Office and Office Hours

Mann Hall Room 308. Telephone: (919) 515-1155 (voice mail).
Office Hours: Tue/Thurs 3:00 to 5:00 pm or by appt.
Electronic Mail: frey@ncsu.edu. Email me anytime. I try to respond within 24 hours.
Course web site: wolfware.ncsu.edu, log-in, then go to Moodle site.
Instructor’s web site: http://www4.ncsu.edu/~frey/

Course Objectives

The student completing this course will be able to: (1) identify, classify, and prioritize major emission sources; (2) categorize and describe major types of regulations; (3) apply mass balance, energy balance, chemical equilibrium, and chemical kinetic concepts to estimate pollutant formation rates for a variety of major stationary and mobile sources; and (4) identify, analyze, design, and evaluate air pollution prevention and control strategies.

Course Description

Fundamentals of air pollutant formation and control from stationary and mobile emission sources. Chemical kinetics, mass and heat transfer, and thermodynamics affecting gaseous and particle pollutant formation in combustion systems and chemical processes. Study of sulfur dioxide, nitrogen oxides, particulate matter, volatile organic compounds, hydrocarbons, and air toxics formation and control. Principles of conventional and advanced flue gas desulfurization, thermal and fuel NOx control, and particle/air toxics emission control will be among the emission topics to be explored.

Required Text

We will use the following text book regularly throughout the course:


In addition, lecture notes and other instructional materials are available on the course web site.

Prerequisites

This course is multi-disciplinary and can accommodate students with diverse engineering backgrounds.
For undergraduate students, the following prerequisites apply:

**Environmental Engineering Majors:** Prerequisites — Introduction to Environmental Engineering (CE 373), Thermodynamics (MAE 301 or ChE 315), and Engineering Economics (CE 390), Corequisites — Statistics (ST 370); or equivalent

**Chemical Engineering Majors.** Prerequisites — Chemical Engineering Design I (ChE 450); or equivalent

**All other majors.** Please discuss with Dr. Frey.

**WARNING:** Students who do not meet the prerequisites and corequisites may be dropped from the course at any time without warning.

For graduate students in CE 576, there are no formal prerequisites or corequisites. Students with background in thermodynamics, heat transfer, chemistry, and related areas will be prepared for this course. Please contact me if you have any questions.

**Academic Integrity**

All students are expected to comply with the letter and spirit of the requirements for academic integrity at North Carolina State University. Furthermore, on individual homework assignments and on exams, students will neither give nor receive unauthorized aid. The instructor will designate those assignments that are individual and strict adherence to this policy is expected.

The University policies on academic integrity can be found in the Code of Student Conduct, which is available on the web at:


It is the instructor’s understanding and expectation that your name and signature on any test or assignment means that you have complied with the academic integrity requirements and that it is equivalent to the following statement:

"I have neither given nor received unauthorized aid on this test or assignment."

I expect you to abide by the letter and spirit of the university policies on academic integrity.

**Diversity**

The university’s Equal Opportunity and Non-Discrimination Policy is available at:

Assignments and Grading

The course is available to both undergraduate and graduate students. The lectures, homeworks, and exams for both groups of students are the same. However, in addition, the students in CE 576 must complete a term paper.

For those in the undergraduate section, CE 476, final grades will be calculated as follows:

- Homework and Quizzes: 30%
- Exams (2): 35%
- Final Exam: 35%

For those in the graduate section, CE 576, final grades will be calculated as follows:

- Homework and Quizzes: 10%
- Exams (2): 30%
- Final Exam: 30%
- Term Project: 30%

I reserve the right to give short, in-class, unannounced “pop” quizzes to test mastery of reading materials and other lecture or homework related materials. If given, these will be part of the homework grade. There will also be quizzes to take via the course website (Moodle) that will be incorporated into the homework and quiz grade.

The homework grade will also include one “mini-project.” The mini-project will entail either:

- Participation in a small group that conducts field measurements of the activity, energy use, and emissions of a car or light duty truck (e.g., SUV, pickup, minivan)
- A five-page paper on a topic of mutual interest agreed to by the student and the instructor (please discuss ideas with the instructor early in the semester)

For CE 576, the term project requirements are described in a separate handout.

All sections will be graded using plus or minus grades. The grading scale for the course is as follows:

<table>
<thead>
<tr>
<th>If your course average is</th>
<th>You are guaranteed to get at least a(n):</th>
<th>Grade Points</th>
</tr>
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<tbody>
<tr>
<td>at least 97 and less than 100</td>
<td>A+</td>
<td>4-1/3</td>
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<tr>
<td>93 and less than 97</td>
<td>A</td>
<td>4</td>
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<tr>
<td>90 and less than 93</td>
<td>A-</td>
<td>3-2/3</td>
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<tr>
<td>87 and less than 90</td>
<td>B+</td>
<td>3-1/3</td>
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<tr>
<td>83 and less than 87</td>
<td>B</td>
<td>3</td>
</tr>
<tr>
<td>80 and less than 83</td>
<td>B-</td>
<td>2-2/3</td>
</tr>
<tr>
<td>77 and less than 80</td>
<td>C+</td>
<td>2-1/3</td>
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</tbody>
</table>
There will be two in-class 75 minute exams. These exams will be given on:

**Exam No. 1:** Tuesday, October 6 – will cover Lectures 1-13 and other materials covered during the same time period.

**Exam No. 2:** Tuesday, November 24 – will cover Lectures 14-25 and other materials covered during the same time period.

There will be a three-hour comprehensive final exam. The final is scheduled for 8 am to 11 am on Thursday, December 10. The exam will be held in the same room as the regular class.

**Regrading**

Questions about grading will be entertained for no longer than one week after the graded work has been returned to you. Any work for which you request regrading will be subject to a thorough review, even if only one part was originally in question. The grade may be adjusted upward, downward, or not at all based upon the review. Changes of only a few points on any one assignment hardly ever impact a final course grade.

**Attendance**

Regular attendance is important and is expected. I will start the class on time and make important announcements at the beginning of class. These announcements will not be repeated for latecomers.

University policies on attendance can be found at:
http://policies.ncsu.edu/regulation/reg-02-20-03

See also the policy on **makeup exams**.

If on-campus attendance becomes an issue, then I will implement in-class quizzes for a grade that will be given starting in the first minute of class. Such quizzes will not be announced in advance.

**Exam Policies**

All exams will be closed book. A one page appendix containing key formulas and data will be provided. You must take the exam at the scheduled time. I reserve the right to restrict the use of calculators to those that are nonprogrammable. If you miss a test without prior approval or a certified medical excuse, there is no makeup exam and you will receive a zero for the missed exam. (See next section on Makeup Exams).

**Makeup Exams**

In accordance with University attendance policy, makeup exams will be given only for excused absences.
Excuses for anticipated or emergency absences shall be accepted at the discretion of the instructor. When an excuse is accepted, an opportunity shall be provided for making up any work missed. When an excuse is not accepted, there is no obligation to provide an opportunity for makeup work.

Excuses for anticipated absences must be cleared with the instructor before the absence. Examples of anticipated absences are: (1) University duties or university trips as certified by an appropriate member of the faculty or staff; (2) required court attendance as certified by the Clerk of the Court; and (3) religious observances as certified by the Department of Student Development.

Excuses for emergency absences must be reported to the instructor as soon as possible, but not more than one week after the return to class. Examples of emergency absences are: (1) illness or injury when certified by an attending physician; and (2) death or serious illness in the family when certified appropriately.

*NOTE*: In all cases, students must provide a written certification for the excuse and a phone number of an appropriate individual to contact regarding the excuse. If you miss a test without prior approval or a certified excuse, there is no makeup exam and you will receive a zero for the missed exam. **NO EXCEPTIONS.**

**Homework Policies and Group Activities**

There will be approximately eight required homework assignments, plus the mini-project.

There will be an optional homework at the end of the semester. If you turn in all required homeworks plus the optional homework, your lowest homework grade, will be dropped in computing your homework average.

Required **homework is due BEFORE the beginning of class** on the due date. Homework submitted while the instructor is lecturing or at the end of class is late.

**For group assignments, each individual in the group must turn in a complete solution.** Put your name on top, and list the names of others in your group. One solution per group will be selected and graded. The grade for that one solution will apply to all members of the group. If it is clear that the group is not working together collaboratively, the assignment that appears to have the lowest portion of correct answers will be selected for grading. If not all group members turn in a solution, 10 points will be deducted from the grade of those who turned in a solution and an appropriate penalty will be assigned to the tardy or nonresponsive group members in accordance with the policy on late homeworks. Thus, it is in the interest of all group members to make sure that all group members turn in the best possible solution on time!

Use 8-1/2 inch by 11 inch paper, **one side** of each page, and **box the solutions**. If answers are not boxed, zero credit will be given, even if a correct answer is somewhere on the page. **All pages must be stapled together**. I do not bring a stapler to class.

Late homework will be accepted, subject to the following penalties. Up until a homework solution is discussed in class or otherwise made available to the class, there will be a penalty of 10 percentage points per calendar day (including weekends) that the assignment is late. An assignment is considered to be one day late if it is turned in anytime after the beginning
of class up to 24 hours after the start of the class period in which it was due. I will not accept homeworks that are turned in after I return graded homeworks to the class or post the solution, whichever comes first.

On many of the homeworks, it is helpful to develop a spreadsheet or other computer model. It is assumed that students have access to a personal computer or to the EOS system. If you use a spreadsheet or other computer program to solve the homework problems, you must clearly document the equations you used and your approach. When working in groups, it is okay for all members within a group to submit a copy of the same spreadsheet. However, it is not permissible for the same spreadsheet to appear in the solutions of multiple groups. This would be a violation of the academic integrity policy.

You are to use software in accordance with the requirements of the software license and per University policies. It is your responsibility to know and understand license and policy requirements.

**Significant Figures.** Please use judgment when reporting numerical results. In many cases, for example, it is not appropriate to report more than three significant digits. Points will be taken off for answers that are reported with excessive numbers of significant figures, such as those that come from unformatted computer output (e.g., if a number should be reported as 2.40 mg/m³, but you report it as 2.3987454542 based on a computer printout, I will take off points). Points will also be taken off if you do not report units (e.g., if you report 2.40 instead of 2.40 mg/m³).

**Office Hours**

Students are welcome to arrange a time to meet with me to discuss anything -- it can be about this class, other classes, career planning, possibilities for graduate school, etc. If you have an emergency, you may try to find me at any time. The best alternative to coming to see me in person is to send me electronic mail (frey@ncsu.edu). You are also welcome to call me (515-1155).

**Auditing**

Auditors receive a notation on their transcript regarding whether their audit is “recognized” or “not recognized.” Auditors are expected to attend class regularly. Students who wish to “sit in” on the course must register for an audit.

To be “recognized” as an auditor in CE 476, you must satisfactorily complete at least five homework assignments and a comprehensive quiz. To be recognized as an auditor in CE 576, you must complete the term project and a comprehensive quiz.

The university policy on audits is at: http://policies.ncsu.edu/regulation/reg-02-20-04

**Incompletes**

According to official university policy: IN (Incomplete) is a temporary grade. At the discretion of the instructor, students may be given an IN grade for work not completed because of a serious interruption in their work not caused by their own negligence. You should come see
me as soon as you are reasonably able regarding the circumstances that you feel merit an incomplete. Documentation of the reasons, as outlined for makeup exams, may be required. Students who receive an incomplete are expected to complete the coursework as soon as possible. Incompletes are given only in exceptional circumstances (e.g., death in the immediate family). Please see the following web site for more information:

http://policies.ncsu.edu/regulation/reg-02-50-03

Accommodations to Students with Disabilities

Reasonable accommodations will be made for students with verifiable disabilities. In order to take advantage of available accommodations, students must register with Disability Services for Students at 1900 Student Health Center, Campus Box 7509, 515-7653. For more information on NC State's policy on working with students with disabilities, please see the Academic Accommodations for Students with Disabilities Regulation (REG02.20.1):

http://policies.ncsu.edu/regulation/reg-02-20-01

Reading Materials

I have placed some reading materials on electronic reserve. See the “E-reserves” link on the course Moodle site. Some physical reserve materials are also available in D.H. Hill Library.
Preliminary List of Topics to be Covered

Introduction
- Overview of Air Pollution Control
- Source Categories
- Taxonomy of Air Pollutants
- Specific Pollutants: Sources & Effects
- Overview of Regulations in the U.S.
- Regulatory Units and Conversions

Fuels
- Energy Consumption
- Natural Gas
- Fuel Oils
- Coal

Fuel Combustion
- Stoichiometry
- Equivalence Ratio
- Exhaust Gas Composition
- Excess Air

Combustion Thermodynamics
- First Law of Thermodynamics
- Enthalpy
- Enthalpy of Reaction
- Higher & Lower Heating Values
- Adiabatic Flame Temperature

Pollutant Formation in Combustion Systems
- Types of Pollutants
- Effect on Mass Balance
- Empirical Approaches
  (emission factors)

Chemical Equilibrium & Pollution
- Chemical Equilibrium Concepts
- CO emissions
- Effect on Mass & Energy Balances

Chemical Kinetics & Pollution
- Reaction Rate
- Differential Rate Law
- Reaction Mechanisms
- Combustion Reaction Mechanisms

Process Design and Economics

VOC Incineration

NOx Formation
- National NOx Emissions
- NOx Formation
  - Thermal NO
  - Fuel NO
  - Prompt NO
- Kinetics of Thermal NO Formation

NOx Control
- Combustion-based Methods
  - Time, Temp., & Concentration
- Post-Combustion Methods
  - Selective Non-Catalytic Reduction
  - Selective Catalytic Reduction
- Other Techniques

Carbon Monoxide
- Kinetics and Mechanisms
- Formation and Control

Mobile Source Emissions
- Internal Combustion Engines
- NOx Formation
- CO Formation
- Hydrocarbon Emissions
- Control of Emissions

Sulfur Dioxide Control
- Major Emission Sources
- General Approaches
  - Precombustion
  - Combustion
  - Post-Combustion

Particulate Matter Control
- Principles of Particle Collection
- Cyclone Separators
- Electrostatic Precipitators
- Fabric Filters
- Wet Scrubbers
<table>
<thead>
<tr>
<th>Lecture No.</th>
<th>Day</th>
<th>Date</th>
<th>Comments (tentative list of topics)</th>
<th>Homeworkb</th>
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<tr>
<td>1</td>
<td>Th</td>
<td>Aug 20</td>
<td>Introduction. Review of prerequisite concepts, intro to class projects</td>
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<td></td>
<td></td>
<td></td>
<td>Read Chapter 1 of Cooper and Alley</td>
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<tr>
<td>2</td>
<td>Tu</td>
<td>Aug 25</td>
<td>Lecture Notes No. 1: introduction</td>
<td>HW#1 given</td>
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<tr>
<td>3</td>
<td>Th</td>
<td>Aug 27</td>
<td>Lecture Notes No. 2: emission sources</td>
<td></td>
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<tr>
<td>4</td>
<td>Tu</td>
<td>Sep 1</td>
<td>Lecture Notes No. 2: emission sources</td>
<td>HW#1 due HW#2 given</td>
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<tr>
<td>5</td>
<td>Th</td>
<td>Sep 3</td>
<td>Lecture Notes No. 3: air pollutants</td>
<td></td>
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<tr>
<td>6</td>
<td>Tu</td>
<td>Sep 8</td>
<td>Lecture Notes No. 3 and No. 4</td>
<td>HW#2 due HW#3 given</td>
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<tr>
<td>7</td>
<td>Th</td>
<td>Sep 10</td>
<td>Lecture Notes No. 4: effects of pollutants</td>
<td></td>
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<tr>
<td>8</td>
<td>Tu</td>
<td>Sep 15</td>
<td>Lecture Notes No. 5: emission factors and inventories</td>
<td>HW#3 due HW#4 given</td>
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<tr>
<td>9</td>
<td>Th</td>
<td>Sep 17</td>
<td>Lecture Notes No. 6: energy and fuels</td>
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<tr>
<td>10</td>
<td>Tu</td>
<td>Sep 22</td>
<td>Lecture Notes No. 7: combustion</td>
<td>CE 576 Term Project Proposal Due</td>
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<tr>
<td>11</td>
<td>Th</td>
<td>Sep 24</td>
<td>Lecture Notes No. 8: thermodynamics</td>
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<tr>
<td>12</td>
<td>Tu</td>
<td>Sep 29</td>
<td>Lecture Notes No. 8: thermodynamics</td>
<td>HW#4 due</td>
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<tr>
<td>13</td>
<td>Th</td>
<td>Oct 1</td>
<td>Lecture Notes No. 9: equilibrium</td>
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<tr>
<td></td>
<td>Tu</td>
<td>Oct 6</td>
<td>Exam No. 1 – will cover Lectures 1-13, HWs 1-4</td>
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<td>Th</td>
<td>Oct 8</td>
<td>Fall Break – No Class</td>
<td>HW#5 given</td>
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<tr>
<td>14</td>
<td>Tu</td>
<td>Oct 13</td>
<td>Review Exam, Lecture Notes No. 9: equilibrium</td>
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<td>15</td>
<td>Th</td>
<td>Oct 15</td>
<td>Lecture Notes No. 10: kinetics</td>
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<td>16</td>
<td>Tu</td>
<td>Oct 20</td>
<td>Lecture Notes No. 10: kinetics</td>
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<tr>
<td>17</td>
<td>Th</td>
<td>Oct 22</td>
<td>Lecture Notes No. 11: cost estimating</td>
<td>HW#5 due HW#6 given</td>
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<td>Read Chapter 2 of Cooper and Alley</td>
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<tr>
<td>18</td>
<td>Tu</td>
<td>Oct 27</td>
<td>Lecture Notes No. 12: VOC emissions, prevention, and control</td>
<td>CE 576 Term Project Progress Report Due</td>
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<td>Read Chapters 11 and 12 of Cooper and Alley</td>
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<tr>
<td>19</td>
<td>Th</td>
<td>Oct 29</td>
<td>Lecture Notes No. 12</td>
<td>HW#6 due HW#7 given</td>
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<tr>
<td>20</td>
<td>Tu</td>
<td>Nov 3</td>
<td>Lecture Notes No 13: NOx emissions, prevention, and control</td>
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<td>Read Chapter 16 of Cooper and Alley</td>
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<td>Day</td>
<td>Date</td>
<td>Lecture Notes</td>
<td>Additional Information</td>
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<tr>
<td>21</td>
<td>Th Nov 5</td>
<td>13 and No. 14 - CO emissions, prevention, and control</td>
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<tr>
<td>22</td>
<td>Tu Nov 10</td>
<td>15: Mobile Sources Read Chapter 18 of Cooper and Alley</td>
<td>HW#7 due HW#8 given</td>
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<tr>
<td>23</td>
<td>Th Nov 12</td>
<td>15: Mobile Sources</td>
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<tr>
<td>24</td>
<td>Tu Nov 17</td>
<td>15: Mobile Sources</td>
<td>HW#8 due</td>
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<tr>
<td>25</td>
<td>Th Nov 19</td>
<td>Mobile Sources</td>
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<td>Tu Nov 24</td>
<td>Exam No. 2, will cover lectures 14-25 and HWs 5-8</td>
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<td></td>
<td>Th Nov 26</td>
<td>Thanksgiving – no class</td>
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<tr>
<td>26</td>
<td>Tu Dec 1</td>
<td>Lecture Notes No. 16: SO₂ control Read Chapter 15 of Cooper and Alley</td>
<td>Optional HW#9c given on Dec 1</td>
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<td></td>
<td>Fr Dec 3</td>
<td>(no classes)</td>
<td>CE 576 Term Project Due Optional HW#9c due</td>
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<tr>
<td>27</td>
<td>Th Dec 10</td>
<td>FINAL EXAM (3 hours) 8 AM - 11 AM</td>
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</table>

aNotes: Homeworks are to be turned in prior to the lecture.

If we cover the topic areas at a different rate than indicated in the schedule above, the dates of the reading assignments will also differ. However, the dates for exams, homeworks, and the term project will not change.

b Reading assignments will also be given. C&A refers to Cooper and Alley, 4th Edition.

c Homework No. 9 is optional. Please see grading policy for homeworks for details. **Schedule is subject to change.** Additional readings may be given.