Teacher Notes to Accompany
Materials on Smog City

Educational objectives:

- Students will learn that ozone is affected by emissions of nitrogen oxides, emissions of volatile organic compounds, sunlight intensity, wind speed and mixing height
- Students will learn that high emissions do not always lead to high ozone concentrations – the meteorological conditions must be right
- Students will learn that, because of the complexities of the chemistry of ozone formation, unexpected phenomena can occur – for example, decreasing emissions of nitrogen oxides can at times lead to increases in ozone concentrations

Suggested lesson plan:

- Review the background materials on Smog City and assess whether the level is appropriate for your students; if you decide to use the presentation, see the answers to the questions raised in the presentation, which are provided below; if the level of the presentation as a whole is too advanced, you can have the students use Smog City as an exploration tool with just the following idea:

OZONE = Reactive Organic Compounds +
Oxides of Nitrogen +
Sunlight +
Stagnant Air

- Whether you use the background presentation or not, you can use smog city as an exploration tool to examine each of the factors that contributes to ozone formation. Directions for running Smog City are simple and are embedded in the software.
- Have your students select a "base case". The "base case" is a set of conditions that you will use as a starting point for systematically varying emissions, wind speed, sunlight and mixing height. I recommend temp = 100^{o}F, inversion height = mid-level; wind speed = lowest setting above zero, population = second setting above zero, all emission types at their mid-point values. When you use these values and click on the start button, you will see a one-day ozone profile. Note the highest concentration. The software will identify which color band (health hazard level) is reached, but you may want your students to break each color region into 3 sub-regions (low, medium and high in each color band). For the base case conditions, the maximum ozone concentration should reach into the low end of the red color band (unhealthy concentrations)
- Have your students systematically vary just one of the adjustable parameters in the box model and plot the results. For example, if we keep all of the parameters

the same in the model except the wind speed, then systematically vary the wind speed, we get the following results:

Zero wind speed:	low purple
Setting 1:	low red
Setting 2:	low yellow
Setting 3:	high green

Plot the results using your 18 possible ozone levels (low , medium and high levels of green, yellow, orange, red, purple and black) as the vertical axis and your 4 wind speeds as the horizontal axis.

- Repeat this process for each parameter
- Have your students try to identify the set of conditions that will lead to the highest ozone concentrations
- Starting from the base case, try to identify the set of emission reductions that leads to the least cost set of controls that will reduce ozone concentrations into the yellow range. Start by assuming that all emission categories must reduce emissions. There are 5 settings for each of the emission categories. Assume that reducing car and truck emissions by one setting is three times as expensive as reducing industry or consumer product emissions (because the number of cars and trucks is greater – look at the bar chart to the left of the settings). Assume that reducing off-road emissions by one setting is half as expensive as reducing industry and consumer product emissions by one setting.
- Starting from the base case, try to identify the set of emission reductions that leads to the least cost set of controls that will reduce ozone concentrations into the yellow range. Assume that you will allow emission trading. Some sectors can increase emissions by paying to have their settings increased. Does this change the result?

Questions and answers from Smog City Background Presentation

Slide 13:

Why does the ozone concentration go down at night?

Ozone formation is driven by reactions that depend on sunlight. Ozone formation is initiated when NO_2 absorbs an ultraviolet photon and breaks down into NO and O.

Is the response to VOC emission reductions linear?

No, it's non-linear. Remember the concept of the limiting reactant. Note that the dependence is monotonic, however. As VOC emissions increase, ozone always increases.

At the lowest levels of VOC emissions, why does the ozone concentration decrease over the second and third day?

If the winds used in the model (which are assumed to blow in clean air) are strong enough and the emissions are low enough, the box will gradually clear out over multiple days.

Slide 15:

Is the response to NOx emission reductions linear? Does it exhibit a maximum/minimum?

Slide 17:

Is the response to temperature changes linear? Does it exhibit a maximum or minimum?

Slide 19:

Is the response to solar irradiation linear? Does it exhibit a maximum/minimum?

Slide 21:

Is the response to wind speed (ventilation) linear?
How does wind speed affect carryover from day to day?