

Click this to switch to Edit mode, which will let you change the model, edit graphs, and otherwise edit. In Edit mode, the model isn't live, but graphs and tables will display results if they're available.

Explore mode

Click this to switch to Explore mode. Explore mode is intended to let you explore results. In this mode, the model is live, and available results are displayed in small graphs on top of each variable. Any change you make, by moving a dial or typing a value into the results panel, will make the model simulate again, and new results will be displayed.

Note: Running a model (from the menu or Run toolbar) switches it to Explore mode. Switching to Explore mode, on the other hand, doesn't run the model. Changing any constant value, through a knob, the Variable control panel, or the results panel, will, however, run the model, regardless of how you entered Explore mode.

Results Panel

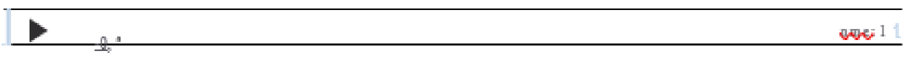
Click to open the Results Panel. If no variable is selected (or multiple variables are selected) you will be asked to choose a variable to show results for.

J Causal Lens

Click to open the Causal Lens™. If no variable is selected (or multiple variables are selected) you will be asked to choose a variable to show the causes of.

Run Toolbar

The Run toolbar appears in the lower left-hand corner of the **Stella** window. It gives you quick access to a lot of the commands on the Run menu. It also gives you a visual indication of the progress of a simulation, and allows you to adjust the time range used for tables and graphs.



or

The items on the Run toolbar are described below.

S-Run Sensitivity Run Button

This is available only if sensitivity has been set up for the model. Click on it so start a sequence of sensitivity runs. Progress will be displayed in the run toolbar, and graphs and tables will update periodically.

O-Run Optimization Run Button

This is available only if a valid optimization has been set up for the model. Click on it so start the optimization. Progress will be displayed in the run toolbar, and graphs and tables will update periodically if it is a long optimization.

Run Button

Click this button to run the simulation. Progress in the run will be displayed in the toolbar.

Pause Button

Click this button to pause the simulation. When a simulation is running, the **Run** button changes to the **Pause** button. When you click the **Pause** button, it changes back to the **Play** button.

Stop Button

Click this button to stop the simulation while it's running. If you start the simulation again, it'll start at the beginning of the simulation.

Data Manager Button

Click this button to open the Data Manager. In you are in analysis mode and have made a new run the run name will be highlighted so you can easily rename it. In edit mode the dialog will open without any highlighting.

Unit 2 Lesson 2-1a
Glossary of Terms: Vocabulary to Help Prepare for the World Climate Simulation
2-1a: Slide 3 - PDF: Glossary of Terms

Afforestation: growing a new forest or stand of trees in an area that was not forested before. Afforestation includes actively planting new forests and allowing forests to develop naturally onland that was not forested.

Carbon dioxide (CO2): a gas that is produced when fossil fuels (i.e., natural gas, coal, oil orgasoline) are used or burned. Carbon dioxide is also produced by living things when they metabolize or use food. It is taken up by plants during photosynthesis and converted into sugars and other forms of organic carbon that can then be used as food and energy.

Climate change: refers to any long-term changes in Earth's weather patterns (rain, temperature, sunshine, storms, etc.). Scientist have studied how Earth's climate has changedover Earth's history and have observed clear increases in global temperature in the last few decades.

See NASA link for more info: https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-climate-change-58.html

Deforestation: the clearing of trees, transforming a forest into cleared or non-forested land.

Delegate: a person who is chosen or elected to represent all the people from that group. Usually the delegate will vote or act for others.

Developed Nation: a country where the average income (what people earn from their work) is much higher than the global average. These countries usually have good education and health care.

Developing Nations: a country where the average income (what people earn from their work) is lower than the global average (see developed nations above). It can also mean a country withpoor education and health care.

Economy: the wealth/money and resources of a country, especially in terms of the production (making) and consumption (using/sale of) of goods and services.

Emissions: making and giving off something (for example: giving off carbon dioxide gas).

Carbon Emissions: usually means the amount of Carbon Dioxide (CO2) gas given off by burningfossil fuels (coal, oil, and natural gas) from cars, machines, factories, power plants and other human activities.

Fossil Fuel Emissions: all the different gases given off by burning fossil fuels such as oil, natural gas, and coal. 90% of the emissions are CO_2 gas, but methane and other gasses are emitted too. Fossil fuels were formed hundreds of millions of years ago from prehistoric photosynthesizing organisms.

Greenhouse Gas Emissions: gases that trap heat in our atmosphere are called greenhouse gases. Greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases used as refrigerants and in industrial processes.

See the EPA link for more info: http://www3.epa.gov/climatechange/ghgemissions/global.html

Gross Domestic Product (GDP): the total value (money) of goods produced and services provided in a country for one year.

Negotiator: someone who tries to help two groups who disagree to reach an agreement with each other, usually so that everyone benefits.

The Right to Development: the idea that people all over the world should as human beings have the right to a good standard of living/economy, education, health, safety, food, politics and other basic human needs.

See the United Nations link for more info:
http://www.un.org/en/events/righttodevelopment/pdf/rtd_at_a_glance.pdf

Verifiable Agreements: something that can be checked scientifically to make sure it is being done.

Written by Ginger Wallis and Juliette Rooney-Varga
More resources available at: World Climate for Classrooms - Climate Change Initiative

Unit 2 Lesson 2-4
Pachamama Alliance Drawdown Solutions Organized by Sector
Lesson 2-4 Slide 19 - PDF: [Pachamama Alliance]

PACHAMAMA ALLIANCE
Drawdown Solutions by Sector

Land Use
Tropical Forests
Temperate Forests
Peatlands
Afforestation
Bamboo
Forest Protection
Indigenous Peoples' Land Management
Perennial Biomass
Coastal Wetlands

Energy
Wind Turbines (Onshore)
Solar Farms
Rooftop Solar
Geothermal
Nuclear
Wind Turbines (Offshore)
Concentrated Solar
Wave and Tidal
Methane Digesters (Large)
Biomass
Solar Water
In-Stream Hydro
Cogeneration
Methane Digesters (Small)
Waste-to-Energy
Micro Wind
Energy Storage (Distributed)
Energy Storage (Utilities)
Grid Flexibility
Microgrids

Food
Reduced Food Waste
Plant-Rich Diet
Silvopasture
Regenerative Agriculture
Tropical Staple Trees
Conservation Agriculture
Tree Intercropping
Managed Grazing
Clean Cookstoves
Farmland Restoration
Improved Rice Cultivation
Multistrata Agroforestry
System of Rice Intensification
Composting
Nutrient Management
Farmland Irrigation
Biochar

Transport
Electric Vehicles
Ships
Mass Transit
Trucks
Airplanes
Cars
Telepresence
High-speed Rail
Electric Bikes
Trains
Ridesharing

Materials
Refrigerant Management
Alternative Cement
Water Saving - Home
Bioplastic
Household Recycling
Industrial Recycling
Recycled Paper

Women and Girls
Educating Girls
Family Planning
Women Smallholders

Building and Cities
District Heating
Insulation
LED Lighting (Household)
Heat Pumps
LED Lighting (Commercial)
Building Automation
Walkable Cities
Smart Thermostats
Landfill Methane
Bike Infrastructure
Smart Glass
Water Distribution
Green Roofs
Net Zero Buildings
Retrofitting

Unit 3 Lesson 3-1a
Build Your Own Carbon Cycle Model
3-1a Slide 19 - PDF: Carbon Cycle Model Handout

Build your own version of the carbon cycle model by following along with the instructional videos. Once your model map is complete, add the equations to the model shown in the table below. Go to Model View and click on each model element to enter these equations:

Model element name	Equation	Units of Measure
Atmosphere Carbon	850	Gt C
Terrestrial Biosphere Carbon	575	Gt C
Soil Carbon	1400	Gt C
Surface Ocean Carbon	750	Gt C
Deep Ocean Carbon	37600	Gt C
Photosynthesis	110	Gt C/Year
Respiration	55	Gt C/Year
Decomposing	55	Gt C/Year
Gas Exchange	(Atmosphere_Carbon – Surface_Ocean_Carbon)/Gas_Exchange_Converter	Gt C/Year
Gas Exchange Converter	75	Years
Downwelling	Surface_Ocean_Carbon*Downwelling_Converter	Gt C/Year
Downwelling Converter	0.03	1/Year
Upwelling	Deep_Ocean_Carbon*Upwelling_Converter	Gt C/Year
Upwelling Converter	0.0007048	1/Year
Atmospheric CO2 Concentration	Atmosphere_Carbon*CO2_Concentration_Converter	ppm
CO2 Concentration Converter	0.472	ppm/Gt C
Temperature	14+(Atmospheric_CO2_Concentration-338)* Temperature_Converter	deg C
Temperature Converter	0.01	deg C/ppm

The current global rate of Fossil Fuel Burning is about 10 Gt C/year and the current rate at which Deforestation adds carbon to the atmosphere is about 2.7 Gt C/year. Start by running your model with the assumption that we will continue burning fossil fuels and deforestation at those rates for the remainder of the 21st century, so enter the following equations

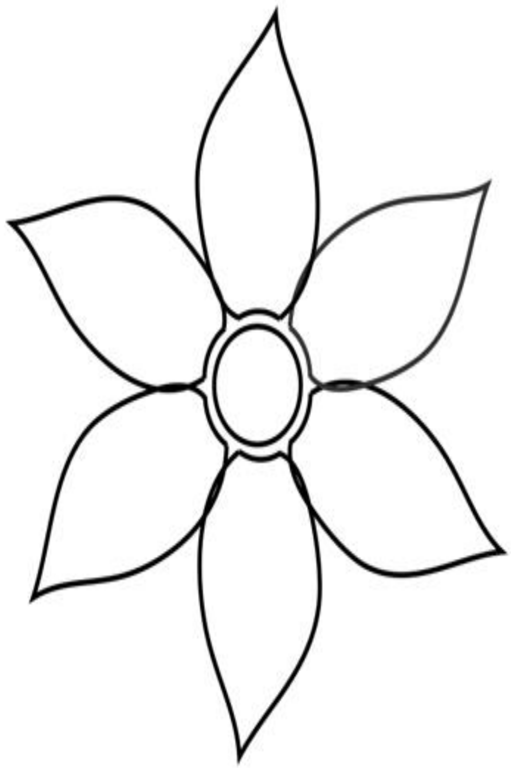
Model element name	Equation	Units of Measure
Fossil Fuel Burning	10	Gt C/Year
Deforestation	2.7	Gt C/Year

Add graphs to your model by clicking on the graph tool in the toolbar, placing the graph tool icon in your workbench, and then selecting the green plus tool to add a data series to your graph. Start with graphs of Atmospheric CO2 Concentration and Temperature (they can be plotted on separate axes on the same graph by selecting 'Right Axis' for Temperature). Then add a graph for Surface Ocean Carbon and Deep Ocean Carbon

Unit 4: Lesson 4-1 Multisolving
How to Make a Multi-Solving Flower Diagram
4-1: Slide 19 - PDF: [How to make a FLOWER with Blank]

FLOWER

The **F**ramework for **Lo**ng-Term,
Whole-System, **E**quity-based **R**eflection

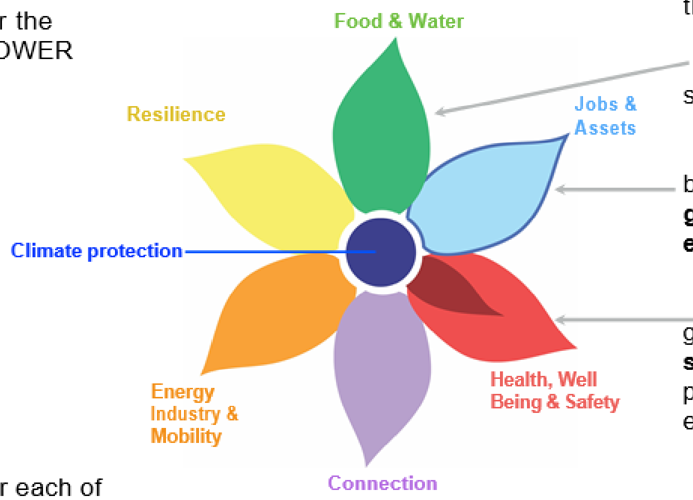


https://www.climateinteractive.org/programs/multisolving/

CLIMATE INTERACTIVE
Tools for a thriving future

To make a FLOWER diagram, answer these three questions:

1. ***Does the project protect the climate?*** If your project reduces GHGs in the atmosphere,color the center of the FLOWER **dark blue**.



2. ***Co-benefits?*** For each of the six petals, ask: does my project produce this benefit? If yes, **color the corresponding petal**. If not, leave the petal uncolored.

3. ***Who benefits?*** For each petal ask: who receives the benefit?

If **everyone benefits**, shade **evenly**.

If the project most benefits **marginalized groups,** shade the **outer edges more darkly.**

If those **already well off** gain most of the benefit, **shade the center** of the petal darker than the edges.

CLIMATE INTERACTIVE Tools for a thriving future

Student Manual Section 4:

Supplementary Materials from 2019 Student Manual

In this section we include selected information sheets, activity sheets, lab sheets and Stella Practice Models that can be used if additional activities are of interest. These resources are taken from the 2019 pilot curriculum that time did not permit including on the 2022 curriculum. Your teacher may ask you to complete some of these in your class for homework.

Supplementary Material Unit 1A: Information Sheet for What is a System?

"A system is an interconnected set of elements that is coherently organized in a way that achieves something." Donella Meadows, Systems Thinking Pioneer

Systems range in size and complexity, and can be natural (for example, forests and the solar system) or human-made (airports and schools). Consider the human body: cells combine to create tissues, which in turn make up organs, which comprise systems, such as the respiratory system, the circulatory system, the skeletal system, and so on. The body is therefore a complex system with multiple subsystems. When one part of a system changes, it affects other parts as well, and ultimately affects the stability and sustainability of the system.

Adapted from: Institute of Play

What makes up a system?

1. **Elements or Parts:** These are discrete pieces within the system. For example, a frame, pedals, handlebars, wheels, chain, brakes, fork, and a seat are pieces that put together make up a bicycle. Elements are the 'nouns' in your

system – people, places and things. In a social system, elements might include different organizations, programs, products, money, institutions, and – of course – citizens (clients, patients, activists, consumers, leaders, etc.).

2. Interconnections: These are the relationships that connect the elements (for example, food webs and predator-prey relationships in ecosystems). In thinking about interconnections, remember that the goal is not to exhaustively list every element in a system, but instead to understand and map the interconnections between them. Those relationships tell a story about what is happening in a system.

3. A Function or Purpose: Sometimes the purpose seems really obvious. The goal of school is to educate, or the purpose of human cells is to keep the body working well. In reality no single part of a system can achieve that purpose alone. The wheels of the bike turn and propel movement, but they don't do it without the other elements of the system. In human systems, each actor in a system may fundamentally hold a different idea or belief of exactly what that purpose is and how it should be accomplished.

4. Dynamics: Systems are constantly changing. These changes are called dynamics. Changes can be seen as good or bad depending on your view of the system. Back to the bicycle. Even an old bike left in a garage, given enough time will change. The tires will rot, the chain will dry up and the bike will be less functional than it was when it was placed there. Eventually it might rust so much that certain parts become unrecognizable. Now your bike won't rust away while you stand there eating a sandwich, but a systems thinker pays close attention to pattern and trends of change in a system.

Supplementary Material Unit 1B
Graphic Organizer Worksheet Sheet for "My System of Interest"

Choose a system of interest to you. Some ideas might include your family, your Upward Bound summer program, your faith community, your school, or a sports team. You may use words or small pictures to address these questions.

First enter a name you can use to identify the system__________________

Then identify key components that describe your system of interest---key elements, interconnections, goals, and dynamics.

1. Elements

2. Interconnections

3. Goals

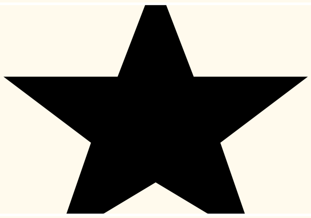
4. Dynamics

How do you connect or fit into to your system of interest?

How do you influence or impact your system?

Supplementary Material Unit 1C: Information Sheet for The Habits of a Systems Thinker

Supplementary Material Unit 1D:
Worksheet for Habits Sort



Habits I practice regularly

Habits I want to get better at

?

Habits I have questions about

Supplementary Material Unit 1E:
Worksheet for Habits of a System Thinker Matrix

	Strengths	Need Practice	Question
Big Picture			
Patterns & trends			
System structure			
Circular cause & effect			
Changes perspectives			
Surfaces & tests assumptions			
Mental models			
Short, long-term & unintended consequences			
Resists the urge to come to a quick conclusion			
Connections			
Accumulations & rates of change			
Time delays			
Leverage			
Successive approximation			

Supplementary Material Unit 1F:
Note Sheet for Green Careers and Habits of a Systems Thinker

What are 12 possible Careers with a focus on Green Jobs? (Include at least 6 of which involve –STEM (science, technology, engineering or math) or STEAM (science, tecnology, engineering, art, or math)

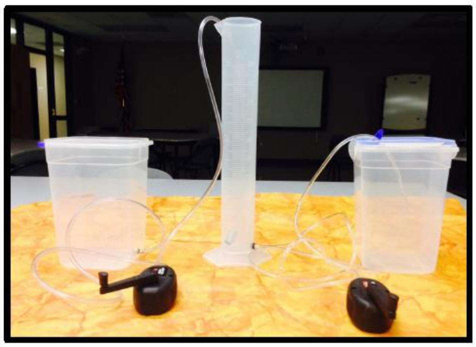
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.

Pick a career or job from the list that is of special interest to you.

What does your Google search reveal about the job that interests you and what is needed to do the job?

What habits of systems thinking does such a career or job involve?

Supplementary Material Unit 1G:
Lab Sheet for the Water Challenge This activity requires some equipment and set up ahead of time.

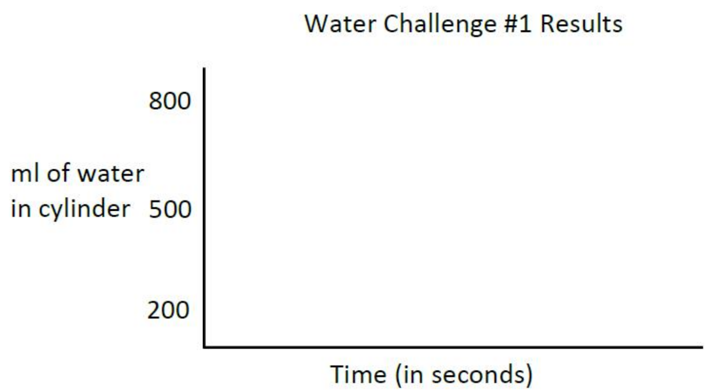


Water Challenges

For each challenge, start with all the *extra* water in the inflow "cloud." Before beginning, graph the goal (what the water should do over time). Then, graph what actually happens in a different color. After completing a challenge, continue with the next one. Feel free to repeat any challenge to improve results.

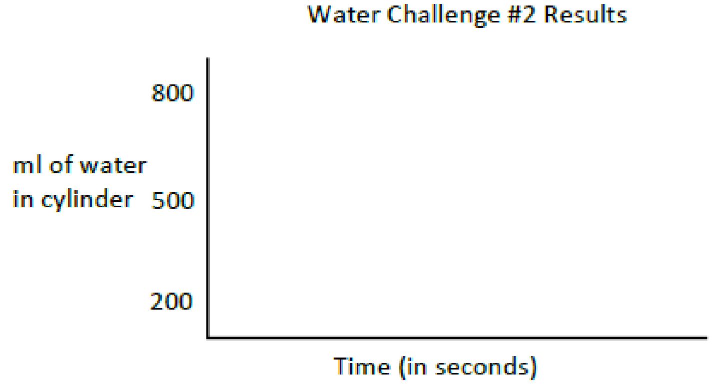
Challenge #1

Start with 200 ml of water in the cylinder, then raise the water from 200 ml to 800 ml while water is always going in and always going out.



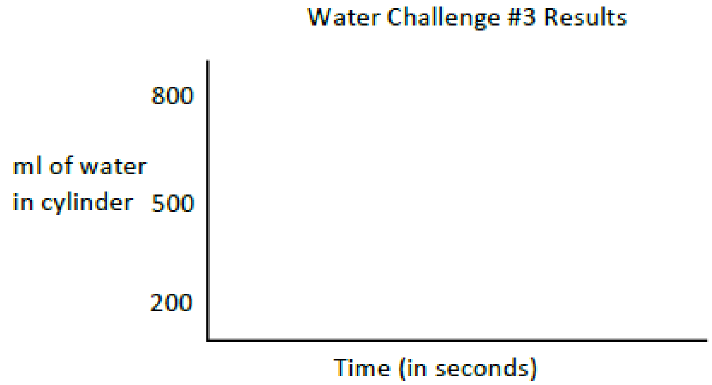
Challenge #2

Start with 800 ml of water in the cylinder, then lower the water from 800 to 200 ml, while water is always going in and always going out.



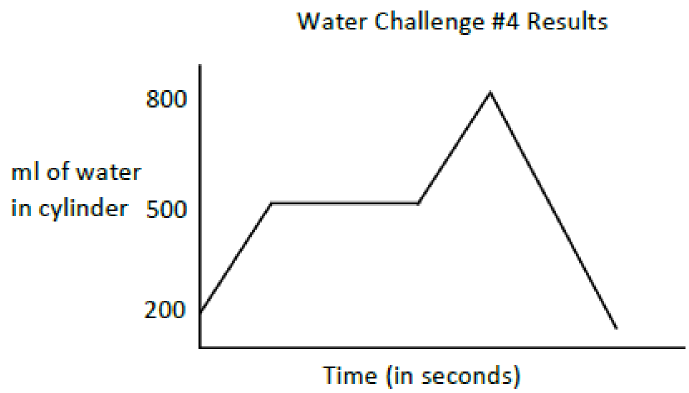
Challenge #3

Start with 500 ml of water in the cylinder, then keep the water at the 500 ml level for at least 30 seconds, while water is always going in and always going out.

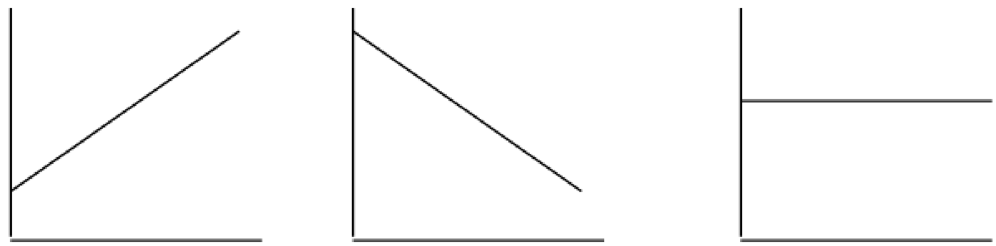


Challenge #4

Create the water level shown on the graph while water is always going in and always going out.



Reflection: Match the graph to the description.



A B C

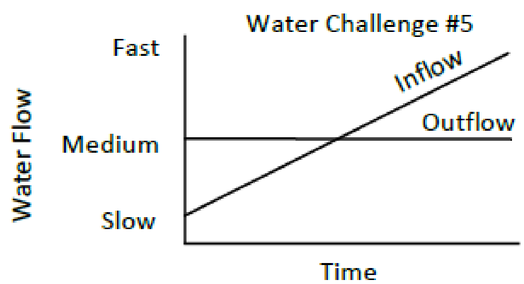
1. Inflow < Outflow
Graph ________ describes this situation because

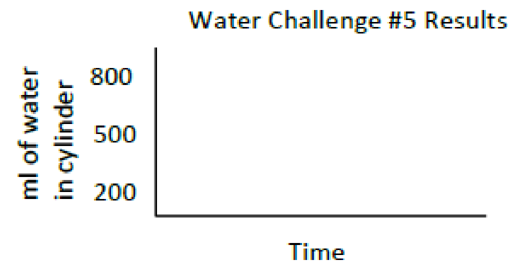
2. Inflow > Outflow
Graph ________ describes this situation because

3. Inflow = Outflow
Graph ________ describes this situation because

Challenge #5

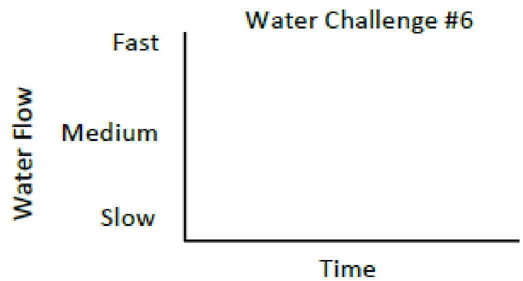
Start with 500 ml in the cylinder. Predict on the graph: What will happen if you adjust the inflow and outflow as shown? Notice the outflow stays the same while the inflow starts at slow and gets faster over time. Use the graph on the right to predict and then record what actually happens over time.

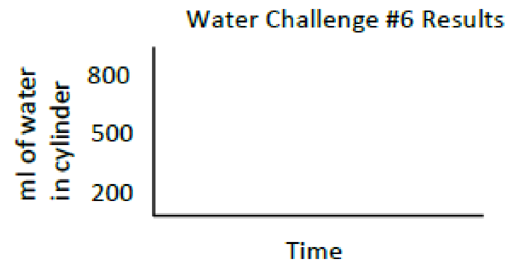




Challenge # 6: Create your own challenge

Create a challenge similar to #5 that graphs what you will do with the flows and predict what will happen to the stock. Make sure to label the inflow and outflow lines.





Reflection: Consider that the water in the cylinder is a stock and the water going in and out are flows. What else in your experience is similar to the stock of water? How do the flows work in that system?

Supplementary Material 1H
Guide Sheet for Drawing a Stock-Flow Map with Social Media Example

Social media is all about increasing followers. In this exercise you will use a stock-flow map to explore and communicate ideas about building followers on social media

Systems Thinkers establish system boundaries. To focus this stock-flow map identify one particular social media platform, e.g. Instagram, Twitter, You Tube or other platform of your choice.

1. On a large piece of paper draw this stock-flow map template. This will be the basis of your group's social media stock-flow map. You will add to it as you work through each item in this exercise.

2. Define your accumulation. Be specific Twitter has followers, You Tube has subscribers. Select the one that is most important to your specific platform. Ask: what elements of your chosen system can you see, feel, count or measure? Be sure everyone in your group has a shared understanding of your accumulation.

3. Label the stock with that specific accumulation on your stock-flow map.
Remember: A stock represents an amount that can increase or decrease over time.

4. Label the inflow, increasing and the outflow, decreasing

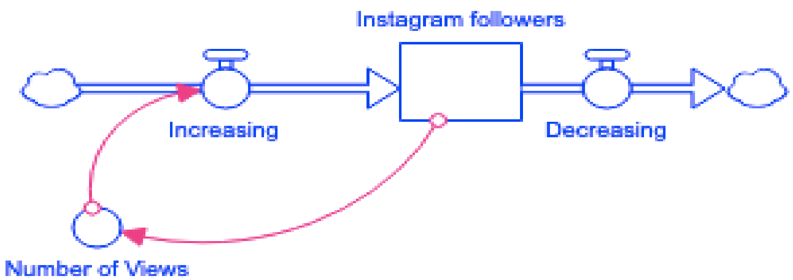
5. Create converters and connectors. What causes the stock to increase? What cause the stock to decrease? Here are some ideas to get you started: number of posts, quality of content, purchased followers, likes. Don't be limited by these ideas. Use

your team's experience with social media. Work to make the most direct connections you can. Ask: Does _______ directly impact _______ or is there something else that more directly connects to the variable. Use connector arrows to show causal connections between other parts of your map, e.g. a change in one convertor may cause a change in another convertor.

Keys for good convertors:

- Don't use qualifiers. Example, it is not more content or less content, simply content. Then decide whether the amount of content has more influence on how many people follow the page (increase) or if the content on the page causes people to unsubscribe, thus affecting the outflow.
- Avoid convertors that are opposites. Decide whether your convertor is more likely to impact how much is added to the stock (rate of inflow) or how much is subtracted from the stock (rate of outflow). Then place that convertor on the correct side. For example, it is not personal passion on the inflow side and lack of personal passion on the outflow side, but rather does personal passion more directly impact the rate of inflow or the rate of outflow.

6. Ask: If the stock changes, does that impact any other part of the map? If so, use a connector to show that causal relationship. This is a very important question. For example, if you identified number of views as a converter that impacts the inflow to the stock, and if you believe the number of followers (stock) impacts the number of views, you would draw a connector out of the stock to the converter, number of views. It would look like this:



Technical Hint: You can draw a connector from a stock, you cannot draw a connector into a stock.

7. Finding leverage: Based on your stock-flow map, what is an action you could take that would likely increase your stock of followers? List your group's answers to these on the bottom of your stock-flow map

8. Upload a photo of your completed stock-flow map.

Supplementary Material Unit 2A
Regional Worksheet for Developing Nations: Get to Know Your Region

Working with other members of your region, access or download C-ROADS World Climate at:

https://croadsworldclimate.climateinteractive.org

- Go to the "Simulation" menu option in the top left corner to make sure your model is set for the number of regions your class is using (6 regions versus 3 regions).
- You will be using the "Graphs" dropdown menu to access the data that will help you compare your region's characteristics to others. You will only need to focus on the graph on the top left-hand side of the page to answer the following questions.

Part A: Using C-ROADS to Understand Regional Contributions to Climate Change

1. Looking at the stacked display of **Historical Cumulative Emissions** (found under GHG Emissions tab) which regions over the *past 100 years* have contributed most to our current climate crisis? (You can drag your mouse over the graph to see each region's quantities.)

You will notice graphs that mention "per capita" after a variable that is being measured. Per capita means "per person" in your region. Working in per capita makes it easier to compare various regions, rather than attempting to understand total amounts within multiple contexts. Let's look at an example. If nothing changes now, which regions are projected to have the highest **Emissions Per Capita** (under the "Economics menu option) in the future?

Are these nations different from those who historically have emitted the most? How do your region and other regions compare to the global average?

2. Describe your region's **Population** (Under the "Economics" menu option) projections as they compare to the projections of other regions. Are there other regions that are similar to yours? Are there population projections which are vastly different?

How do you think population growth relates to climate change? How does population contribute to your region's carbon emissions? How might population affect your region's ability to respond to climate impacts?

3. What is Gross Domestic Product (GDP)? How do the projections of your **Region/Bloc's GDP Per Capita** compare to others' in the future? Are they higher? Are they lower?

Why do you think GDP Per Capita is important to consider in climate negotiations with other regions? From your region's perspective, who should contribute most to the Green Climate Fund?

Part B: Global Impacts

Working with other members of your region, access the Climate Impact Map from the Climate Impact Lab:

http://www.impactlab.org/map/#usmeas=absolute&usyear=19812010&gmeas=absolute&gyear=1986-2005&tab=global

- Be sure that your settings directly above the map are set to "Global Map."
- Above this setting, make sure you begin looking at the map with the "Historical 1986 – 2005" setting selected.
- Along the left-hand-side of the map, you have the option to view the map in degrees Fahrenheit (Imperial System the US uses) or degrees Celsius (Metric System.)

This map displays the average June, July, and August temperatures across the globe. Increasing global average temperatures have varying levels of impacts on average regional temperature, depending on where your region is located on the globe. Those regions who rely on rain-fed agriculture are particularly at risk, if drought leads to crop failure and food insecurity. Food security aside, extreme temperatures also cause heat stress, which has the potential to lead to death.

One at a time, select the settings "Next 20 Years," "Mid-Century" and "End of Century" to view the projections for extreme heat in each region if the globe continues to emit at its current rate.

Which regions of the globe will be most impacted by extreme heat?

Part C: What Role Does Your Region Play?

Reflect on the information you gathered above. Which regions do you feel are most vulnerable to the impacts of climate change? Which regions do you feel have the greatest responsibility for greenhouse gases that have already accumulated in the atmosphere? Support your answer with evidence from the C-ROADS and Impact Map projections data.

Part D: Sea Level Rise in Your Region

One impact of climate change is the rise of sea levels, due to both melting ice from glaciers and ice sheets, as well as from heating ocean temperatures which causes “thermal expansion.” Select a city below that resides within your region.

China: Shanghai

United States: New York

European Union: London, UK

Other Developed: Nagoya, Japan

India: Mumbai

Other Developing Nations: Hanoi, Vietnam

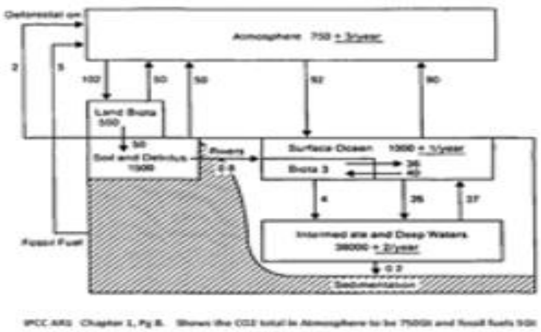
Compare the two maps on the left and right. The map on the left shows how high the ocean would rise if we do not take action to lower our CO_2 emissions. The map on the right shows sea level rise if we do cut our emissions. What are the differences between the two?

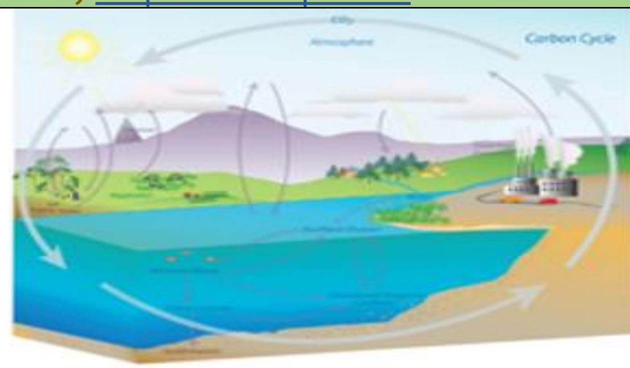
What does sea level rise mean for the people who reside in your city? For your city’s transportation system, including the transport of food? For your city’s businesses and financial situation? What would sea level rise mean for hazardous waste sites close to the coast?

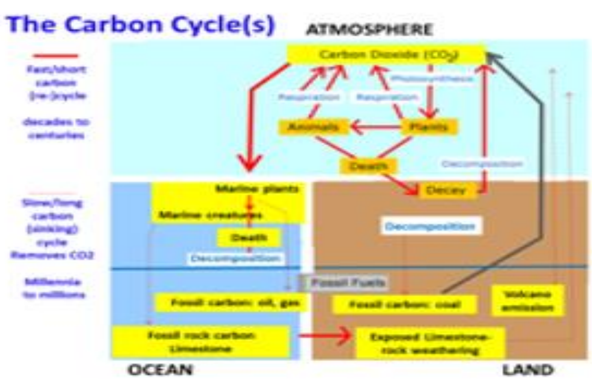
Written by Ginger Wallis and Juliette Rooney-Varga
More resources available at climate-change-initiative.org/world-climate-classrooms

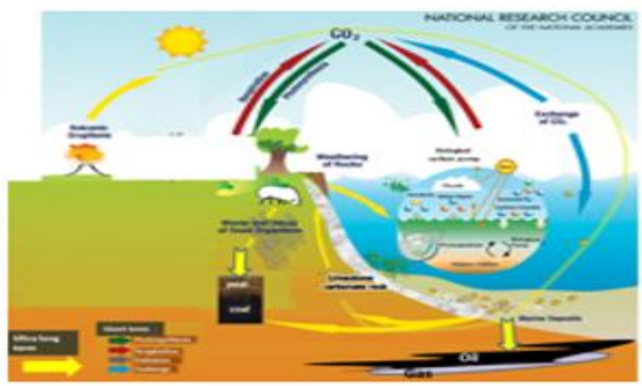
Supplementary Material Unit 3A
Images of Different Carbon Cycle Models

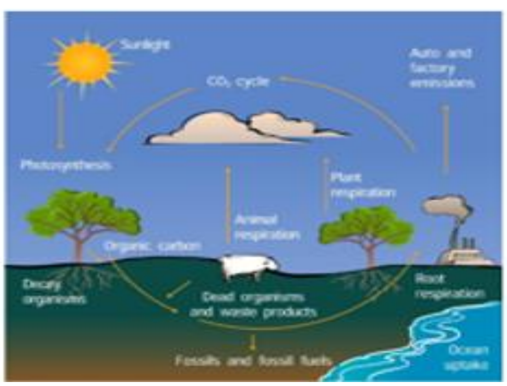
From public use websites such as NASA's Earth Observing Site https://www.earthobservatory.nasa.gov/features/CarbonCycle and U.N.'s Intergovernmental Panel on Climate Change (IPCC) https://www.ipcc.ch/

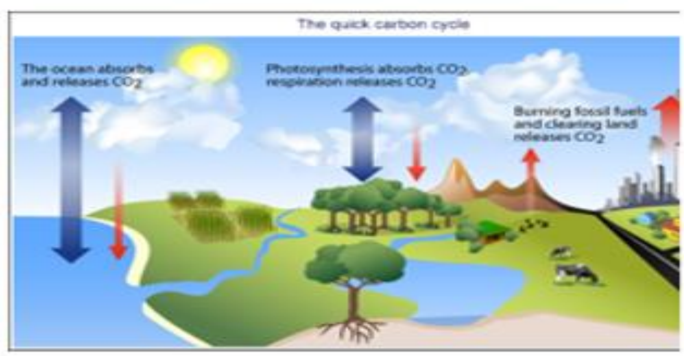












Supplementary Material Unit 3B

What Do We Mean by Empathetic Inquiry as a Part of Systems Modeling?

One of the key developers of Stella Systems modeling (Barry Richmond) referred to systems modeling as "empathetic inquiry"? He wrote "*Being able to empathize is a skill that can be developed—and is in some ways, the ultimate Systems Thinking skill because it leads to extending the boundary of true caring beyond self (a skill almost everyone could use more of).*"

Empathy is defined as the capacity to understand or feel what another person or being is experiencing from within their frame of reference, that is, the capacity to place oneself in another's position.

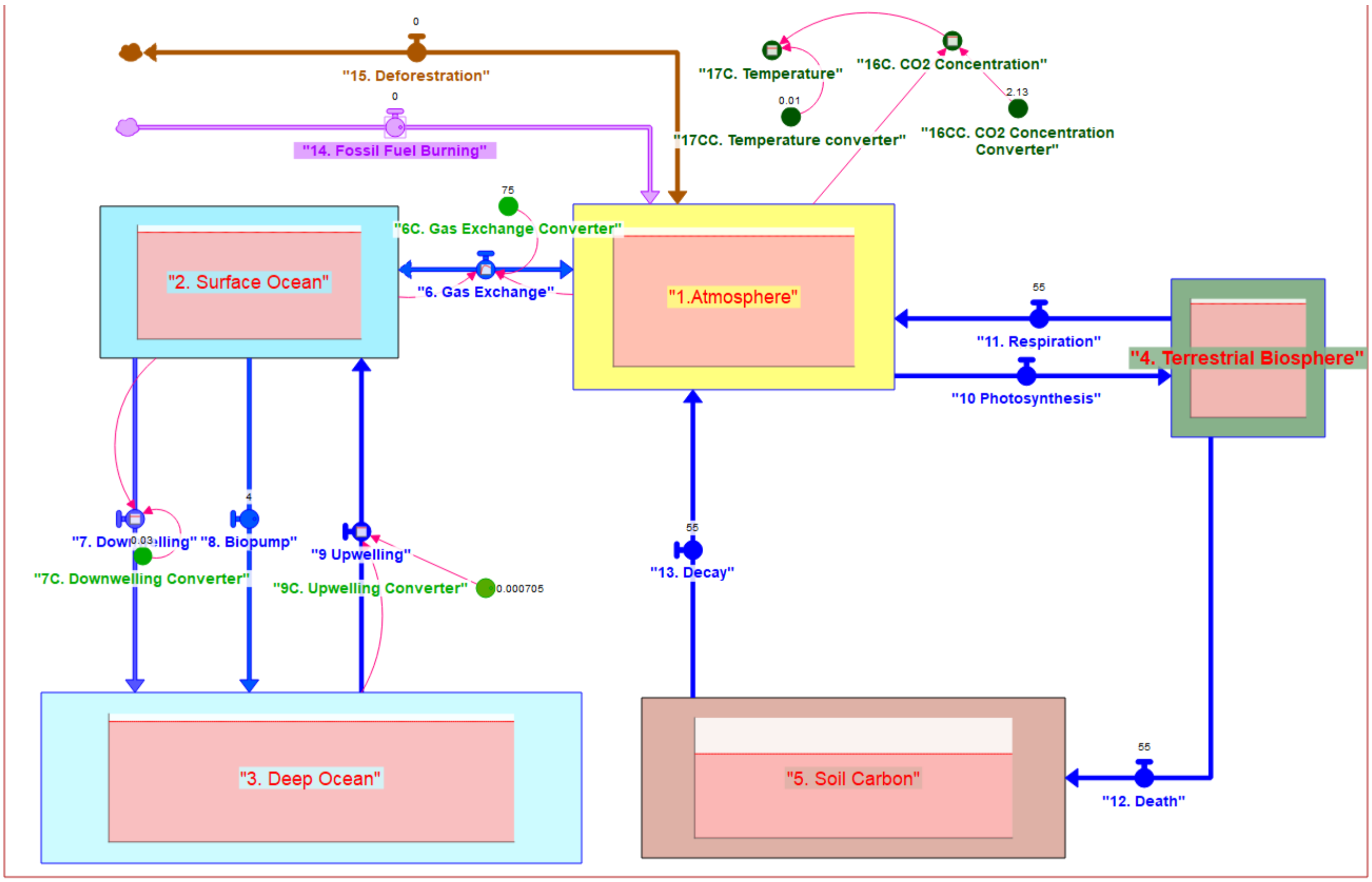
General systems theory thinker, Joanna Macy, known for her "*Work that Reconnects*" and the "*Council of all Beings*" has said: "*The central purpose of the "Work that Reconnects" is to help people uncover and experience their innate connections with each other and with the systemic, self-healing powers of the web of life, so that they may be enlivened and motivated to play their part in creating a sustainable civilization*

Richmond Barry, (1992). *An Introduction to Systems Thinking: Ithink Software*. With Steve Peterson and Chris Charyk. High Performance Systems; (2000). *The "thinking" in systems thinking: Seven Essential Skills*. Pegasus Communications. ISBN 1-883\823-48-X

Joanna Macy https://workthatreconnects.org/about-joanna-macy/ https://workthatreconnects.org/

http://www.rainforestinfo.org.au/deep-eco/coab.htm

Supplementary Material Unit 3C
A Stella Model for An Empathetic Carbon Cycle Role Play



This Stella model that is keyed to the Role Play can be accessed at:
https://www.dropbox.com/s/hs2uw6riuamt9k3/May28Preload3-2%263Carbon%20Cycle.stmx?dl=0

Additional Resources on the carbon cycle are at:
https://www.earthobservatory.nasa.gov/features/CarbonCycle
https://climatekids.nasa.gov/nasa-research/

Supplementary Material Unit 3D
Carbon Cycle Role Play: Lab Role Play Introduction
Carbon Cycle Model

These Lab Guide Sheets provide the "scripts" for the Carbon Cycle Model Role Play. The Stella Model Script identifies each element in the model and gives the associated Stella equations. Through the role play in which you will represent one or more of the Carbon Model elements, you will gain a deeper understanding of the earth's climate system. Through reviewing the model components together with your classmates, you will also have an opportunity to gain a greater understanding of how Stella works. You will learn how to define variables so they can be used in the simulation models.

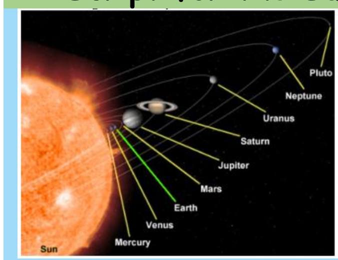
For this Role Play there are at least 19 Very Important Parts to be played and each participant can be assigned one or more roles. These are:

- Sun (B-1) and Carbon (B-2) (background roles not in model per se)
- There are 5 Stocks in the preload model (1-5)
- There are 9 Flows (6 to 15) 3 of which have attached Converters
- There are additional Converters (16 to 17) to specify conversion of Atmospheric Carbon to CO_2 Concentration and Temperature in Celsius. These take information in the Atmosphere stock and convert it to CO_2 and to Temperature—two elements of special interest.

Supplementary Unit 3E Background Role Play Scripts for Our Sun and Carbon

This sheet provides background information for the Carbon Cycle Model and has at least two additional roles to be assigned (Sun and Carbon). For the Sun more than one person may need to be assigned

Script for the Sun



A Very Good Day to you all, I'm ______. To provide background for the dive into the Carbon Cycle I (or "We" if more than 1 person) will represent the Sun today. Located 93 million miles away, the sun is the source of all energy on Earth. The relationships modeled in the carbon cycle reflect the characteristics of the sun and the earth's relationship to the sun, based on its nearness to the sun and the tilt of its orbit. The earth's climate system has evolved over eons to a relative equilibrium in such a manner that makes it ideal for the life forms currently found on Earth. As conditions change in the capacity of the Earth to absorb and emit carbon into the atmosphere, the Earth's climate system, will change and seek a new equilibrium that will not be as ideal for current life forms.

Scientists calculate the total amount of energy I radiate to the Earth, by measuring the quantity of solar energy per second reaching every square meter of Earth and then multiplying that by the total surface area of a sphere with radius equal to the radius of Earth's orbit. *Based on these measures I give the Earth a huge amount of energy.* In one second, I produce enough energy for almost 500,000 years of the current needs of Earth's so-called civilization. This means I continuously pelt the earth with 35,000 times the amount of energy required by all those on earth who now use electricity on the planet!

The key is finding how to harness my energy on Earth. The good news is that the Earth Engineers and Scientists have been doing their jobs. There is actually the capacity to harness some of the energy that I radiate each day to generate enough energy to power the needs Earth has with existing Earth known technology. For example, Earth Scientists have estimated that concentrated solar would take only as much as the square on the US map to provide all U.S. energy needs. https://www.solarpowerrocks.com/solar-politics/how-far-could-68b-go-in-securing-our-energy-independence-pretty-damn-far/

The question is more do the citizens of Earth have the will to take advantage of the daily energy that I provide each day.

Role Play Background Information for Carbon

Carbon: Hello, I'm ______and I'm representing the Carbon today. I was forged in the heart of aging stars, and I am the fourth most abundant element in the Universe. On Earth, I'm mostly stored in rocks, about 65,500 billion metric tons. I'm also in the ocean, atmosphere, plants, soil, and fossil fuels. I am an essential part of life on Earth. I comprise about half the dry weight of most living organisms. I play an important role in the structure, biochemistry, and nutrition of all living cells. Living biomass holds about 550 gigatons of me (carbon), most of which is made of terrestrial plants (wood), while some 1,200 gigatons of carbon are stored in the terrestrial biosphere as dead biomass.

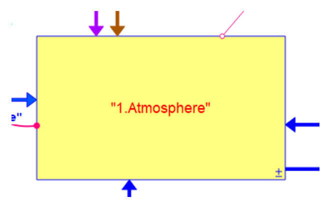
I flow between each reservoir (stock) in an exchange called the Carbon Cycle, which has slow and fast components. Any change in "My Cycle" that shifts me out of one reservoir (stock) puts more of me into the other reservoirs. Changes that put more of me in my gas form into the atmosphere result in warmer temperatures on Earth.

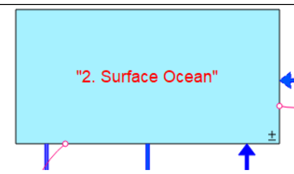
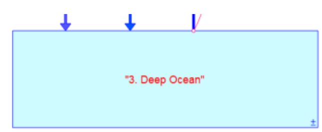
https://www.earthobservatory.nasa.gov/features/CarbonCycle
https://climatekids.nasa.gov/nasa-research/

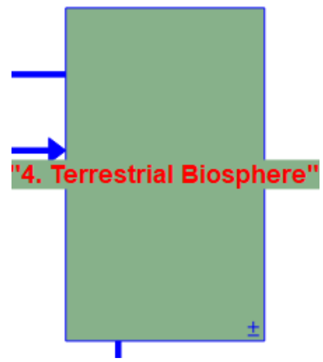
Supplementary Material Unit 3F
Role Play Script and Stella Drawing Directions
Carbon Cycle Model

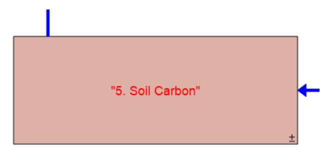
Note in this model we are using Gt Carbon. Remember that 1 Gt carbon = 3.66 Gt. CO_2.

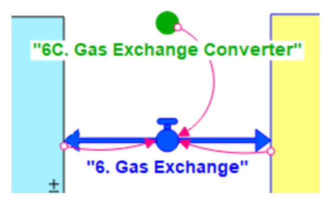
There are 5 Stocks in the Carbon Model. These are presented first and they are numbered 1 to 5. The Stocks are represented by the color "Red"

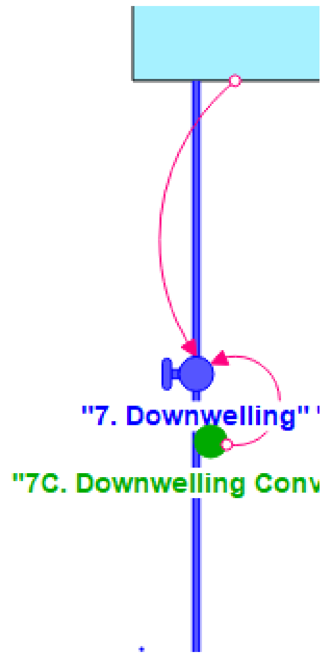
1. **Hello, I'm _____ and I represent the Stock, Atmosphere, in this Carbon Cycle Model. I am** a layer or a set of layers of gases surrounding a planet or other material body. I'm held in place by the gravity of that body. On Earth, I am composed of nitrogen (about 78%), oxygen (about 21%), argon (about 0.9%), carbon dioxide (0.04%) and other gases in trace amounts. Without this particular composition on Earth there could not be the life on Earth as it has evolved over eons. I help to protect living organisms from genetic damage by solar ultraviolet radiation, solar wind and cosmic rays. My current composition on earth is the product of billions of years of biochemical modification of the paleo-atmosphere by living organisms. In this model I'm initially set at 750 Gt.	**1.Atmosphere** **= 750** **Units: Gt** 
2. **Surface Ocean: Hello, I'm _______and I represent the Stock, (or reservoir), of the Surface Ocean.** My circulation is driven primarily by surface winds. Winds blow from areas of high atmospheric pressure to regions of low atmospheric pressure and this causes me to	**2. Surface Ocean** **= 750** **Unit: Gt**

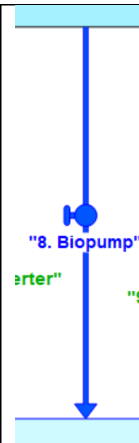
change. These winds are generally transferring heat from areas where there is excess incoming radiation (the tropics and subtropics) to temperate and higher latitude regions where there is a net loss of heat. My low or high pressure situation differs depending on location. The distribution of pressure on the Earth's ocean surface is zonal or meridional, with high-pressure bands covering the subtropics and polar-regions and low-pressure bands, the equatorial regions, and subpolar regions. In this model I'm initially set at 750 Gt. https://www.e-education.psu.edu/earth103/node/684	
3. **Deep Ocean: Hello, I'm ______ and I represent the Stock, (or reservoir), of the Deep Ocean.** In the oceanic carbon cycle (or marine carbon cycle) I am composed of processes that exchange carbon between various pools within the ocean as well as between the atmosphere, Earth interior, and the seafloor. The total active pool of carbon in the Earth's surface for durations of less than 10,000 years is roughly 40,000 gigatons C (Gt C, a gigaton is one billion tons, or the weight of approximately 6 million blue whales). About 95% (~38,000 Gt C) of this Carbon stored in me (Deep Ocean), mostly as dissolved inorganic carbon. The speciation of dissolved inorganic carbon in the marine carbon cycle is primary controller of acid-base chemistry in the oceans.	**3.Deep Ocean** **= 37,600** **Unit = Gt** 

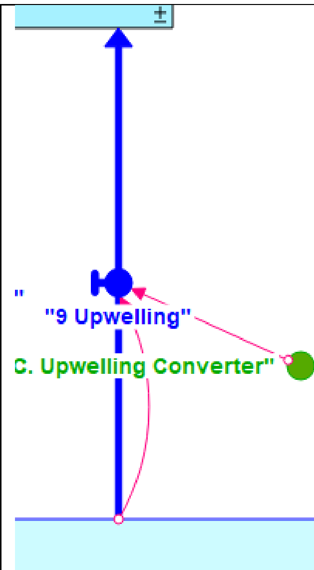
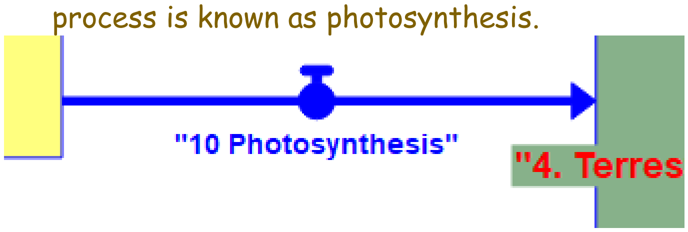
In this model I'm initially set at 37,600 Gt.	
4. **Hello, I'm _________and I represent the Stock, (or reservoir), of the Terrestrial Biosphere. I am** part of the Earth system comprising all ecosystems and living organisms on land including derived dead organic matter such as litter, soil organic matter Carbon is cycled through me (the terrestrial biosphere) with varying speeds, depending on what form it is stored in and under which circumstances. It is exchanged most quickly with the atmosphere, although small amounts of carbon leave the terrestrial biosphere and enter the oceans as dissolved organic carbon (DOC). Most carbon in me (the terrestrial biosphere) is stored in my forests. My forests hold 86% of the planet's terrestrial above-ground carbon and my forest soils also hold 73% of the planet's soil carbon. Carbon stored inside plants can be transferred into other organisms during plant consumption. When animals eat plants, for example, the organic carbon stored in the plants is converted into other forms and utilized inside the animals. The same is true for bacteria and other heterotrophs. Dead plant material in or above soils remains there for some time before being respired by heterotrophs. Thus carbon is transferred in every step of the food chain from one organism to another. In this model I'm initially set at 575 Gt.	**4.Terrestrial_ Biosphere** **= 575** **Unit: Gt** 

https://en.wikipedia.org/wiki/Terrestrial_biological_carbon_cycle	
5. **Soil Carbon: Hello, I'm ______and I represent the Stock, (or reservoir), of Soil Carbon. Representing soil, I am a very important part of the Carbon Cycle.** World-wide I hold around twice the amount of carbon that is found in the atmosphere and in vegetation. Organic material is manufactured by plants using carbon dioxide from the air and water. Plants (and animals, as part of the food chain), die and return to me (the soil) where they are decomposed and recycled. Minerals are released into the soil and carbon dioxide is released into the atmosphere. In this model I'm initially set at 1400 Gt. https://www.e-education.psu.edu/earth103/node/684	**5. Soil Carbon** **= 1400** **Unit: Gt** 
Flows Role Scripts with Converters and Connecters **Units: Gt/yr. There are 9 flows in the Carbon Cycle drama 3 of which have Converters to determine their flow rate. These are numbered 6 to 15. Flows are in blue and their Converters are in Green**	
Flows Element Script Definitions and Directions	**Flows Names and Equations**

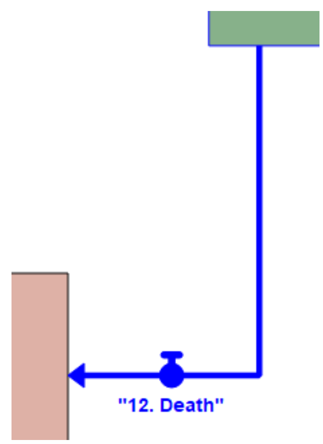
6. Gas Exchange: **Hello, I'm ______and I represent the Flow, (or flux), of the Gas Exchange. I am a biflow meaning I flow two ways. I represent an exchange between the atmosphere and the ocean.** Gas Exchange between the atmosphere and the oceans removes carbon dioxide and sequesters some of it for long periods of time in the deep sea. My Gas Exchange Bi-flow rate is determined by the values of the Surface Ocean- Atmosphere divided by the Gas Exchange Converter. To draw me in Stella choose "Biflow" option from the Flow Menu and draw a Biflow between 2. Surface Ocean and 1.Atmosphere. Now draw Connectors between me 6. Gas Exchange, and each of the Stocks 2. Surface Ocean and 1. Atmosphere. I have a Converter named 6C. Gas Exchange Converter. This is connected to me. I'm defined in the model equation as follows 6. Gas Exchange = (2.Surface Ocean- 1.Atmosphere)/6C. Gas Exchange Converter The 6C. Gas Exchange Converter = 75 Units: Gt/year	**6. Gas Exchange** **=** **(2. Surface Ocean-** **1.Atmosphere)/** **6C. Gas Exchange** **Converter** **6C. Gas Exchange Converter** **= 75** **Units: Gt/year** 
7. **Downwelling: Hello, I'm ______and I represent the Flow, (or flux), of Downwelling.** I'm the process of accumulation and sinking of higher density material beneath lower density material, such as cold or saline water beneath warmer or	**7. Downwelling =**

fresher water or cold air beneath warm air. In the carbon cycle model I (Downwelling) am a Flow whose rate is determined by the value of the Stock, 2.Surface Ocean, times the value of the 7C.Downwelling Converter. *Draw me 7. Downwelling coming from the Stock, 2. Surface_Ocean. I have a* Connector from 2. Surface Ocean to 7. Downwelling. I also have a Converter, called 7C. Downwelling Converter, and a Connecter from 7C. Downwelling Converter to 7.Downwelling. The rate of my 7.Downwelling Converter is set at .03 Gt/yr	**2.Surface_Ocean *** **7C.Downwelling** **Converter** **7C. Downwelling** **Converter** **= .03** **Units: Gt/year** 
8. **Biopump: Hello, I'm _______and I represent the Flow, (or flux), of Biopump.** I'm a biological pump that in my simplest form, is the ocean's biologically driven sequestration of carbon from the atmosphere to the ocean interior and seafloor sediments. I'm a part of the oceanic carbon cycle responsible for the cycling of organic matter formed mainly by	**8.Biopump** **= 4** **Units: Gt/year**

phytoplankton during photosynthesis (soft-tissue pump), as well as the cycling of calcium carbonate ($CaCO_3$) formed into shells by certain organisms such as plankton and mollusks(carbonate pump). ***To represent my Flow,* 8.Biopump,** *draw a one-way Flow from the Stock,* ***2.Surface Ocean*** ***to the*** ***3.Deep Ocean.*** ***Notice that for my Flow, Biopump, a Converter is not used as Biopump is defined here by a simple number.*** **I'm defined in the Stella model equation as follows** 8.Biopump **= 4 Units: Gt/year**	
9. **Upwelling: Hello, I'm ______and I represent the Flow, (or flux), of Upwelling. I'm involved in massive movements of water in which carbon is carried.** The deep ocean floor looks placid and undisturbed by movement, except for the occasional bottom-dwelling creatures. But, behind the calm, there are massive movements of water. And in that water, carbon is carried. Through deep sea currents dissolved carbon is transferred around the globe. My upwelling process journey can take hundreds of years, until the carbon reaches certain parts of the polar and equatorial regions. **To represent me, Upwelling, in our Carbon Cycle Model, draw a one-way Flow from the Stock, 3.Deep Ocean to the Stock, 2.Surface Ocean.** The amount of my Flow, **Upwelling, is determined by the Stock 3.Deep Ocean times the 9C.Upwelling**	9.Upwelling = 3.Deep_Ocean * 9C.Upwelling Converter 9C.Upwelling Converter = .0007048 Units: Gt/year

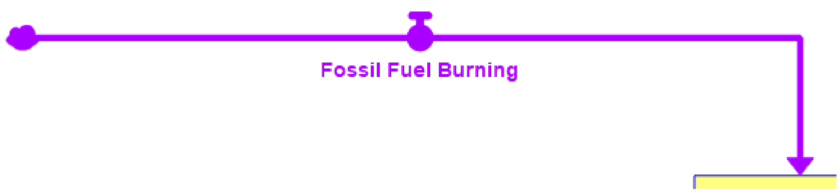
Converter. To represent this relationship there is a Connector from 3.Deep_Ocean to 9.Upwelling. There is also a Converter named 9C.Upwelling_Converter. There is a Connecter from 9C.Upwelling Converter to 9.Upwelling. My, Upwelling, equation is thus 9.Upwelling = 3.Deep_Ocean * 9C.Upwelling Converter The 9C.Upwelling Converter is set at a rate of = .0007048 Units: Gt/year	
10. Photosynthesis: **Hello, I'm ______and I represent the Flow, (or flux), of Photosynthesis.** Plants and photosynthetic algae and bacteria use energy from sunlight to combine carbon dioxide (CO_2) from the atmosphere with water (H_2O) to form carbohydrates. These carbohydrates store energy. Oxygen (O_2) is a byproduct that is released into the atmosphere. This process is known as photosynthesis. 	10.Photosynthesis = 110 Units: Gt/year 

Without my process of ***Photosynthesis*** *humans could not live as we need Oxygen to breath.* ***To represent my Flow,*** **Photosynthesis,** ***there is a one-way*** **Flow** ***coming from the Stock,*** *1.****Atmosphere and going to the Stock*** **4.Terrestrial Biosphere.** ***Notice in this model, my Flow,*** **10.Photosynthesis,** ***does not use a Converter as it is defined by a simple number.*** **My Flow, Photosynthesis, is defined in the Stella equation as follows:** **10.Photosynthesis = 110 Units: Gt/year**	
11. **Respiration: Hello, I'm ______and I represent the Flow, (or flux), of Respiration.** My process involves organisms exchanging gases, especially oxygen and carbon dioxide, with the environment. In air-breathing vertebrates, **respiration** takes place in the lungs. I'm intimately linked to photosynthesis. Cellular respiration releases carbon dioxide into the environment, photosynthesis pulls carbon dioxide out of the atmosphere. Carbon is released to the atmosphere through the burning of fossil fuels, organic respiration, wood burning, and volcanic eruptions. The uptake of carbon from the atmosphere occurs through carbon dissolution into the oceans, Photosynthesis, and the consequent storing of carbon in various forms such as peat bogs, oil, materials, accumulation, and formation of minerals, such as coal and copper. It also happens when carbohydrates are changed into carbon dioxide.	**11.Respiration** **= 55** **Units: Gt/year** 

To represent my Flow, Respiration, draw a one-way flow coming from the Stock, 4.Terrestrial Biosphere and going to the Stock 1.Atmosphere. *Notice in this model, my Flow, Respiration, does not use a Converter as it is defined by a simple number.* My Flow, *Respiration*, is defined in the Stella equation as follows: 11.Respiration = 55 Units: Gt/year	
12. Death (Burial): Hello, I'm ______and I represent the Flow, (or flux), of Death. I'm related to but not the same as the word "Death" that will involve us all. Organic carbon burial is an input of energy for underground biological environments and can regulate oxygen in the atmosphere at long time-scales (> 10,000 years). Burial can only take place if organic carbon arrives to the sea floor, making continental shelves and coastal margins the main storage of organic carbon from terrestrial and oceanic primary production. Fjords, or cliffs created by glacial erosion, have also been identified as areas of significant carbon burial, with rates one hundred times greater than the ocean average. Particulate organic carbon is buried in oceanic sediments, creating a pathway between a rapidly available carbon pool in the ocean to its storage for geological timescales. Once carbon is sequestered in the seafloor, it is considered blue carbon. Burial rates can be calculated as the difference between the rate at which organic matter sinks and the rate at which it decomposes.	12.Death = 55 Unit: Gt/year 

To represent my Flow, Death, draw a one-way flow *coming from the Stock,* ***4.Terrestrial Biosphere*** *and going to the Stock* 5.Soil Carbon *Notice in this model, my Flow,* Death, ***does not use a*** *Converter* ***as it is defined by a simple number.*** My Flow, Death, is defined in the Stella equation as follows: 12.Death = 55 Unit: Gt/year	
13. Decay: Hello, I'm ______and I represent the Flow, (or flux), of Decay. Particles of organic carbon (POC) are decomposed by a series of microbe-driven processes. My processes occur before Death or burial. Degradation of POC also results in microbial methane production which is the main gas hydrate on the continental margins. ***To represent my Flow,*** Decay, there is a one-way Flow *coming from the Stock,* 5.Soil Carbon *and going to the Stock* ***1.Atmosphere. Notice in this model, my Flow,*** Decay, ***does not use a*** *Converter* ***as it is defined by a simple number.*** My Flow, Decay, is defined in the Stella equation as follows: 13.Decay = 55 Unit: Gt/year	13. Decay = 55 Unit: Gt/year 

14. **Fossil Fuel Burning: Hello, I'm _______and I represent the Flow, (or flux), of Fossil Fuel Burning.** I consist of fuels formed by natural processes such as anaerobic decomposition of buried dead organisms. I am very old. The age of the organisms from which I am formed is typically millions of years, and sometimes exceeds 650 million years. As such I contain high percentages of carbon and include coal, petroleum and natural gas. My burning by humans is the largest source of emissions of carbon dioxide, which is one of the greenhouse gases that allows radiative forcing and contributes to global warming.



To represent my Flow, Fossil Fuel Burning, there is a one-way flow coming from the Cloud and going to the Stock 1.Atmosphere . Notice in this model, I do not use, a Converter as in this model I am defined by a simple number. We could use a Converter to tell Stella to do something more complex for me related to change over time, but you are going to change me by hand.

I am defined at the start of this model as 0 as it was in pre-industrial times when I was largely left in the ground. When I am set to 0 in the Stella model the atmosphere of the Earth is in a state of "equilibrium." Set me to different levels and run for various lengths of time, 50, 100, 200 years and see what happens.

The starting Stella equation as follows:

14. Fossil Fuel Burning

= 0

Once the role play introductions are complete, set and differing rates over time to see differences made by various rates of burning over time.

0—pre-industrial

5---1990's

8---Closer to today

Unit: Gt/year

Start me at "0" which can be thought of as "pre-industrial" times.

Next set me to "5" which is about what it was in 1991.

Fossil Fuel Burning = 0	**Next try me at "8" which is closer to the levels of today.** **Observe and record what happens to the Atmosphere,** **CO_2 concentration and Temperature**
15. **Deforestation: Hello, I'm ______and I represent the Flow, (or flux), of Deforestation. In deforestation I am cut down and my forest** trees removed from land which is then converted to a non-forest use. Deforestation can involve conversion of forest land to farms, ranches or urban use. About 31% of Earth's land surface is covered by forests. Deforestation can occur for several reasons: trees can be cut down to be used for building or sold as fuel (sometimes in the form of charcoal or timber), while much cleared land is used as pasture for livestock and plantation. The removal of trees without sufficient reforestration has resulted in habitat damage, biodiversity loss, and aridity. It has adverse impacts on biosequestration of atmospheric carbon dioxide. When land is deforested and my forest trees cut down typically there are serious consequences. There are significant adverse soil erosion and frequently the land degrades into wasteland. Disregard of ascribed value, lax forest management, and deficient environmental laws are some of the factors that lead to large-scale deforestation. Deforestation causes extinction, changes to climatic	**15. Deforestation** **= 0 pre-industrial time** Differing Numbers can be set and differing rates over time to see differences made by various rates of Deforestation over time. **0** **2** **4** **Unit: Gt/year**

conditions, desertification, and displacement of populations, as observed by current conditions and in the past through the fossil record.

The current most concentrated deforestation occurs in tropical rainforests. More than half of all plant and land animal species in the world live in tropical forests. Between 2000 and 2012, 2.3 million square kilometres (890,000 sq mi) of forests around the world were cut down. As a result of deforestation, only 6.2 million square kilometres (2.4 million square miles) remain of the original 16 million square kilometres (6 million square miles) of tropical rainforest that formerly covered the Earth. An area the size of a football field is cleared from the Amazon rainforest every minute, with 136 million acres (55 million hectares) of rainforest cleared for animal agriculture overall.

To represent my Flow, Deforestation, draw a one-way flow coming from the Cloud and going to the Stock 1.Atmosphere Notice in this model, my Flow, Deforestation: is defined by a simple number and does not use a converter. **My Flow, Deforestation, is defined at the start of this model as 0. The model when Deforestation is set to 0 represents pre-industrial times before the great forests of the temperate regions had been cut down. We will set it to different levels (0, 2, 4) and observe the impact over various lengths of time, 50, 100, 200 years.**

The starting Stella equation as follows:

15. Deforestation = 0 Unit: Gt/year

Converters for CO_2 Concentration and Temperature	
Additional Converters Glossary Definitions and Directions	Names and Equations

16. CO_2 Concentration: **Hello, I'm ______and I represent a Converter to convert Carbon in Gt. to CO_2 Concentration and to parts per million (ppm).** You have also seen CO_2 concentration expressed in parts per million (ppm) or parts per million by volume (ppmv). Each 1 ppmv (part per million by volume) of the atmosphere weighs approximately 2.1357 Gt. of CO_2

My concentrations are greatly rising mostly because of the fossil fuels that people are burning for energy. Fossil fuels like coal and oil contain carbon that plants pulled out of the atmosphere through photosynthesis over the span of many millions of years; we are returning that carbon to the atmosphere in just a few hundred years.

In fact, the last time I was as high as I am now was more than 3 million years ago, when temperature was 2°–3°C (3.6°–5.4°F) higher than during the pre-industrial era, and sea level was 15–25 meters (50–80 feet) higher than today.

The element 16.CO_2 Concentration is itself a Converter and here there are two Converters connected together. The first is 16.CO_2 Concentration **coming out from and connected to the Stock, 1.Atmosphere. The second is the 16C. CO_2 Concentration Converter. There is a Connecter between 16.CO_2 Concentration and 16C.CO_2**

16.CO_2 Concentration

=

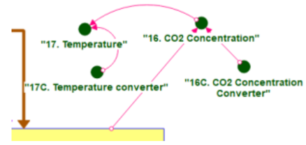
1.Atmosphere/ 6C.CO_2 Concentration Converter

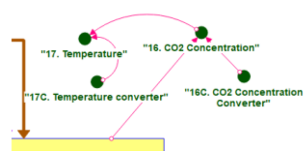
16C.CO_2 Concentration Converter

=

2.13

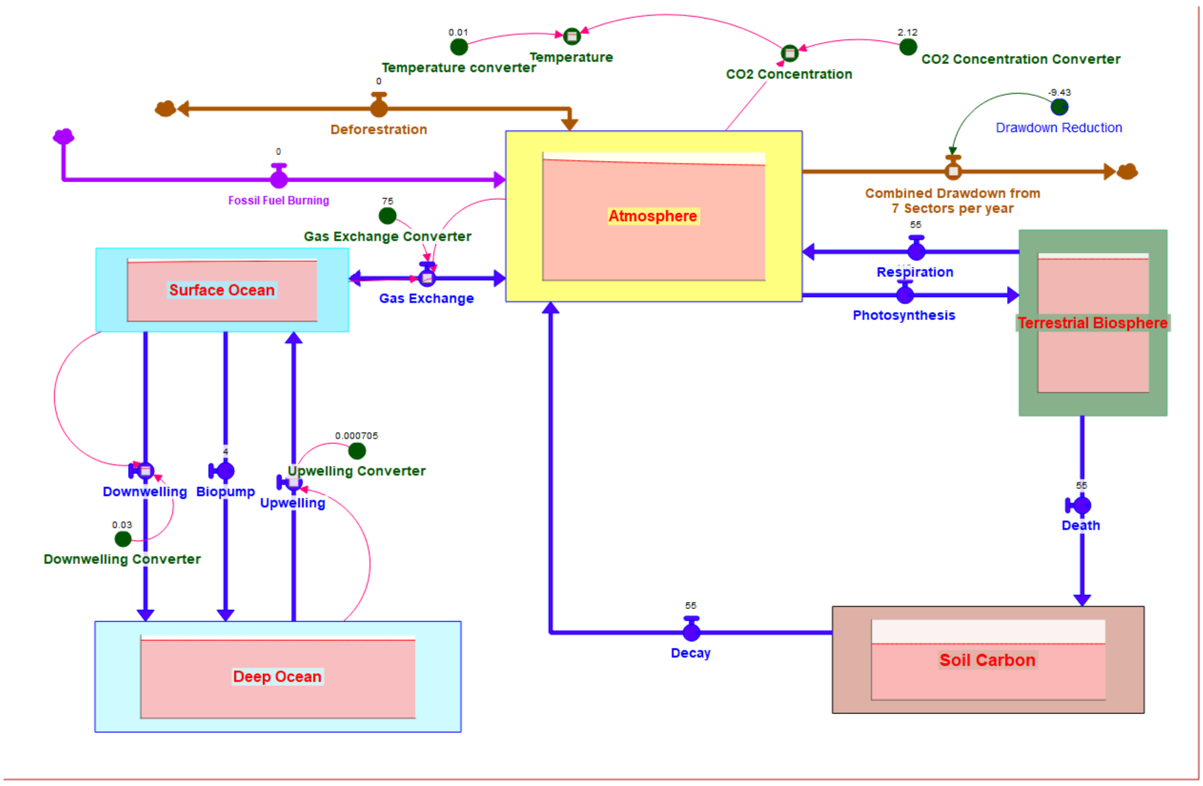
Units: ppmv



Concentration Converter. 16.CO_2 Concentration is in turn connected to the 17.Temperature	
17. **Temperature: Hello, I'm ______and I represent a Converter of CO_2 Concentration to Temperature in Celsius.** Global temperature is calculated by tracking thousands of readings from around the world, year after year, and distilling them down to a single number, which is now about 59 degrees Fahrenheit or 14 degrees C . It takes a lot to change me because of feedback seemingly small changes can have big impacts. Given the size and tremendous heat capacity of the global oceans, it takes a massive amount of accumulated heat energy to raise Earth's average yearly surface temperature even a small amount. Behind the seemingly small increase in global average surface temperature over the past century is a significant increase in accumulated heat. That extra heat is driving regional and seasonal temperature extremes, reducing snow cover and sea ice, intensifying heavy rainfall, and changing habitat ranges for plants and animals—expanding some and shrinking others. Since the start of the twenty-first century, the annual global temperature record has been broken five times. From 1900 to 1980 a new temperature record was set on average every 13.5 years; however, since 1981 it has increased to every 3 years. *17.Temperature is linked to CO_2 concentration in our model* as represented by the 16.CO_2 Concentration Converter and also to the 17C.Temperature Converter. There are Connecters between 16.CO_2	**17.Temperature** **= 14 +(16.CO_2 Concentration-338) *(17C.Temperature converter)** **UNITS: degC** **17C.Temperature Converter** **= 0.01** **Units:** **degC/ppmv** 

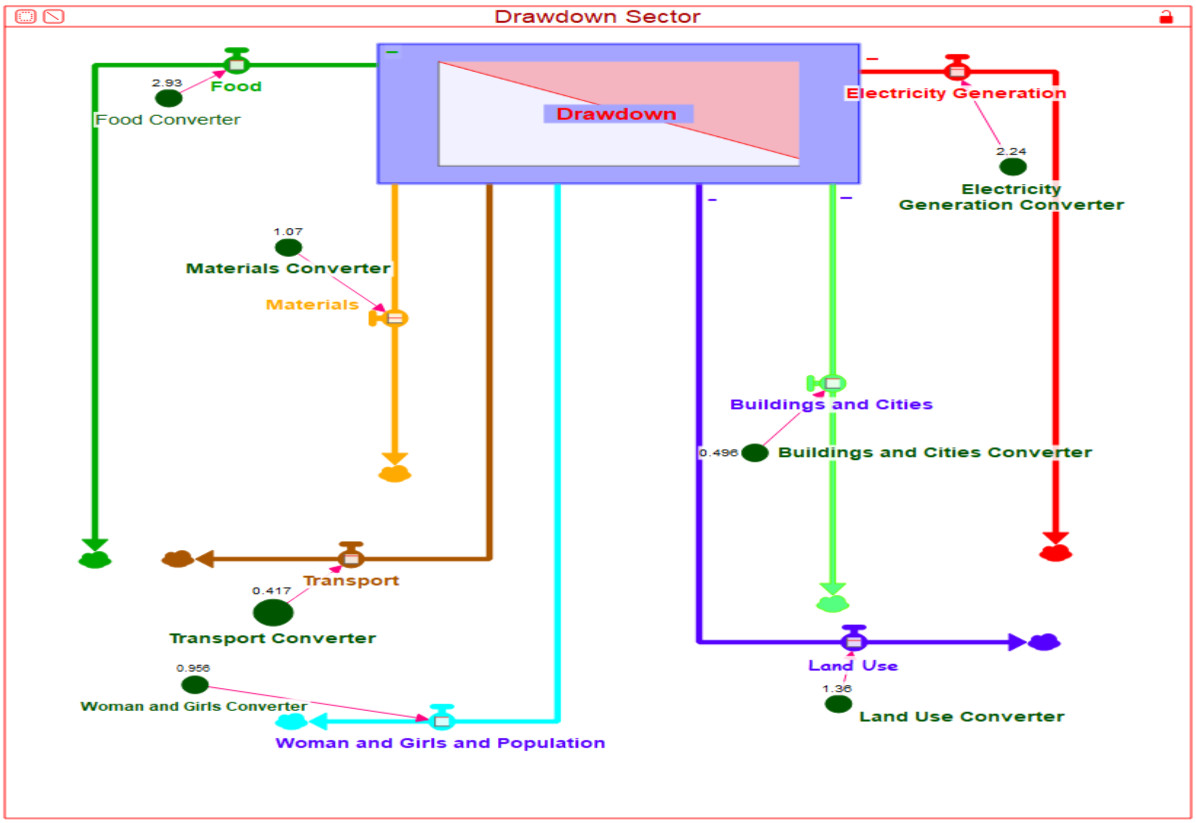
Concentration and 17.Temperature and between 17.Temperature and 17C.Temperature Converter	

Supplementary Material Unit 3G
A Simple Model of Putting Drawdown Solutions into a Carbon Cycle Model



This practice Stella model can be accessed at the following link.
https://www.dropbox.com/s/9m4tpzhabb6d6cb/May28Stella3-4PreloadCarbon%20Cycles%26Drawdown%20%281%29.stmx?dl=0
Additional Resources: https://www.drawdown.org/solutions
Pachamama Alliance https://connect.pachamama.org/

Supplementary Material Unit 3H
Drawdown Solutions Organized by Seven Sectors



This practice Stella model can be accessed at the following link.
https://www.dropbox.com/s/9m4tpzhabb6d6cb/May28Stella3-4PreloadCarbon%20Cycles%26Drawdown%20%281%29.stmx?dl=0

Links to Sector Descriptions in Drawdown

Electricity Generation, Food, Women and Girls, Buildings and Cities, Land Use, Transport, Materials.

Supplementary Material Unit 4A
Frequently Asked Questions About Project Drawdown
Information Sheet Prepared by Pachamama Alliance

What is Drawdown?---Drawdown is the point in time when the concentration of greenhouse gases in the atmosphere peak and begin to decline on a year to year basis.

Goal of the Drawdown Project - To identify, measure and model the 100 most impactful, substantive solutions to global warming that either reduce emissions or remove greenhouse gases from the atmosphere and to determine whether it is possible to achieve Drawdown within the next 30 years, by 2050.

Drawdown Team - Drawdown is a coalition of over 200 contributors from over 22 countries including 62 researchers, 130 advisors and 49 outside experts.

How to achieve Drawdown - To achieve drawdown we need to draw greenhouse gases down from the atmosphere back to the earth. This already happens every year via photosynthesis but we have to rebalance the quantity of emissions with the earth's capacity to bring those gases back home.

The Mandate - To map, measure and model substantive, technological, ecological, and behavioral solutions and analyze their potential to reduce and draw down greenhouse gases over a 30 year period.

Greenhouse Gases - Greenhouse gases include carbon dioxide, methane, fluorinated gases and several others all with different global warming impacts. To enable consistency, scientists calculate the warming potential of different greenhouse gases and convert it to a carbon equivalent to use as a common 'carbon' currency. In Drawdown, references to carbon dioxide include the impact of other, equivalent greenhouse gases, such as methane or fluorinated gases, based on their global warming potential.

The Science behind Drawdown

Assessment - The project focused on existing solutions with sufficient data available for global modeling. The solutions were then evaluated based on their current performance, scalability, economic viability, potential to reduce greenhouse gases over 30 years and the balance of other positive/negative impacts.

Three-stage Process - Every solution was researched in a 3 step process:
(i) analyzing technical reports with financial and climate data;
(ii) reviewing to ensure data integrity;
(iii) modeling to assess integration of solutions and eliminate double counting.

Modelling - Each solution is measured and modeled to determine its global carbon impact over the period of 2020-2050. The results include the (i) ranking (ii) carbon avoided, reduced, or sequestered (iii) the cost to implement and (iv) net cost/savings over a 30 year period. The impacts are quoted in gigatons of carbon dioxide referenced against a 'business as usual' baseline.

Scenarios - Three different scenarios were modeled using different underlying assumptions (e.g. future growth rates, cost reductions, improvements in tech etc.) The most conservative scenario (the "plausible' scenario in the book) reaches drawdown by 2060, the middle "drawdown" scenario by 2050 and the more aggressive, or "optimum" scenario, reaches drawdown potentially as early as 2045.

The Findings

Ranking - The solutions are ranked based on total amount of carbon they can potentially avoid or remove from the atmosphere on a global basis over a 30 year period.

Sectors - The top 80 solutions are grouped into seven sectors: Energy; Food; Women & Girls; Building & Cities; Land Use; Transport; Materials

Top 10 Ranked Solutions:

#1 Refrigerant Management
#2 Wind Turbines (onshore)
#3 Reduced Food Waste
#4 Plant Rich Diet
#5 Tropical Forests
#6 Educating Girls
#7 Family Planning
#8 Solar Farms
#9 Silvopasture
#10 Rooftop Solar

Co-Benefits - Nearly all the solutions are 'no regrets' solutions, meaning, they have so many advantages they are commendable irrespective of their impact on greenhouse gases. These co-benefits include saving money, creating jobs, enhancing security, advancing human health, eliminating hunger, preventing pollution and restoring the environment.

The Plan - Of the 80 ranked solutions some have more impact than others, but there is no silver bullet and no 'small' solutions. Reversing global warming is not possible unless we do them all. Under the Drawdown Scenario, over a 30 years period, the 80 solutions would draw down 1,372 GT.

Net cost to reverse Global Warming - The total "first cost" to implement all 80 modelled solutions is $129 trillion over 30 years under the plausible scenario. That's $27 trillion over what "business as usual" would cost, for example the cost of using solar instead of coal. The net operating cost for all solutions over 30 years is actually a ***savings*** of $78 trillion. So at the point of drawdown in 2050 the total net savings will be $51 trillion!

Coming Attractions - In addition to the top 80 solutions, the book includes 20 "coming attractions". These are 20 emerging solutions that, while they are scientifically valid, as yet there is insufficient economic and/or scientific data to accurately model the net impact on carbon and cost. These innovations include marine permaculture, smart grids, the hyperloop, autonomous vehicles and living buildings.

For more information see www.drawdown.org and www.pachamama.org

Supplementary Material Unit 4B

Solutions by Sector with Short Descriptions

Pachamama Alliance Drawdown Initiative *Solution Descriptions by Sector*

LAND USE

Afforestation	Creating forests where there were none before—creates a carbon sink, drawing in and holding on to carbon and distributing it into the soil.
BAMBOO	Bamboo rapidly sequesters carbon in biomass and soil and can thrive on degraded lands. It has more than 1,000 uses, from buildings to food to paper.
COASTAL WETLANDS	The world's salt marshes, mangroves, and sea grasses provide vital habitat, flood protection, and water filtration, and sequester huge amounts of carbon in plants and soil.
FOREST PROTECTION	With mature canopy trees and complex understories, primary forests contain 300 billion tons of carbon and are the greatest repositories of biodiversity on the planet.
INDIGENOUS PEOPLES' LAND MANAGEMENT	Growing the acreage under secure indigenous land tenure can increase above- and belowground carbon stocks and reduce greenhouse gas emissions from deforestation.
PEATLANDS	Although peatlands cover just 3 percent of the earth's land area, they are second only to oceans in the amount of carbon they store.
PERENNIAL BIOMASS	Using perennial bioenergy crops (e.g., switchgrass, silver grass, willow, eucalyptus) rather than annuals (e.g., corn) reduces emissions and raises carbon sequestration in soil.

TEMPERATE FORESTS	Ninety-nine percent of temperate forests have been altered in some way—timbered, converted to agriculture, disrupted by development. Restoring them sequesters carbon and revives ecosystems.
TROPICAL FORESTS	Tropical forests have suffered extensive clearing, fragmentation, degradation, and depletion of biodiversity. Restoring them may sequester as much as six gigatons of carbon dioxide per year.
WOMEN & GIRLS	
EDUCATING GIRLS	Education lays a foundation for vibrant lives for girls and women, their families, and their communities. It also avoids emissions by curbing population growth.
FAMILY PLANNING	Securing women's right to voluntary, high-quality family planning dramatically improves the health and well-being of women and their children. It also avoids emissions.
WOMEN SMALLHOLDERS	If women smallholders receive equal farming resources and land rights, their yields will rise by 20 to 30 percent, avoiding emissions from deforestation
BUILDINGS AND CITIES	
BIKE INFRASTRUCTURE	Infrastructure is essential for supporting safe, pleasant, and abundant bicycle use—which can relieve city congestion, improve public health, and reduce emissions from cars.
BUILDING AUTOMATION	Building automation systems serve as the "brain" of large commercial buildings. Controlling temperature, lighting, and more, they can improve energy efficiency and occupants' comfort.
DISTRICT HEATING	With district systems, a central plant channels hot and/or cool water via a network of pipes to many buildings—heating and cooling them more efficiently.
GREEN ROOFS	Green roofs use soil and vegetation as living insulation. Cool roofs reflect solar energy. Both reduce building energy use for heating and/or cooling.
HEAT PUMPS	Heat pumps transfers heat from a cold space to a hot one. Highly efficient, they can dramatically lower building energy use for heating and cooling.
INSULATION	Insulation is one of the most cost-effective ways to make buildings more energy efficient—both in new construction and through retrofitting older buildings.
LANDFILL METHANE	Landfills are a top source of methane emissions. Instead, landfill methane can be captured, preventing emissions, and used as a fairly clean energy source.
LED LIGHTING (COMMERCIAL)	Lighting accounts for 15 percent of global electricity use. LEDs (light emitting diodes) require less energy and create less waste heat than other bulbs.
LED LIGHTING (HOUSEHOLD)	By transferring most of their energy use into creating light—rather than heat, like older technologies—LEDs reduce electricity consumption and air-conditioning loads.

NET ZERO BUILDINGS	A net zero building is one that has zero net energy consumption, producing as much energy, through onsite renewables, as it uses in a year.
RETROFITTING	Up to 80 percent of the energy buildings consume is wasted. Retrofitting them can address waste through efficient insulation, heating and cooling systems, and lighting.
SMART GLASS	Compared to walls, windows are inefficient insulators. Smart glass can respond to sunlight and weather, reducing a building's energy load for lighting, heating, and cooling.
SMART THERMOSTATS	Thermostats are mission control for heating and cooling homes. Smart thermostats use algorithms and sensors to learn and become more energy efficient over time.
WALKABLE CITIES	Walkable cities prioritize two feet over four wheels through careful planning and design. As people need to drive less and want to walk more, emissions decrease
WATER DISTRIBUTION	Pumping water requires enormous amounts of energy. By minimizing leaks in water-distribution networks—currently wasting 8.6 trillion gallons annually—both energy and water are saved.
MATERIALS	
ALTERNATIVE CEMENT	Cement, a vital material for infrastructure, generates 5 to 6 percent of annual emissions. The key strategy to reduce them is to change its composition.
BIOPLASTIC	Ninety percent of plastics could be derived from plants instead of fossil fuels. Bio-plastics can be biodegradable and often have lower emissions.
HOUSEHOLD RECYCLING	Household recycling can reduce emissions because producing new products from recovered materials often saves energy. It also reduces resource extraction and creates jobs.
INDUSTRIAL RECYCLING	Industrial recycling reduces emissions when new products are made from recovered materials, rather than virgin resources. It can also address the challenge of resource scarcity.
RECYCLED PAPER	Half of paper is used once and then trashed. Recycling makes paper's journey circular, rather than a straight line from logging to landfill, which reduces emissions.
REFRIGERANT MANAGEMENT	The primary chemical refrigerant, HFCs, is a potent greenhouse gas. Phasing out its use will reduce global warming by nearly one degree Fahrenheit.
WATER SAVING - HOME	Cleaning, transporting, and heating water requires energy. More efficient fixtures and appliances can reduce home water use by 45 percent, thereby reducing emissions.
FOOD	
BIOCHAR	Biochar results from slowly baking biomass in the absence of oxygen. Retaining most of the feedstock's carbon, biochar can be buried for sequestration, while enriching soil.

CLEAN COOKSTOVES	Traditional cooking practices produce toxic smoke and 2 to 5 percent of annual greenhouse gas emissions. Clean cook stoves reduce emissions and protect human health.
COMPOSTING	From backyard bins to industrial-scale operations, composting food waste converts organic material into stable soil carbon and valuable fertilizer, averting methane emissions.
CONSERVATION AGRICULTURE	Conservation agriculture avoids tilling and employs cover crops and crop rotation. By protecting the soil, it makes land more resilient and sequesters carbon
FARMLAND IRRIGATION	Pumping and distributing water requires large quantities of energy. Drip and sprinkler irrigation, among other practices and technologies, make water use more precise and efficient.
FARMLAND RESTORATION	The world's abandoned farmland is an opportunity for drawdown. Restoring it sequesters carbon and can improve food security, farmers' livelihoods, and ecosystem health.
IMPROVED RICE CULTIVATION	Flooded rice paddies produce large quantities of methane—10 percent of agricultural emissions. Techniques exist to reduce methane, while improving production and sequestering carbon.
MANAGED GRAZING	Managed grazing imitates the activity of migratory herds to improve soil health, carbon sequestration, water retention, and forage productivity.
MULTISTRATA AGROFORESTRY	Multistrata agroforestry blends taller trees and one or more layers of crops. It achieves high rates of carbon sequestration, similar to forests, while producing food.
NUTRIENT MANAGEMENT	When overused, nitrogen fertilizers destroy soil organic matter, pollute waterways, and create nitrous oxide. They can be more efficiently managed to reduce these negative impacts.
PLANT-RICH DIET	Meat-centric diets come with a steep climate price tag: one-fifth of global emissions. Plant-rich diets dramatically reduce emissions and rates of chronic disease
REDUCED FOOD WASTE	Producing uneaten food squanders resources and generates 8 percent of emissions. Interventions can reduce waste at key points, as food moves from farm to fork.
REGENERATIVE AGRICULTURE	The practices of regenerative agriculture increase carbon-rich soil organic matter. Enhancing and sustaining the health of the soil sequesters carbon and improves productivity.
SILVOPASTURE	Silvopasture is an ancient practice, integrating trees and pasture into a single system for raising livestock. It sequesters carbon while improving animal health and productivity

SYSTEM OF RICE INTENSIFICATION	SRI is a holistic approach to sustainable rice cultivation. It improves soil, lowers inputs of seeds and water, and increases yields, while reducing emissions.
TREE INTERCROPPING	Like all regenerative land-use practices, tree intercropping—intermingling trees and crops— increases the carbon content of the soil and productivity of the land.
TROPICAL STAPLE TREES	Tropical staple trees provide important foods, such as bananas and avocado. Compared to annual crops, they have similar yields but higher rates of carbon sequestration.
BIOMASS	Biomass energy is a "bridge" solution for transitioning to 100 percent clean, renewable energy. Using sustainable feedstock—waste biomass or perennial crops—is crucial.
Electricity Generation	
COGENERATION	Power plants produce large amounts of waste heat. Cogeneration systems capture that thermal energy and put it to work—for district heating or additional electricity.
CONCENTRATED SOLAR	Concentrated solar power uses solar radiation as its primary fuel. Arrays of mirrors concentrate incoming rays to heat a fluid, produce steam, and turn turbines.
ENERGY STORAGE (DISTRIBUTED)	Standalone batteries and electric vehicles make it possible to store energy at home or work. They ensure supply even when variable renewables are not producing
ENERGY STORAGE (UTILITIES)	Energy storage—daily, multiday, and longer-term or seasonal—is vital to reduce emissions from polluting "peaker" plants and accommodate the shift to variable renewables.
GEOTHERMAL	Geothermal power—literally "earth heat"—taps into underground reservoirs of steamy hot water, which can be piped to the surface to drive turbines that produce electricity.
GRID FLEXIBILITY	For electricity supply to become predominantly or entirely renewable, the grid needs to become more flexible and adaptable than it is today.
IN-STREAM HYDRO	Placed within a free-flowing river or stream, in-stream turbines capture water's energy without a dam. In remote communities, they can replace expensive, dirty diesel generators.
METHANE DIGESTERS (LARGE)	Industrial-scale anaerobic digesters control decomposition of organic waste, and thus its methane emissions. They also produce biogas, an energy source, and digestate, a nutrient-rich fertilizer.
METHANE DIGESTERS (SMALL)	At backyard- and farmyard-scale, anaerobic digesters are used to manage organic waste. They control methane emissions, while producing biogas (an energy source) and digestate (nutrient-rich fertilizer).
MICRO WIND	With capacity of 100 kilowatts or less, micro wind turbines are often used to pump water, charge batteries, and provide electrification in rural locations.

MICROGRIDS	A microgrid is a localized grouping of distributed energy sources, like solar and wind, together with energy storage or backup generation and load management tools.
NUCLEAR	Nuclear power is complex, expensive, and risky, but it has the potential to avoid emissions from fossil fuel electricity. We consider it a "regrets solution
ROOFTOP SOLAR	Rooftop solar is spreading as its cost falls, driven by incentives to accelerate growth, economies of scale in manufacturing, and advances in photovoltaic technology.
SOLAR FARMS	Solar farms tap the sun’s virtually unlimited, clean, and free fuel, using large-scale arrays of hundreds, thousands, or in some cases millions of photovoltaic panels.
SOLAR WATER	Water heating is a major energy use. Solar water heaters use the sun’s radiation and can reduce energy consumption by 50 to 70 percent.
WASTE-TO-ENERGY	Incineration, gasification, and pyrolysis are means of deriving energy from trash. A transitional solution, waste-to-energy can reduce emissions, but has high social and environmental costs.
WAVE AND TIDAL	Wave- and tidal-energy systems harness natural oceanic flows—among the most powerful and constant dynamics on earth—to generate electricity.
WIND TURBINES (OFFSHORE)	With competitive costs and investment growing, offshore wind energy is at the crest of initiatives to supply the world with clean power
WIND TURBINES (ONSHORE)	Proliferation of turbines, dropping costs, and heightened performance mean onshore wind farms are at the forefront of initiatives to address global warming.
TRANSPORT	
AIRPLANES	The airline industry produces at minimum 2.5 percent of emissions, and it is growing. Fuel efficiency measures are on the rise to reduce that impact.
CARS	Hybrid cars pair an electric motor and battery with an internal combustion engine. The combination makes them more efficient, improving fuel economy and lowering emissions.
ELECTRIC BIKES	Electric bikes get a boost from a small battery-powered motor. They are the most environmentally sound means of motorized transport in the world today.
ELECTRIC VEHICLE	Electric vehicles are the cars of the future. If powered by solar energy, their carbon dioxide emissions drop by 95 percent compared to gasoline-powered vehicles.
HIGH-SPEED RAIL	High-speed rail is the fastest way to travel distances between 100 to 700 miles. Compared to driving or flying, it reduces emissions up to 90 percent.
MASS TRANSIT	Riding a streetcar, bus, or subway—rather than driving a car or hailing a cab—averts greenhouse gases, relieves traffic congestion, and reduces air pollution.

RIDESHARING	Ridesharing pairs drivers and riders who share common origins, destinations, or stops en route. When trips are pooled, people split costs, ease traffic, and curtail emissions.
SHIPS	Shipping produces 3 percent of global emissions. Fuel-saving ship design, onboard technologies, and practices can have a sizable impact, because of huge shipping volumes.
TELEPRESENCE	Telepresence integrates high-performance visual, audio, and network technologies to enable people who are geographically separated to interact. By reducing travel, it can reduce emissions.
TRAINS	Most trains are powered by diesel-burning engines. Technology and operations can improve fuel efficiency, and rail electrification has the potential to provide nearly emissions-free transport. TRUCKS Road freight is responsible for about 6 percent of global emissions. Increasing fuel efficiency in both new trucks and existing fleets can significantly reduce emissions
COMING ATTRACTIONS	
ARTIFICIAL LEAF	The artificial leaf is technology inspired by photosynthesis. It combines solar energy, water, and carbon dioxide, to feed bacteria that synthesize energy-dense fuel.
AUTONOMOUS VEHICLES	Autonomous vehicles are on the rise. They have the potential to shrink the auto fleet and accelerate ridesharing and the adoption of electric vehicles.
BUILDING WITH WOOD	High-performance wood materials are transforming construction. They can reduce emissions by (1) sequestering and storing carbon and (2) avoiding emissions of cement and steel.
A COW WALKS ONTO A BEACH	Asparagopsis taxiformis, a species of seaweed, shows promise for reducing methane emissions from livestock—currently 4 to 5 percent of annual greenhouse gas emissions.
DIRECT AIR CAPTURE	Direct Air Capture systems are a nascent sequestration technology. Functioning like a chemical sieve and sponge, they capture carbon dioxide from air and release it in purified form.
ENHANCED WEATHERING OF MINERALS	Natural weathering of silicate rock sequesters carbon dioxide. Enhanced weathering aims to hasten that process by milling rock powder and applying it to landscapes.
HYDROGEN-BORON FUSION	Tri Alpha Energy has achieved one-half of the nuclear fusion equation. It could herald clean, safe, affordable energy to take the world beyond fossil fuels.
HYPERLOOP	The promise of Hyperloop is speed. The virtue is moving people and cargo with 90 to 95 percent less energy than planes, trains, or cars.
INDUSTRIAL HEMP	Hemp is a global warming solution primarily because of what it can replace: cotton. Cotton has high chemical use and depends on fossil fuel inputs.

INTENSIVE SILVOPASTURE	Intensive silvopasture intercrops a leguminous woody shrub with grasses and trees. Through rapid rotational grazing, livestock yields increase alongside carbon sequestration in soil.
LIVING BUILDINGS	The Living Building Challenge holistically defines how buildings can benefit both people and planet. One key criteria: Living buildings produce more energy than they use.
MARINE PERMACULTURE	Marine permaculture utilizes floating, latticed structures designed to grow rich kelp forests and foster marine life. It could sequester billions of tons of carbon dioxide.
MICROBIAL FARMING	Microbes have the potential to dramatically reduce the need for synthetic fertilizers, pesticides, and herbicides, while improving crop yields and plant health.
OCEAN FARMING	Small-scale ocean farms have the potential to provide sustainable food and biofuel, while oysters filter nitrogen pollution and seaweed sequesters carbon dioxide
PASTURE CROPPING	In a pasture cropping system, annual crops are grown in a perennial pasture. Double-cropping grains and animals sequesters carbon and improves farm health and productivity
PERENNIAL CROPS	Perennial crops sequester carbon because they leave the soil intact. Researchers are pursuing grain, cereal, and oilseed plants that are perennial food providers.
REPOPULATING THE MAMMOTH STEPPE	A vast ecosystem called the mammoth steppe once dominated the frozen north. Restoring grazers and grassland could prevent carbon-rich permafrost from thawing and releasing emissions
SMART GRIDS	With two-way communication between suppliers and consumers, smart grids accommodate the fluctuations of wind and solar power. They also improve grid stability and overall efficiency.
SMART HIGHWAYS	The world's first sustainable highway is being pioneered south of Atlanta, Georgia, emphasizing electric vehicle infrastructure and solar power to reduce carbon emissions.
SOLID-STATE WAVE ENERGY	Solid-state wave energy technology converts the ocean's kinetic energy without external moving parts. It is more robust in marine environments, rich with untapped renewable energy.

Supplementary Material Unit 4C
Information Sheet
Summary of Solutions by Rank CO_2-EQ Reduction in GT
Circle Your Top Three Solutions of Interest

Rank	Solution	Sector	Total Atmospheric CO2-EQ Reduction (GT)	Net Cost (Billions US$)	Savings (Billions US$)
1	Refrigerant Management	Materials	89.74	N/A	($902.77)
2	Wind Turbines (Onshore)	Electricity Generation	84.6	$1,225.37	$7,425.00
3	Reduced Food Waste	Food	70.53	N/A	N/A
4	Plant-Rich Diet	Food	66.11	N/A	N/A
5	Tropical Forests	Land Use	61.23	N/A	N/A
6	Educating Girls	Women and Girls	51.48	N/A	N/A
7	Family Planning	Women and Girls	51.48	N/A	N/A
8	Solar Farms	Electricity Generation	36.9	($80.60)	$5,023.84
9	Silvopasture	Food	31.19	$41.59	$699.37
10	Rooftop Solar	Electricity Generation	24.6	$453.14	$3,457.63
11	Regenerative Agriculture	Food	23.15	$57.22	$1,928.10
12	Temperate Forests	Land Use	22.61	N/A	N/A
13	Peatlands	Land Use	21.57	N/A	N/A
14	Tropical Staple Trees	Food	20.19	$120.07	$626.97
15	Afforestation	Land Use	18.06	$29.44	$392.33
16	Conservation Agriculture	Food	17.35	$37.53	$2,119.07
17	Tree Intercropping	Food	17.2	$146.99	$22.10
18	Geothermal	Electricity Generation	16.6	($155.48)	$1,024.34
19	Managed Grazing	Food	16.34	$50.48	$735.27

20	Nuclear	Electricity Generation	16.09	$0.88	$1,713.40
21	Clean Cook stoves	Food	15.81	$72.16	$166.28
22	Wind Turbines (Offshore)	Electricity Generation	14.1	$545.30	$762.50
23	Farmland Restoration	Food	14.08	$72.24	$1,342.47
24	Improved Rice Cultivation	Food	11.34	N/A	$519.06
25	Concentrated Solar	Electricity Generation	10.9	$1,319.70	$413.85
26	Electric Vehicles	Transport	10.8	$14,148.00	$9,726.40
27	District Heating	Buildings and Cities	9.38	$457.10	$3,543.50
28	Multistrata Agroforestry	Food	9.28	$26.76	$709.75
29	Wave and Tidal	Electricity Generation	9.2	$411.84	($1,004.70)
30	Methane Digesters (Large)	Electricity Generation	8.4	$201.41	$148.83
31	Insulation	Buildings and Cities	8.27	$3,655.92	$2,513.33
32	Ships	Transport	7.87	$915.93	$424.38
33	LED Lighting (Household)	Buildings and Cities	7.81	$323.52	$1,729.54
34	Biomass	Electricity Generation	7.5	$402.31	$519.35
35	Bamboo	Land Use	7.22	$23.79	$264.80
36	Alternative Cement	Materials	6.69	($273.90)	N/A
37	Mass Transit	Transport	6.57	N/A	$2,379.73
38	Forest Protection	Land Use	6.2	N/A	N/A
39	Indigenous Peoples' Land Management	Land Use	6.19	N/A	N/A
40	Trucks	Transport	6.18	$543.54	$2,781.63
41	Solar Water	Electricity Generation	6.08	$2.99	$773.65
42	Heat Pumps	Buildings and Cities	5.2	$118.71	$1,546.66
43	Airplanes	Transport	5.05	$662.42	$3,187.80
44	LED Lighting (Commercial)	Buildings and Cities	5.04	($205.05)	$1,089.63
45	Building Automation	Buildings and Cities	4.62	$68.12	$880.55
46	Water Saving - Home	Materials	4.61	$72.44	$1,800.12

47	Bioplastic	Materials	4.3	$19.15	N/A
48	In-Stream Hydro	Electricity Generation	4	$202.53	$568.36
49	Cars	Transport	4	($598.69)	$1,761.72
50	Cogeneration	Electricity Generation	3.97	$279.25	$566.93
51	Perennial Biomass	Land Use	3.33	$77.94	$541.89
52	Coastal Wetlands	Land Use	3.19	N/A	N/A
53	System of Rice Intensification	Food	3.13	N/A	$677.83
54	Walkable Cities	Buildings and Cities	2.92	N/A	$3,278.24
55	Household Recycling	Materials	2.77	$366.92	$71.13
56	Industrial Recycling	Materials	2.77	$366.92	$71.13
57	Smart Thermostats	Buildings and Cities	2.62	$74.16	$640.10
58	Landfill Methane	Buildings and Cities	2.5	($1.82)	$67.57
59	Bike Infrastructure	Buildings and Cities	2.31	($2,026.97)	$400.47
60	Composting	Food	2.28	($63.72)	($60.82)
61	Smart Glass	Buildings and Cities	2.19	$932.30	$325.10
62	Women Smallholders	Women and Girls	2.06	N/A	$87.60
63	Telepresence	Transport	1.99	$127.72	$1,310.59
64	Methane Digesters (Small)	Electricity Generation	1.9	$15.50	$13.90
65	Nutrient Management	Food	1.81	N/A	$102.32
66	High-speed Rail	Transport	1.52	$1,038.42	$368.10
67	Farmland Irrigation	Food	1.33	$216.16	$429.67
68	Waste-to-Energy	Electricity Generation	1.1	$36.00	$19.82
69	Electric Bikes	Transport	0.96	$106.75	$226.07
70	Recycled Paper	Materials	0.9	$573.48	N/A
71	Water Distribution	Buildings and Cities	0.87	$137.37	$903.11
72	Biochar	Food	0.81	N/A	N/A
73	Green Roofs	Buildings and Cities	0.77	$1,393.29	$988.46
74	Trains	Transport	0.52	$808.64	$313.86
75	Ridesharing	Transport	0.32	N/A	$185.56

76	Micro Wind	Electricity Generation	0.2	$36.12	$19.90
77	Energy Storage (Distributed)	Electricity Generation	N/A	N/A	N/A
77	Energy Storage (Utilities)	Electricity Generation	N/A	N/A	N/A
77	Grid Flexibility	Electricity Generation	N/A	N/A	N/A
78	Microgrids	Electricity Generation	N/A	N/A	N/A
79	Net Zero Buildings	Buildings and Cities	N/A	N/A	N/A
80	Retrofitting	Buildings and Cities	N/A	N/A	N/A
			1034.75	**$29,609.30**	**$74,362.37**

Supplementary Material Unit 4D
Solutions by Sector with Short Descriptions Worksheet on 3 solutions of interest

What are the 3 solutions you felt drawn to and want to explore further?

Sector	Name of Solution of Interest	Gt. Carbon Reduced	Overall Rank
1.			
2.			
3.			

Why are these important to you?

Do you know of how and where this solution might already be in operation?

What makes these solutions super cool?

Supplementary Material Unit 4E Worksheet on Six Levels of Action	
Pick a Solution of interest to you. Brainstorm with your partner about the Solution considered at the various levels of action listed below. Think of opportunities or challenges for implementing that Solution at each level. For example, if your chosen Solution is Reducing Food Waste (the third largest potential impact Solution), some opportunities might be: (1) saving leftovers (individual); (2) better meal planning and composting food scrapes to build soil (family); (3) structures for surplus food distribution (community);(4) laws against food wastage in commercial establishments (state law/policy); (5). National Agricultural policy requiring leaving some land fallow and requiring surplus food distribution; (6) International agreements on structures needed to ensure food distribution to those who need it most.	
Enter Name of Solution Here:	
Level	Notes on Opportunities and Challenges
Individual	
Family	

Local Community	
State	
Nation	
Global	

Supplementary Material Unit 5A
Engineering Project Worksheet

NAME **Project**	Date Start: ________ Date End: ________

Compelling Question

Proposed Solution

Action or Project

Impact of Idea

What action do I want my community to take?

Local Connections, Resources and Related Green Jobs

How would you express your solution or idea in terms of a Stock-Flow Map and a Stella Model?

Research Summary

Important Facts for this Investigation (Main Idea)	Where did I find my information? (Source)

What information do I still need or what questions do I have?

Investigation

Steps for the investigation?

Presentation Criteria

Category	Scoring Criteria	Total Points	Score
Compelling Question	The question is clearly stated.	20	
Research Summary	The research summary is well-explained, documented, and complete.	20	
STELLA Model	Illustrates the proposed solution in an organized manner.	20	
Systems Thinking	Evidence of how the Habits of a Systems Thinker was applied to the research.	20	
Next Steps	A clear explanation of the next steps for the presenters and the community is communicated.	20	
Score	**Total Points**	**100**	

Presentation

Category	Scoring Criteria	Total Points	Score
Organization	Introduction is clear and interesting.	10	
	The flow of the presentation is smooth from introduction through the conclusion.	10	
Content	The material presented is well-researched and follows the Habits of a Systems Thinker.	10	
	Use evidence and examples from your research beyond what is written in your visual aid	15	
	Make explicit connection to Drawdown	10	
	Explain how your model shows impact of your idea	10	
	Identify next steps and why this idea is important to your community	15	
Presentation	Communicate ideas clearly	5	
	Demonstrate poise and enthusiasm	5	
	Use standard English grammar	5	
	Share your new knowledge with confidence	5	
Score	**Total Points**	**100**	

Supplementary Material Unit 5B
Criteria for an Effective Presentation

- Introduction is clear and interesting
- Communicate ideas clearly
- Make explicit connection to Drawdown
- Explain how your model shows impact of your idea
- Articulate next steps and why this idea is important to your audience
- Use evidence and examples from your research beyond what is written in your visual aid
- Use standard English grammar
- Demonstrate poise and enthusiasm
- Share your new knowledge with confidence

Supplementary Material Unit 5C
Peer Feedback Sheet

- **Comments on Introduction (Captures the audience's attention? Clear Topic?)**

- **Comments on Content (Topic match the investigation board? Does it have a clear connection to drawdown? Does it include information on the thinking that went into the idea and the model? Are there clear next steps?)**

- **Do you have any questions for the presenter about their idea that might need to be answered in the presentation?**

- **Comments on Delivery**
    - **Speaking (clear? Easy to understand? Grammar? Volume?)**

- **Body Language (eye contact? Gestures? Nervous mannerisms?**