Chapter 1

Introduction to the Chemical Industry

This chapter will serve to briefly describe the characteristics of the global chemical industry, to familiarize the reader with the names of the leading companies responsible for chemical production, and to provide a summary of the emergence of industrial organic chemistry.

1.1 The Chemical Industry

The international chemical industry can be thought of as the collection of chemical process industries responsible for the production of:

- Basic chemicals
- Fine and specialty chemicals
- Plastic and fibers
- Pharmaceuticals
- Paints and coatings

It is a high-skill, high-technology industry, requiring enormous investments in infrastructure, and hence a solid national infrastructure as well: favourable political/economic conditions, access to transportation and energy, and a technically-educated workforce. The chemical industry has the highest investment of current capital of *any* industry: although other industries invest more funds up-front, their risk of obsolescence is not as great, nor as rapid.

The chemical industry is driven by the basic rules of economy of scale: a company must invest a significant amount of capital to build large plants in order to minimize overhead and produce chemicals cheaply on a large scale. This can soon lead to alternating gluts and shortages: the market is flooded, prices fall, and less efficient plants are shut down (since they are no longer cost-effective). When the remaining supply is used up, the cycle begins again.

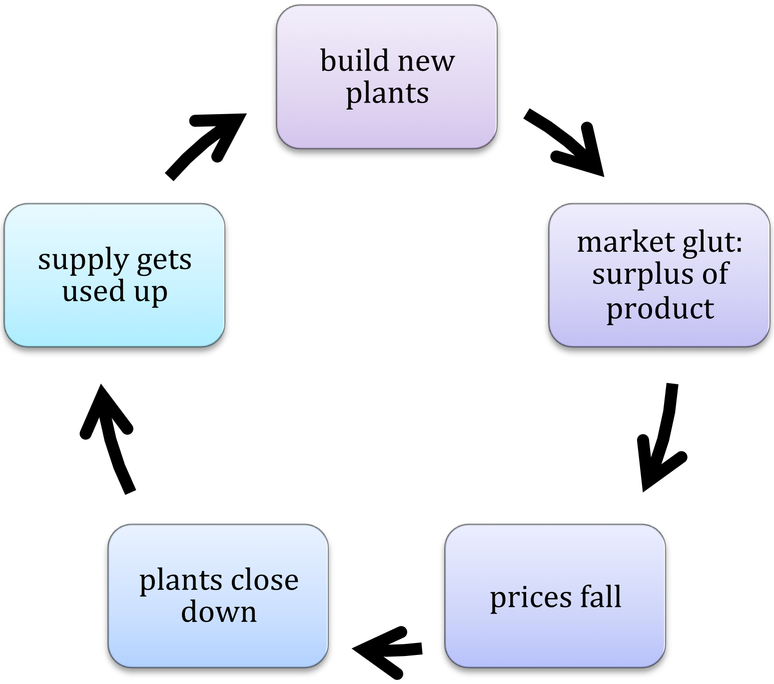


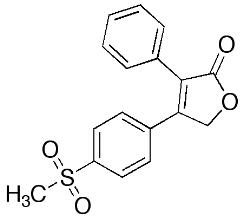
Figure 1.1. The economic cycle of the chemical industry.

To avoid this cycle, as in any industry, companies must then put some effort into improving existing technologies or developing novel ones. In the chemical industry, research and development (R&D) are a crucial factor in attaining and maintaining market prominence.

The chemical industry faces major risks, since market issues related to health or environmental issues can rapidly change the sales for products that take years of research to develop or where specialized plants were built with major capital investment. The three examples below illustrate risk in the chemical industry.

1.1.1 RISK AND CONSEQUENCES IN THE CHEMICAL INDUSTRY

(i) An Example of Market Risk: The Vioxx Withdrawal



Vioxx
Rofecoxib

On Sept. 30th, 2004, Merck voluntarily removed Vioxx, its arthritis and acute pain medication from shelves. During the course of an independent placebo-controlled clinical trial, it was found that patients taking daily doses of Vioxx experienced an increased risk of heart attack and stroke.

Launched in 1999, Vioxx has been marketed by Merck in over 80 countries, with worldwide sales of $2.5 billion in 2003. Following the withdrawal announcement, Merck predicted immediate losses of $700 million (in returned and unsold product). The pharmaceutical giant is still embroiled in the fallout, due to accusations concerning leaked internal documents suggesting it was aware of the problem significantly earlier. Merck has defended itself, stating that it delayed removal until the correlation was fully understood and documented. Nevertheless, numerous class action lawsuits are surfacing against Merck, and initial estimates of the ensuing legal costs range from $4 to $18 billion. Figure 1.2 shows the sudden drop in the value of Merck shares resulting from the withdrawal of Vioxx; it would take several years to recover from the impact of this decline in share value.

Figure 1.2. Decline in Merck shares value following the withdrawal of Vioxx.

(ii) MTBE from good to bad

Methyl-*tert*-butyl ether, or MTBE was introduced as a fuel additive in 1973; its effect is to increase the octane rating of gasoline, something we will study later in the course. MTBE was one of several oxygenated replacements for tetraethyl lead, a gasoline additive used for nearly 50 years starting in the 1920s. Tetraethyl lead was phased out in the 1970s because of the toxicity of lead and its deleterious effect on catalytic converters. MTBE was one of the fastest growing chemicals until environmental issues became and issue.

Local officials in Santa Monica, California had no idea they would trigger an international legal brawl when they sent their water out for routine testing in 1996 and discovered it contained the foul-smelling gasoline additive MTBE. At the time, some scientific research articles concluded that MTBE has carcinogenic properties, and it was subsequently banned in California in 2004 because of the perceived threat to humans and the water supply. Since then many other locations have banned MTBE and its sales have seen a massive decline (see Figure 1.3). In Canada the health regulatory agency, Health Canada, concluded that the odour of MTBE would make drinking water unacceptable to Canadians at concentrations much lower than those that may pose a health risk. As a result, an aesthetic objective of 0.015 mg/L has been established for MTBE in Canadian drinking water.[1] Today, MTBE is largely being replaced by ethanol, for which the US production increased by 450% between 2000 and 2008.

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[1] Health Canada (2006) Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Methyl Tertiary-Butyl Ether (MTBE). Water Quality and Health Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario

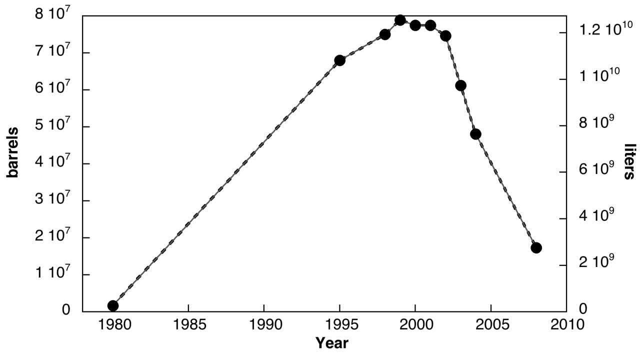

Figure 1.3. MTBE production over the years (USA data).

(iii) Acetonitrile shortages due to the Olympics and more

Acetonitrile provides an example of the relationship of globalization, balanced processes and the rational commercialization of by-products. Starting in October 2008, the worldwide supply of acetonitrile (extensively used in the pharmaceutical industry) was low because Chinese production had been shut down for the Beijing Olympics. Further, a U.S. factory was damaged in Texas during Hurricane Ike, leaving the plant in Lima, Ohio as virtually the only acetonitrile supplier for some time. Owing to the global economic slowdown, the production of acrylonitrile that is used in acrylic fibers and acrylonitrile-butadiene-styrene (ABS) resins decreased. Because acetonitrile is a by-product in the production of acrylonitrile,[2] its production also decreased. The combination of these factors led to a global shortage of acetonitrile that continued for nearly a year into Summer 2009, providing an example of how a sports event and a weather event could disrupt the manufacture of drugs and temporarily induce a dramatic increase in the price of a key solvent.

As noted above, research and development (R&D) are a crucial factor in attaining and maintaining market prominence R&D can be separated into to categories:

- *Basic research:* this research for a "technology push" is carried out without a specific goal in mind. When a breakthrough occurs, it is then developed and markets found to exploit it. This approach requires a long-term perspective: it may be more costly initially, but significant advances can lead to greater success. Successful technologies stemming from this type of research include television, sulfonamide drugs and lasers.

- *Applied research:* this is research resulting from a "demand pull", where a specific market need is identified. R&D is subsequently carried out to develop the required technology. Products which arose in this fashion from consumer demands include hardwater detergents, jets, and cars with low emissions (catalytic converters).

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[2] While there are a number of synthetic methods for the production of acetonitrile, none of these is employed by any commercial manufacturer. The reason for this is quite simple: acetonitrile is a byproduct of the synthesis of acrylonitrile ($CH_2=CHCN$), which is produced commercially by ammoxidation of propylene. The production of acrylonitrile is done almost exclusively by the Sohio process, and depending on the catalyst and detailed synthesis conditions about 2-3% of acetonitrile is also produced.

1.1.2 FROM R&D TO BUSINESS INCOME

Industry regularly invests a significant portion of their profits into R&D. For example, in 2009, the value of Canadian chemical shipments topped $47 billion (Figure 1.4). R&D spending as a share of revenue among the top 92 companies that reported revenue was 2.8% in 2010. In the year 2010, 22 companies in Canada spent over $100M in research; the top 10 are listed in Table 1.1.

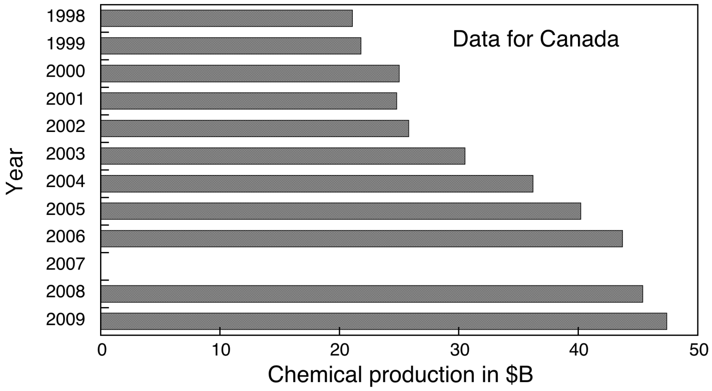


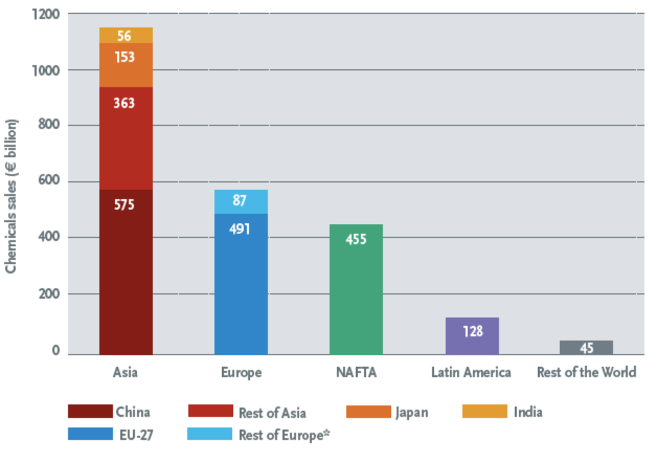
Figure 1.4. Canadian chemical shipments (billion of dollars).

Table 1.1: Top 10 companies in the “100 million dollar club” in Canada in 2010.[#]

2010 Rank	Company	Industry
1	Research In Motion	Comm/Telecom Equipment
2	BCE	Telecommunications Services
3	IBM Canada (fs)	Software & Computer Services
4	Atomic Energy of Canada	Engineering Services
5	Magna International	Automotive
6	Pratt & Whitney Canada (fs)	Aerospace
7	Ericsson Canada (fs)	Comm/Telecom Equipment
8	AMD Canada (fs)	Electronic Systems & Parts
9	Alcatel-Lucent (fs)	Comm/Telecom Equipment
10	Bombardier	Aerospace

[#] Source: RE$EARCH Infosource Inc. 2011
fs = Foreign subsidiary

To put this in perspective, Figure 1.5 gives the world distribution of chemical sales in 2010. Note that Asian chemicals production equals that of Europe plus America. The largest Canadian company is Potash Corp. with sales just under $10B in 2009.



World chemicals sales in 2010 are valued at € 2353 billion. The EU accounts for 21% of the total.

Figure 1.5. World chemicals turnover was valued at €2353 billion for 2010.[3]
Data given in Euros: 1 Euro ~ CAN $1.33

In an era of increasing globalization, foreign trade has become more important than ever to the chemical industry. As a result, intense competition is increasingly widespread in the chemical industry. Certain other factors also fuel this competition, including:

- *Transportation*: decreasing costs and increasing availability of around-the-globe shipping makes large international trade feasible
- *Larger Plant Operations:* larger plants help minimize manufacturing costs, leading to large production volumes (thus requiring an export market)
- *Diversity:* variety in products, as well as the manufacturing processes themselves, with different companies specializing in each product or process, depending on their access to specific precursors or proprietary technology – for example, there are 6 different industrial syntheses of acrylic acid and 5 for phenol!
- *Patent System:* patented technology or processes are proprietary, and must be licensed from the company holding the patent. After this period, technology is “open-use” for all, thus inspiring a new R&D push

As we shall see in the upcoming chapters, the feedstocks for all of the chemical industry are coal, natural gas, and petroleum. As a consequence, profits are indelibly linked to the prices and availability of these starting materials, and are constantly working to develop new processes to maximize efficiency.

Table 1.2 below lists some of the world’s largest chemical companies and their typical annual profits. You may recognize some of these names, while others may seem unfamiliar. These companies and many others are responsible for the production of the chemical materials needed for the manufacture of thousands of goods.

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[3] Source: Facts and Figures 2011. The European chemical industry in a worldwide perspective, CEFIC 2011.

Table 1.2. A Selection of Some of the World's Largest Chemical Companies.

Company	Country	Chemical Sales ($M)
Dow Chemical	USA	46,307
Agrium	Canada	3,491
DuPont	USA	28,114
BASF	Germany	53,207
Nova Chemicals	Canada	5,616
ExxonMobil	USA	31,186
Solvay	Belgium	10,655
Rohm and Haas	USA	7,064
Azko Nobel	Netherlands	16,179
Bayer	Germany	34,078
Mistubishi Chemicals	Japan	21,878
Ciba Specialty Chemicals	Switzerland	5,955
BOC International	United Kingdom	8,383
ICI	United Kingdom	10,580

From: Chemical & Engineering News, **July 10, 2006**.
Sales are in millions of US dollars.

The industry has over $2 trillion in annual sales, playing a supportive role to virtually all other industries, providing the building blocks necessary to the manufacture of all the products used in daily life. In the upcoming chapters, we shall see just how vital the chemical industry truly is!

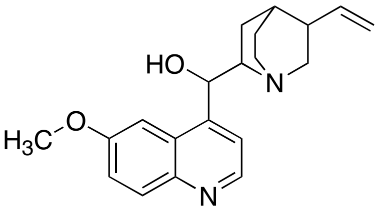
1.2 The Emergence of Industrial Organic Chemistry

Up until around 1850, the chemical industry was essentially concerned with *inorganic* products, such as ammonium nitrates, sulfuric acid, and sodium carbonate, and was largely controlled by France and England. At the time, "organic chemistry", as it came to be known by the end of the century, was primarily occupied with elucidating the structure of simple hydrocarbons. Today, the development of the dyestuff industry, specifically William Perkin's discovery of coal tar dyes, is recognized as the origin of the *organic* chemical industry.

1.2.1 ORGANIC CHEMISTRY IN THE 19TH CENTURY

In 1853, at the age of 15, William Perkin joined the Royal College of Chemistry in London. Perkin studied under the tutelage of August Wilhelm Hofmann, a German who had joined the institute in 1845. Hofmann had obtained a doctorate studying the chemistry of coal tar and its derivatives, and imparted his knowledge to his many notable pupils. In particular, he challenged Perkin to devise a synthetic route to quinine, an expensive natural extract used to treat malaria.

At the time, the rapid growth of the gas lighting industry (see Chapter 4) had left large amounts of waste products in the form of coal tar. This residue could be separated through distillation and crystallization into benzene, toluene, and xylene derivatives, as well as anilines and phenols. Industrial uses for these compounds were soon discovered. For example, phenol (then known as carbolic acid) became popular as a disinfectant, thanks to appearance of germ theory and the rise in personal hygiene.

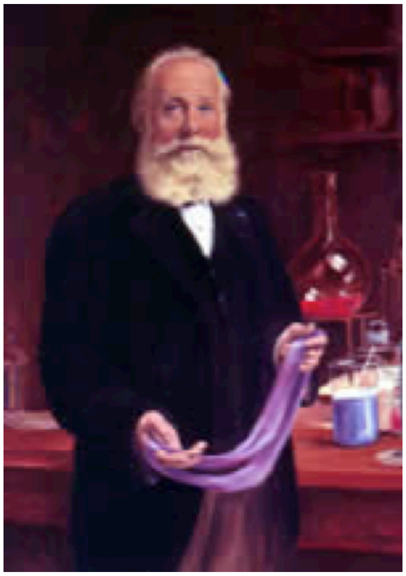


Scheme 1.1. The structure of quinine, an anti-malarial agent.

Despite the application of many of these compounds, experimentalists knew nothing of structure, only chemical formulas reasoned from careful and elaborate chemical analysis. Thus, Perkin believed that he could make quinine ($C_{20}H_{24}N_2O_2$) through reaction of two molecules of "aniline" (later discovered to be allyl toluidines, $C_{10}H_{13}N$, see box below) with potassium dichromate. In 1865, while Hofmann was away in Germany, Perkin performed his experiments in his simple laboratory in his apartment. To his dismay, he obtained a dark crude mixture. However, when extracted with alcohol, he found it gave a solution with an intense purple colour. Perkin, who dabbled in painting and photography, was intrigued with the results, and carried out further experiments with his colleague Arthur Church and his brother Thomas. They performed these investigations in secret, since it deviated away from Hofmann's quinine project, and soon found that silk stained with this colour was stable to washing and light.

Perkin had prepared the first synthetic dye, a brilliant purple compound later called *mauveine.* Previously, bright colours were inaccessible to ordinary people due to their high cost: all dyes or pigments came from natural sources such as insects, barks, flowers, berries, animal organs, and eggs. In particular, purple colours were very expensive and so had been associated with royalty and prestige since ancient times. Dyes and pigments were a huge industry: for example, in 1856, over 75,000 tonnes of natural dye materials were imported into Britain. Perkin thus quickly realized the commercial potential of his discovery.

In spite of Hofmann's objections (who likely believed he was too young to leave academia and start his own business) Perkin applied for a patent at the age of 18, and along with his father and brother, built a factory at Harrow and began large scale production of his dye.



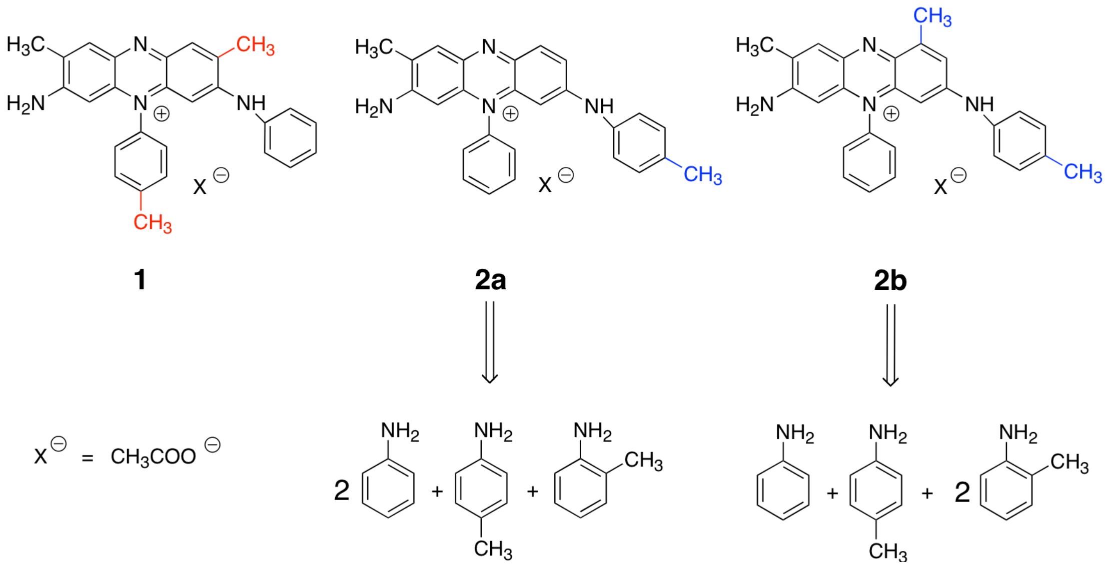
William H. Perkin

Due to the enormous demand, mauveine was a huge hit, sparking intense research into coal tar derivatives and making Perkin a rich man. Although it was not, in fact, the first synthetic dye (the French were already making purple colours from murexide derivatives made from uric acid and nitric acid), Perkin's discovery is usually cited as the "birth" of the organic chemical industry because it was the first reaction to be scaled up dramatically while keeping it relatively safe. The breakthrough of mauveine showed how scientific discovery could be directly applied to the marketplace, and that chemists could become successful businessmen.

The debate over mauveine

When William Perkin attempted to make quinine by the oxidative dimerization of "aniline" with potassium dichromate, he obtained a black powder from which he extracted a purple dye that was subsequently named mauveine. However, the aniline was derived from a crude coal tar and thus contained impurities, such as a high content of toluene. For years, the accepted structure of mauveine was that of the acetate salt of **1**, yet no rigorous structural analysis was performed to confirm this.

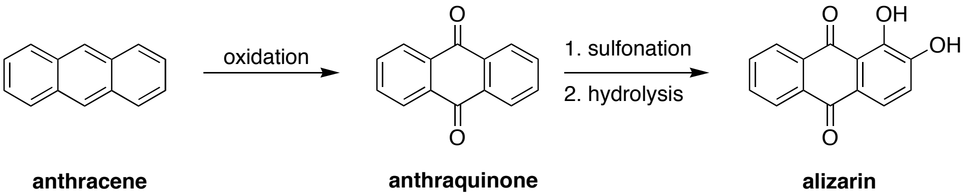
The true structure was not elucidated until 1994, when O. Meth-Cohn and M. Smith (University of Sunderland, UK) obtained a historical sample of mauveine prepared by Perkin's factory. It was found that the dye Perkin had discovered was actually a mixture of two components, **2a** and **2b**. The authors reasoned that the original crude mixture had produced toluidines, which combined with aniline to form the two components, as shown below in the retrosynthetic analysis.



J. Chem. Soc. Perkin Trans. 1, **1994**, *1*, 5-7

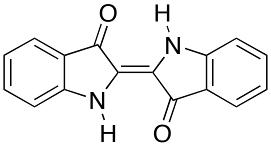
Unfortunately, the early British and French advantage in dyestuffs was quickly dissipating, as German chemists made significant headway in coal tar research. Some historians refer to the synthesis of alizarin as the turning point in the industry. Unlike Perkin's accidental discovery, the route to alizarin was a systematic effort to produce a specific colour (red) based on structural knowledge available at the time.

The natural source of red dye was the root of the madder plant, and in the nineteenth century a healthy industry thrived on its cultivation. In the 1860s, the molecule responsible for this colour, alizarin, was extracted from the madder plant and analyzed. Soon a synthetic route was devised using coal tar derivatives as starting materials: anthracene was oxidized to anthraquinone, which could then be hydrolyzed to alizarin. This route was established simultaneously by Perkin and two German chemists working for BASF, Carl Graeme and Carl Liebermann. Unfortunately for Perkin, who had patented his process on June 26th, 1869, BASF patented the German synthesis less than 24 hours earlier, on June 25th. As a result, Perkin and the British missed out on the lucrative market for red dyes, giving the Germans the advantage in the dyestuff industry. Synthetic alizarin had an immediate and enormous economic impact: the market for madder root collapsed virtually overnight and madder farmers were devastated.



Scheme 1.2. Industrial synthesis of alizarin, the red dye found in the madder plant.

Germany permanently secured the lead with their development of indigo, the so-called "king of the dyestuffs". The first synthetic route to this brilliant blue compound was discovered by BASF's Adolf Baeyer in the late 1870s. However, it was not produced on an industrial scale until 1897. The development of indigo was a combination of vision, risk-taking and systematic investigation by professional chemists. BASF had the prestige of the first calculated synthesis and structural elucidation of a complex organic molecule. When success seemed certain, BASF invested millions into the construction of indigo factories – by 1900, five German plants and one Swiss plant were in production. Meanwhile, British firms remained ignorant of the indigo process up until WWI. Although this may due to failed industrial espionage, it is more likely due to a lack of vision: British investors were simply too busy protecting their interests in the highly profitable natural indigo trade. Indigo was thus the final nail in the coffin for British and French prominence in the dyestuff industry.



Scheme 1.3. The structure of indigo, the primary colouring agent for blue jeans.

A number of reasons have been offered to explain the British and French decline, which by 1868 was already evident. In the nineteenth century, instruction in chemistry in Britain was usually reserved as a pursuit for well-to-do gentlemanly scholars with private laboratories. Meanwhile, the Germans focussed instead on training chemistry students in public labs with enthusiastic professors. Around 1825, Justus von Liebig established a chemistry institute at Giessen, where the curriculum was strongly weighted towards organic chemistry and a systematic, scientific approach was taken to organic synthesis. Following Liebig's success, institutes proliferated throughout Germany, attracting hundreds of British and American students. In fact, it had been Perkin's mentor Hofmann (who had studied under Liebig himself) who brought the German model of teaching through laboratory instruction to London in 1845.

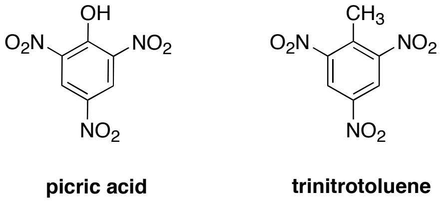
Unlike British competitors, Hofmann's German colleagues understood that, once the theory of chemical structure had been elucidated by Kekulé, the secret to successful industry lay in continuous research and a collaborative relationship with academia. British chemists generally lacked long-term financial support for their research – investors only followed projects which showed immediate returns, and were extremely reluctant to establish and fund permanently staffed, well-equipped research labs, a feat which BASF had already achieved in the 1870's.

Meanwhile, France had its own difficulties: according to French patent law, only the product could be patented, regardless of the manufacturing process. Consequently, competitors left and set up factories elsewhere in Switzerland and Germany. In addition, all of its coal supplies had to be imported, driving down possible profits. As a result, France was left behind along with Britain, leaving Germany as the uncontested leader in dyestuffs.

From 1870-1900, German chemists created world markets in dyes, synthetic perfumes, drugs, photographic chemicals, and explosives. By the turn of 20th century, Germany was widely acknowledged to be far ahead of other nations in number of trained chemists and published papers, and six German companies dominated world production and distribution of synthetic dyestuffs. Their *modus operandi* of having in-house research teams consulting with members of academia soon became the working model for many chemical manufacturing firms. Basic and applied research thrived, and the field of chemical engineering emerged to adapt the chemist's reaction in the laboratory to large-scale manufacture.

1.2.2 THE 20TH CENTURY AND THE WORLD WARS

Technological advances abounded in the early 1900s, due in part to the continued dedication to research. With the onset of World War I, however, the focus of operations was shifted to supply wartime needs, spurring research in synthetic alternatives for valuable, and sometimes inaccessible, commodities. WWI came to be known as the "chemist's war": their principal job was large-scale production of explosives, and by 1915, poisonous gases. The British and French industries developed picric acid-based explosives, while the Germans favoured trinitrotoluene (TNT), thanks to their superior coal-tar industry.



Scheme 1.4. Explosive materials introduced in World War I

Following Germany's defeat in WWI, the 6 major German chemical companies formed a cartel known as I.G. Farben ("Community of Interest") in order to reduce competition. These companies were BASF, Bayer, Hoechst, AGFA, Cassella and Kalle. By joining together, they consolidated financial gains and technical expertise, developing processes which exploited their abundant sources of coal and coal-derived products.

Over the next 20 years, I.G. Farben products dominated the world markets and a series of discoveries ensued: lubricating oil, synthetic gasoline, synthetic rubber, dyes, nitrogen, ammonia, explosives, synthetic silks, photographic materials, fertilizers, and pharmaceuticals such as Salvarsan, Novocaine, aspirin, heroin, and sulfa drugs. In addition, numerous Nobel Prizes were won by its scientists.

In the meantime, those countries that had fallen behind were struggling to catch up. For example, German technology was either bought or expropriated by the U.S. government after WWI and then resold to American chemical companies to boost the local markets. By then, petroleum had been recognized as a valuable alternative to coal as a source for organic compounds and fuels. Worldwide efforts were directed towards finding substitutes for key materials, such as rubber, to combat shortages and ensure each nation’s autonomous supply. WWII accelerated this research, spawning discoveries such as synthetic rubbers, nylons and plastics, high-octane fuels, and of course, nuclear devices.

When WWII ended, those chemical companies dedicated to the mass production of materials found themselves with surpluses of products and professional chemists and chemical engineers. Then, in the following decades, an explosion of polymers occurred, replacing traditional materials like steel, glass, and wood and inspiring new research.

Today, the chemical industry has moved into fine chemicals and value-added products, such as silicon wafers for computer chips and high-performance polymers. However, increasing environmental awareness has led the industry to investigate sources other than fossil fuels for starting materials and industrial processes which are not harmful to the environment, a new field now known as “Green Chemistry”.

1.2.3 FOSIL FUELS DRIVE THE WORLD ECONOMY, BUT ALSO CLIMATE CHANGE

Fossil fuels, particularly petroleum, are major determinants of the progress of nations and the quality of life its citizens enjoy; their prices control market trends, influence the stability of governments and countries and are international stress factors that challenge global peace. The wise (or unwise) use that we make of these valuable resources will determine how long known reserves will last and how sustainable their use will be. Unfortunately, there is already evidence that their extensive usage as fuels is a contributor to increasing atmospheric CO_2 levels and as a consequence to global warming.

This book deals mainly with the chemistry of petroleum. For example, we assume that crude oil has already been extracted; that is, the extraction technologies and the methods leading to the discovery of new reserves are not part of our coverage. However, we do recognize that the different origins also determine the detailed chemical composition, and therefore the chemical reactions that are required to obtain the compounds that will meet market demands.

The ‘road map’ in this book will therefore take us from crude oil to fuels and basic feedstocks, those key molecules required by the chemical industry to make most of the synthetic products that we use in homes, clothing, communications and transportation, among many other uses. Many of these molecules are polymers (plastics), fibers, detergents, etc. In some cases it is important for these products to be robust and durable; in others, durability becomes the source of environmental concerns and degradability (e.g., biodegradation) is regarded as an asset. Whenever degradation is involved, understanding the new products formed in the process, and their potential environmental impact is essential. We will cover stories of chemicals introduced, used and later withdrawn as their health and environmental consequences became evident.

We have paid special attention to combustion, the subject of Chapter 5. It is unfortunate that our main use of fossil fuels is to convert them into CO_2 and water in order to meet our energy requirements; indeed, the most important reaction in all of organic chemistry is in fact combustion, and the organic reactions that account for the largest volume of organic transformations are those used to enhance the performance of fuels for internal combustion engines. While environmental chemistry is not the main topic of this book, we feel that it is important for readers to have at least an overview of how the chemistry of petroleum, which is many respects is an unfortunate measure of our quality of life, also contributes to long term environmental problems and how some of these could be reduced. Table 1.3 summarizes the total world reserves of different fossil fuels and their annual exploitation. The ration of the two numbers gives an idea of the number of years of reserves left if no additional reserves were discovered, and if the rate of production/consumption remained constant.

Table 1.3. Carbon content in Gigatons of known reserves and annual exploitation (2005).

Fossil fuel	World reserves	Annual production
Coal	678	3.2
Petroleum	146	3.6
Natural gas	98	1.5

There are three strategies that may be followed to decrease the level of CO_2 emissions, widely accepted as one of the main origins of climate change, they are:

- Reduce the amount of energy used, through conservation, increased efficiency, or both.
- Use energy resources that do not generate CO_2, such as wind, nuclear energy, solar energy or hydroelectric power.
- Capture CO_2 directly at the point of use of fossil fuels (referred as CO_2 sequestration) or at a later stage, and store it or convert it into materials that will not release CO_2 or other carbon forms to the atmosphere.

Interestingly, a century ago, in 1912, Giacomo Ciamician in Bologna, sometimes referred as the father of solar energy research, pointed out "*The photochemistry of the future should not however be postponed to such distant times; I believe that industry will do well in using from this very day all the energies that nature puts at its disposal. So far, human civilization has made use almost exclusively of fossil solar energy. Would it not be advantageous to make better use of radiant energy?*". Indeed it is useful to view fossil fuels as simply a form of storage for solar energy; from this perspective the solar energy received by Earth one hour exceeds the world energy usage in one year, and this is resource that will not be exhausted in the foreseeable future and that does not release CO_2 into the atmosphere!

In fact, along the same lines, Henry Ford predicted "*I foresee the time when industry shall no longer denude the forests which require generations to mature, nor use up the mines which were ages in the making, but shall draw its materials largely from the annual produce of the fields*". As we see a trend toward biofuels, we may not be far from seeing this prediction come true, at least in part.

Canada has the third largest oil reserves in the world. Canada has 175 billion barrels of oil that can be recovered economically with today's technology. Of that number, 170 billion barrels are located in the oil sands. Oil sands are a natural mixture of sand, water, clay and bitumen. Bitumen is oil that is too heavy or thick to flow or be pumped without being diluted or heated. Some bitumen is found within 200 feet from the surface but the majority is deeper underground. About 20% is close enough to the surface to be mined with mining shovels and trucks. Many environmental issues related to oil sands have been in the news in recent years.[4]

Figure 1.6. Location of oil sand resources in Canada.

In the upcoming chapters, we shall examine how the three main carbon feedstocks – coal, natural gas, and petroleum – are converted into useful starting materials, and then how these are transformed into the myriad of products encountered in our everyday lives.

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[4] Canadian Association of Petroleum Producers "The Facts on Oil Sands 2011",

1.3 For further reading

F. Aftalion A *History of the International Chemical Industry: From the "Early Days" to 2000;* Chemical Heritage Press: Philadelphia, PA, 2001.

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Science magazine, issue of February 9, 2007, dedicated to Sustainability and Energy.

Canadian Association of Petroleum Producers “The Facts on Oil Sands 2011”, October 2011.

1.4 Study Questions

1) Approximately how long does patent protection last? 1 year, 10 years, 20 years, 50 years, 100 years?

2) If you publish or make information public, you can lose your right to patent an invention. True or false? Explain.

3) Describe the differences between basic and applied research, and give examples for each.

4) Check out some of the major Canadian chemical companies that currently trade on the Toronto Stock Exchange (e.g. Potash, Agrium, Methanex, etc.) Which would currently be the best investment and why? Do chemical companies make better short-term or long-term investments?

5) What is the formula of "carbolic acid"? Investigate some of the other early products of the organic chemical industry.

6) List some reasons why British scientists lost their early lead in industrial organic chemistry.

7) Look up the history of I.G. Farben. What happened to this cartel? Which participating companies still exist today?

8) How much has atmospheric CO_2 increased since before the industrial revolution? (Hint: you can use the year 1800 as your reference point) What are the sources of the additional CO_2?