Instructor's Manual

Module 7: ***Air Pollution Solutions for the Mid-Atlantic United States***

A. Typical class length:
45-60 minutes

B. Target students:
General public, or entry-level state employees

C. Module objectives:
The goals of this module are to have the students:
- Understand the hierarchy of emission control solutions and options being used in the Mid-Atlantic U.S.
- Identify some of the emission control technologies and the pollutant(s) they control
- Understand the basics of air pollution markets
- Participate in solutions to local air pollution problems

D. Instructor preparation:
Go to the course web site and download all relevant materials for Module 7:
Instructor's Slides (Powerpoint)
Student Handouts (PDF)
Instructor's Manual Overview (PDF)

http://bigmac.cee.mtu.edu/marama/Modules/Modules.html

Review all the materials, make any changes you feel are necessary for your version of the course, master the material, then deliver your class!

E. Understand the sub-module objectives
Each course module is constructed of a series of sub-modules based on modern learning theory. The sub-module typically focuses on a narrow aspect of the module topic. The module can be viewed as the collection of several discrete topics presented in a fashion more appropriate for the range of learning styles among students in your class. Most sub-modules are constructed around a *motivation-theory-application-analysis* learning cycle. While it is good practice to have this cycle for each sub-module, it is acceptable to have a portion of the sub-modules that do not have all four components of the cycle. In general though, it is poor practice to have only the theory sections, as this will likely achieve the low-retention rates found in lecture-based learning environments. The rest of this manual provides tips and insight into specific slides. Please refer to the *Module 7 Instructor's Slides* to follow along.

Sub-Module 1: Introduction (Slides 1-7)
The primary purpose of these slides is to engage the student almost immediately upon entering the classroom. Educational research suggests that in a typical class, the first ten minutes is lost on most students as they are disconnecting from what they were previously doing. A suggested approach for this phase of the module is:

Slide 1 – Have this photograph projecting before the students enter the classroom. Each module starts with a photograph connected to the content. Most students will subconsciously begin thinking about the course material when looking at a photograph. In this, maybe simply reflect on a time they have seen a rainbow after a storm. A happy place to start a class.

Slide 2 – Introduce the topic. This will make sure everybody in the room belongs in the class.

Slide 3 – This slide serves as the initial Motivation section. Feel free to substitute a similar compelling fact, observation, or finding from your own experiences. This slide should be put up long enough for the students to review, and perhaps some short comment from you. In this case, a reasonable question might be whether anybody knew you could buy air pollution (if this class is comprised of the general public you made need to explain what sulfur dioxide is…).

Slide 4 – All modules have a preliminary quiz. The purpose of the preliminary quiz is two-fold: (1) it gets the students thinking more about the subject, and (2) gives you a comparative benchmark at the post-module quiz. Feel free to substitute questions with some of your own, but bear in mind that the total time expended here should be about two minutes. Simply have the students circle the answers on their copies of the student handouts, or produce a handout quiz if you want to tally the results. One way to engage the class as a whole is simply to ask for a show of hands for each answer. The solutions to this quiz can be found in the post-course quiz slide below.

Slide 5 – The course goals slide is a good one to emphasize. Tell the students clearly what they will learn by the end of the class. If you add to, or delete, any material modify the course goals as needed.

Slide 6 – This slide is merely a visual representation of the course topics. It also presents the choices available to planners, engineers, and decision-makers for solving air pollution problems.

Slide 7 – This slide provides a decision-making flowchart that a plant manager might have her environmental staff consider upon plans to expand production (and hence emissions). These decisions are forced on the plant from the existing regulatory solutions in place (non-deterioration). Decision 1 would be whether there is a way to create no emissions; this would require a re-engineered process or product. If emissions are determined to be inevitable then Decision 2 is whether there is a way to offset those emissions. If no, then the plant will have to design and install emission control technology, so that there is no increase in emissions to the atmosphere. If yes, then a review of available emissions markets is Decision 3. If there is not a market available, perhaps there is another facility the company owns that could reduce their emissions by an amount equal to the planned increase at this one. If there is a market, then emission credits must be purchased to offset the planned increase in emissions at the plant. The flow chart also serves as a visual guide to remember some of the control options available.

Sub-Module 2: Regulatory Solutions (Slides 8-13)
The primary purpose of this sub-module is to address the first course objective, namely understanding some of the solution approaches.

Slide 8 – This slide provides an overview of key regulations, all modifications to the cornerstone air pollution regulation in the United States, the Clean Air Act. The CAA emerged after a decade where the U.S. and Europe experienced several severe air pollution episodes resulting in thousands of people dying (Donora, Pennsylvania in the U.S., London, and the Meuse Valley in Europe). It was finally clear that poor air quality was bad for human health. The subsequent amendments added more stringent rules, first targeting the most common pollutants and establishing concentration limits to protect the public – this is via the National Ambient Air Quality Standards. As evidence pointed to additional air quality problems, the CAA was further amended over the years. For descriptions of the other acronyms and abbreviations, consult the U.S. EPA's online glossary:

http://www.epa.gov/air/acronyms.html

Slide 9 – The implementation of regulatory solutions is highlighted on this slide. Note the critical role of the state environmental regulatory agencies – they craft a plan for how the state will meet the federal regulations, assess compliance of industry in meeting the regulations, and balance the needs of the public's welfare and industry's need to function. The federal government provides oversight of the states to ensure compliance (the states can enact tougher regulations, but not easier).

Slide 10 – Details the permitting process for large sources. Emissions are acceptable as long as they stay within permitted limits. The regulatory agencies are also responsible for enforcement of these limits, and associated penalties for violations.

Slide 11 – The CAIR initiative is an example of one modern approach to solve two of the most challenging air quality problems for the Mid-Atlantic region, ozone and particulate matter. The centerpiece of this plan is setting a declining total emission for the eastern U.S. (a *cap*) and then allowing individual sources to trade emissions. For example, facilities that are emitting less than their permits (due to engineering advances, pollution prevention plans, etc.) can sell these "unused" emissions to a plant that might release more than they are permitted to release (this is the *trade*). The theory behind this approach hypothesizes that it is simply most important to limit the total emissions in the region, and not be concerned with their distribution within the region. The CAIR has a very aggressive emission reduction plan to reduce NO_x (an important ingredient in the formation of ozone) and SO_2 (which creates some particulate matter).

Slide 12 – This slide depicts the projected improvements from CAIR over the next few years. Ask the students for any observations they have regarding the difficulty in solving the ozone and particulate problems (much of the Mid-Atlantic is still projected to violate the ozone standard in 2010 despite CAIR). Why is that?

Slide 13 – This activity aims to get the students thinking about the good (uniform goals among the states, forces action, etc.) and bad aspects (air quality is not the same everywhere, paperwork, etc.) of solving air quality problems through regulations. Ask the student groups (3-5 students in a group is good, if convenient for the classroom layout) to share a couple ideas. Consider writing them on the board to make a master list.

Sub-Module 3: Engineering Solutions (Slides 14-28)
The primary purpose of this sub-module is to address the first and second course objective, namely understanding some of the solution approaches and especially the control technologies available.

Slide 14 – An overview of the engineering options available, and the order of preference are provided. Option 1 would generate no emissions, but is difficult (if not impossible) in many industries. Option 2 requires a re-thinking (and re-design) of how a product is manufactured (or service created/delivered). Emissions reduction could be one design criteria, but it must be balanced with product criteria and costs. Option 3 tries to capture some emissions and re-use them in some capacity. This is limited to pollutants that can be captured, concentrated, often purified, and used in a beneficial way; such systems are often complicated and expensive to install. Option 4 is the traditional way of dealing with emissions. Various engineered control devices have been created that can capture and/or destroy some (but rarely all) of the emissions prior to the air being exhausted to the atmosphere. An example most students could reflect on is controlling emissions from automobiles. An example of Option 1 could be not using the car. Walk. Or combine errands to result in less driving. An example of Option 2 could be a hybrid (or any more fuel efficient) engine. Less fuel used, few emissions. Option 3 could include the vapor recovery system in the engine. Unspent fuel vapors are collected, condensed, and returned to the fuel line. An example of Option 4 is the catalytic converter, a control device to transform carbon monoxide from the incomplete combustion of fuel into carbon dioxide.

Slide 15 – Several characteristics of the air stream off industrial operations must be measured (or estimated) in order to select appropriate emission control technologies. If the air is extremely hot, for example, it could damage certain equipment.

Slide 16 – Simply a presentation of some of the challenges (mobile sources, ozone precursors) and constraints (size and weight of control devices for vehicles). Also challenging are the small sources that fall below the minimum emission limits in the regulations.

Slide 17 – The table lists a few of the control technologies available for gaseous emissions. An important point is that each technology is generally effective at reducing specific pollutants. There is simply no device that captures every pollutant. It will be difficult to include all the control technologies presented in the next few slides. Pick a few to illustrate and skip the others (refer the students to reviewing them on their own, as they will have them in their copy of the notes).

Slide 18 – This is an introduction to thermal oxidizers (or incinerators as they used to be called). The name was changed partly to escape the bad history of poorly designed and operated incinerators of past decades. New thermal oxidizers are some of the most efficient control technologies available, reducing emissions by up to 99.999%. These are very costly to operate, though (fuel costs). Note there are limits on the pollutants that can be controlled (organic compounds in this case) and the minimum effective concentration of the pollutant in the air stream coming into the thermal oxidizer (100 ppm or greater – like any fuel its easier to burn the pollutants when their concentration is higher rather than lower). If these are operated properly, the combustion products in the exhaust should be much more benign than the organic compounds coming into the thermal oxidizer. In old incinerators, this was not always the case, some producing the highly toxic dioxin compounds.

Slide 19 – Absorption is a technology used at many coal-fired power plants to remove sulfur from the exhaust of the combustion chamber (flue gas desulfurization). The technique focuses on moving the air pollutant into water, sometimes requiring chemicals to be added to the water to speed up this transfer. Lime and limestone are two such chemicals that can be added (lime is more effective, but more expensive). Gypsum ($CaSO4$) is produced if those chemicals are added, and some power plants are selling that material to manufacturers of cement blocks, or sheetrock. It can also be used as a soil treatment and is sometimes applied to agricultural lands. Outside of power plant use, the technique is good one for industries with highly water soluble gases in their emissions. Ammonia and chlorine are two such gases.

Slide 20 – Adsorption involves transferring the air pollutant (sorbate) onto a solid material (sorbent), like activated carbon. These solids have massive surface areas, and hence plenty of space to stick air pollutant molecules. Eventually all those spaces get filled up, and the sorbents must be regenerated (they are too expensive to simply throw away). So a common way to regnerate the sorbent is to flood the column with high pressure steam to drive the pollutant off the sorbent. When this happens the pollutant is captured, condensed, and put into containers for proper disposal (or maybe recycling and reuse). After the column dries out, the unit can be used again.

Slide 21 – Biofilters are relatively new technology, entering wide spread use in the 1990s in the U.S. Their strength is simplicity and low costs, but they are limited in the types of pollutants, and conditions of the air streams they can deal with successfully. These units are essentially a big box of woodchips with bacteria growing on them. The air stream is blown through the woodchips (bio media) and the bacteria consume the pollutants as they pass by. Since this is a living system, the air stream must be relatively cool, and the pollutant concentrations relatively low. As such, these units cannot be used for many industrial sources.

Slide 22 – Controlling particles requires very different technologies. Some available solutions are provided in the table; a critical point to stress is that particle size strongly influences the effectiveness of the control device.

Slide 23 – A settling chamber is simply a large box that the air stream passes through. This technology only works for large particles (a human hair is about 50 µm in diameter, so these are sand-sized particles or larger that are effectively collected in this device). The principle is straight forward, the chamber is big enough to give the particles time to settle out before the air gets to the far side.

Slide 24 – Cyclones are commonly used in particle control due to their simplicity, effectiveness, and low costs. It operates on the principle of centrifugal force; the particles impact the cyclone's inner walls and stays within the cyclone, the air flows out. Cyclones are effective for particles about 10 µm and bigger, the smaller particles move through the device and out with the air.

Slide 25 – Baghouses are chambers full of hundreds of fabric bags (think of an industrial-sized vacuum cleaner bag). The air stream is split and passes into the opening of these bags (they are open on one end, and closed on the other, just like a sock), leaving the particles trapped with the bags as the air flows out. A vacuum cleaner is like a one-bag mobile baghouse. Eventually the bags fill up with particles and the bags are shaken knocking the particles out for collection. The unit can then be used again. Due to advances in bag fabric technology, baghouse can capture fairly small particles (1 µm and larger).

Slide 26 – There are not many technologies available for ultrafine particles. The electrostatic precipitator (ESP) is one such technology. These units are extremely effective, but also expensive due to the electricity needed to run them. The unit is a box with a series of metal plates which the air stream moves between. In between the plates are charged wires that created a charged field. As the particles move through this field they become electrostaticly charged. Now charged the particles are attracted to the plates (which have an opposite charge) and accumulate on the plate surface. The air passes out of the unit virtually particle-free. Eventually the plates fill up with particles and the plates are rapped by a mechanical hammer which causes the particles to slide off into the collection hopper. The particulate matter can be collected in a truck and taken away for disposal, or for incorporation into some product (some fly ash particles have been used to make concrete for example).

Slide 27 – This slide features a design tool, the Air Compliance Advisor, that helps the engineer make the initial decisions on what technology may be appropriate as an emission control for the air stream coming off an industrial process. It's free, easy-to-use and available for download at the EPA (see the first resource on Slide 41 *Further Learning*).

Slide 28 – This activity asks the students to ponder a question that may already have been asked by an insightful student. Have the student groups offer some of their ideas on this. A key reason is ***containment*** of the pollutant. Air pollutants go where the winds take them. Water pollutants are easier to contain and control, solid waste problems even more so. Such containment usually has benefits for exposure reasons too, i.e. we can keep the pollutant away from people or the environment.

Sub-Module 4: Market-Based Solutions (Slides 29-34)
The goal of this sub-module is to address the first and third objectives of the course module, understanding solutions, notably market-based ones.

Slide 29 – Cap-and-trade market solutions are introduced on this slide. There are three existing markets: a nationwide sulfur dioxide market, a newer nitrogen oxides market that focuses on the Eastern U.S. (due to regional ozone issues), and a voluntary international market for carbon dioxide. The emission markets are administered through the Chicago Board of Trade, which handles trading of many commodities. Anyone (industry, citizens, etc.) can buy emissions on this market.

Slide 30 – This slide provides some details on the sulfur dioxide market.

Slide 31 – This slide shows some of the price history for one ton (one allowance) of sulfur dioxide. Ask the students for their conclusions. One should be that the program seems to be successfully meeting its main objective; total emissions are decreasing.

Slide 32 – A visual confirmation that decreasing sulfur dioxide emissions seem to be having an effect – decreased sulfate concentrations in this case. This should mean lower particulate levels and less impact from acid deposition.

Slide 33 – The map shows the early results from the NOx market. The states in white are the target states for lower ozone. The grey states (non-OTC, ozone transport commission) are the upwind states with significant contributions of ozone-forming NOx emissions to the white states. The primary bars to compare are the light blue (1990 NOx emissions during the ozone season, May 1 to September 30), dark blue (2000 values) and pink (2004 values). The yellow bars are the target amount for the 2004 ozone season. The green bars are emission targets plus an additional amount (the compliance supplement pool, CSP, which was used as an incentive for early participation – the white states got their CSP in 2003), whereas the magenta bars are the target NOx emissions for the upwind states during the ozone "control period" (May 31 to September 30). The primary observations are that emissions are down (compare light blue to dark blue to pink). Another common feature among the states is that the pink bar is higher than the yellow bar – actual emissions are higher than targeted levels (except in NY and MA). This points to the challenges in reducing these emissions. Nevertheless, progress is being made.

Slide 34 – An important question to have the students discuss. Many opponents to the market-based solutions mention that the total cap approach still allows severe polluters to exist, thereby creating local pollution problems even if the region is meeting the cap. Would this be a problem with SO_2, NO_x, or CO_2? What if the market solution approach was expanded to include other compounds, say mercury or benzene? Have the student groups share their thoughts.

Sub-Module 5: Voluntary Solutions (Slides 35-39)
The goal of this sub-module is to address the first and last objectives of the course module, understanding solution options and recognizing the power of participation.

Slide 35 – This slide introduces some ways that the public can participate in solutions to air quality problems; the regulations provide various venues for the public to engage in the regulatory process, and the public often has lifestyle choices that can influence emissions of pollutants. These efforts can make a difference. The public can also influence their employers to create or participate in emission reduction programs.

Slide 36 – This example is one that has affected many cities around the world. The uncontrolled wood burning in the fireplaces of many homes can collectively create significant air quality problems (high particulate levels). In many of these communities the solutions are more challenging than those targeting large industrial sources. The public is forced to make a value judgment. Which is more desirable – a cozy fire in your home, or clean air in your community? Which do you put first – your own wants, or the needs of society?

Slide 37 – This is an example of a voluntary corporate solution. The company gets nothing other than good PR, and maybe some enhancement of employee morale and loyalty. Is it worth the cost? Ask the students.

Slide 38 – The 3M example is a longer-term approach with clear emission impacts. What kind of benefits might 3M gain from such programs?

Slide 39 – This is a good activity so students can digest the knowledge from the class and strengthen retention by putting it all into practice. There are many good answers, but some possibilities include:
• Regulatory: applying for a new emission permit, allowing you to generate more power but with stricter controls; offsetting increased emissions at this plant with decreases at another
• Engineering: switching to a different (lower-sulfur) supply of coal; improving flue gas desulfurization units
• Market-based: buying emission credits on the SO_2 market
• Voluntary: distributing energy conservation tips and products so less energy is used by individual customers, and the total generated could decrease even with more customers (as would SO_2 emissions)

Sub-Module 6: Conclusion (Slides 40-43)
These slides provide a meaningful ending to the learning. Don't underestimate their importance.

Slide 40 – The post-quiz goes here. The students should only need 30-60 seconds. Collect their responses, if assessment is needed, else a show of hands with discussion is fine. The purpose of the post-quiz is simply to force retention of key points. The answers for this quiz are:

1.) *c.) pollutant emission trading*, is the newest general approach of the four, getting started in the U.S. in the early 1990s with the sulfur dioxide market
2.) This is a bit of a trick question. CAIR's goals are to decrease *c.) particulate matter* and *d.) ozone* concentrations. But one way to control particulate matter is through the reductions in *a.) sulfur dioxide* that are outlined on Slide 11. So the most correct answer is all three of these pollutants.
3.) A baghouse is designed to control *c.) particulate matter*.

Slide 41 – This slide has some resources for the students to learn more on their own. Add to it, as relevant. Encourage additional learning with references that you know to be particularly helpful. The Air Compliance Advisor site has links to the software and user's manual. The second reference points to Title 40 in the CFR, which concerns U.S. air quality regulations. The complex NOx Trading Program is explained in the document in the third site. CAIR is explained in more detail at the fourth resource. The MARAMA Guide is provides additional insight into solutions for the Mid-Atlantic region.

Slide 42 – The moment to reflect is an important pause before concluding the class. It helps the student sort and summarize what they have learned, and if desired can be a good summative assessment for your efforts. For example, as an assessment tool, simply ask the students to write their response to the question on a scrap of paper and leave it behind following the class. Read through the responses to adjust any future offerings of the class. It will be extremely informative to learn what the students think is the best air quality solution. Is there broad agreement? Substantial disagreement? This activity could take some time, so set time limits up front. Nevertheless, this activity will probably leave the students talking as they leave the course (perfect!), particularly if you ask for them to share their thoughts. Don't try to reach consensus, there are no right answers for opinions.

Slide 43 –Thank the class for coming and for their participation! This is a simple yet powerful way to end the class.