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.

<table>
<thead>
<tr>
<th>Industrial Chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Introduction</strong></td>
</tr>
<tr>
<td><strong>B. Major Inorganic Chemical Processes: Bulk Commodity Chemicals</strong></td>
</tr>
<tr>
<td>Industrial Gases:</td>
</tr>
<tr>
<td>Industrial Acids/Bases:</td>
</tr>
<tr>
<td><strong>C. Major Organic Chemical Processes: Fine Specialty Chemicals</strong></td>
</tr>
<tr>
<td>Fossil Fuels &amp; Petrochemicals:</td>
</tr>
<tr>
<td>Polymer Chemistry:</td>
</tr>
<tr>
<td>Major Commercial Products:</td>
</tr>
<tr>
<td><strong>D. Industrial Activity &amp; Environmental Impact: Challenges/Solutions</strong></td>
</tr>
<tr>
<td>Global warming, acid rain, smog, ozone depletion, eutrophication, toxic metals, carcinogens, endocrine-disrupting substances</td>
</tr>
</tbody>
</table>

• 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. 2nd, 2005.

Grading procedure

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

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

* 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](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 from 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 from the petrochemical industry, including polyethylene, polypropylene, polystyrene and polyethylene terephthalate. 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.
**Haber-Bosch Process**

Fe catalyst

\[
\begin{align*}
\text{N}_2 + 3\text{H}_2 & \rightleftharpoons 2\text{NH}_3 + \text{Heat} \\
\Delta H^\circ & = -46 \text{kJ/mol} \\
\Delta S^\circ & = -199 \text{J/K} \\
\Delta G^\circ & = -33 \text{kJ/mol}
\end{align*}
\]

"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 Buieck, Former ACS President

"Many of our technology related problems arise because of unforeseen consequences when apparently benign techniques are employed 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."

Melvre Krausenberg, Historian of Technology

**Sulphur Extraction & Claus Process**

Thermal Step

\[
\begin{align*}
\text{H}_2\text{S} (\text{g}) + 3/2 \text{O}_2 (\text{g}) & \overset{\text{1000C}}{\longrightarrow} \text{SO}_2 (\text{g}) + \text{H}_2\text{O} (\text{g}) \\
\text{SO}_2 (\text{g}) + 2\text{H}_2\text{S} (\text{g}) & \overset{\text{300C}}{\longrightarrow} 3\text{S} (\text{l}) + 2\text{H}_2\text{O} (\text{g})
\end{align*}
\]

Catalytic Step

ACIDS: H$_2$SO$_4$ (Claus/Contact Process) $\rightarrow$ S/H$_2$S (sour gas) major feedstock

H$_3$PO$_4$ (Wet Process) $\rightarrow$ Phosphate rock/H$_2$SO$_4$ major feedstocks

HNO$_3$ (Ostwald Process) $\rightarrow$ NH$_3$ (natural gas) major feedstocks

GASES: N$_2$ (Liquefaction of Air) $\rightarrow$ Air (77 % N$_2$) / Microbial denitrification

O$_2$ (Liquefaction of Air) $\rightarrow$ Air (21 % O$_2$) / Plant photosynthesis

NH$_3$ (Haber-Bosch Process) $\rightarrow$ Air (N$_2$)/natural gas major feedstocks

CO$_2$ (Steam Reforming) $\rightarrow$ Natural gas major feedstock
Catalytic Ozone Depletion

Crude Oil Refining

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

Industrial Polymer Chemistry

Polymerization by opening of double bonds
Options for Carbon Capture and Storage

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