Lesson 2: Cloud in a Bottle

Grade Level: 6-12

Estimated Time for Activity: 90 minutes

Learning Outcomes and NGSS

	Content Knowledge	**Skills**
Expected Learning outcome	Students will learn about one climate engineering technology (Marine Cloud Brightening) researched currently. Students will learn how a cloud is formed and how a cloud's components can be modified to change its brightness (reflectance).	Students will exercise the scientific method through developing hypotheses, running experiments, collecting data, interpreting the data, and drawing conclusions.
NGSS	**MS-ETS1-3 Engineering Design.** Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success. **MS-ETS1-4 Engineering Design.** Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved. **HS-ESS3-4 Earth and Human Activity.** Evaluate or refine a technological solution that reduces impacts of human activities on natural systems. **HS-ETS1-2 Engineering Design.** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.	

Materials:

500 ml water + more for rinsing and cleaning, clean 1-liter bottles, [hand air pump, #3 hard rubber stopper + tire valve plug] OR "Fizz Keeper", aerosol hairspray, graduated cylinder (precision of 10 ml), lux meter, medium to large size flashlight, dark/non-reflective background (curtain, sheet, cardboard painted flat black, etc.).

Key Terms:

Albedo, cloud condensing nuclei, lux meter, marine cloud brightening

Background:

The traditional cloud-in-a-bottle activity has become a ubiquitous experiment to perform in classrooms to educate students on condensation, cloud condensing nuclei (small aerosol particles for the moisture to condense upon), cloud formation, and how variables such as pressure and temperature can impact the development of the cloud. Here, a novel twist on the cloud-in-a-bottle experiment is constructed by demonstrating to the students that the number of cloud condensing nuclei will alter the brightness (albedo) of a cloud. This physical process was described in landmark papers by Sean Twomey in the mid-1970s (Twomey, 1974, 1977). Known colloquially as the Twomey Effect, this process is the foundation for an active climate engineering research field called Marine Cloud Brightening (MCB). MCB centers on the idea that introducing additional aerosols (cloud condensing nuclei) in marine environments will increase the number of cloud droplets per cloud providing more surface area to reflect more solar shortwave radiation. Recent research has even shown that MCB has the potential to counteract some of the human-caused warming in the Earth system (e.g., Stjern et al., 2018). Along with Stratospheric Aerosol Injection (SAI), MCB is the most plausible geoengineering that could be used to limit global warming and climate change with relatively (and subjectively) few tradeoffs. SAI and MCB will be presented and discussed throughout the Geoengineering Module.

Activity: Cloud brightening experiment

Materials: Listed above plus the marine cloud brightening worksheet for each student and the Excel data spreadsheet for the teacher.

Procedure (Student methods are also in the worksheet, but below are more details for the teacher (also see accompanying PowerPoint and Videos for visuals on experimental set-up and procedures)):

Before the class:

- Run trials yourself, adjust the set-up if necessary. The high-aerosol experiment should create clouds with a noticeably higher reflectivity (difference between the bottle with the cloud and the bottle after the cloud dissipates) compared to the low-aerosol experiment.
- Familiarize yourself with the lux meter and its settings so that you are prepared to troubleshoot with your students if their observed values seem unrealistic. (For example, the Smart Sensor lux meter has a button that switches the units from lux to footcandles, this would greatly alter the magnitude of the reading as 1 footcandle = 10.8 lux).
- Test how many pumps it takes to pressurize the bottle and create a cloud - this will differ depending on whether you use the bike pump and plug+valve or the Fizz Keeper.

Setup:

- Set up the area for the experiment before class, have the materials at hand and clean. See the PowerPoint slides and the videos for help with the set-up.
- The lux meter sensor should be pointed at the middle of the bottle. Please note that the lux meters are very sensitive. If possible, conduct the experiment in a dark room; if there is a main source of light, set-up with the lux meter pointing away from the source (& away from windows).
- [Ensure that the rubber stopper and tire valve plug fits securely in the bottle top. A snug fit is necessary to pressurize the bottle. If the plug is loose, try a different plug, or wrap the rubber stopper in a layer of Duct tape to improve the fit.] - OR - [Twist the Fizz Keeper onto the bottle top and familiarize yourself with the apparatus.]

Activity	Procedure
Pre-activity questions and discussions: worksheet questions 1-3	1. Have the students complete the pre-Experiment One questions, 1-2, on the worksheet. Review questions and answers with students before proceeding to the Research Question (the PowerPoint slides 2-6). 2. Review the Research Question (use the PowerPoint slides 7-9) and have students hypothesize whether the clouds will be brighter with more aerosols (CCNs). Question 3 in the worksheet. 3. Run through the experiment design, materials, and methods before beginning the trials (the PowerPoint slides 10-18 may be helpful).
Data collection-Experiment 1	1. It is helpful to have a student assist with handing materials to the experimenter and to (or have another student) write down the lux meter reading right after the clouds are formed. 2. Begin with Experiment One, the "Low-Aerosol" environment. Experiment One requires 3 sprays of hairspray. Do at least 4 trials for each experiment, up to 10. 3. Start by putting ~20 ml of water into a 1-liter bottle and swishing the water around so it has touched the inner surface area of the bottle. 4. Spray 3 sprays of hairspray into the bottle. 5. Cap the bottle securely with the rubber stopper and valve plug. 6. [Secure the hand pump to the valve and pump 15 times (you want the bottle to be pressurized, but don't risk injury – the number of air pumps can be altered to your needs but keep the number of pumps consistent across all experiments and trials).] - OR - [with the Fizz Keeper on, squeeze the ball as many times as possible (about 30-35 squeezes) to generate enough pressure to create the cloud.] 7. After the last air pump, [quickly detach the air pump from the valve and remove the rubber stopper] - OR - [Release the Fizz Keeper] (you'll hear the pressure release). 8. A cloud in the bottle should immediately form and you need to get the lux meter reading ASAP after the cloud forms (note, the lux meter reading will go down as the cloud dissipates, so it is important to get a reading after the bottle is in place and hands are removed). 9. Have an assisting student record the lux meter reading on their worksheets. 10. Let the bottle remain in place until the cloud has completely dissipated. About 1-2 minutes. The lux meter reading will decrease as the cloud dissipates and when the numbers are not changing, record the value. Gather the reading of the bottle without the cloud in it (the reading should be less than with the cloud present). This reading captures the reflectance of the bottle with the residue of hair spray on the interior left over from aerosols not used in the cloud formation. It's possible that the lux meter reading of just the bottle will be lower for the high-aerosol experiment because more hairspray residue will be on the interior sides of the bottle. But, the difference between the lux meter reading with and without the cloud will be larger for the high-aerosol versus low-aerosol experiment. 11. Repeat Experiment One until at least 4 trials have been conducted, max 10. 12. After a 1-liter bottle has been used, it is important to rinse out the hairspray/water mixture before using the bottle again. You do not need to use soap or detergent between trials, but before long-term storage you will want to clean the bottles thoroughly.

Activity	Procedure
Data collection-Experiment 2	1. Conduct the Experiment Two trials, the "High-Aerosol" environment. Experiment Two requires 10 sprays of hairspray. Again, do at least 4 trials for each experiment, up to 10. 2. Repeat the steps 3-12 above for Experiment Two with 10 sprays of hairspray instead of 3 sprays.
Post activity questions and discussions. Worksheet questions 4-9	1. Post experiment trials, have the students complete the data table and remaining questions from the worksheet. The remaining questions can be assigned as homework if time is limited. 2. Review and discuss answers with class upon their completion of the worksheet.

Data Collection and Interpretation:

An Excel Spreadsheet is provided with tables for Experiment One and Experiment Two. Equations to calculate the mean, standard deviation, and two-tailed t-test are defined in the associated Excel cells. Note, the difference column must be calculated only for the trials with data – do not enter zeros in the difference column if no trial was run with respect to that row -- else the T-test p-value will be incorrect. You may wish to put the data into the spreadsheet after all trials are finished and the students are working on calculating the averages themselves (Question 4). There is also an Excel Spreadsheet with sample data that was recorded during the creation of this module.

Review the data and T-test results with the students. Then, assign Questions 5-9 to the students (can be given as homework). We recommend reviewing the answers with the students, particularly Questions 7-9, before proceeding to Lesson 3 of this Climate Engineering Teaching Module.

Gear up: with question 3 in the worksheet. Teachers can facilitate a discussion about experiment design. What are the dependent variables, independent variables, and the constants in the experiment design? This activity explored how the aerosol which is one of the variables affects the brightness of the cloud. Students are encouraged to explore other variables such as the amount of water. Teachers can help the students design the experiments and test them out.

References:

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Twomey, S. (1974). Pollution and the planetary albedo. *Atmospheric Environment (1967)*, *8*(12), 1251–1256. https://doi.org/10.1016/0004-6981(74)90004-3

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