Industrial Chemistry: CHEM 3I03

Instructor: Dr. Philip Britz-McKibbin *Office:* ABB-231 *Lab:* ABB-205
Time/Room: T, W & F: 12:30-12:20 PM in BSB-121
Textbook: No required textbook (class notes/handouts/group research)
Office Hours: W: 9:30-10:30AM (ABB-231) or by appointment
Tel: ext. 22771 *E-mail:* britz@mcmaster.ca

What is industrial chemistry?

• The development, optimization and monitoring of fundamental chemical processes used in industry for transforming raw materials and precursors into useful commercial products for society.

How is it important and relevant to you?

• Industrial chemistry plays a vital role as an applied science in diverse areas that influence human society ranging from economic, environmental and political stability.

Goals of this course: Why are you here?

• This is a survey course that will focus on industrial processes used in the production of major primary bulk chemicals (*e.g.*, gases, acids, bases, fossil fuels) and their secondary commercial products (*e.g.*, dyes, pesticides, drugs, polymers). Emphasis will be placed on a **holistic** understanding of the relationship between natural resources, chemical transformation and waste generation for a **sustainable** future based on insights derived from green chemistry and environmental chemistry.

• By the end of the course students should be able to:

1. Define, describe, and apply basic chemical processes involved in the production of major commercial products used in society.
2. Develop critical skills at analyzing the cost/benefit/impact of traditional industrial chemical processes on society as a whole.
3. Appreciate the role of green chemistry for efficient yet sustainable industrial chemical processes with low impact on the environment and human health.

Course strategy: Hints on how to succeed in this course

• If you **attend** every class on time and conscientiously do assigned reading and problem sets. This is particularly important as there is no assigned textbook for the course.

• Actively **participate** in class/group discussions.

• **Relate** knowledge gained in class which can be applied to "real-world" problems.

• Creative **contributions** to group project and presentations.

• During the course, **compile** a concise set of notes (1 page) from lecture and material that includes basic principles and equations of chemical analysis (review for final exam).

• If you have any **questions** or doubts about the material being taught (*before an exam!*), feel free to ask questions in class, drop-by for a visit in my office or send an e-mail message.

• Working in **groups** for support throughout the term.

• Keep an **update** on any changes in test or report schedule announced in class or on **WebCT**.

• But most important of all, keep a **balanced** body and mind (relax) and have fun!

Course Outline: The Big Picture!

• Most of the information for the course will be delivered as class lectures with additional input from invited guest speakers and student group presentations. Industrial chemistry will be presented in context of long-term sustainability and environmental impact based on green chemistry.

Industrial Chemistry
A. Introduction: History, chemical industry survey (Top 20), traditional industrial chemistry VS green chemistry, thermodynamic & kinetic considerations, holistic view. Case study: Haber-Bosch process
B. Major Inorganic Chemical Processes: Bulk Commodity Chemicals
Industrial Gases: N_2, O_2, NH_3, Cl_2, CO_2
Industrial Acids/Bases: H_2SO_4, H_3PO_4, HNO_3, NaOH, Na_2CO_3,
C. Major Organic Chemical Processes: Fine Specialty Chemicals
Fossil Fuels & Petrochemicals: Ethylene, propylene, ethylenedichloride, benzene, MTBE, vinyl chloride etc.
Polymer Chemistry: PVC, acrylic, polyethylene, polystyrene, teflon.
Major Commercial Products: Food additives, refrigerants, dyes, surfactants, pharmaceuticals etc.
D. Industrial Activity & Environmental Impact: Challenges/Solutions
Global warming, acid rain, smog, ozone depletion, eutrophication, toxic metals, carcinogens, endocrine-disrupting substances

• Any changes to the course material will be notified if necessary. In most cases, formal class lectures will be held on Tues. & Wed., whereas invited speakers and group discussions will be held on Fri. afternoons based on assigned reading. The last two weeks of class will be devoted to student group presentations. Last day of class is Fri Dec. 2^{nd}, 2005.

Grading procedure

• Your final grade in this course will be based on following assessment. Dates are *tentative* only:

1. Problem Sets (1)	5 %	Held throughout semester prior to mid-term & final
2. Mid-Term Exam	20 %	Oct. 18 (tentative: details to follow)
3. Group Project	35 %	Report (20%) and presentation (15%) - see handout
5. Class Participation	10 %	Attendance & group discussions
6. Final Exam	30 %	Dec. 7-21: Comprehensive; Date to be announced
Total	100 %	Last day of class, Dec. 2: (Review)

** Invited guests: Dr. Nicole Baryla, Research Scientist, Eli Lilly Canada Inc.: Fri. Sept. 23 2005*
Dr. Chris Marvin, Senior Research Scientist, Canadian Centre for Inland Waters: Fri. Oct. 21, 2005

Academic Dishonesty

• Failure to attend a class for an exam will result in a grade of **zero**, unless absence is documented for a valid reason (i.e., a doctor's note). Plagiarism, improper collaboration in groups and copying or using unauthorized tests/exams can result in a grade of **zero**, **loss of credit**, or **suspension** from university. Although working in groups is encouraged, **plagiarism** is not! Please refer to the Academic Integrity Policy (Appendix 3) for further details: http://www.mcmaster.ca/senate/academic/ac_integrity.htm

Industrial Chemistry (CHEM 3I03)

OVERVIEW OF CHEM 3I03: MAJOR PRINCIPLES & APPLICATIONS

In CHEM 3I03, students will learn important chemical processes used in industry, ranging from the large-scale production of bulk chemical commodities, industrial gases, fertilizers, explosives, petrochemicals and polymers. Industrial chemistry will also examine the current economic and environmental consequences of expanding industrial activity including ozone depletion, acid rain, global warming and endocrine-disrupting chemicals. Emphasis will be placed on emerging chemical technologies based on green chemistry principles, water recycling and alternative fuels. The course is primarily a survey course aimed at providing students a background to industrial chemistry as applied to real-world applications, which will be supplemented by invited guest speakers from industry.

A. History of Industrial Chemistry, Top 20, Haber-Bosch & Green Chemistry

A brief survey into the historical developments of industrial chemistry, as well as a survey of the current top 20 chemicals manufactured in the world today. Special emphasis will be placed on the "Haber-Bosch Process" as a classic example of the role of industrial chemistry in transforming modern society, as well as providing an introduction to the principles of heterogeneous catalysis, thermodynamic yield, kinetic rate of reaction, continuous-feed operations and recycling of reagents. An introduction to the principles of green chemistry will also be discussed.

B. Major Bulk Inorganic Chemicals

Students will first learn major processes for the manufacture of bulk inorganic chemicals, ranging from caustic soda to nitrogen gas to sulphuric acid. Emphasis will be placed on holistic understanding of the major feedstocks and precursors, as well as chemical reaction conditions and side-product or waste generation. Applications and products generated from major bulk chemicals will also be discussed.

C. Major Bulk Organic Chemicals & Petrochemical Industry

Students will first learn major processes for the manufacture of bulk organic chemicals derived form fossil fuels, ranging from ethylene, benzene and xylenes. An introduction to the major processes used in refining and transforming crude oil will be discussed, including fractional distillation, thermal and catalytic cracking. Anti-knocking additives and blends used in gasoline will also be examined

D. Industrial Polymer Chemistry

Students will learn the fundamentals of polymer chemistry based on primary precursors derived form the petrochemical industry, including polyethylene, polypropylene, polystyrene and polyethyleneterephthalate. Different catalyzed-polymerization reaction mechanisms will be explored for producing low polydisperse materials with unique properties. Insight in the chemical viability of polymer recycling will also be discussed.

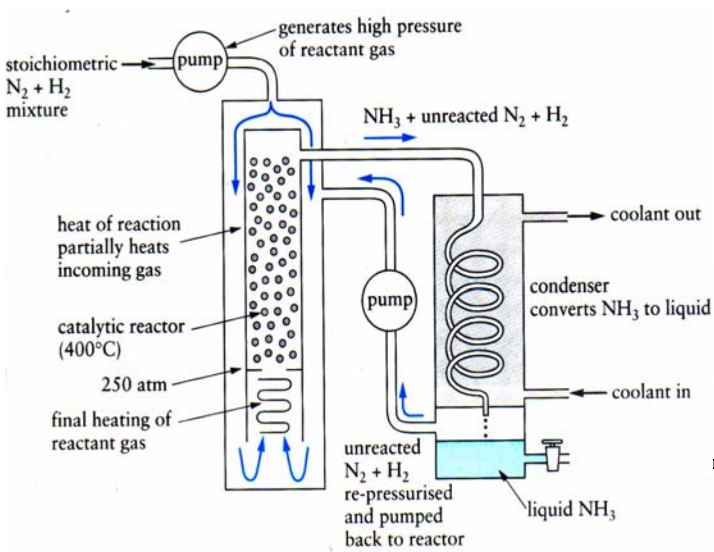
E. Environmental Chemistry & Future Industries

A discussion of emerging environmental issues related to chemical industry will be discussed throughout the course including ozone depletion, global warming and acid rain. Future industries based on green chemistry to reduce economic and ecological impact will also discussed.

The climax of the course is reflected by a group student presentation as well as individual report based on a proposed green chemistry alternative to a major industrial process, product or feedstock that is both economically and environmentally sound.

DIAGRAMS & FIGURES FROM CHEM 3I03

Haber-Bosch Process



$$N_2 + 3H_2 \xrightleftharpoons{\text{Fe catalyst}} 2NH_3 + \text{Heat}$$

$$\Delta H^o = -46 \text{ kJ/mol}$$
$$\Delta S^o = -199 \text{ J/K}$$
$$\Delta G^o = -33 \text{ kJ/mol}$$

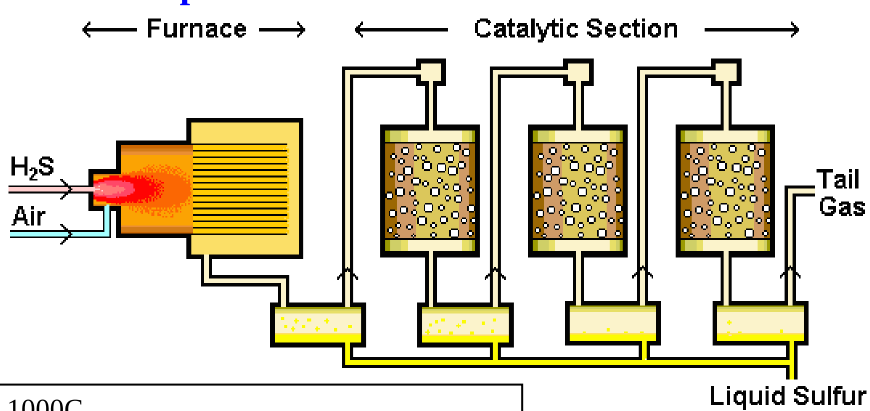
"Green chemistry represents the pillars that hold up our sustainable future. It is imperative to teach the value of green chemistry to tomorrow's chemists."

Dr. Daryle Busch, Former ACS President

"Many of our technology related problems arise because of unforeseen consequences when apparently benign techniques are mployed on a massive scale. Hence many technical applications that seem a boon to man when first introduced become a threat when their use becomes widespread"

Melvin Kranzberg, Historian of Technology

Sulphur Extraction & Claus Process



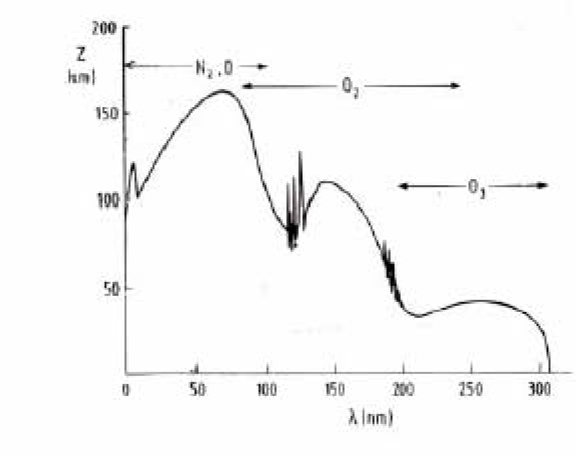
$$H_2S\ (g) + 3/2\ O_2\ (g) \xrightleftharpoons{1000C} SO_2\ (g) + H_2O\ (g) \quad \text{Thermal Step}$$

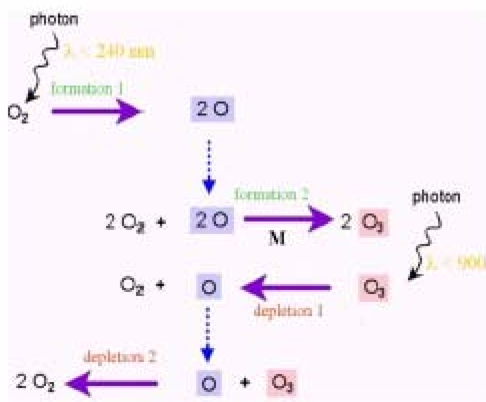
$$SO_2\ (g) + 2H_2S\ (g) \xrightleftharpoons[Al_2O_3]{300C} 3S\ (l) + 2H_2O\ (g) \quad \text{Catalytic Step}$$

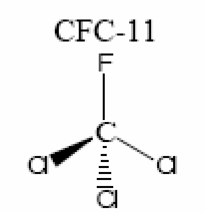
ACIDS: H_2SO_4 (Claus/Contact Process) → S/H_2S (sour gas) major feedstock
H_3PO_4 (Wet Process) → Phosphate rock/H_2SO_4 major feedstocks
HNO_3 (Ostwald Process) → NH_3 (natural gas) major feedstocks

GASES: N_2 (Liquefaction of Air) → Air (77 % N_2) / Microbial denitrification
O_2 (Liquefaction of Air) → Air (21 % O_2) / Plant photosynthesis
NH_3 (Haber-Bosch Process) → Air (N_2)/natural gas major feedstocks
CO_2 (Steam Reforming)→ Natural gas major feedstock

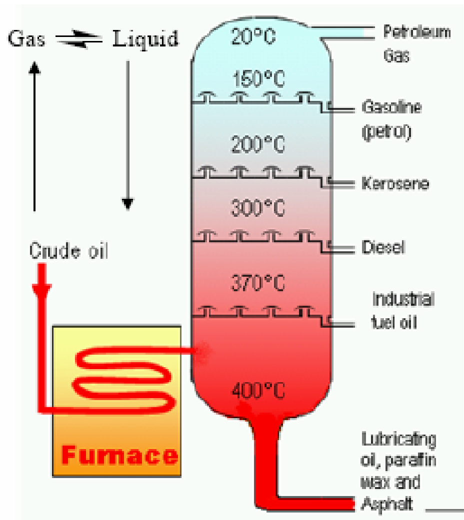
Catalytic Ozone Depletion



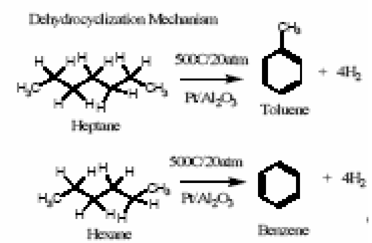


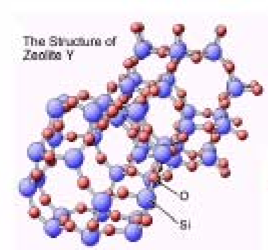


Crude Oil Refining

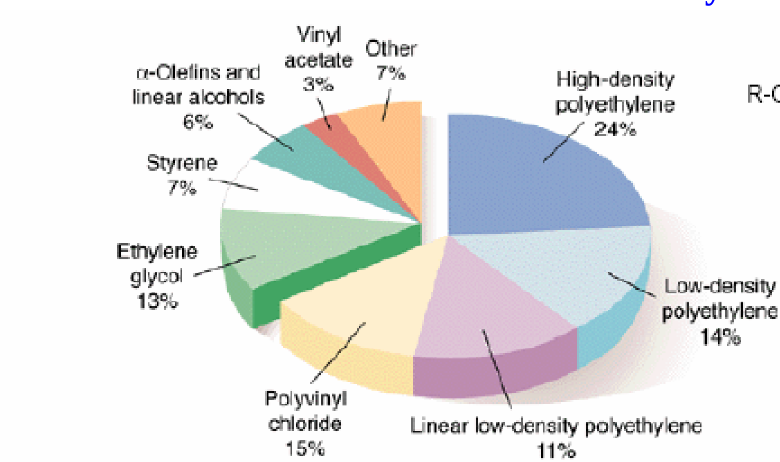


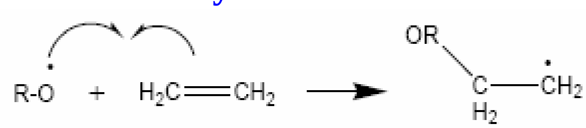
Vacuum Still: Heavy Fraction
0.01 atm → Energy efficient & less thermal decomposition

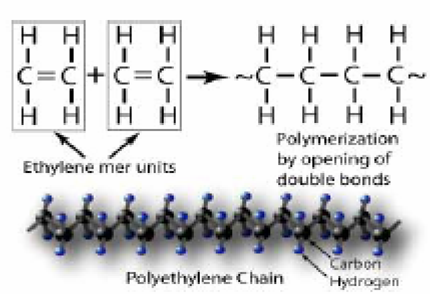




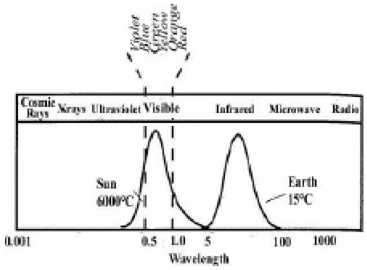
Industrial Polymer Chemistry

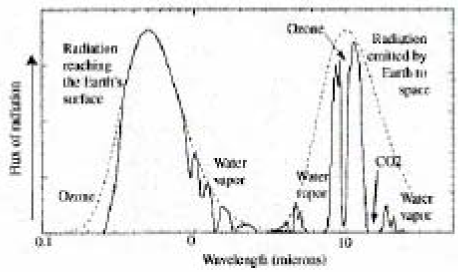


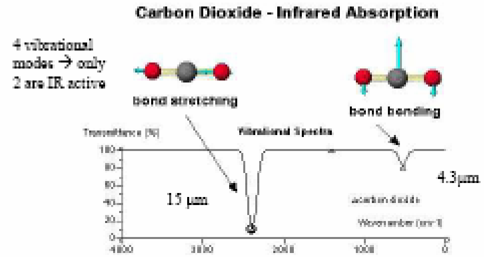


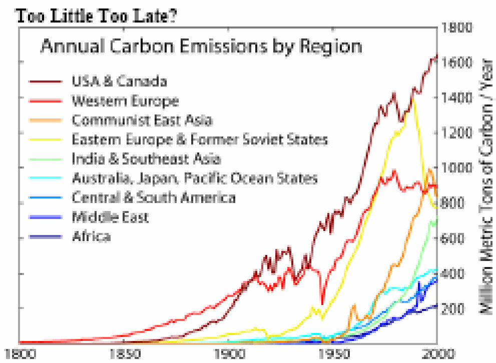


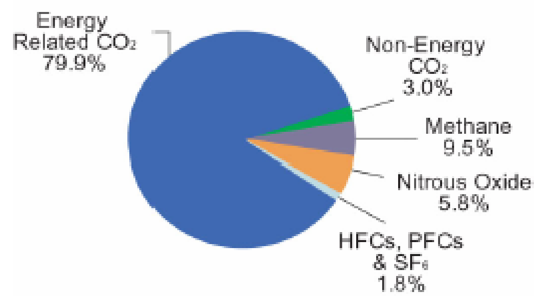
Enhanced Greenhouse Effect & Global Warming





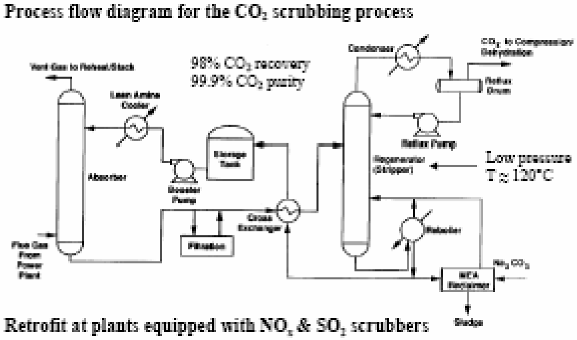






Chemical Processes for Industrial Emission Reduction

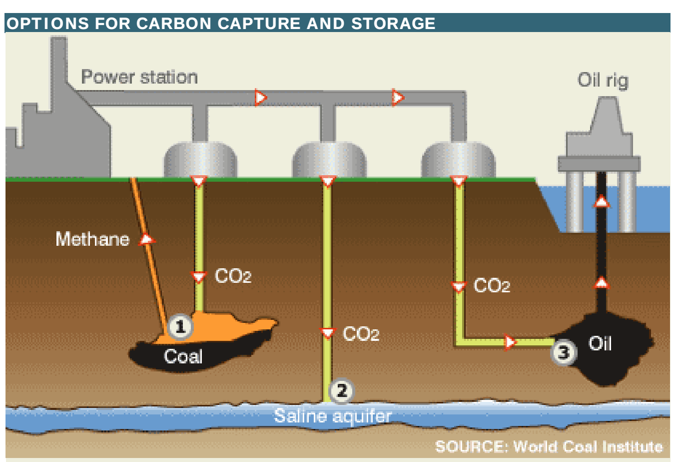
Process flow diagram for the CO_2 scrubbing process



Retrofit at plants equipped with NO_x & SO_2 scrubbers

Emissions from a Typical PF-fired Power Plant

Species	Amount emitted (kg/MWh)	Examples of control technology applied
CO_2	830	Amine scrubbers
$NO + NO_2$	2.16	Staging, low-NO_x burners, SCR, SNCR
SO_2	0.6	Wet and dry FGD processes
Particulates	0.1	Electrostatic precipitators, bag filters, cyclones, hot gas cleanup systems



1. CO2 pumped into disused coal fields displaces methane which can be used as fuel
2. CO2 can be pumped into and stored safely in saline aquifers
3. CO2 pumped into oil fields helps maintain pressure, making extraction easier