Welcome!

You have found the permanent home for the History of Chemical Engineering web site. This site was activated on September 18, 2000. We are very happy to have a new web home and hope you enjoy it! Please let us know what you think.

Also, we are now willing to accept supplementary materials. If you have something that you think our visitors would find enjoyable and informative please let us know. We will consider placing it online...

-Wayne Pafko

You can also view our content at three mirror sites:

1) History of Chemical Engineering mirrored by Minnesota's Chemical Engineering Department

2) History of Chemical Engineering mirrored on Homestead.com

3) History of Chemical Engineering mirrored at Tripod.com

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History of Chemical Engineering

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pafko.com/history/

Introduction & Overview!

Welcome to our **History of Chemical Engineering & Chemical Technology**.

Our goal is to bring you a history of chemical engineering that encompasses its **conceptual origins in Great Britain**, subsequent **struggle for survival** in the **United States**, and concludes with a cornucopia of **contributions** made in this Century.

Along the way, many **tables and figures** help illustrate the **growth and change** in the **chemical industry**, the **chemical engineering profession**, and its **educational infrastructure**.

Some questions we hope to examine **include**:

What is chemical engineering?

How, and why, did chemical engineering develop?

What obstacles did the profession face and overcome?

What contributions have chemical engineers made?

How has the profession grown and changed over the last Century?

While the following documents cover a fair amount of ground, it is important to keep in mind that this is **only a brief tour** of this topic which **leaves many important events untouched**. If you find our short history interesting and informative we hope you will **continue to explore the subject**, as there are **many excellent sources available**. In any case, we hope to hear your **reactions**, **comments**, and **suggestions**.

-Wayne Pafko

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Welcome

What is Chemical Engineering?

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WORLD WIDE WEB

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Comments and Suggestions

We hope you have enjoyed this web site. Thank you for continuing to help us improve it. All of your **comments**, **suggestions**, **praise**, and **snide remarks** are **greatly appreciated**....**keep them coming**!

-Wayne Pafko

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or, Send a Comment via E-Mail to:

Wayne Pafko (pafko@excite.com) "The Author"

About the Author

Wayne M. Pafko (Dec. 31, 1973 - Present)

The author holds a B.S. degree in chemical engineering from the **University of Minnesota** (1997). He is presently working in food product development for the **Procter & Gamble** Company in Cincinnati, Ohio. Previous positions have included a technical aide position at 3M, summer internship at AlliedSignal Laminate Systems, and co-owner of Cedar Lake Software (a small shareware software publisher). This web site (a history of chemical engineering targeted primarily at high school and college students) was initiated as a special project during an introductory class on the history of science and technology at the University of Minnesota. It has since grown into one of the most popular chemical engineering web sites, and provides a good introduction to what the profession is all about.

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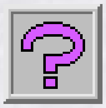
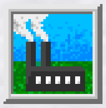
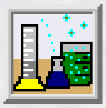


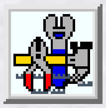
What is a Chemical Engineer?



a) An *Engineer* who manufactures chemicals,



b) A *Chemist* who works in a factory, or

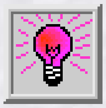


c) A glorified *Plumber*?

This is actually a trick question as the correct answer is **d) "None of the above."** (Note however that chemical engineering students bored with the relentless "pipe-flow example" during fluid dynamics class may begin to think of themselves as simply "glorified plumbers".)

The first two incorrect answers make sense based upon the narrow sounding title; "chemical engineer." Surely such a person must be either a "chemist who builds things", or an "engineer who makes chemicals". Yet, the English language has never really made any sense and the name "chemical engineer" is a case in point.

"Enough already...go to the bottom."



All Right, So What is a Chemical Engineer?

It is true that chemical engineers are **comfortable with chemistry**, but they do much more with this knowledge than just make chemicals. In fact, the **term "chemical engineer"** is not even intended to describe the type of work a chemical engineer performs. Instead it **is meant to reveal what makes the field different** from the **other branches of engineering**.

All **engineers employ mathematics, physics, and the engineering art to overcome technical problems in a safe and economical fashion**. Yet, it is the chemical engineer alone that draws upon the vast and powerful science of chemistry to solve a wide range of problems. The strong technical and social ties that bind chemistry and chemical engineering are unique in the fields of science and technology. This marriage between chemists and chemical engineers has been beneficial to both sides and has rightfully brought the envy of the other engineering fields.

The breadth of scientific and technical knowledge inherent in the profession has caused some to describe the chemical engineer as the "**universal engineer**." Yes, you are hearing me correctly; despite a title that suggests a profession composed of narrow specialists, chemical engineers are actually extremely versatile and able to handle a wide range of technical problems.

So What Exactly Does This "Universal Engineer" Do?

During the past Century, chemical engineers have made tremendous contributions to our standard of living. To celebrate these accomplishments, the American Institute of Chemical Engineers (AIChE) has compiled a list of the "**10 Greatest Achievements of Chemical Engineering.**" These triumphs are summarized below:

The Atom, as Large as Life:

Biology, medicine, metallurgy, and power generation have all been revolutionized by our ability to **split the atom** and **isolate isotopes**. Chemical engineers played a prominent role in achieving both of these results. Early on facilities such as DuPont's Hanford Chemical Plant used these techniques to bring an abrupt conclusion to **World War II** with the production of the atomic bomb. Today these technologies have found uses in more peaceful applications. **Medical doctors** now use isotopes to monitor bodily functions; quickly identifying clogged arteries and veins. Similarly **biologists** gain invaluable insight into the basic mechanisms of life, and **archaeologists** can accurately date their historical findings.

The Plastic Age:

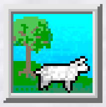
The 19th Century saw enormous advances in **polymer chemistry**. However, it required the insights of chemical engineers during the 20th Century to make mass produced polymers a viable **economic reality**. When a plastic called **Bakelite** was introduced in 1908 it sparked the dawn of the "Plastic Age" and quickly found uses in electric insulation, plugs & sockets, clock bases, iron cooking handles, and fashionable jewelry (see OIL). Today plastic has become so common that we hardly notice it exists. Yet nearly all aspects of modern life are positively and profoundly impacted by plastic.

The Human Reactor:

Chemical engineers have long studied complex chemical processes by breaking them up into smaller "**unit operations.**" Such operations might consist of heat exchangers, filters, chemical reactors and the like. Fortunately this concept has also been applied to the human body. The results of such analysis have helped improve **clinical care**, suggested improvements in **diagnostic and therapeutic devices**, and led to mechanical wonders such as **artificial organs**. Medical doctors and chemical engineers continue to work hand in hand to help us **live longer fuller lives**.

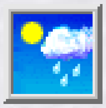
Wonder Drugs for the Masses:

Chemical engineers have been able to take small amounts of **antibiotics** developed by people such as Sir Arthur Fleming (who discovered penicillin in 1929) and **increase their yields** several thousand times through **mutation** and special **brewing** techniques. Today's **low price, high volume,** drugs owe their existence to the work of chemical engineers. This ability to bring once scarce materials to **all members of society** through industrial creativity is a defining characteristic of chemical engineering (see Plastics above, Synthetic Fibers, Food, and Synthetic Rubber below).



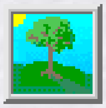
Synthetic Fibers, a Sheep's Best Friend:

From blankets and clothes to beds and pillows, synthetic fibers keep us **warm**, **comfortable**, and provide a **good night's rest**. Synthetic fibers also help **reduce the strain** on natural sources of **cotton and wool**, and can be tailored to specific applications. For example; **nylon stockings** make legs look young and attractive while **bullet proof vests** keep people out of harm's way.



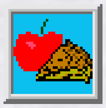
Liquefied Air, Yes it's Cool:

When air is cooled to very low temperatures (about **320 deg F below zero**) it condenses into a liquid. Chemical engineers can then separate out the different components. The purified **nitrogen** can be used to recover petroleum, freeze food, produce semiconductors, or prevent unwanted reactions while **oxygen** is used to make steel, smelt copper, weld metals together, and support the lives of patients in hospitals.



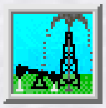
The Environment, We All Have to Live Here:

Chemical engineers provide **economical answers** to clean up yesterday's **waste** and prevent tomorrow's **pollution**. **Catalytic converters**, reformulated **gasoline**, and smoke stack **scrubbers** all help keep the world clean. Additionally, chemical engineers help reduce the strain on natural materials through **synthetic replacements**, more **efficient processing**, and new **recycling** technologies.



Food, "It's What's For Dinner":

Plants need large amounts of **nitrogen**, **potassium**, and **phosphorus** to grow in abundance. Chemical **fertilizers** can help provide these nutrients to crops, which in turn provide us with **a bountiful and balanced diet**. Fertilizers are especially important in certain regions of Asia and Africa where food can sometimes be scarce (See NITROGEN). Advances in **biotechnology** also offer the potential to further increase worldwide food production. Finally, chemical engineers are at the forefront of **food processing** where they help create better tasting and most nutritious foods.



Petrochemicals, "Black Gold, Texas Tea":

Chemical engineers have helped develop processes like **catalytic cracking** to **break down** the complex organic molecules found in crude oil into much simpler species. These **building blocks** are then separated and recombined to form many useful products including: **gasoline**, **lubricating oils**, **plastics**, **synthetic rubber**, and **synthetic fibers**. Petroleum processing is therefore recognized as an **enabling technology**, without which, much of modern life would cease to function (see OIL).

Running on Synthetic Rubber:

Chemical engineers played a prominent role in developing today's synthetic rubber industry. During **World War II**, synthetic rubber capacity suddenly became of paramount importance. This was because modern society runs on rubber. **Tires**, **gaskets**, **hoses**, and **conveyor belts** (not to mention **running shoes**) are all made of rubber. Whether you drive, bike, roller-blade, or run; odds are you are running on rubber.

Chemical Engineering Today & Tomorrow

The "**Big Four**" engineering fields consist of **civil, mechanical, electrical, and chemical engineers.** Of these, **chemical engineers** are **numerically** the **smallest** group. However, this relatively small group holds a very prominent position in many industries, and chemical engineers are, on average, the **highest paid** of the "Big Four" (see WAGES). Additionally, many chemical engineers have found their way into **upper management**. A chemical engineer is either currently, or has previously, occupied the CEO position for**: 3M, Du Pont, General Electric, Union Carbide, Dow Chemical, Exxon, BASF, Gulf Oil, Texaco, and B.F. Goodrich**. Even a former director of the **CIA**, John M. Deutch, was a chemical engineer by training.

More typically, chemical engineers concern themselves with the chemical processes that turn **raw materials into valuable products**. The necessary skills encompass all aspects of design, testing, scale-up, operation, control, and optimization, and require a detailed understanding of the various "**unit operations**", such as distillation, mixing, and biological processes, which make these conversions possible. Chemical engineering science utilizes **mass, momentum, and energy transfer** along with **thermodynamics** and **chemical kinetics** to analyze and improve on these "unit operations."

Today there are around **70,000 practicing chemical engineers** in the United States (57,000 of these are AIChE members) (see AIChE MEMBERSHIP). During the entire **history of the profession** there have been only about **135,000 American chemical engineers** (including those alive today). This means that **more than a half** of all the chemical engineers who have ever existed are **contributing to society right now**! Chemical engineering is not a profession that has to dwell on the achievements of the past for comfort, for its greatest accomplishments are yet to come.

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Introduction

Setting the Stage (1888)

"The end already...go back to the top."

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This page was last updated on September 18, 2000 by Wayne Pafko...

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pafko.com/history/h_whatis.html

Setting the Stage for a New Profession, Chemical Engineering in 1888.

For all intents and purposes the **chemical engineering** profession **began in 1888**. While, the term "chemical engineer" had been floating around technical circles throughout the 1880's, there was no formal education for such a person. The "chemical engineer" of these years was either a mechanical engineer who had gained some knowledge of chemical process equipment, a chemical plant foreman with a lifetime of experience but little education, or an applied chemist with knowledge of large scale industrial chemical reactions.

An effort in 1880, by **George Davis** (see Davis below), to unite these varied professionals through a "**Society of Chemical Engineers**" proved unsuccessful. However, this muddled state of affairs was changed in 1888, when **Professor Lewis Norton** of the **Massachusetts Institute of Technology** (see MIT below) introduced "**Course X**" (ten), thereby uniting chemical engineers through a **formal degree**. Other schools, such as the **University of Pennsylvania** and **Tulane University**, quickly followed suit adding their own four year chemical engineering programs in 1892 and 1894 respectively.

"Enough already...go to the bottom."

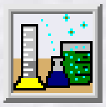
Questions to Ponder

- What events led to the formation of this new profession?
- Was this new profession really necessary?
- Why did it emerge at the end of the 19th Century?
- Why did England need chemical engineers?
- How did America become the cradle of this new profession?

The Story: Early Industrial Chemistry

Chemical Engineering Needed in England

As the **Industrial Revolution** (18th Century to the present) steamed along certain basic chemicals quickly became necessary to sustain growth. **Sulfuric acid** was first among these "industrial chemicals". It was said that a nation's industrial might could be gauged solely by the vigor of its sulfuric acid industry (C1). With this in mind, it comes as no surprise that **English industrialists** spent a lot of **time**, **money**, and **effort** in attempts to improve their processes for making sulfuric acid. A slight savings in production led to large profits because of the vast quantities of sulfuric acid consumed by industry.

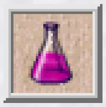


Sulfuric Acid Production

To create sulfuric acid the long used (since 1749), and little understood, **Lead-Chamber Method** (see Lead-Chamber below) required air, water, sulfur dioxide, a nitrate, and a large lead container. Of these ingredients the nitrate was frequently the most expensive. This was because during the final stage of the process, nitrate (in the form of nitric oxide) was **lost to the atmosphere** thereby necessitating a make-up stream of fresh nitrate. This additional nitrate, in the form of **sodium nitrate** (see Nitrates below), had to be imported all the way from **Chile**, making it very **costly** indeed!

In 1859, **John Glover** helped solve this problem by introducing **a mass transfer tower to recover some of this lost nitrate**. In his tower, sulfuric acid (still containing nitrates) was trickled downward against upward flowing burner gases. The flowing gas absorbed some of the previously lost nitric oxide. Subsequently, when the gases were recycled back into the lead chamber the nitric oxide could be re-used.

The **Glover Tower** represented the trend in many chemical industries during the close of the 19th Century. **Economic forces were driving the rapid development and modernization of chemical plants**. A well designed plant with innovative chemical operations, such as the Glover Tower, often meant the difference between success and failure in the highly competitive chemical industries. (see Sulfuric Acid below, or FIGURE: SULFURIC ACID GROWTH).

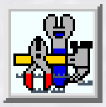


Alkali & The Le Blanc Process

Another very competitive (and ancient) chemical industry involved the manufacture of **soda ash** (Na_2CO_3) and **potash** (K_2CO_3) (see Carbonates below) . These **Alkali compounds** found use in a wide range of products including **glass**, **soap**, and **textiles** and were therefor in tremendous demand. As the 1700's expired, and English trees became scarce, the only native source of soda ash remaining on the British Isles was **kelp** (seaweed) which irregularly washed up on its shores. Imports of Alkali, from America in the form of wood ashes (potash) or Spain in the form of barilla (a plant containing 25% alkali) or from soda mined in Egypt, were all very expensive due to high shipping costs.

Fortunately for English coffers (but unfortunately for the English environment) this dependence on external soda sources ended when a Frenchman named Nicholas Le Blanc invented a process for converting common **salt into soda ash**. The **Le Blanc Process** (see Le Blanc below) was adopted in England by 1810 and was continually improved over the next 80 years through elaborate engineering efforts. Most of this labor was directed at recovering or reducing the terrible byproducts of the process. Hydrochloric acid, nitrogen oxides (see Glover Tower above), sulfur, manganese, and chlorine gas were all produced by the Le Blanc process, and because of these chemicals many manufacturing sites could easily be identified by the ring of dead and dying grass and trees.

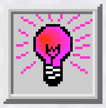
A **petition against the Le Blanc Process** in 1839 complained that "the gas from these manufactories is of such a deleterious nature as to blight everything within its influence, and is alike baneful to health and property. The herbage of the fields in their vicinity is scorched, the gardens neither yield fruit nor vegetables; many flourishing trees have lately become rotten naked sticks. Cattle and poultry droop and pine away. It tarnishes the furniture in our houses, and when we are exposed to it, which is of frequent occurrence, we are afflicted with coughs and pains in the head...all of which we attribute to the Alkali works." Needless to say, many people strove to replace the Le Blanc Process with something less offensive to nature and mankind alike.



Soda Ash & The Solvay Process

In 1873 a new and long awaited process swept across England rapidly **replacing Le Blanc's** method for producing Alkali. While the **chemistry** of the new **Solvay Process** was much **more direct** than Le Blanc's, the necessary **engineering** was **many times more complex**. The straight-forward chemistry involved in the Solvay Process had been discovered by A. J. Fresnel way back in 1811, however **scale up** efforts had proven fruitless until Solvay came along **60 years later.** No doubt this is why the method became known as the Solvay Process and not the Fresnel Process.

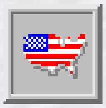
The center piece of Solvay's Process was an **80 foot tall** high-efficiency **carbonating tower**. Into this, ammoniated brine was poured down from the top while carbon dioxide gas bubbled up from the bottom. These chemicals reacted in the tower forming the desired **Sodium Bicarbonate**. Solvay's **engineering** resulted in a **continuously operating** process **free of hazardous by-products** and with an **easily purified final product**. By 1880 it was evident that the Solvay Process would rapidly replace the traditional Le Blanc Process. (see Solvay below)



George Davis

Enter **George Davis**, a heretofore unremarkable **Alkali Inspector** (see Alkali below) from the "Midland" region of England. Throughout his long career Davis' daily rounds had carried him through many of the chemical plants in the region. Inside he was given **intimate access** to **monitor pollution levels** as necessitated by the Alkali Works Act of 1863. These rounds included the Lead-Chamber, Le Blanc, and Solvay processing plants which had **undergone a revolution due to engineering efforts**. This revolution in operation clarified the necessity for a new branch of engineering that was equally comfortable with both applied chemistry and traditional engineering. In 1880 George Davis acted upon these ideas and proposed the formation of a "**Society of Chemical Engineers**". While the attempt was unsuccessful, he continued to promote chemical engineering undaunted.

In 1884 Davis became an independent consultant applying and synthesizing the chemical knowledge he had accumulated over the years. In 1887 he molded his knowledge into a series of **12 lectures** on chemical engineering, which he presented at the Manchester Technical School (see Davis below). This chemical engineering course was organized around individual chemical operations, later to be called "**unit operations**." Davis explored these operations **empirically** and presented operating practices employed by the British chemical industry. Because of this, some felt his lectures merely shared **English know-how** with the rest of the world. However, his lectures went far in convincing others that the time for chemical engineering had arrived. Some of these people lived **across the Atlantic**, where the need for chemical engineering was also real and immediate.



Chemical Engineering in the United States

In **1888** Americans were entranced by their local papers which carried news from across the Atlantic. However, it was not the **emergence of chemical engineering** that was exciting the populace. Instead "**Jack the Ripper**" grabbed headlines by slaying six women in the foggy, twisting London streets. With all the hype, sensationalism, and overblown coverage surrounding the world's first serial killer, it seemed that the emergence of chemical engineering might slip past unnoticed. However, the **blueprint** for the **chemical engineering profession**, as laid down **by George Davis** (see Davis above), was recognized and **fully appreciated** by a few.

MIT's "Course X"

Only a few months after the lectures of George Davis, **Lewis Norton** (see Norton below) a chemistry professor at the **Massachusetts Institute of Technology** (MIT) initiated the first four year bachelor program in chemical engineering entitled "**Course X**" (ten). Soon other colleges, such as the **University of Pennsylvania** and **Tulane University** (see Penn & Tulane below), followed MIT's lead starting their own four year programs. These fledgling programs often **grew from chemistry departments** which saw the need for a profession that could apply the chemical knowledge that had been accumulated over the last hundred years. These pioneering programs were also **dedicated to fulfilling the needs of industry**. With these goals in mind, and following Davis' blueprint, they taught their students a combination of mechanical engineering and industrial chemistry with the emphasis most defiantly on engineering.

From its beginning chemical engineering was tailored to fulfill the **needs of the chemical industry**. At the end of the 19th Century these needs were as acute in America as they were in England. **Competition** between manufacturers was brutal, and all strove to be the "**low cost producer**." To reach this end some unscrupulous individuals stooped so low as to bribe shipping clerks to contaminate competitor's products. However, to stay ahead of the pack dishonest practices were not enough. Instead **chemical plants** had to be **optimized**. This necessitated things such as; **continuously operating reactors** (as opposed to batch operation), **recycling and recovery** of unreacted reactants, and cost effective **purification** of products. These advances in-turn required **plumbing systems** (for which traditional chemists where unprepared) and detailed **physical chemistry knowledge** (unbeknownst to mechanical engineers). The new chemical engineers were capable of designing and operating the increasingly complex chemical operations which were rapidly emerging.

"Enough already...go to the bottom."

Summary: The Details Worth Remembering

People to Remember

George E. Davis (1850 - 1906) (see Davis above)

An industrial Alkali inspector from **Manchester England**. In 1880 he proposed the unsuccessful formation of a "**Society of Chemical Engineers in London**" (F6). In 1887 he presented a series of **12 lectures** on the operation of chemical processes (now called "unit operations") at the Manchester Technical School. In 1901 he published a

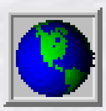
"**Handbook of Chemical Engineering**" which was successful enough to demand a second edition in 1904 (V1). In this handbook he stressed the value of large scale experimentation (the precursor of the modern **pilot plant**), **safety** practices, and **a unit operations** approach. Davis was the man most responsible for applying **the term "chemical engineering"** to the emerging profession, and in many ways helped to **define the scope of today's chemical engineer**.

Lewis Mills Norton (1855 - 1893) (see Norton above)

A Professor of Organic and Industrial Chemistry at **MIT.** Taught the first four year course in chemical engineering entitled "**Course X**" (P2). Died at age 38.

William Page Bryant

In 1891 he was the first of seven students to graduate from "Course X" and thereby became the world's **first formal chemical engineer**. Spent the rest of his life as a rating auditor in the **insurance business** for the Boston Board of Fire Underwriters (V1). Even back then, college students did not always find jobs in their chosen profession.



Places of Interest

Manchester England

Location of the **first formal class** on chemical engineering; consisting of 12 lectures by **George E. Davis** in 1887.

Massachusetts Institute of Technology (see MIT above) (Founded at Boston in 1861, moved to Cambridge in 1916.)

Offered **"Course X"** in 1888, the **first four year chemical engineering degree** which was taught by **Lewis M. Norton**. The program offered a mixture of mechanical engineering and industrial chemistry; however the emphasis was definitely on engineering. MIT gained an independent chemical engineering department in 1920. Throughout its prestigious history the University has provided nearly 5000 bachelor degrees in chemical engineering, and is consistently rated one of the top two chemical engineering programs in the country (right **behind Minnesota**).

University of Pennsylvania became the second school to offer a four-year degree in chemical engineering with its introduction in 1892. As at MIT, the emphasis was placed on mechanical engineering even though the degree sprang from the chemistry department.

Tulane University in 1894 became the first Southern school (located in New Orleans), and the third in the United States to offer a four-year curriculum in chemical engineering.

Industrial Chemicals & Processing

Sulfuric Acid (Oil of Vitriol) & "Fuming" Sulfuric Acid (Oleum) (H_2SO_4) (see Acid above)

During the 19th Century sulfuric acid was necessary in the production of **alkali salts** and **dyestuffs**, two giants of the day. Today the largest single use is in the manufacture of **fertilizers**. It is also necessary in **petroleum** purification, **steel** production, **electroplating**, and **automobile batteries**. The production of **TNT** (trinitrotoluene), **nitroglycerin**, **picric acid**, and all other mineral and inorganic acids require sulfuric acid. "Fuming" sulfuric acid contains excess amounts of sulfur trioxide and fumes when exposed to air; hence it's name.

Lead-Chamber Method was developed in England in 1749 to make **sulfuric acid**. A mixture of **sulfur dioxide** (SO_2), **air**, **water**, and a **nitrate** (potassium, sodium, or calcium nitrate) are mixed in a large lead lined chamber thereby forming sulfuric acid (C1).

Potassium Nitrate (**saltpeter**, Nitre) (KNO_3) Was obtained primarily from India and used to prepare **matches**, **explosives**, and **fertilizers**. Alternate sources of nitrates include: **Chile saltpeter**, an impure form of **sodium nitrate** ($NaNO_3$), which was deposited along the Pacific coast by large flocks of birds which nested (and went to the bathroom) for thousands of years, & **Lime saltpeter** (Norwegian saltpeter) which is composed of **calcium nitrate** ($CaNO_3$). (see Sulfuric Acid above)

Sodium Carbonate (Soda ash, Sal Soda, Washing Soda) (Na_2CO_3) & **Sodium Bicarbonate** (**baking soda**) ($NaHCO_3$) are used to manufacture **glass, soap, textiles, paper**, and as a **disinfectant**, **cleaning agent**, and **water softener**. (see Solvay Process above)

Potassium Carbonate (**Potash**) (K_2CO_3) Produced by slowly running water through the ashes of burned wood (**leaching**) and boiling down the resulting solution in large pots ("pots of ashes" hence the name Potash). Potash can be used in place of **Sodium Carbonate** (soda ash) to make glass or soap.

Alkali Hydroxides (usually just called "**Alkali**") are used to produce **glass**, **paper**, **soap**, and **dyestuffs** for **textiles**, aid in **oil refining**, make **bleaching** compounds, and preparing **leather**. **Sodium Hydroxide** (NaOH) (caustic soda or **lye**) and **Potassium Hydroxide** (KOH) (caustic potash) are the two most common and important chemicals in this class. In 1863 the Alkali Works Act was initiated by the British government. It set limits for chemical emissions in an attempt to reduce the pollution that had devastated the "Midland" region of England for nearly a century and a half. (see Davis above)

Le Blanc Process (see Le Blanc above)

A method for converting common **salt** into **soda ash** using **sulfuric acid**, **limestone** and **coal** as feedstocks (raw materials) and thereby creating **hydrochloric acid** as a by product. It was invented in 1789 by Nicholas Le Blanc (1742-1806), a French **industrial chemist**. In 1794, just prior to the French Revolution, the French government seized Le Blanc's process and factory without payment. Although **vast fortunes** where accumulated through his process, Le Blanc died in poverty. In many ways, his process began the modern chemical industry. While the precise chemistry involved in the process remained obscure for nearly 100 years, it was later found to consist of several steps:

a) 2 NaCl (salt) + H_2SO_4 (sulfuric acid) => Na_2SO_4 (saltcake, intermediate) + 2 HCl (hydrochloric acid gas, a horrible waste product)

b) Na_2SO_4 (saltcake) + Ca_2CO_3 (calcium carbonate, limestone) + 4 C(s) (coal) => Na_2CO_3 (soda ash extracted from black ash) + CaS (dirty calcium sulfide waste) + 4 CO (carbon monoxide)

Solvay Process (see Solvay above) was perfected in 1863 by a Belgian chemist named **Ernest Solvay**. The chemistry was based upon a half century old discovery by A. J. Fresnel who in 1811 had shown that **Sodium Bicarbonate** could be precipitated from a **salt** solution containing **ammonium bicarbonate**. This chemistry was far simpler than that devised by Le Blanc, however to be used on an industrial scale many **engineering obstacles** had to be overcome. Sixty years of attempted scale-up had failed until Solvay finally succeeded. **Solvay's contribution was therefor one of chemical engineering**. The heart of his design embodied an **80 foot tall** high-efficiency **carbonating tower** in which ammoniated brine trickled down from above and carbon dioxide rose from the bottom. Plates and bubble caps helped create a large surface area over which the two chemicals could react forming sodium bicarbonate. Solvay's process had several **advantage**s over the Le Blanc process which it rapidly replaced: **1) continuous operation, 2) a product which was easier to purify**, and **3) no dirty, hazardous, and hard to dispose of bi-products**.

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Struggle for Survival

"The end already...go back to the top."

We always welcome COMMENTS, SUGGESTIONS, OR REACTIONS.

Last updated on 4/4/98 by Wayne Pafko...

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pafko.com/history/h_1888.html

The Struggle for Survival

While **chemical engineers** gained a formal education in 1888, this was certainly **no guarantee of success**. Many prominent people **saw no need for this new profession**. Additionally, it was unclear **what role chemical engineers would play** in industry.

To survive, chemical engineers had to **claim industrial territory** by **defining themselves and demonstrating their uniqueness and worth**. With this goal in mind, the **American Institute of Chemical Engineers** (AIChE) was formed in June of 1908. However, AIChE also faced difficult challenges in **defining its own territory**. The old (since 1876) and powerful (5000 members) **American Chemical Society** (ACS) had already laid claim to all realms of American Chemistry, both pure and applied.

Just weeks after the formation of AIChE, the ACS would launch its own "Division of Industrial Chemistry & Chemical Engineering" placing itself in **direct competition** with AIChE for the hearts and minds of the new engineers. The establishment of chemical engineering in America would involve a fierce struggle for survival.

"Enough already...go to the bottom."

Questions to Ponder

- Why did chemical engineering not develop in Germany?
- What challenges did the newly formed chemical engineering profession face?
- Why was the American Institute of Chemical Engineers (AIChE) formed?
- How did AIChE deal with the possible conflict with the ACS?
- How has AIChE helped gain a high status for the chemical engineering profession?

The Story: Establishing the American Chemical Engineer

German Chemical Engineers? "Just say 'Nein'!

With the rapid **growth** of the **American chemical industry** around the turn of the century, the **gap** between **laboratory processes and full-scale industrial production** needed to be **bridged**. To many prominent chemists, educated at popular German universities, the approach to accomplish this had already been tried and proven. Germany had experienced its own rapid period of growth (on their way to becoming the world's greatest chemical power) during the 19th Century. The **German solution** to industrial **scale up** involved **teaming research**

chemists and mechanical engineers to take a reaction from the lab bench to the factory floor. They believed this allowed the **research chemist** to **remain creative** by not being tied down with the drudgery of engineering practice (whether or not this belief is justified is a whole other topic). Because of their scale up method **the chemical engineer was entirely unneeded**, being instead replaced by a chemist and a mechanical engineer.

However, the **American chemical industry** was **fundamentally different** from German's counterpart. Instead of specializing in fine chemicals or complicated dyestuffs (often made in batch reactors, something all chemists are familiar with), the American industries produced **only a few simple but widely used chemicals** such as sulfuric acid and alkali (both made in continuous reactors, something chemists have little experience with). These bulk chemicals were produced using **straightforward chemistry**, but required **complex engineering** set on vast scales. American chemical reactors were no longer just big pots, instead they involved complex plumbing systems where **chemistry and engineering were inseparably tied together**. Because of this, the chemical and engineering aspects of production could not be easily divided; as they were in Germany. The **chemical engineer therefore found a role to play in America** despite their absence in the Germany until around 1960.

Strong Support for an American Chemical Engineer

The **American chemical industry** (initially following the German example, and why not?) **employed chemists and mechanical engineers** to perform the functions that would later be the chemical engineer's specialty. However these chemists were of an entirely different nature. The **prominent research chemists** employed in Germany were almost **non-existent** in America until after World War I. **Instead** the American chemical industry employed both **analytical chemists** (involved in materials testing and quality control) and a smaller number of **production chemists** (consisting of plant managers and chemical consultants engaged in engineering design, construction, and troubleshooting). However, unlike the highly praised German research chemists, these American counterparts were **given very little respect** from the chemical industry which employed them. It was noted that "analytical chemists were regarded as being of the same grade as machinists, draftsmen, and cooks." This low status carried over to the weekly paycheck, where in 1905 American analytical chemists received only half the salary of skilled artisans (R4).

Therefore at the turn of the Century, calling yourself a chemist did not bring the immediate admiration of your audience. Because of this many **production chemists** (people more closely engaged in management and engineering than chemistry) **wanted** very dearly **to shed the term "chemist" from their title**. While production chemists were still held in higher regard than their analytical cousins (and also higher paid, funny how that works) they still felt great anxiety over the **falling status of chemists** as a whole. In short, how could they assure that the production chemist would continue to keep their high status with manufacturers? This was a problem that could hit them where it would hurt most, the paycheck! The need for action was most imminent! As a solution, the **production chemists** began **referring to themselves as chemical engineers** (for this is what they were in practice if not in education), and engaged themselves in the **formation of an institute** devoted to securing greater recognition for their profession.

An "AIChE Breaky" Beginning

The formation of a society of chemical engineers was originally proposed by **George Davis** in 1880, a full ten years before the profession could boast of a formal education (see SETTING THE STAGE). The first serious proposal for an American Society of Chemical Engineers was presented in a 1905 editorial by Richard K. Meade. He argued that such a society could help secure greater recognition for the chemical engineer, and also help convince the chemical industry that **chemical engineers instead of mechanical engineers should be designing**

and operating their plants. The idea must have rung true, for **in 1908** such an organization was formed (however its published goals did not include stealing jobs from mechanical engineers). Hence, the **American Institute for Chemical Engineers (AIChE) was born**.

In 1908, the year AIChE was formed, the powerful and influential **American Chemical Society** had already been around for 30 years and boasted nearly **5000 members**. Additionally, this academic giant had recently committed itself to **preventing anymore splinter groups** from succeeding from the society. The ACS had been sensitized to the succession problem by the electrochemists and leather chemists who had left the ACS in 1902 and 1904 respectively. Both groups had formed their own independent societies to the dismay of the ACS. So when it seemed that the chemical engineers were also preparing to jump ship (and possible take a lot of production chemists with them, see Strong Support above) the ACS quickly reacted forming a "**Division of Industrial Chemistry and Chemical Engineering**."

Avoiding Conflict by "Speaking Softly"

Faced with the **possibility of direct conflict with the ACS**, **AIChE decided** on a course of action designed **to minimize rivalry** and remain on as good of terms as possible. It accomplished this in three main ways:

1) Utilizing very restrictive membership criteria (through 1930) so as not to pose a threat to ACS membership. Part of this exclusive criteria required a full 10 years of **industrial experience** (5 years if you had a B.S.), thereby excluding most chemists in academia from full membership. This selective criteria made **membership very attractive** to those who could gain it and many compared AIChE membership to belonging to an exclusive **men's club**.

2) Emphasizing a role in which AIChE membership would compliment, not compete with, ACS membership. By requiring industrial experience, the first wave of AIChE members included **chemical manufactures, plant management, and consultants** (the group formerly called production chemists, see Strong Support above) . This provided a **distinct departure** from the **typical ACS member** which was more likely than not to be associated with academia.

3) Finally, AIChE avoided conflict by always approaching possible problems with the utmost discretion. Whether it was membership criteria or the societies political activities; AIChE always acted in a **methodical and conservative fashion**. An example of this occurred in 1920, when the Institute considered adding a new class a membership so analytical chemists working in industry could also gain membership. However, it was recognized that this action conflicted with a founding principle that the Institute should cover a professional field not already represented by other societies. As usual, **slow sustained growth** was recognized as the way to **establish the profession** while not stepping on too many toes along the way.

The **conservative course of action** undertaken by AIChE may have **slowed membership growth**, but it certainly helped bring **chemical engineers and chemists** into a state of **cooperation** rather than competition.

How To Define Professional Boundaries?

Another **challenge** facing chemical engineers involved **defining who they were** and **how they were unique**? How the AIChE answered these questions had a tremendous impact on the **industrial territory** chemical engineers could **lay claim to**.

Certainly one way the profession could be defined was through the **formal education** its members received.

Because of this AIChE spent a lot of time and effort evaluating and improving educational activities.

They strove to **standardize the chemical engineering education** which was often erratic and inconsistent. But how exactly to improve education? In an age when chemical engineers learned mountains of industrial chemistry; where each chemical had its own long and varied history of production, what central theme could chemical engineering education rally around?

The answer came in **1915**, when in a letter to the President of MIT, **Arthur Little** stressed the potential of "**unit operations**" to **distinguish chemical engineering** from all other professions and also to give chemical engineering programs a **common focus**.

Unit Operations, The "Big Stick" of Chemical Engineering

In **transforming matter** from **inexpensive raw materials** to **highly desired products**, chemical engineers became very **familiar** with the **physical and chemical operations** necessary in this metamorphosis. Examples of this include: filtration, drying, distillation, crystallization, grinding, sedimentation, combustion, catalysis, heat exchange, extrusion, coating, and so on. These "**unit operations**" repeatedly find their way into industrial chemical practice, and became a **convenient manner of organizing chemical engineering knowledge**. Additionally, the knowledge gained concerning a "unit operation" governing one set of materials can easily be applied to others. Whether one is distilling alcohol for hard liquor or petroleum for gasoline, the underlying principles are the same!

The "unit operations" concept had been latent in the chemical engineering profession ever since George Davis had organized his original 12 lectures around the topic. However, it was Arthur Little who first recognized the potential of using "unit operations" to separate chemical engineering from other professions. While **mechanical engineers** focused on **machinery**, and **industrial chemists** concerned themselves with **products**, and **applied chemists** studied individual **reactions**, no one, before **chemical engineers**, had concentrated upon the underlying **processes common to all chemical products, reactions, and machinery**. The chemical engineer, utilizing the conceptual tool that was unit operations, could now claim to industrial territory by showing his or her **uniqueness and worth** to the American chemical manufacturer.

Educational Standardization & Accreditation

While the "**unit operation**" concept went a long way in standardizing the chemical engineering curriculum, it **did not solve the whole problem**. A 1922 AIChE report (headed by Arthur Little, the "originator" of the "unit operation" concept) pointed out the continuing need for standardization due to chronic **divergence in nomenclature** and **inconsistencies in course arrangement and worth**. Again **AIChE took action** by making chemical engineering the **first profession** to **utilize accreditation** in assuring course **consistency and quality**. AIChE representatives traveled across the country evaluating chemical engineering departments. In 1925 these efforts culminated with a list of the first 14 schools to gain accreditation (see EDUCATIONAL GROWTH). Such efforts were so effective in consolidating and improving chemical engineering education that **other engineering branches quickly joined the effort**, and in 1932 formed what would later become the Accreditation Board for Engineering and Technology (ABET).

Summary: Some Details to Remember

People to Remember

Arthur D. Little

Consultant and co-founder, with William Walker, of "Little and Walker" which later became "**Arthur D. Little, Inc**." He **coined the term "unit operations"** in 1915 and headed up AIChE's Committee on Chemical Engineering Education which emphasized the "unit operation" concept along with accreditation to standardize courses in chemical engineering programs.

Places & Organizations of Interest

AIChE (American Institute of Chemical Engineers)

AIChE is the smallest of the societies representing one of the "big four" engineering fields (mechanical, electrical, civil, and chemical engineering). The Institute was **formed in June of 1908** as the sole institutional **home for chemical engineers**. However, almost before the echoes of McKenna's founding keynote address had finished reverberating with the audience, the ACS had launched a new division; joining in a battle for the chemical engineer's heart, mind, and financial dues.

Because of this, the AIChE spent the first third of its life as a very **exclusive organization**. While it contributed to industry through publications such as the "**Transactions of AIChE**" (which evolved into "**Chemical Engineering Progress**" in 1947 and still provides news and technical information today), or through **scholastic accreditation**, AIChE hardly represented the chemical engineering profession as a whole.

This changed in the 1930's when membership requirements were relaxed, and chemical engineers joined in droves. Today there are five classes of membership (student, affiliate, associate, member, and fellow) through which nearly **60,000 chemical engineers** have become members (see AIChE & THE FUTURE). The Institute has a yearly **budget of around $21 million**, which it spends providing technical education, safety training, career counseling, governmental advising, and social activities for its members.

ACS (American Chemical Society)

ACS represents the best American chemistry has to offer. ACS **grew rapidly** after its **founding in 1876** (even before chemical engineering existed). Because of its success, smaller factions within the society often felt they could go it alone, and **splinter groups soon became a problem**. At the turn of the century chemical engineers became one of these splinter groups, forming the AIChE in 1908. The ACS responded by creating the "**Division of Industrial Chemistry & Chemical Engineering**."

Today the ACS remains at the **center of American Chemical developments** boasting 150,000 members. Through its "**Chemical Abstracts**" service and "**Chemical & Engineering News**" the ACS continues to provide valuable information to chemists & chemical engineers alike. Despite bitter feelings concerning the creation of the AIChE, today chemical engineers and chemists have a relationship unlike anything found in other engineering fields.

A Brief History Through Quotations

- (**1880**) Sir Harold Hartley said (in 1958, but referring to 1880): "From their experience in chemical plants, both **chemists with an instinct for engineering** and **engineers with a taste for chemistry** grew **into chemical engineers** without realizing it and indeed without being willing to admit it."

- (**1886**) E. K. Muspratt said: "It is very **difficult to find a manager** who has a **knowledge of engineering combined** with a **knowledge of chemistry**. **Such men must be educated**, and it is only now .. that we are beginning to follow in [this] path." (shows the need for chemical engineers) (F6).

- (**1888**) MIT catalog ("Course X") said in 1888-1889: "This course is arranged to **meet the needs of students** who desire a **general training** in **mechanical engineering** and to devote a **portion of their time** to the study of the **application of chemistry** to the arts, especially to those engineering problems which relate to the use and **manufacture of chemical products**." (chemical engineering education begins) (V1).

- (**1904**) George Davis (in his "Handbook of Chemical Engineering) said: "The object of this handbook is not to enable anyone to erect works of special character ... but to illustrate the principles by which a **plant of any kind** may be **designed and erected** when certain conditions and requirements are known. We cannot make the best use of our abilities unless we are taught to **investigate the principles underlying** the construction of the appliances with which we have to work." (early recognition of the need to understand underlying physical and chemical principles in chemical engineering) (D1).

- (**1904**) Hugo Schweitzer (at an ACS meeting) said: "**I am absolutely against the introduction of chemical engineering in the education of chemists**." (not everyone was excited about chemical engineering).

- (**1908**) Charles McKenna (founder of AIChE referring to that founding) stated: "..the **noblest aim before us**, gentlemen, the one which most amply justifies us before all the world, is our ambition for the enlightenment and ample equipment of our successors: that is for the **improvement of the training of the chemical engineer of the future**." (education was important to AIChE from the start) (R3).

- (**1910**) F. W. Atkinson (Brooklyn Polytechnic Institute) said: "**Chemical engineering needs to be more sharply defined**. Its scope is still in a somewhat indeterminate state and as yet its position as one of the professions is not clearly recognized." (defining what chemical engineers were, and what made them unique, was an early problem) (R3) .

- (**1911**) Milton C. Whitaker (professor at Columbia University, stating his ideas of what chemical engineering education should consists of) said: "The chemical engineer works in the organization, operation and management of existing or proposed processes with a view to **building up a successful manufacturing industry**... His fundamental training in **chemistry, physics, mathematics**, etc., must be **thorough** and must be **combined** with a natural **engineering inclination** and an acquired knowledge of engineering methods and appliances." (Sounds pretty modern doesn't it?) (P2)

- (**1911**) Olaf Hougen (an eminent professor at the University of Wisconsin, revealing that the actual teaching practices of the past were very different indeed) said in 1972: "**The 1911 curriculum in chemical engineering ... bares no resemblance to that of today**. ... there were: no courses in unit operation, none in material and energy balances, none in heat and mass transfer, none in thermodynamics for chemical engineers, none in chemical kinetics and catalysis, none in process design, none in process control ... and, physical chemistry was not a required course." (OK, so maybe their education wasn't so modern.) (H7)

(**1915**) Arthur D. Little (consultant responsible for bringing "unit operations" into the lime light) said: "**Any chemical process**, on whatever scale conducted, **may be resolved into a coordinate series of what may be termed 'unit operations'**, as pulverizing, dyeing, roasting, crystallizing, filtering, evaporation, electrolyzing, and so on. The number of these basic unit operations is not large and **relatively few of them** are involved in any particular process. The complexity of chemical engineering results from the variety of conditions as to temperature, pressure, etc., under which the unit operations must be carried out in different processes, and from the limitations as to material of construction and design of apparatus imposed by the physical and chemical character of the reacting substances." (unit operations, the rallying point of chemical engineering for 30 years) (R3).

(**1921**) H. O. Chute (a chemical engineer specializing in distillations and holding over a dozen patents) said: "**We are not even able to convince other engineers that we are engineers**." (the unit operations concept was slow to take hold and did not solve all the problems) (R3).

(**1922**) A "monumental" AIChE report on education conducted by Arthur Little declared: "**Chemical engineering**..., as distinguished from the aggregate number of subjects comprised in courses of that name, is not a composite of chemistry and mechanical and civil engineering, but a **science of itself,** the **basis of which is those unit operations** which in their proper sequence and coordination constitute a chemical process as conducted on the industrial scale." (The heart of this report involved recommendations to stress the "unit operation" concept, standardize university programs, and begin university accreditation.) (R3).

(**1922**) Ralph McKee (AIChE director 1923-25) said: "**The Committee have written a prescription, and it is our duty to see that the prescription is filled** .. and given to the patients..." (AIChE takes action) (R3).

(**1928**) Alfred Holmes White (AIChE president 1929-30) said: "**Almost all schools which teach chemical engineering now recognize** these unit processes (i.e. **unit operations) as providing the framework for** the engineering side of **chemical engineering**." (unit operations a continued rallying point for standardization) (R3).

(**1932**) J. V. N. Dorr (AIChE president from 1932-33) said: "The four founder societies while tending **originally to regard us as 'queer kinds of chemists' now recognize us as a fifth classification of basic engineering**." ("Fifth" referring to Civil, Mechanical, Electrical, Mining, and of course Chemical engineering). (It was working, the profession was becoming established) (R3).

Quotations from the University of Minnesota

(Don't take all of these too seriously!)

(**1993**) Rutherford Aris (or is it Aris Rutherford, sometimes it is hard to tell "Who's Who") (Chemical Engineering Professor at the University of Minnesota) said: "...it is easy to accept **mathematical modeling as a poetic activity**, for, in doing it, we are engaged in a form of imitating nature in mathematical terms." (A2)

(**1995**) Cussler said: "The score is kept in dollars!"

(**1995**) Lanny Schmidt said: "You can count the number of ... [insert your favorite phrase here] .... on the fingers of one hand of an explosives expert."

(**1995**) The University of Minnesota student bulletin said: "The **chemical engineer** is **primarily a producer** whose special province is to develop a process from its laboratory beginnings ... to full-scale production.

Chemical engineering is based on applications of **chemistry, physics, mathematics, economics**, and increasingly, **biology** and **biochemistry**. Because of this broad-based foundation .. the chemical engineer is considered the **universal engineer**. ... Chemical engineering deals with unit operations... These operations are vital to the commercial success of industries based on chemical or physical transformation of matter. A chemist uses these operations qualitatively in a laboratory, but to apply them to a **complex or large-scale industrial process** requires a chemical engineer who has a complete and quantitative understanding of the engineering principles as well as the scientific principles on which the operations rest. ... Because many industries are based on some **chemical or physical transformation of matter**, the **chemical engineer is much in demand**." (I1)

more quotations to come...

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A Century of Contributions

"The end already...go back to the top."

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A Century of Contributions

While **chemical engineering** was **first conceptualized** in **England** over a Century ago (see SETTING THE STAGE), its **primary evolution**, both educationally and industrially, has occurred in the **United States**. After an early **struggle for survival** (see STRUGGLE FOR SURVIVAL), the profession **emerged from** under its **industrial chemistry heritage** with the **help of** the **unit operations** concept.

However, the **metamorphosis** of chemical engineering did not stop there. The addition of **material and energy balances**, **thermodynamics**, and **chemical kinetics** brought the profession closer to something a modern chemical engineer would recognize. With stress on **mathematical competence**, as necessitated by **chemical reactor modeling** and a more detailed examination of **transport phenomena**, chemical engineering continues to broaden in scope. A further requirement in **computer literacy**, as necessary for **process control**, allows today's chemical engineer to be much more efficient with their time.

Along the way, this **changing educational emphasis** has helped the chemical engineer keep up with the **changing industrial needs** and continue to make significant **contributes to society** (see TIMELINE). Today their broad background has opened doors to many **interdisciplinary areas** such as **catalysis**, **colloid science**, **combustion**, **electrochemical engineering**, **polymer technology**, **food processing**, and **biotechnology**. The **future** of chemical engineering seems to lie with these **continuing trends** towards greater **diversity**.

"Enough already...go to the bottom."

Questions to Ponder

- How has the role of chemical engineering evolved over the past Century?
- How has chemical engineering education evolved over the past Century?
- What might be in store for chemical engineers in the 21st Century?

The Story: Chemical Engineering Evolution

World War I

Outbreak of Hostilities

On June 28, **1914** crowds of people lined the streets of **Sarajevo**, the capital of **Bosnia** (then a province of Austria-Hungary), in hopes of seeing the **Archduke Francis Ferdinand** and his wife **Sofia**. A young student, **Gavrilo Princip**, leaped from the crowd, **assassinating both** the **Archiduke and his wife**. Suspecting the **plot** originated in **Serbia**, **Austria-Hungary** (including Bosnia) **declared war** on the small country. By the end of

1914, **Europe** had been **swept** into a horrendous conflict referred to as **World War I** (maybe we should be more concerned with the ongoing hostilities between the Bosians and Serbians!)

The American Situation

Prior to the war, **Germany** had **reigned supreme** in **organic chemistry** and **chemical technology**. It was said that in 1905 that **America lagged fifty years behind** the Germans in organic chemical processing (H7). Even America's chemistry and chemical engineering **professors** had been primarily trained in **German Universities**, and a working knowledge of the **German language** was essential to keep up with the **latest chemical advances**. All in all, **America's chemical industry** was very **narrow**, concentrating in only a few **high volume chemical products**, such as sulfuric acid.

America's Opportunity

As war raged in Europe, the **U.S. became isolated** from Germany. British blockades prevented valuable **dyes** and **drugs**, produced only in Germany, from reaching the shores of America. Suddenly the **American chemical industry** was given the opportunity to **enter these markets** without foreign competition.

The Problem

However, **chemical engineers** were **not entirely ready** for this turn of events. Their **education** had consisted primarily of instruction in **engineering practice** and **industrial chemistry**. This memorization of existing chemical processes was fine for supervising established chemical plants, but left them at a great **disadvantage** when faced with tackling **entirely new problems**.

Faced with this challenge, how could the technological know-how concerning one set of chemicals be transferred to another process? The answer came in 1915, when **Arthur Little** stressed the "**unit operations**" concept. With it, chemical engineers where trained about **chemical processes** in a more **abstract** manner. Their **expertise** became **independent** of the **actual chemicals** involved, allowing the **rapid establishment** of **new industries**. In short, *education had responded to the needs of industry*.

The Industry of War

In **1917**, after loosing several ships and many lives, the **United States declared war** on Germany and her Allies. One of the **first actions** of the U.S. Government was to assure that **chemists and chemical engineers** did **not die in the trenches** as had happened to many European nations. **Instead**, they were enlisted to **create the materials necessary to wage war**. Suddenly, united by a **common foe**, America's chemical industries began **cooperating** instead of competing. This cooperation built the **ammonia plants** that produced the **explosives** (and **fertilizers**) that helped win the war (see NITROGEN: FOOD OR FLAMES).

World War II

Hostilities Re-Ignite

On September 18, 1931, **Japan invaded Manchuria**. Eight years later, on September 1, 1939, **Germany invaded Poland** and war again raged on the European continent. With Japan's infamous **bombing of Pearl Harbor**, on December 7, 1941, **America** was once again **thrust into a World War**.

Synthetic Rubber

The **importance** of rubber in warfare had been demonstrated by the **Germans** in **World War I**. The Germans had been **cut off** from their foreign **rubber supply** by the **British blockade**. Without rubber their **trucks** ran out of **tires** while their **troops** had to go without walking **boots**. In an effort to salvage the situation, Germany began experimenting with **synthetic rubber.** However they could **never** find a formulation that **worked well enough** or could be produced in large enough quantities.

Similarly, in the opening days of **World War II, Japan** rapidly **captured** rubber producing lands in the **far east**, **depriving America of 90%** of its natural **rubber** sources. Suddenly America found itself in the same undesirable position that had confronted Germany forty years before.

However, with the help of their new educational emphasis on the underlying principles of chemistry and engineering as opposed to the gross memorization of existing industrial chemical reactions, American chemical engineers were in a position to make great contributions to the synthetic rubber effort. The **unit operations** concept, combined with **mass and energy balances** and **thermodynamics** (which had been stressed in the 30's), allowed the rapid **design, construction, and operation** of **synthetic rubber plants**. Chemical Engineers now had the training to build industries from the ground up. With funds from the government, the chemical industry was able to increase synthetic **rubber production** by over a **hundred times**. This synthetic rubber found uses in tires, gaskets, hoses, and boots; all of which contributed to the war effort.

High Octane Gasoline

As **German tanks and bombers** swept across Europe using **Blitzkrieg** tactics, it became evident that World War II would be a **highly mechanized conflict**. The Allies needed tanks, fighters, and bombers all supplied with **large quantities** of **high quality gasoline**. In supplying this fuel the American petroleum industry was stretched to its limit (See OIL).

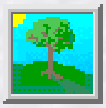
However, the development of **Catalytic Reforming** in 1940 by the Standard Oil Company (Indiana) had given the **Allies an advantage**. The reforming process produced **high octane fuel** from **lower grades of petroleum** (it also made **Toluene** for **TNT**). Because of the performance edge given by this better fuel, **Allied planes** could successfully **compete** against **German & Japanese fighters**.

The Atomic Bomb

In the early 1900's **scientists** were busy **exploring the atom**. Einstein's mass-energy equivalence ($E = m c^2$) showed that **matter** contained **tremendous energy**. By 1939 many scientists had succeeded in **splitting atoms** of uranium and some envisioned the possibility of a chain reaction. In 1942, **Fermi** and his co-workers, produced the first **man-made chain reaction** under the **University of Chicago**. The success proved that an atomic weapon was possible, and the **Manhattan Project** was soon underway. However, despite these early successes, **enormous technical obstacles** still laid ahead.

Only certain materials underwent **fission** rapidly enough to be considered for an atomic bomb. **Uranium 235**, a very scarce from of uranium (only 0.7% of uranium is 235), and **plutonium**, an element which did not exist naturally, were two possible candidates. However, both elements were **exceeding rare** (or nonexistent) and had only been produced on **tiny laboratory scales**. For example, in 1942 only a milligram of Plutonium (1/28,000th of an ounce) was in existence.

Late in 1942, General Leslie R. Groves approached **Du Pont** to ask if they could build and operate a **plutonium production plant**. The company accepted the challenge, but due to intense secrecy, not even its top level people new the whole story. During the next three years the "**Hanford Engineering Works**" was designed, built, and operated by chemical engineers. **Equipment** never before conceived of; had to be **designed**, **built**, and **tested** using great **haste**. **Remote processing** and **control** of the plutonium pile was a must. Even **remote repair** was put into place to fix equipment which broke down after becoming radioactive. The Hanford plant was **big**, **complex**, and had to deal with the **most dangerous material** on the planet. It demonstrated what is expected of chemical engineers. **Seemingly impossible problems** must be **solved quickly**, **correctly**, **economically**, and **safely**, using knowledge of both **chemistry and engineering**.



Post-War Growth

During World War II, American chemical engineers where called upon to build and operate many new facilities; some never having been before conceived (see Atomic Bomb above). After the war, **Germany's massive chemical industry lay in ruins** while the **Americans** were still operating at full production. Never-the-less, the United States Government **still feared** the **German chemical complex**. They therefor **dismantled** Hitler's enormous **I.G.Farben** and out of it three new companies where **created**; **BASF**, **Bayer**, and **Hoechst**.

With foreign competition almost non-existent, the **U.S. chemical industry** continued its **meteoric rise**; with **petroleum** continuing to be the **foundation** of the industry. From **fuels** and **plastics** to **fine chemicals**, petroleum was where the action was. Some have even argued that World Wars I & II were fought exclusively for the control of petroleum resources (see "The Prize" by Daniel Yergin). The **success** of the **petroleum industry** helped the chemical engineering profession greatly, and is one of the reasons **today's wages are so high** (see WAGES).

With America firmly leading the world in chemical technology, **chemical engineering education** began to **change**. Suddenly, the best way to discover the latest events in chemical technology was **not to pick up a German technical journal**, but **instead** to **make those discoveries for yourself**. **Chemical engineering** was **becoming** more **focused** on **science** than on engineering tradition.

Two universities did much to encourage these events. At the **University of Minnesota**, **Amundson and Aris** began emphasizing the importance of **mathematical modeling** (using dimensionless quantities) in **reactor design**. And at the **University of Wisconsin, Bird, Stewart, & Lightfoot** presented a **unified mathematical description** of **mass, momentum, and energy transfer** in their now famous text, "**Transport Phenomena**." These events were **far removed** from the **early days** of the profession, when the possibility of **eliminating most mathematical courses** was strongly **considered**.

Today's Multi-disipline

For the last **twenty years**, large **changes** have been occurring in the American chemical industry. Most of the **major engineering obstacles** found in petroleum processing have been **overcome**, and **petroleum** is becoming a **commodity industry**. This means that **employment opportunities** for engineers in the petroleum industry are becoming **few and far between**.

Also, **foreign competition** has again **picked up**. Today the **three largest chemical companies** in the world are **BASF**, **Bayer**, and **Hoechst** (perhaps our government's fears where justified, see Post War Growth above; also it is important to point out that **Japan** does **not** represent a **major chemical threat**, instead the competition comes from Europe). While **America's chemical industry** can still compete very well, **growth** has **slowed** immensely. In short, the **unprecedented economic success** which **followed World War II** is **coming to a close** and economic realities are catching up with us.

However, the strong **scientific**, **mathematical**, and **technical background** found in chemical engineering education is **allowing** the **profession** to **enter new fields** that often lay in the white space between disciplines. The largest growth in employment is occurring in up-and-coming fields which show tremendous potential. **Biotechnology**, **electronics**, **food processing**. **pharmaceuticals**, **environmental clean-up**, and **biomedical implants** all offer possibilities for chemical engineers. The educational emphasis of the last twenty years has helped to realize these opportunities. *Once again, chemical engineering education has responded to, and influenced, the industrial realities of the profession*.

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The Struggle for Survival

Sulfuric Acid Production

"The end already...go back to the top."

We always welcome COMMENTS, SUGGESTIONS, OR REACTIONS.

Last updated on 4/4/98 by Wayne Pafko...

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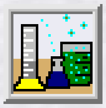
pafko.com/history/h_contrb.html

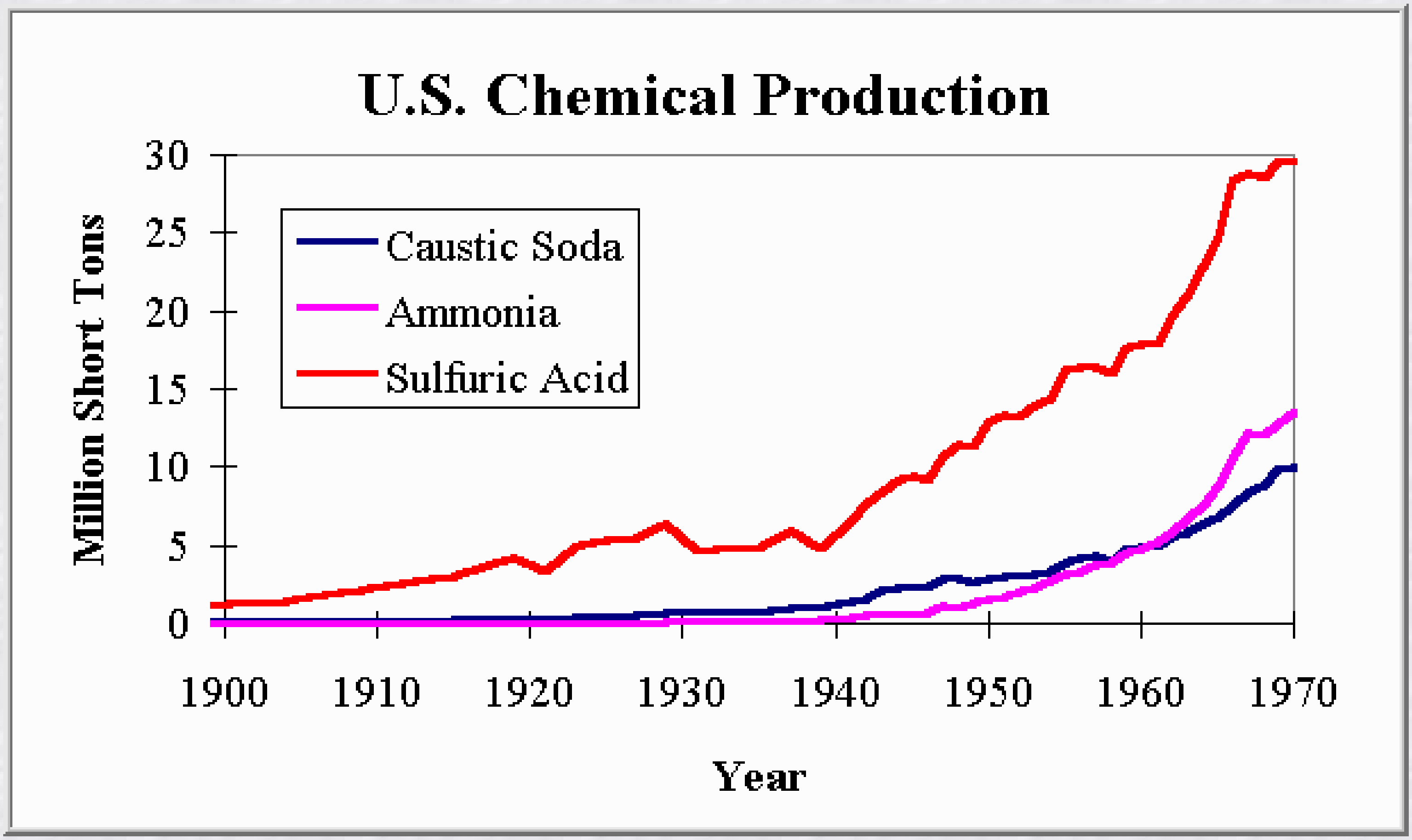
Figure 1: Sulfuric Acid Growth



Sulfuric Acid Production

Because of its **importance**, sulfuric acid was considered an excellent **indicator of a country's industrial well-being**. Below we see the amount of sulfuric acid produced in the United States during the first seven decades of this Century.

"Enough already...go to the bottom."



Note: 1 short ton = 2000 lb. (whereas a metric ton = 2205 lb. and a long ton = 2240 lb.)

Figure 1-1, Source: "US Bureau of the Census, Historical Statistics from Colonial Times to 1970."

Notice how **sulfuric acid production closely mirrors historical events** effecting the American economy. Sulfuric acid production dropped after the American involvement in **World War I** (1917-1919) and open world trade resumed. The stock market crash of 1929 further stagnated growth which was restored at the outbreak of **World War II** (1938). As the U.S. entered the war (1941) our economy was rapidly brought up to full production capacity. The post war period (1940-1965) saw the greatest economic growth in America's history, and this was reflected in ever increasing sulfuric acid production. Massive **inflation** during the late sixties and the **energy crisis** and economic recession of the early seventies also reveal themselves in the sulfuric acid curve. Two other important chemicals, Caustic Soda (NaOH) and Ammonia (NH_3), help emphasis the scale of sulfuric acid production while also displaying the same basic trends.

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Setting the Stage (1888)

A Century of Contributions

AIChE Membership

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pafko.com/history/h_s_acid.html

Figure 2: AIChE Growth & The Future

Membership for the American Institute of Chemical Engineers

A **strong AIChE reflections** a strong **chemical engineering profession.** This is because today's AIChE represents the profession as a whole. However, for thirty years after its **formation (in 1908)**, the Institute remained a very exclusive organization (notice the slow initial growth shown below). Its "**club** like" atmosphere made membership desirable to those who could obtain it, while at the same time helping to **avoid direct conflict** with the powerful American Chemical Society (**ACS**).

"Enough already...go to the bottom."

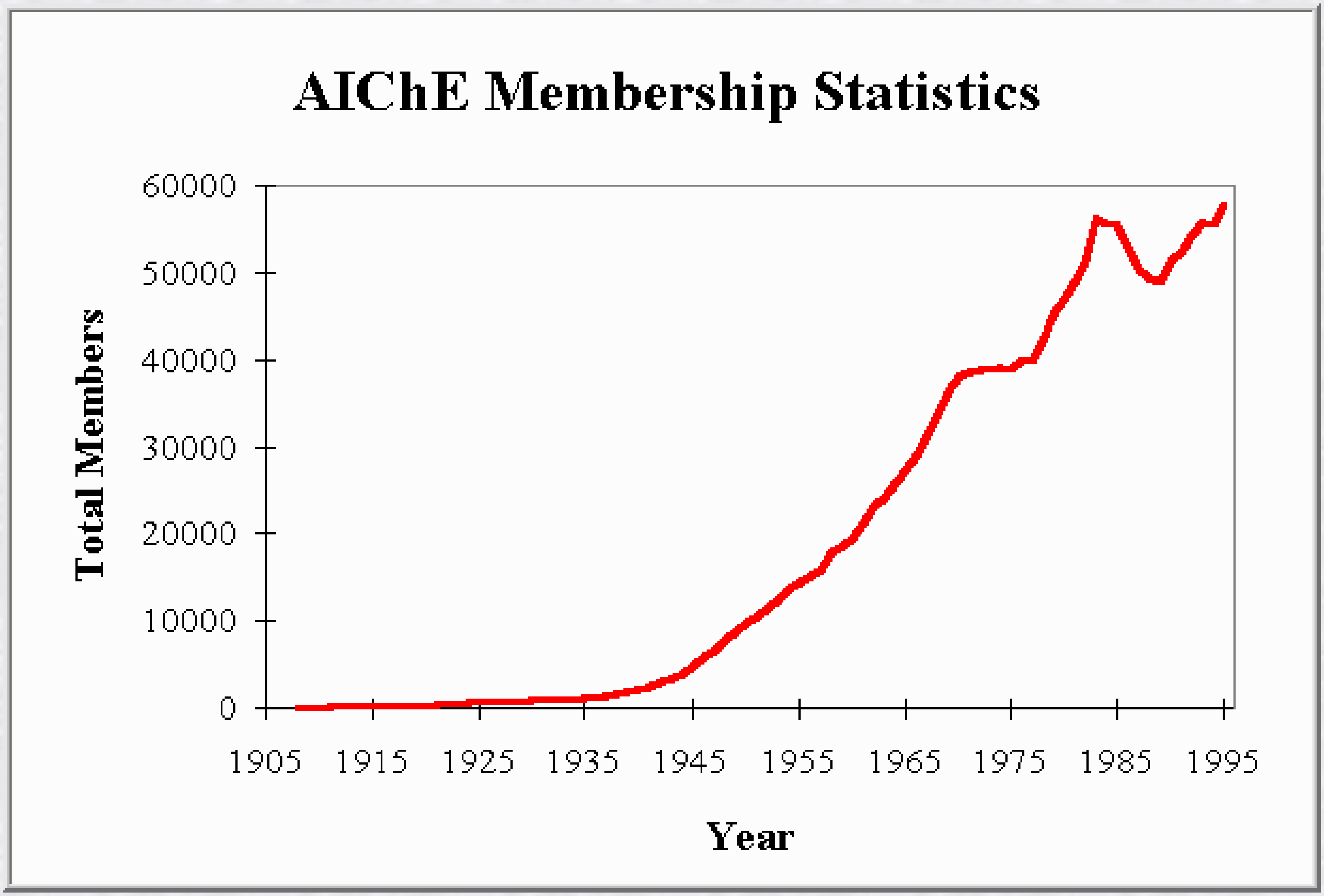

Figure 2-1, (R3) & "AIChE Correspondence"

In the **latter half of the century**, its highly restrictive membership was lifted, and students were welcomed into the organization with open arms. By the 1990's nearly **70%** of all individuals calling themselves "**chemical engineers**" could also call themselves **AIChE members**. AIChE membership therefore provides a reasonable picture of American chemical engineers as a whole. Therefore, that dramatic membership slump seen around 1985 should start worrying any prospective chemical engineer (see Graph above)!

"The Future Ain't What it Used to Be!"

Each year about **5000 chemical engineers graduate** and replace the **1000 chemical engineers who retire**. With the **rapid growth** seen from **1945 to 1970** slowing down, employment in today's chemical industry is not as certain. Only **two-thirds of new chemical engineering graduates find full-time work within their first six months** out of college (however, this employment rate for new graduates is the highest of any major engineering field). Additionally, **the average chemical engineering graduate can expect to work for 6-8 employers over a career**. This is in sharp contrast to twenty years ago, when chemical engineers found secure employment with only 1-2 employers over a lifetime. In short, while future prospects are still good, things ain't what they used to be.

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Struggle for Survival

Sulfuric Acid Production

Chemical Engineering Education

"The end already...go back to the top."

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pafko.com/history/h_aiche.html

Figure 3: Chemical Engineering Education.

Emergence & Growth

Chemical engineering education **emerged** from the American tradition in **industrial chemistry** at the turn of the Century. However, the **coursework** for these first programs **varied greatly in substance and emphasis**. While all envisioned chemical engineering as bridging the gap between mechanical engineers and chemists, this still allowed for wide **divergence**.

In 1925 the **AIChE** attempted to rectify this situation by becoming the **first organization to use accreditation**. This concept quickly spread to other engineering fields. Today, **ABET's** audits strike fear and foreboding across the country as it strives to **raise the quality of higher education higher and higher**. Below we see the number of chemical engineering programs that must undergo this scrutiny.

"Enough already...go to the bottom."

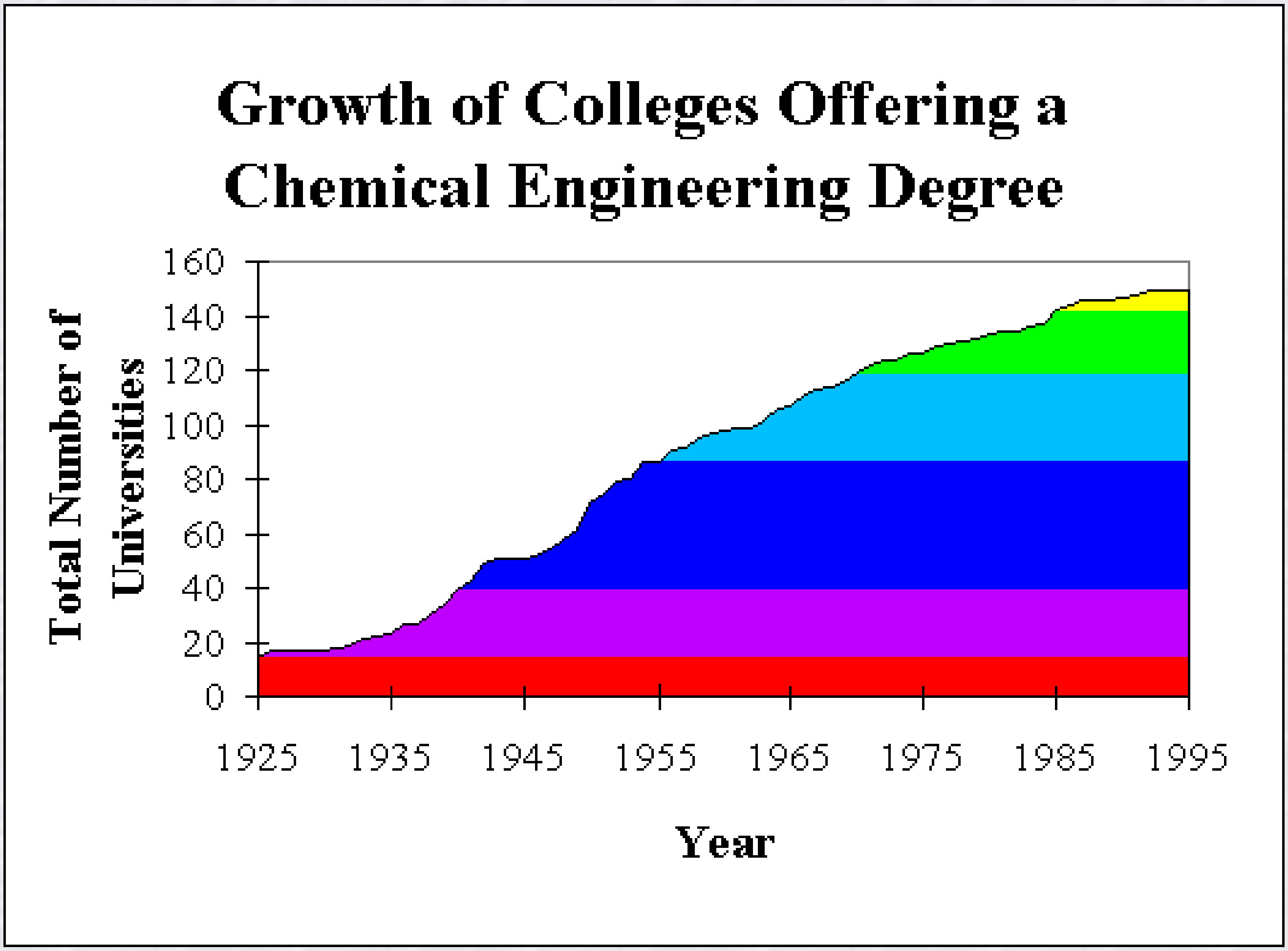

Figure 3-1, Source: (R3) & "AIChE Correspondence"

Enormous growth in chemical engineering education was seen in the years **just prior to,** and the **decades following, World War II**. Today, this **growth** has **stagnated**, and no new programs have been accredited **since 1992**. Despite the stagnation, many feel there are still too many new chemical engineers graduating (about 5000) each year. It is therefor unlikely that many new University will seek accreditation in chemical engineering.

Take a Look at the Original Programs (1925)

Carnegie-Mellon University (Pittsburgh, PA)

Case Western Reserve University (Cleveland, OH)

Columbia University (New York, NY)

Illinois Institute of Technology (Chicago, IL)

Iowa State University (Ames, IA)

Massachusetts Institute of Technology (Cambridge, MA)

Ohio State University (Columbus, OH)

Polytechnic University (Brooklyn, NY)

Renssalaer Polytechnic Institute (Troy, NY)

University of Cincinnati (Cincinnati, OH)

University of Michigan (Ann Arbor, MI)

University of Minnesota (Minneapolis, MN)

University of Wisconsin at Madison (Madison, WI)

Yale University (New Haven, CT)

The Geographic Trends in Chemical Engineering Education (1925 to the Present)

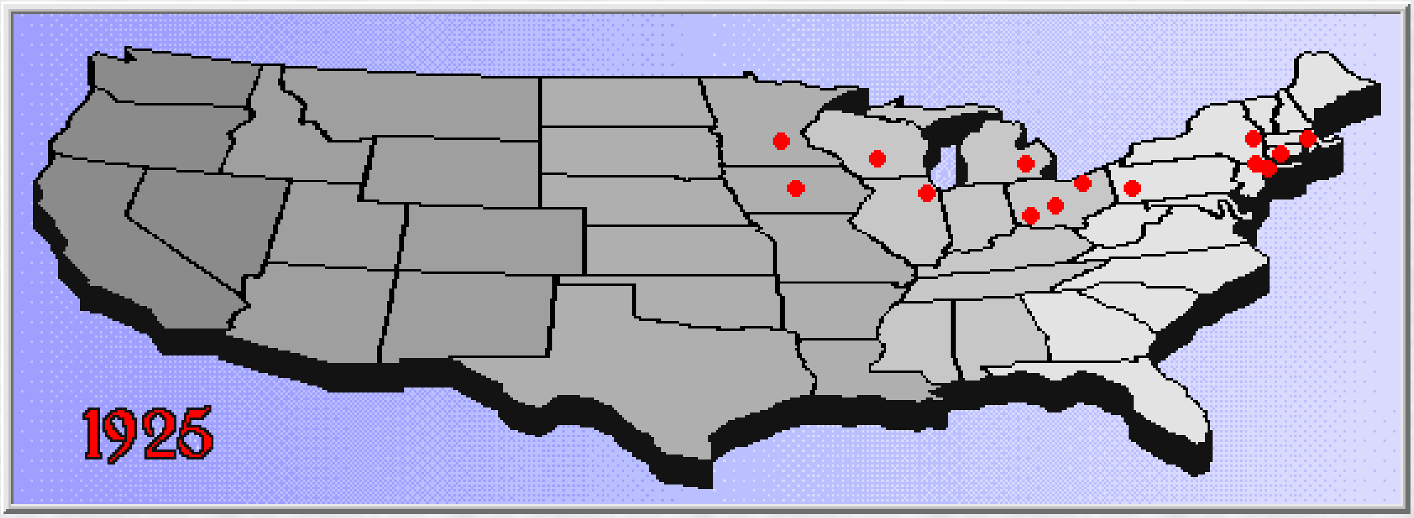

Figure 3-2, Source: (R3) & "AIChE Correspondence"

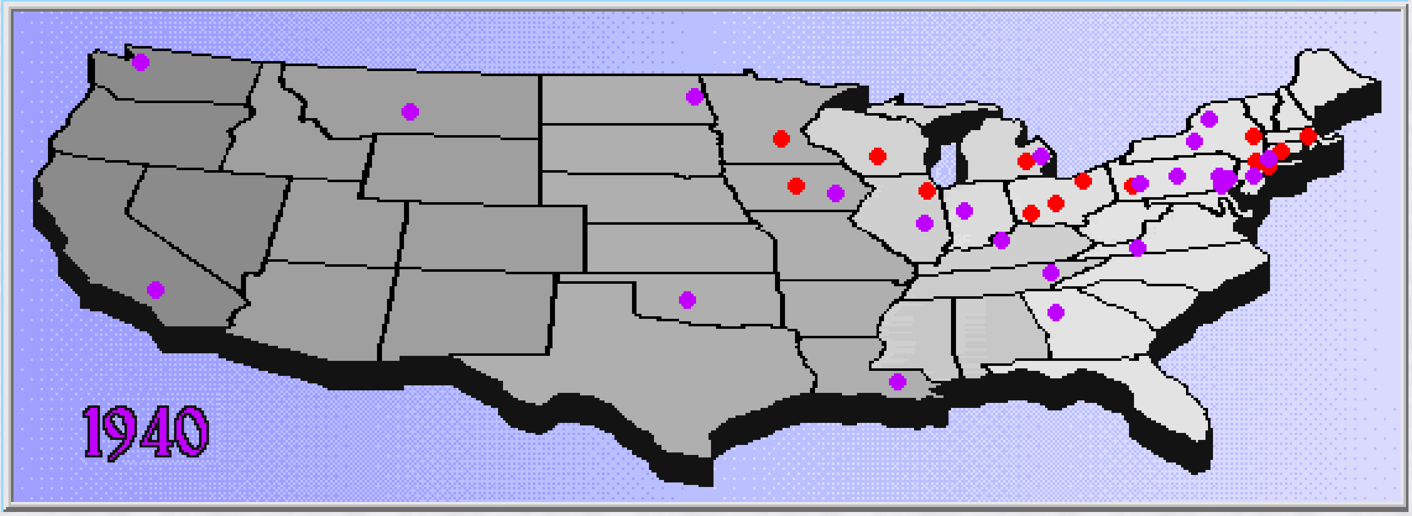

Figure 3-3, Source: (R3) & "AIChE Correspondence"

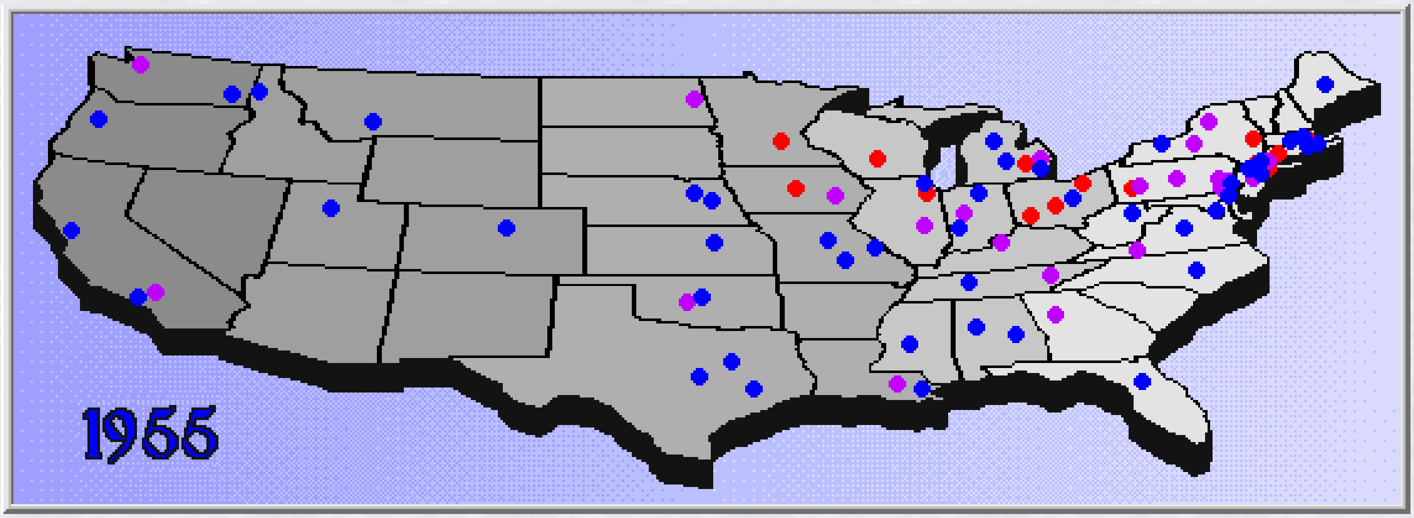

Figure 3-4, Source: (R3) & "AIChE Correspondence"

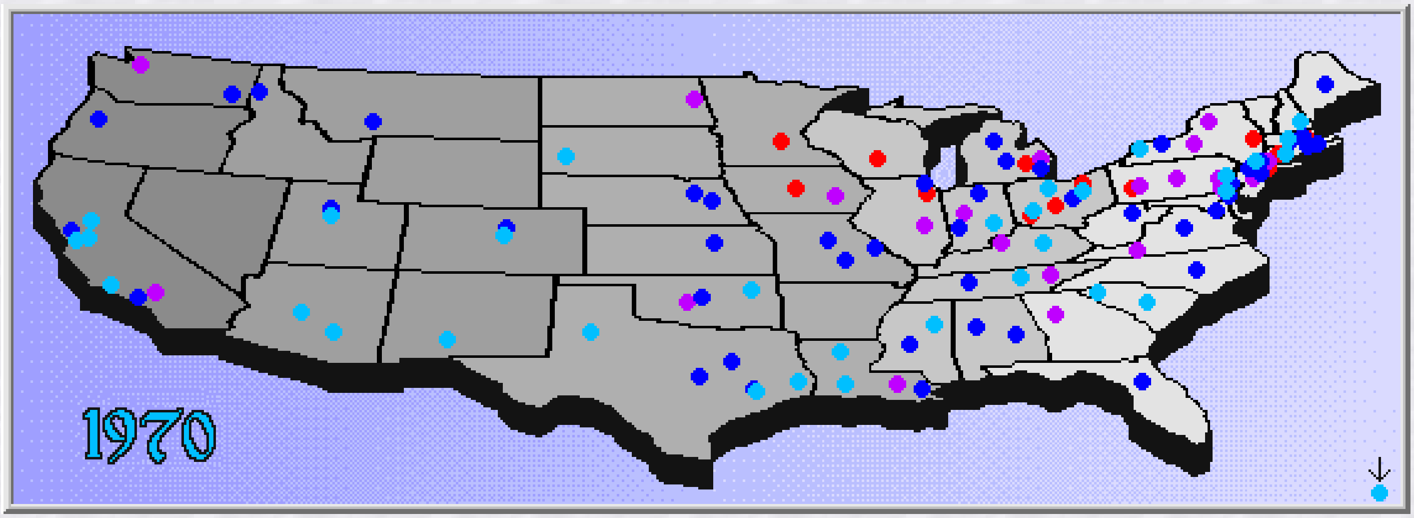

Figure 3-5, Source: (R3) & "AIChE Correspondence"

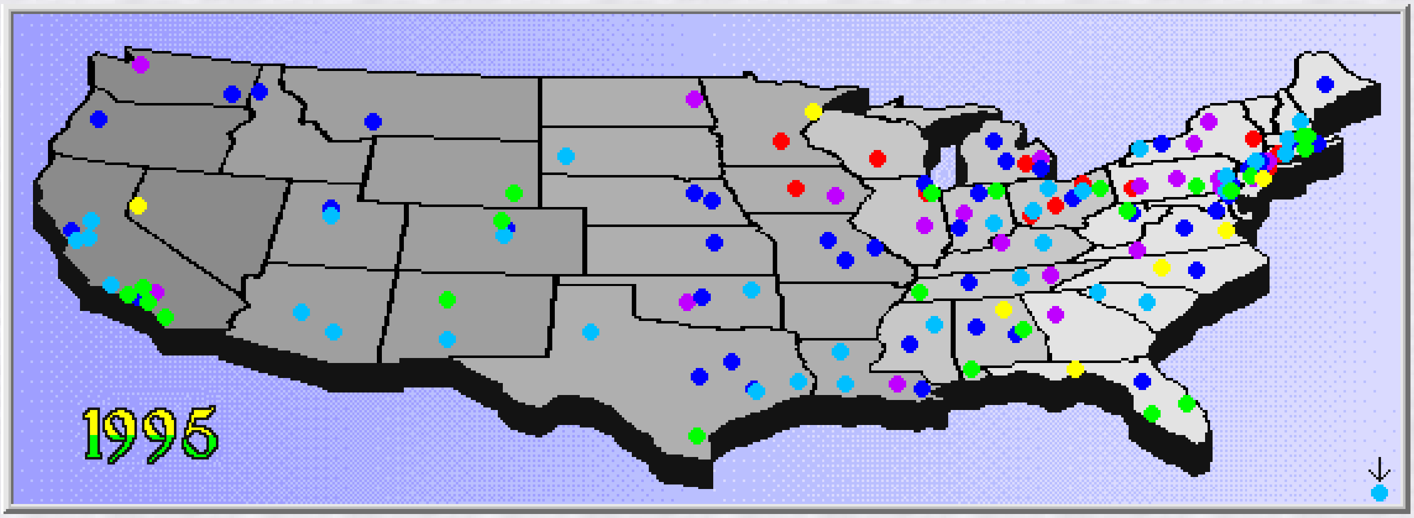

Figure 3-6, Source: (R3) & "AIChE Correspondence"

Note: All dates are based upon the first year of accreditation. This is often much later than the year in which a given chemical engineering program may have begun.

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Struggle for Survival

AIChE & The Future

Nitrogen: Food or Flames

"The end already...go back to the top."

We always welcome COMMENTS, SUGGESTIONS, OR REACTIONS.

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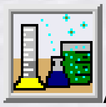
pafko.com/history/h_grow.html

Figure 4: Nitrogen: Food or Flames

Nitrogen gas surrounds us all, yet we barely notice this **benign compound** exists (78% of the atmosphere is composed of nitrogen gas, N_2). However, when combined with other elements, nitrogen can have a very **schizophrenic personality**. Nitrogen compounds can be used to **feed, or kill, with equal ease**. This ironic nature of nitrogen was tragically demonstrated in the **Oklahoma City Bombing** when fertilizer was used as an explosive, killing hundreds.

"Enough already...go to the bottom."



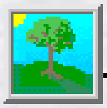
A Little Chemistry

All living things **require nitrogen to live** (it is the "amino" in "amino acids", a major component in DNA, RNA, and proteins) however few creatures can make direct use of the sea of nitrogen surrounding us all. This is because the two nitrogen atoms that make up a nitrogen molecule are held firmly together by a **triple bond** which is exceedingly difficult to break.

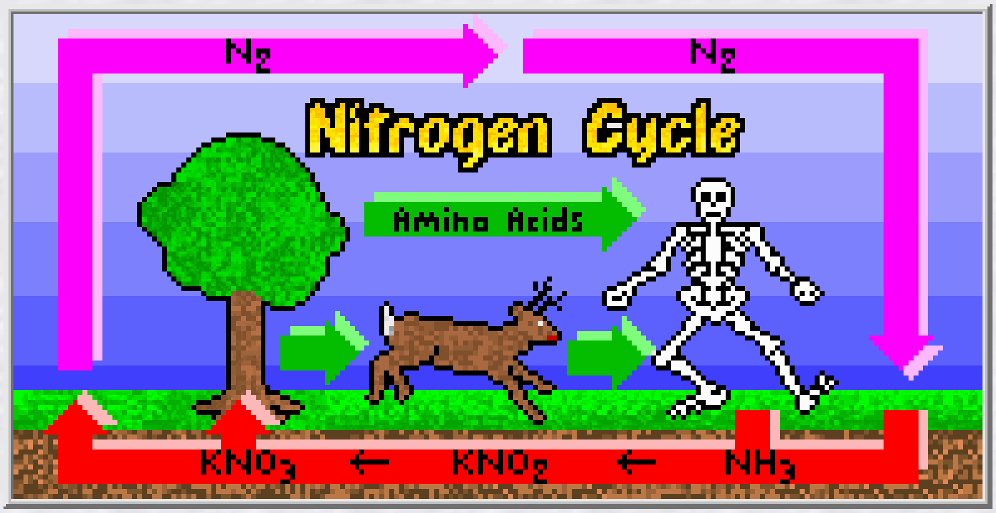
Because of this bond, **nitrogen gas** simply does not participate in any reactions at room temperature (or even at the higher temperatures found in small fires), and is therefore described as **inert**. Only at **extremely high temperatures** (such as those found near a lightning bolt or in an automobile's engine), or through the magic of "**nitrogen fixing" bacteria** (who work their trick with a complex set of enzymes instead of heat), can this triple bond energy be overcome, making nitrogen gas momentarily reactive while in an excited state.

If this excited nitrogen molecule is **combined with oxygen** (which incidentally composes the rest of the atmosphere) nitrogen oxide (NO) is produced. This readily oxidizes to nitrogen dioxide (NO_2), which provides the brownish haze seen in **smog** (as all Los Angeles residents are well aware).

If, on the other hand, the excited nitrogen gas **combines with hydrogen**, it forms **ammonia** (NH_3). And ammonia, unlike smog, is a very useful compound indeed. It can be used to make **fertilizers, high explosives, nitric acid, and household cleaning agents**.



The Nitrogen Cycle



Converting nitrogen gas into more reactive (and useful) nitrogen compounds, such as ammonia, encompasses the first stage in the "**nitrogen cycle**". Once converted from its gaseous form, fixed nitrogen compounds allow **plants to grow large and healthy**. **Animals** gain access to this nitrogen by **eating the plants**, and **deposit excess nitrogen in their feces**. Fixed nitrogen is also returned to the soil when **plants and animals die**. **Bacteria then decompose** this organic matter first into **ammonia**, then into **nitrites** (like potassium nitrite: KNO_2), and finally into **nitrates** (like potassium nitrate: KNO_3), which are again used by plants. Additional bacteria return some of the fixed nitrogen back to the atmosphere (in the form of nitrogen gas), thereby regulating the whole cycle.

The State of Affairs in 1913

For thousands of years, humans had little impact on the nitrogen cycle. The strong bond found in nitrogen gas prevented its simple conversion to other, much more useful, nitrogen compounds. People were therefore entirely dependent upon bacteria for the initial nitrogen fixation. Once fixed in the cycle, nitrogen compounds could be collected.

One of the best, and largest, **sources** of this **fixed nitrogen** was found in **Chile**. This outcrop was due to a vast number of **sea birds** which **nested**, and went to the bathroom, along its coasts. Over thousands of years these "**natural" deposits** called "**Guano**" accumulated and became several feet thick. A huge industry developed to supply this Chilean saltpeter to the rest of the world.

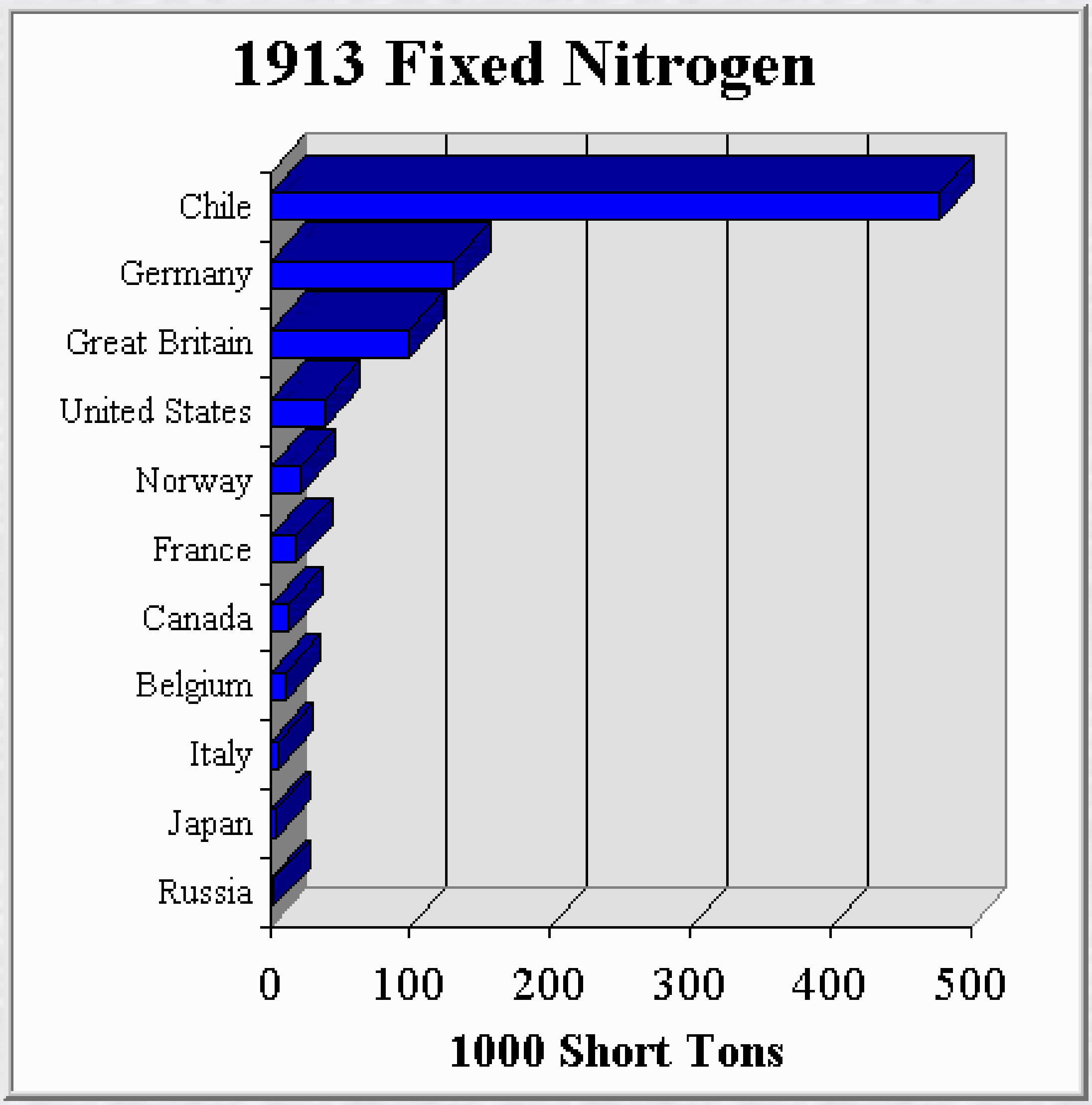


Figure 4-1, Source: (M3)

With synthetic production almost non-existent, the world was **entirely dependent** on the **Chilean resource** for **fertilizers and high explosives**. This was a fact which military leaders did not overlook. They realized that if war broke out, the countries which lacked (or were denied) access to the Chilean supply (like Germany) would quickly **run out of munitions**.

In 1913 if you were an up and coming nation, intent on **feeding your people**, or **conquering your enemies** through conquest, you **needed as much Chilean saltpeter as possible**. In short, the fate of the world depended upon who could get their hands on the most bird shit. It is therefor no coincidence that the first major naval battle of World War I occured off the coast of Chile.

Synthetic Ammonia Production

Shortly before the outbreak of World War I, two patriotic Germans developed a method for producing **synthetic ammonia**. The first plants using this "**Haber-Bosch Process**" were constructed shortly after the outbreak of the war. They had discovered that ammonia could be made by placing **nitrogen gas** and **hydrogen gas** in a **high pressure** chamber. With the addition of a suitable **catalyst**, and a little **heat** to speed things up, **vast quantities of fixed nitrogen could be produced**. Without the Haber-Bosch Process, **Germany would have run out of munitions in 1916** thereby ending the war.

To compete with this, other countries copied the process and quickly scaled up their own synthetic ammonia production capabilities. When the war was over, fixed nitrogen continued to be produced in large amounts because of its use as a fertilizer. By 1934 Chile was supplying only 7% of the worlds fixed nitrogen (a huge drop from the 56% supplied in 1913). **Synthetic ammonia production had arrived in force**.

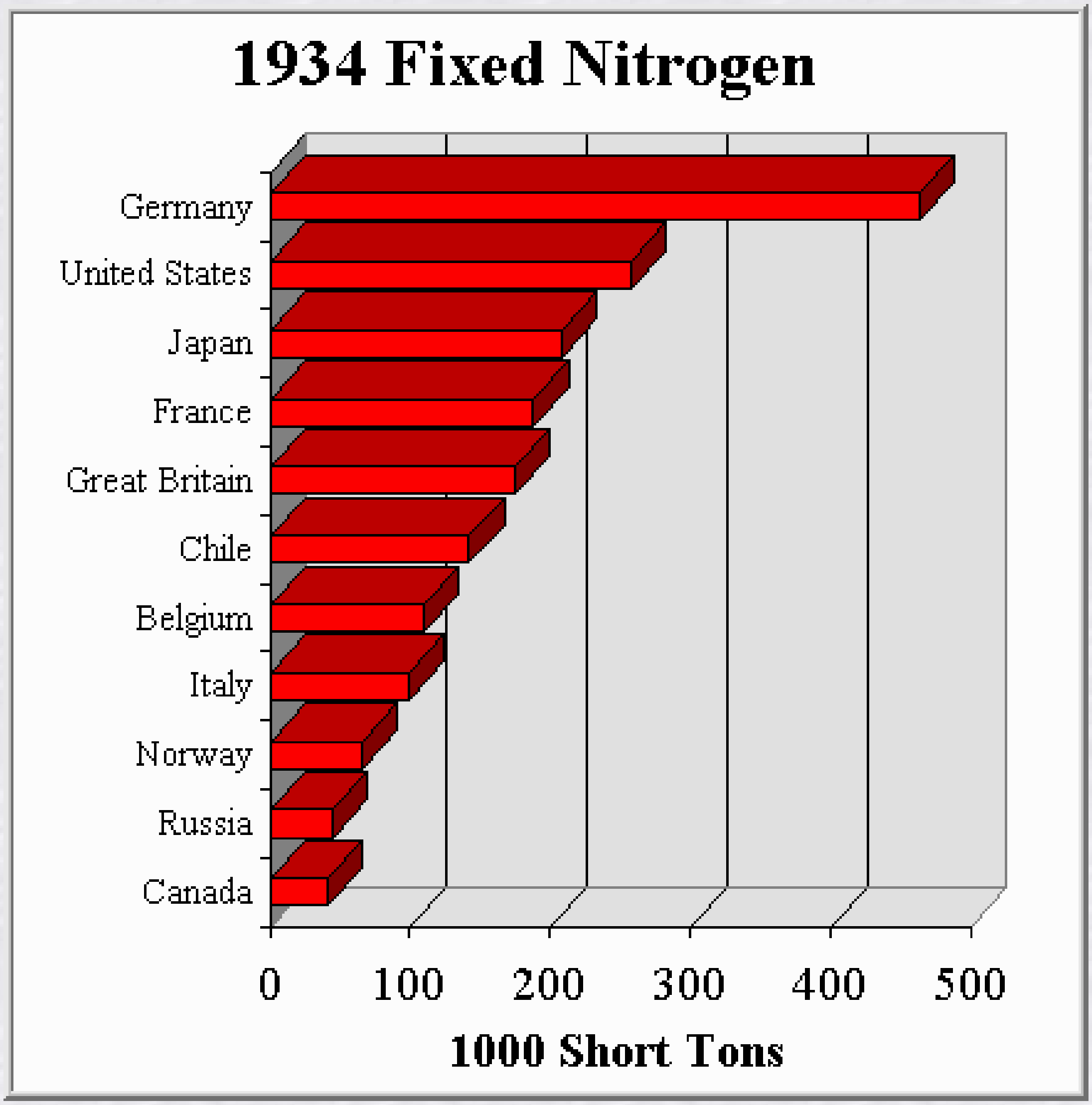


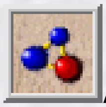
Figure 4-2, Source: (M3)

Tabulated data for previous two graphs is shown below...

Fixed Nitrogen Production		
(1000 short tons)	1913	1934
World	**843.5**	**1972.0**
Chile	56.5%	7.2%
By-product	36.4%	17.7%
Cyanamide	5.0%	11.3%
Synthetic	2.1%	63.8%
Chile	476.7	141.8
Germany	131.6	462.5
Great Britain	99.5	175.0
United States	39.5	256.7
Norway	22.0	65.5
France	18.9	187.6
Canada	12.7	41.1
Belgium	11.0	109.8
Italy	6.3	98.6
Japan	3.9	208.0
Russia	3.2	45.0

Figure 4-3, Source: (M3)

As these figures show, **synthetic ammonia** production **eliminated** the worlds **dependence upon Chilean saltpeter**. Chemical engineers played a large role in designing, building, and operating the ammonia plants that made this possible. In 1934 if you wanted to **feed your country** or **wage a war** you turned to a chemical engineer. This fact brought with it a **moral dilemma** for the **chemical engineer** asked to build an **ammonia plant**...



A Few Important Nitrogen Compounds

- **Amino Acids** are the **building blocks of life**. All living things are composed of only 20 such compounds, with the amino group (NH_2) common to them all.

- **Nitrous Oxide** (dinitrogen oxide) (N_2O) Otherwise known as **laughing gas**, this compound is a colorless gas at room temperatures and pressures.

- **Nitrogen Oxide** (NO) A colorless bi-product formed in internal combustion engines where high temperatures and pressures are capable of combining the nitrogen and oxygen gases found in the air.

Nitrogen Dioxide (NO_2) Otherwise known as **smog**, this brown gas comes about as nitrogen oxide is spontaneously oxidized in the atmosphere.

Potassium Nitrate (KNO_3) Often referred to as **saltpeter**, it can be placed directly on the soil as a **fertilizer**, or when mixed with sulfur and coal forms **gunpowder**. Saltpeter is **prized by both farmers and generals**.

Trinitrotoluene (TNT, $CH_3C_6H_2(NO)_3$) A high explosive used as the explosive charge in shells and bombs.

Nitroglycerin ($C_3H_5(ONO_2)_3$) Being the **principle explosive ingredient in dynamite**, this chemical packs quite a punch. It is three times as powerful as an equal amount of gunpowder, is smokeless, and its explosive wave travels 25 times faster. Because of its many uses, and high demand, dynamite producers were able to amass great fortunes. **Alfred Nobel** was one early manufacturer, and his fortune continues to finance the **Nobel Prize Award** today.

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A Century of Contributions

Chemical Engineering Education

Oil, Energy, & Petrochemicals

"The end already...go back to the top."

We always welcome COMMENTS, SUGGESTIONS, OR REACTIONS.

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pafko.com/history/h_s_n2.html

Figure 5: Oil: Energy or Petrochemicals

Power for an Energy Hungry Nation

At the birth of our Nation (1776) **energy was used** primarily to **heat houses** and **cook food;** requiring only **timber and coal**. **Water power** was sufficient for the **textile factories** and **grain mills** that existed, while **animal power** helped **till the fields** and provide **transportation**. However, as the **Industrial Revolution** (18th Century to today) rolled along, larger quantities of **mechanical energy** were soon required. Several inventions helped meet these needs, but in the process they also consumed vast quantities of **fossil fuels**.

"Enough already...go to the bottom."

- **Steam Engines**: Developed by the likes of Savery, Newcomen, and Watt; steam engines **burned coal** to supply energy for **locomotives, paddleboats, and factories**.

- **Gasoline Engines**: With the invention of the **internal combustion engine**, and the advent of **gasoline automobiles** in 1885 by Karl Benz, **petroleum** soon became a sought after energy source.

- **Electricity**: With the perfection of the **electric light** in 1879, Thomas Edison had enlightened the world. However, he had also invented a new energy consuming device. Because of the **failings of nuclear power to gain widespread acceptance**, electricity generation continues to consume vast amounts of coal.

The modern **American household** is packed full of **energy consuming devices** all designed to **make life a little easier**. Central heating, air conditioners, fans, electric lights, ovens, microwave ovens, hot water heaters, washing machines, dryers, dish washers, refrigerators, freezers, television sets, computers, and who can forget the automobile; when used cumulatively consume huge amounts of energy. Despite having only about **5% of the worlds population**, modern convenience has caused the **United States to consume 30% of the world's energy**. The non-renewable fuels used to supply this energy hungry lifestyle are shown below.

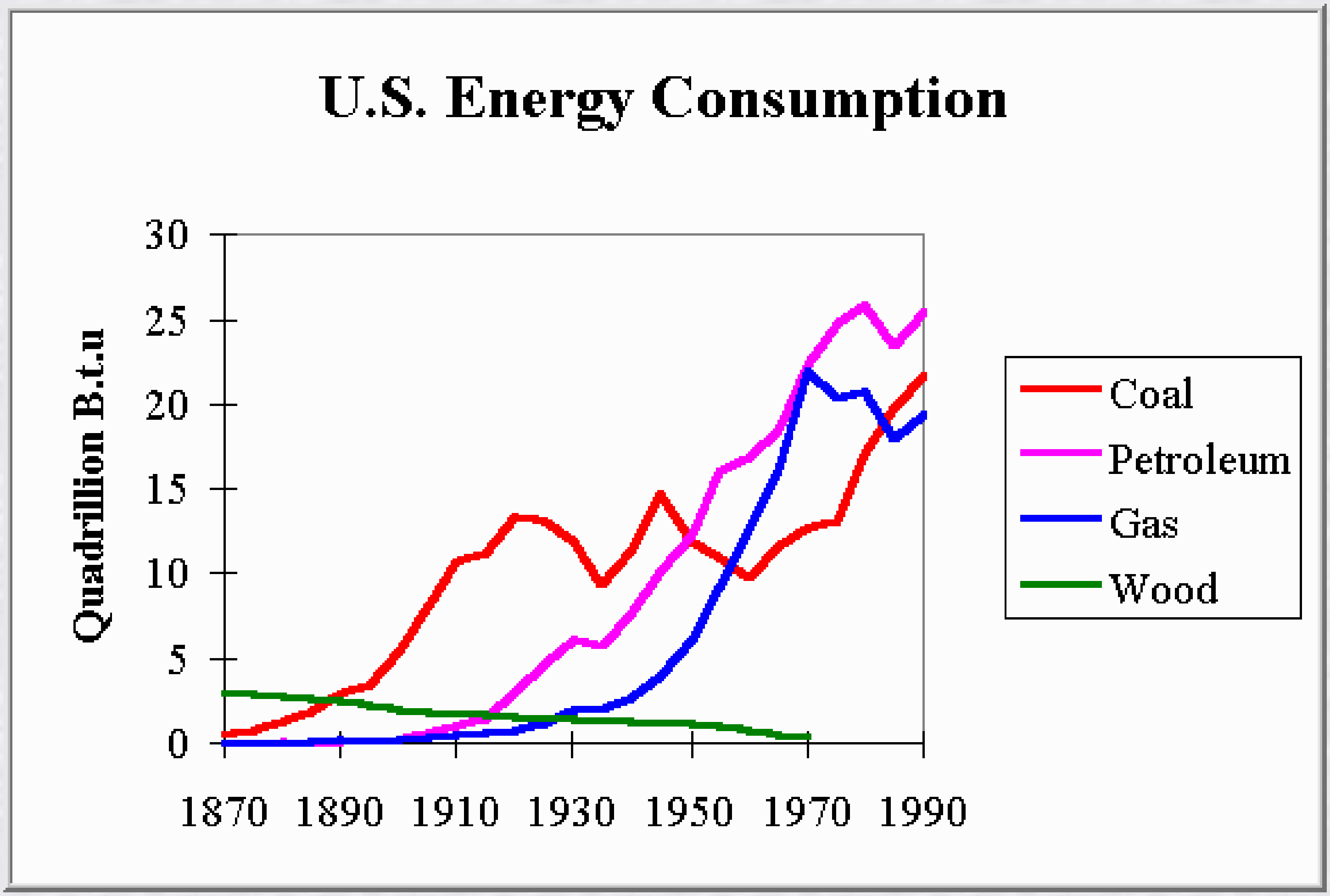
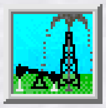


Figure 5-1, Source: "US Bureau of the Census, Historical Statistics from Colonial Times to 1970."

U.S. Energy Consumption (Quadrillion of B.t.u)				
	Bituminous	Crude	Nature	Fuel
Year	Coal	Petroleum	Gas	Wood
1870	0.5	0.0		2.9
1880	1.3	0.1		2.9
1890	2.9	0.2	0.3	2.5
1900	5.4	0.2	0.3	2.0
1910	10.7	1.0	0.5	1.8
1920	13.3	3.0	0.8	1.6
1930	11.9	6.1	2.0	1.5
1940	11.3	7.7	2.7	1.4
1950	10.2	12.3	6.2	1.2
1960	9.7	16.9	12.7	0.8
1970	12.7	22.4	22.0	0.4
1980	17.1	34.2	20.8	
1990	21.8	33.6	19.5	

Figure 5-2, Source: "US Bureau of the Census, Historical Statistics from Colonial Times to 1970."



Petroleum: For Fuel or Plastic?

Petroleum is so **important to our society** that it has rightfully earned the title "**black gold**." When used to supply energy, petroleum is converted into; **gasoline**, **fuel oils**, **lubricants**, **kerosene**, and **jet fuels**. However, it is also necessary for; **plastics**, **waxes**, **asphalt**, and all nature of fine **organic chemicals**. Because of its value as a raw material, some claim that **petroleum is to valuable to burn**! About **half** of all **American chemical engineers** are **employed** by the **petroleum industry;** and a huge industry it is (see below). The petroleum industry is one of the main reasons chemical engineers have enjoyed such **success**.

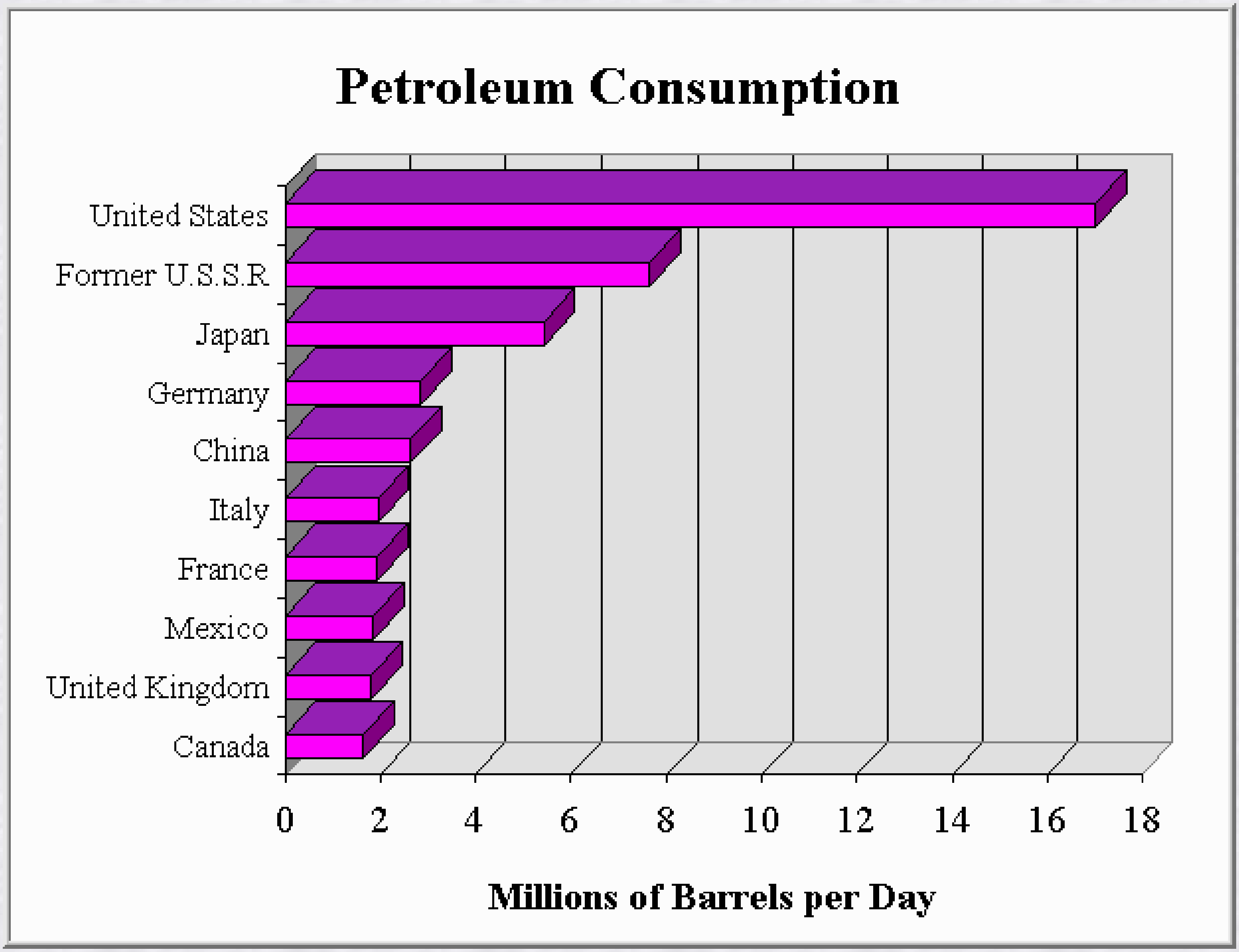


Figure 5-3, Source: "US Bureau of the Census, Historical Statistics from Colonial Times to 1970."

1992 World Petroleum Consumption		
(Million barrels per day)	Consumption	Percent
World	66.7	
United States	17.0	25.5%
Former U.S.S.R	7.6	11.4%
Japan	5.5	8.2%
Germany	2.8	4.3%
China	2.6	3.9%
Italy	1.9	2.9%
France	1.9	2.9%
Mexico	1.9	2.8%
United Kingdom	1.8	2.7%
Canada	1.6	2.5%
Rest of World	23.6	35.4%

Figure 5-4, Source: "US Bureau of the Census, Historical Statistics from Colonial Times to 1970."

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"The end already...go back to the top."

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Figure 6: Engineering & Technical Wages

The **chemical engineer**, with a bachelors degree, is usually **paid very well**. While this may be partly because of a **broad background in science and engineering**, it also has a lot to do with the **type of industries** that employ chemical engineers. About half of today's chemical engineers work in the **petroleum** and **petrochemical industry**. Often these industries require enormously **expensive capital equipment**, and therefor **employee salaries** becomes a much **smaller part of the overall cost of doing business**. Because of this, it makes good sense for these companies to pay handsomely to get the best person for the job.

"Enough already...go to the bottom."

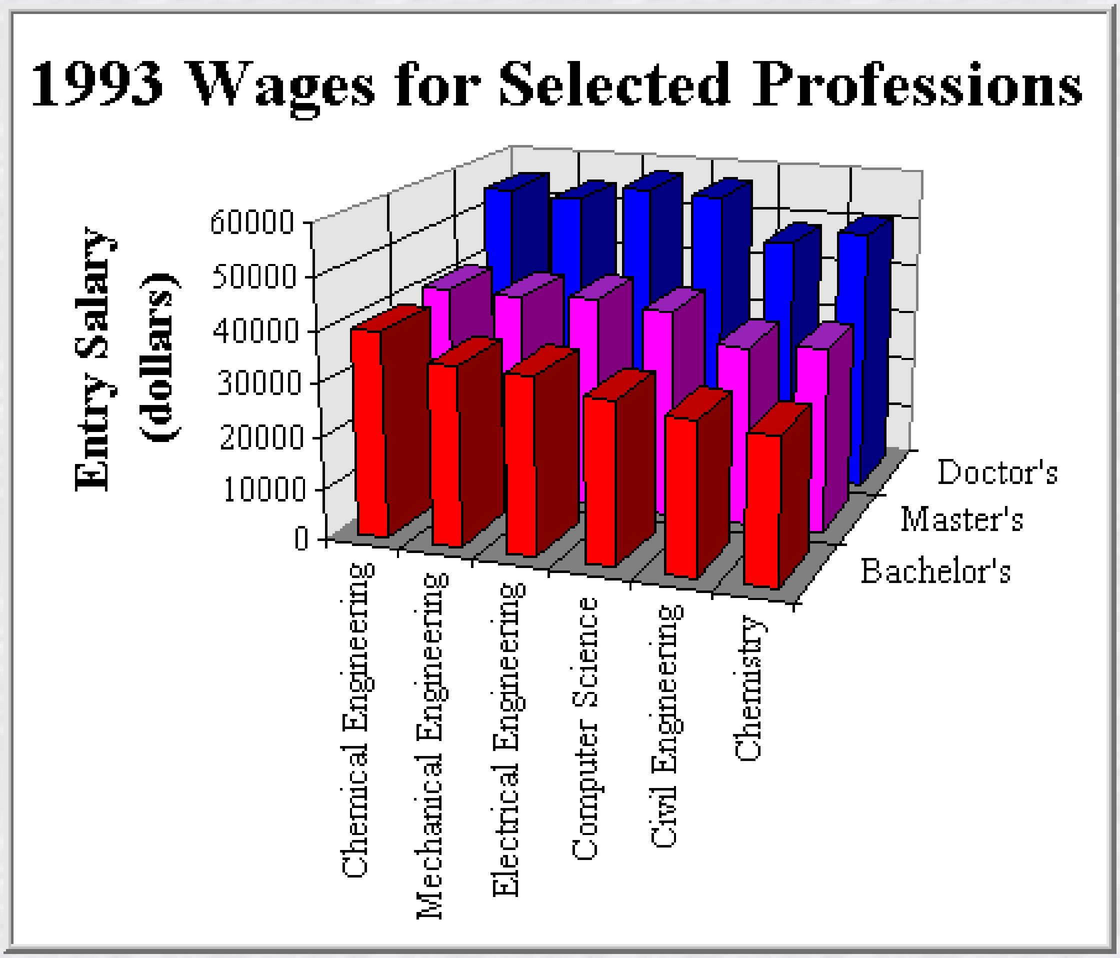

Figure 6-1, Source: "US Bureau of the Census, Historical Abstract 1993."

One interesting trend in these wage figures is the **relatively low salary increase chemical engineers receive by acquiring higher degrees**. In some professions, such as chemistry, it makes a lot of financial sense to attain the highest degree possible. However, this is not necessarily the case for chemical engineers.

1993 Entry Level Wages Based On Degree Earned			
(In dollars)	Bachelor's	Master's	Doctor's
Chemical Engineering	39482	40874	55078
Mechanical Engineering	34460	40457	54217
Electrical Engineering	34313	41291	57076
Computer Science	31329	40115	56513
Civil Engineering	29211	34606	48268
Chemistry	28002	35690	50933

Figure 6-2, Source: "US Bureau of the Census, Historical Abstract 1993."

It is also informative to examine the **number of degrees awarded** to each of these professions over the last thirty years or so. In the 1980's the **personal computer** craze fueled an incredible **surge** in the number of **computer science** degrees. The PC also dramatically increased the number of **electrical engineering** graduates. An unrelated, but interesting point, is the number of **chemistry majors** which go on to get their **Ph.D. degrees**. Chemists undoubtedly are very aware of how their **pay scale** is structured and try to take advantage of that insight. **Chemical engineers** are also aware of this, and those who go on to higher education do **not usually stop** at a **Master's degree**.

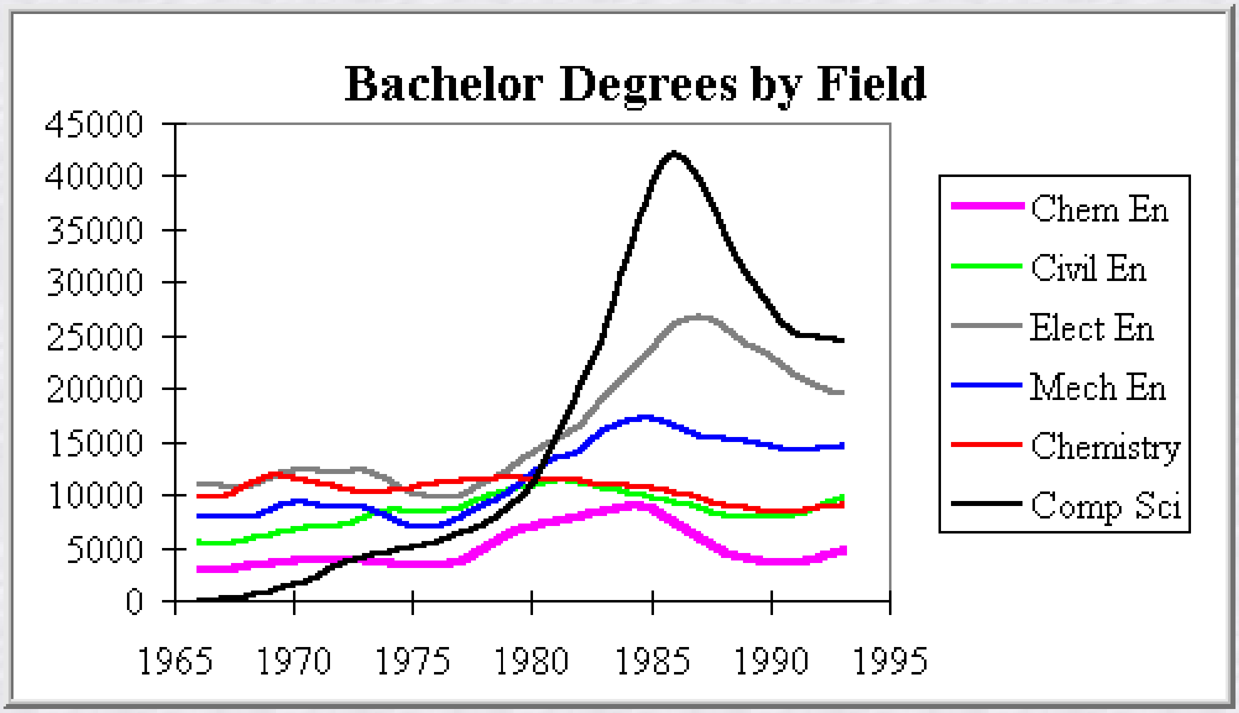

Figure 6-3, Source: "US Bureau of the Census."

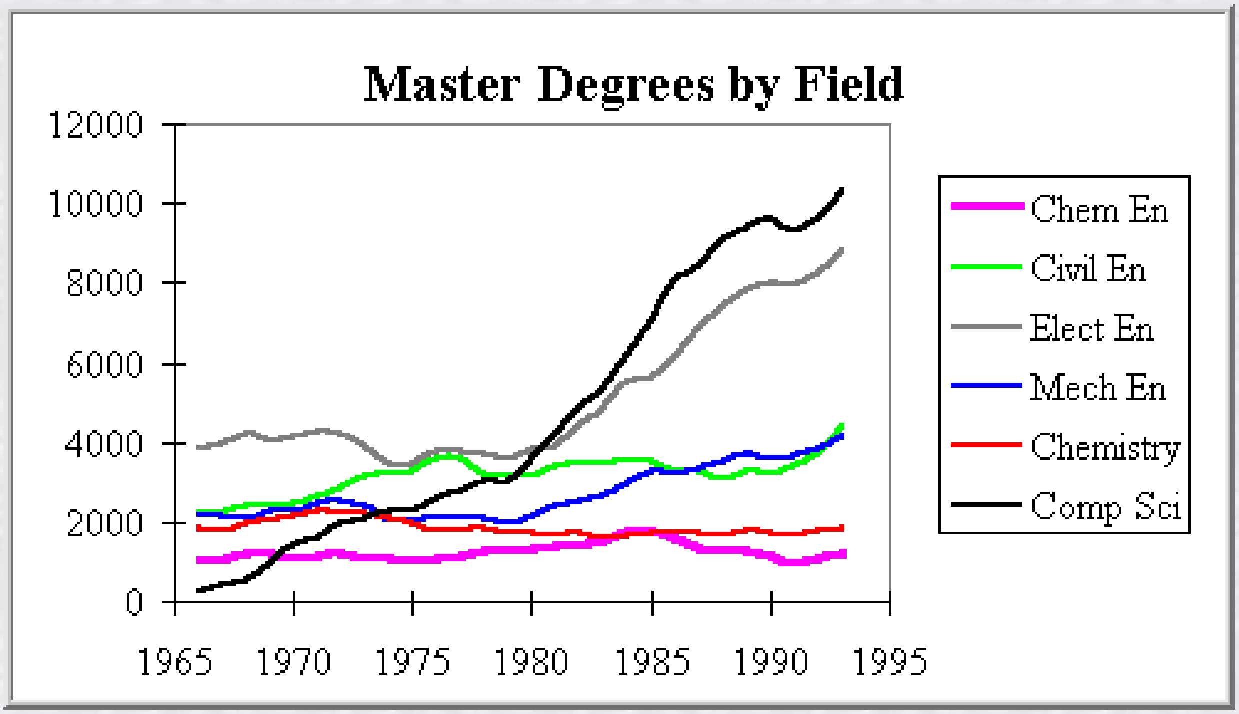

Figure 6-4, Source: "US Bureau of the Census."

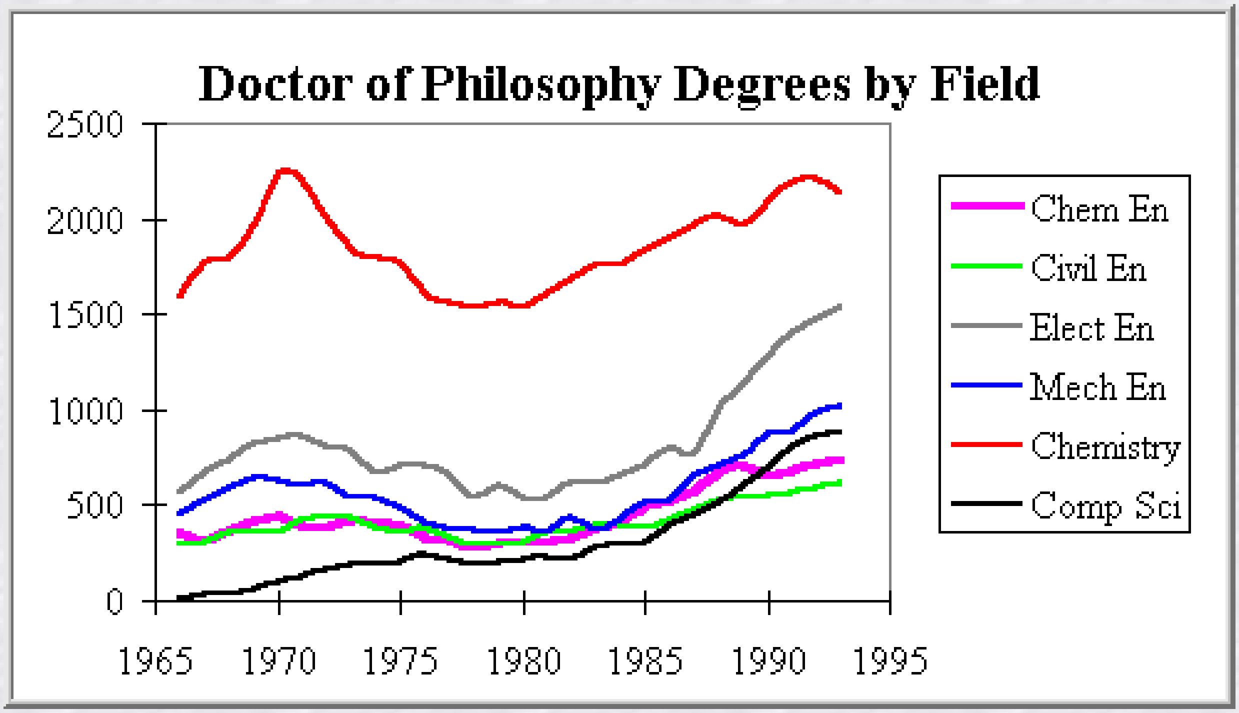

Figure 6-5, Source: "US Bureau of the Census."

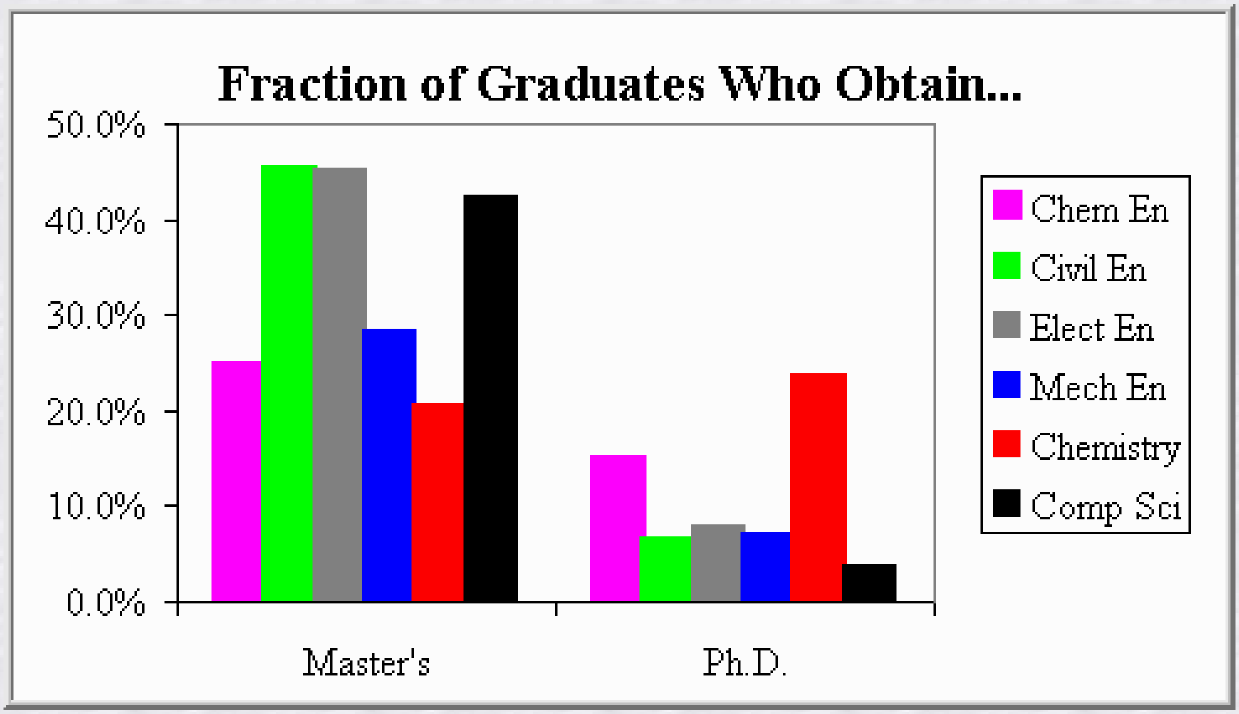

Figure 6-6, Source: "US Bureau of the Census."

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Case Study: Petroleum

Origins of the Industry

The **American chemical engineer** and the **American petroleum industry** developed side by side over the past century. The petroleum industry **began** when **Edwin L. Drake** drilled a **successful oil well** at Titusville **Pennsylvania in 1859**. Others quickly followed his lead, and before long oil wells covered the countryside. Just ten years after California's Gold Rush, Pennsylvania had developed its own brand of "**gold fever**". Some, like **John D. Rockefeller**, accumulated **vast fortunes** from this "black gold", while others like **Mr. Drake died broke**. The difference between success and failure was often a fine line.

"Enough already...go to the end."

Ancient, and Less Ancient, Times

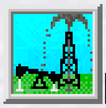
Small amounts of petroleum have been used throughout history. The **Egyptians** coated **mummies** and sealed their mighty **Pyramids** with pitch. The **Babylonians**, **Assyrians**, and **Persians** used it to **pave their streets** and hold their **walls** and **buildings** together. **Boats** along the Euphrates were constructed with woven reeds and sealed with pitch. The **Chinese** also came across it while digging holes for brine (salt water) and used the petroleum for heating. The Bible even claims that **Noah** used it to make his Ark seaworthy.

American Indians used petroleum for **paint, fuel, and medicine**. Desert **nomads** used it to treat **camels for mange**, and the **Holy Roman Emperor**, Charles V, used petroleum it to treat his **gout**. Ancient **Persians and Sumatrans** also believed petroleum had **medicinal value**. This seemed a popular idea, and up through the 19th Century jars of petroleum were sold as **miracle tonic** able to cure whatever ailed you. People who drank this "**snake oil**" discovered that petroleum doesn't taste very good!

The Search for Oil

Yet despite its usefulness, for **thousands of years** petroleum was **very scarce**. People collected it when it bubbled to the surface or seeped into wells. For those digging wells to get drinking water the petroleum was seen as a nuisance. However, some thought the oil might have large scale economic value. **George Bissell**, a lawyer, thought that petroleum might be converted into **kerosene for use in lamps**. An analysis by Benjamin Silliman, Jr., a Yale chemistry and geology professor, confirmed his hunch.

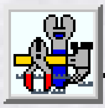
In **1854** Bissell and a friend formed the unsuccessful **Pennsylvania Rock Oil Company**. Not one to be easily dismayed, in **1858** Bissell and a group of business men formed the **Seneca Oil Company**. They hired an ex-railroad conductor named **Edwin Drake** to drill for oil along a secluded creek in **Titusville Pennsylvania**. They soon dubbed him "Colonel" Drake to impress the locals. But the "Colonel" needed help so he hired **Uncle Billy Smith** and his two sons who had experience with **drilling salt wells**. In 1859 this motley crew **found oil at a depth of 69 ½ feet**.



Pennsylvania's "Black Gold"

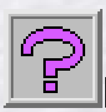
Drake's well produced only **thirty-five barrels a day**, however he could sell it for **$20 a barrel**. News of the well quickly spread and **brought droves of fortune seekers**. Soon the hills were covered with prospectors trying to decide where to dig their wells. Some used Y-shaped **devining rods** to guide them. Others followed Drake's lead and **drilled close to water**, a technique that was dubbed "**creekology**". Many found oil, but usually at **4 or 5 hundred feet** below the surface. Drake had just been lucky to find oil so high up!

To dig the wells **six-inch wide cast iron pipes** were **sunk down to the bedrock**. A **screw like drill** was then used to scoop out dirt and rock from the middle. Many discovered to their dismay that once they hit oil they had no way to **contain all of it**. Until caps were added to the wells vast quantities of **oil flowed into** the appropriately named **Oil Creek**.



The First Pipeline

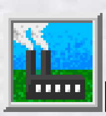
Transporting the oil was also a problem. In 1865 **Samuel Van Syckel**, an oil buyer, began construction on a **two-inch wide pipeline** designed to span the distance to the railroad depot **five miles away**. The **teamsters**, who had previously transported the oil, didn't take to kindly to Syckel's plan, and they used pickaxes to **break apart the line**. Eventually Van Syckel brought in **armed guards**, finished the pipeline, and made a ton-o-money. By **1865** wooden derricks were bled **3.5 million barrels a year** out of the ground. (Giddens) Such large scale production caused the price of crude oil to plummet to **ten cents a barrel**.



How Much Oil?

Andrew Carnegie was a large stockholder in the **Columbia Oil Company**. Carnegie **believed** that the **oil fields would quickly run dry** because of all the drilling. He persuaded Columbia Oil to **dig a huge hole** to **store** 100,000 barrels of **oil** so that they could make a killing when the country's wells went dry. **Luckily there was more oil than they thought!** But don't feel too sorry for Carnegie, he didn't let the setback slow him down very much, and went on to make his **millions in the steel industry**.

In contrast, "**Colonel" Drake** was committed to the oil business. He scoured the country looking for **customers** willing to buy his **crude oil**. However, the **bad smell**, **muddy black color**, and highly **volatile component**, called naphtha, caused few sales. It became obvious that one would have to **refine** the oil to find a market.



Early Refining

By **1860** there were **15 refineries** in operation. Known as **"tea kettle" stills**, they consisted of a large **iron drum** and a **long tube** which acted as a condenser. Capacity of these stills ranged from 1 to 100 barrels a day. A **coal fire** heated the drum, and three fractions were obtained during the distillation process. The first component to boil off was the highly volatile **naphtha**. Next came the **kerosene**, or "lamp oil", and lastly came the **heavy oils and tar** which were simply left in the bottom of the drum. These early refineries produced about **75% kerosene**, which could be sold for high profits. (Giddens, p.14)

Kerosene was so valuable because of a **whale shortage** that had began in **1845** due to **heavy hunting**. **Sperm oil** had been the main product of the whaling industry and was used in **lamps**. **Candles** were made with another whale product called "**spermaceti**". This shortage of natural sources meant that kerosene was in great demand. Almost all the families across the country started using **kerosene to light their homes**. However, the **naphtha and tar fractions** were seen as valueless and were **simply dumped into Oil Creek**. (I would like to point out that these first refineries were not operated by chemical engineers!)

Later these waste streams were converted into valuable products. In 1869 Robert Chesebrough discovered how to make **petroleum jelly** and called his new product **Vaseline**. The **heavy components** began being used as **lubricants**, or as **waxes** in **candles** and **chewing gum**. **Tar** was used as a **roofing material**. But the more **volatile components** were still **without much value**. Limited success came in using **gasoline** as a local **anesthetic** and **liquid petroleum gas** (LPG) in a compression cycle to **make ice**. The success in refined petroleum products greatly spread the technique. By **1865** there were **194 refineries** in operation.

John D. Rockefeller

In **1862** John D. Rockefeller **financed his first refinery** as a side investment. He soon discovered that he liked the petroleum industry, and devoted himself to it full time. As a **young bookkeeper** Rockefeller had come to love the order of a **well organized ledger**. However, he was appalled by the **disorder and instability** of the **oil industry**. Anyone could drill a well, and **overproduction** plagued the early industry. At times this overproduction meant that the **crude oil** was **cheaper than water**. Rockefeller saw early on, that **refining and transportation**, as opposed to production, were the **keys to taking control of the industry**. And control the industry he did!

In **1870** he established **Standard Oil**, which then controlled 10% of the refining capacity in the country. **Transportation** often encompassed 20% of the total production cost and Rockefeller made **under-the-table deals** with **railroads** to give him **secret shipping rebates**. This cheap transportation allowed Standard to **undercut its competitors** and Rockefeller expanded aggressively, buying out competitors left and right. Soon standard built a network of "iron arteries" which delivered oil across the Eastern U.S. This **pipeline system** relieved Standard's dependence upon the railroads and reduced its transportation costs even more. By **1880** Standard controlled **90% of the country's refining capacity**. Because of its **massive size**, it brought **security** and **stability** to the oil business, guaranteeing continuous profits. With Standard Oil, **John D. Rockefeller** became the **richest person in the World**.

So What?

But what came out of all this activity? In short the early petroleum industry:

- Brought a **revolution in lighting** with kerosene.
- Helped keep **machines** in good conditions with **lubricants**. (it was the "**Machine Age**" after all)
- Provided a new source of **national wealth** (in 1865 it was the countries 6th largest export).
- **Aided the Union** in the Civil War by strengthening the economy (also petroleum was used to treat wounded soldiers at the battle of Gettysburg).

A Few Terms

The petroleum industry, like other chemical industries, has a **plethora of terms** designed to **scare off anyone** who wants to understand exactly what is going on. Mastering this nomenclature is one of the **main tasks facing chemistry and chemical engineering students**. Here are a few commonly used terms, but be forewarned; because of the complexity of compounds in the petroleum industry some of these terms are very **vague**.

- **Hydrocarbons** are chemical compounds made mainly of **carbon and hydrogen**. Both petroleum and coal contain many different hydrocarbons. Methane, ethanol, and benzene are examples of hydrocarbons, though there are many many others.

- **Bitumen** is a another term for **hydrocarbons**. Both petroleum and coal are sometimes referred to as Bituminous.

- **Organic compounds** are chemicals made of **carbon** (although the classification is not totally consistent and some carbon compounds, like carbon dioxide, are not considered organic). **Hydrocarbons** are commonly referred to as organic compounds, and it is fair to think of the two as equivalent. Carbohydrates, proteins, and urea (found in urine) are examples or organic compounds. It was once thought that organic compounds could only be produced from organic sources. Because of their usefulness, a **huge chemical industry** developed around organic chemicals during the 19th Century. **Dyes** and **pharmaceuticals** where products of this industry. As chemists increased their skills they found that organic compounds could be synthesized from inorganic sources. However, by this time the classification had been firmly rooted in industry and universities and so it remains today.

- **Inorganic compounds** include **everything** that is **not** considered **organic** (every compound in the world is ether organic or inorganic).

- **Aromatic** compounds are **organic compounds** which always have a **benzene ring** in them. Because of this they can be quite **reactive** and have some **interesting properties**. The **dye** and **pharmaceutical** industries depend heavily on aromatic compounds.

- **Aliphatic** compounds are **organic compounds** which are **not aromatic**. They include single bonded (ethane, propane, butane), double bonded (ethene or called ethylene, propene, butene), and triple bonded (ethyne or called acetylene, propyne, butyne) straight chain hydrocarbons as well as cyclic non-benzene structures (cyclopentane, cyclobutane) (every organic compound in the world is either aromatic or aliphatic).

- A **Barrel** (bbl.) of crude contains **42 gallons** or 158.8 liters. No one actually ships petroleum in barrels anymore because they are too small, but the term is still used to describe a defined volume.

- **Petroleum** literally means "**rock oil**". It is a very broad word referring to all **liquid hydrocarbons** which can be collected from the ground. Even **natural gas** and **solid** hydrocarbons are sometimes referred to as petroleum. When petroleum first comes from the ground it is called **crude oil**. Later it is usually just referred to as **oil**. It can flow like water or be as viscous as peanut butter. It can be yellow, red, green, brown, or black.

- **Fractions** are **complex mixtures** of chemical compounds that all have a **similar boiling point**. **Light** and **heavy** fractions **refer to** a compound's **boiling point** and **not** their actual **density** (these are two entirely different things). Light fractions can be very heavy (dense), and heavy fractions can be very light (go figure)!

- **Isomers** are chemicals which have the **same number and type of atoms** but have them **arranged in a**

different way. Methane (CH4), ethane (C2H6), and propane (C3H8) have no isomers because their is only one way the carbons can hook together. **Butane** (C4H10) has **two isomers** (n-butane and isobutane). **Decane** (C10H22) has **seventy five isomers**, and a molecule with **20 carbon atoms** (C20H42) has **over 100,000 isomers**. **Crude oil** contains molecules having **1 to 100+ carbon atoms**. Naming these compounds based upon normal chemical rhetoric would be **hell on earth**! The huge number of possible molecular arrangements is why people talk of **fractions** instead of using proper chemical nomenclature.

Natural Gas is a mixture of very **low boiling hydrocarbons**. Natural gas can only be liquefied under extremely high pressures and very low temperatures. It is called "**dry**" when **methane** (CH4) is the primary component, and "**wet**" if it contains higher boiling hydrocarbons. If it smells bad, because of **sulfur** compounds, it is called "**sour**". Otherwise, it is called "**sweet**".

Liquefied Petroleum Gas (LPG) is a **very light fraction** of petroleum. It is also a fairly **simple** fraction containing mainly **propane and butane**. First, it should be noted that under normal pressures **LPG is actually a gas**, unlike gasoline (often just called "gas") which is really a liquid (ugh). However, under **modestly high pressures** these compounds can be **converted to a liquid** (hence their name). Being able to store them as a liquid **reduces** the **container size** by a factor of a **hundred**. This is no doubt why propane stoves are so popular. As **cracking methods** have evolved **more and more LPG** has been produced by refineries.

Gasoline is a light fraction of petroleum which is quite **volatile** and **burns rapidly**. Straight run gasoline refers to gasoline produced by distillation instead of cracking, although it really doesn't make a difference. **Gasoline is often just called "gas"**, however it is a liquid at typical pressures. This confusing state of affairs developed because the **first internal combustion engines ran on town gas** (a mixture of carbon monoxide, CO, and hydrogen, H2, both actual gases). These engines were therefore called "**gas engines**". When gasoline replaced town gas people still called the motors "gas engines" and also started calling gasoline "gas". Today, the **average American** uses **450 gallons** of gasoline **a year**.

Octane Number rates a fuel's ability to **avoid premature ignition called knock**. Premature ignition **reduces** an engine's **power** and quickly **wares it out**. The octane scale arbitrarily defines **n-heptane** a value of 0, and **isooctane** (2,2,4-trimethyl pentane) an octane number of 100. Isooctane is then added to heptane until the mixture has the same knock characteristics as the fuel being tested, and the percent isooctane is taken as the unknown fuels octane number. **Tetraethyl lead** used to be a common anti-knock additive which would raise a fuels octane number. **High octane fuel** can be used in engines with **high compression ratios** which in turn produce much **more power**. However, the additive is no longer used because of concerns over **lead pollution**.

Naphtha is a light fraction of petroleum used to **make gasoline**. Naphtha also produces **solvents** and **feedstocks** for the **petrochemical industry**.

Kerosene was the **first important petroleum fraction**, replacing **whale oils** in **lamps** over a hundred years ago. Some unscrupulous refiners failed to distill off all the **naphtha** from the kerosene fraction thereby increasing the volume of their final product. This lead to many lamp **explosions and fires**.

Diesel fuels find use in the **fleet of trucks** which transport the **nations goods**. Diesel engines power these larger engines, and use **higher compression ratios** (and temperatures) than their gasoline cousins. They are therefore **more efficient**. It is also interesting to note that diesel engines have **no spark plugs**, instead the fuel-air mixture is **ignited** by the rising temperatures and pressures during the **compression stroke**.

Gas Oil (or fuel oils) are used for **domestic heating**. In the **winter** refineries **produce more gas oil**, whereas during the **summer driving months** they produce **more gasoline**.

Heavy Fuel Oil is often **blended** with gas oils for easier use in industry. **Ships** burn heavy fuel oils but they call it **bunker oil**.

Atmospheric Residual is everything that **cannot be vaporized under normal pressures**. Atmospheric residual is fed into another distillation column, operating at lower pressures, which can separate out some of the lighter compounds. **Lubricants and waxes** reside in this fraction.

Vacuum Residual is the **bottom of the barrel**. It includes **asphalt and some coke**.

Pitch is a thick, black, sticky material. It is left behind when the lighter components of coal tar or petroleum are distilled off. Pitch is a **"natural" form of asphalt**.

Asphalt is a **high boiling** component of **crude oil**. It is therefore found at the "**bottom of the barrel**" when petroleum is distilled.

Tars are **byproducts** formed when **coke** is made from coal or **charcoal** is made from wood. It is a thick, complex, oily black mixture of heavy organic compounds very similar to pitch or asphalt, though from a different source.

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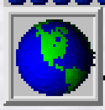
Case Study: Petroleum

Modern Refining

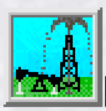
Petroleum refineries are marvels of **modern engineering**. Within them a **maze** of **pipes**, **distillation columns**, and **chemical reactors** turn **crude oil into valuable products**. Large refineries cost billions of dollars, employ several thousand workers, operate around the clock, and occupy the same area as **several hundred football stadiums**. The U.S. has about 300 refineries that can process anywhere between 40 and 400,000 barrels of oil a day. These refineries turn out the **gasoline** and **chemical feedstocks** that keep the country running.

"Enough already...go to the end."



The Search

Locating an oil field is the **first obstacle** to be overcome. The first explorers used Y-shaped devining rods and other supernatural, but ineffective, means of locating petroleum. Today **geologists** and **petroleum engineers** employ more tried and true methods. Instruments to aid the search include; **geophones** (uses sound), **gravimeters** (uses gravity), and **magnetometers** (uses the Earth's magnet field). While these methods narrow the search tremendously, a person **still has to drill** a exploratory well, or **wildcat well**, to see if the oil actually exists. Success brings visions of gushers soaring skyward, however today wells are capped before this happens.



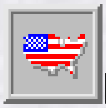
Drilling

There are three main types of **drilling operations**; cable-tool, rotary, and off-shore. **Cable-tool** drilling involves a **jack-hammer** approach were a chisel dislodges earth and hauls up the loose sediment. **Rotary drilling** works at much **greater depths**, and involve sinking a **drill pipe** with a rotating steel bit in the middle. **Off-shore drilling** involves huge **semisubmersible platforms** which lower a shaft to the ocean floor, containing any oil which is located.

All crude oil contains some amount of **methane** or other gases **dissolved** in it. Once the drilling shaft makes contact with the oil it **releases the pressure** in the underground reservoir. Just like opening a **can of soda pop**, the dissolved gases fizz out of solution **pushing crude oil to the surface**. The dissolved gases will allow about 20% recovery of oil. To get better recovery water is often pumped into the well, this forces the lighter oil to the surface. **Water flooding** allows recoveries of about 50%. The addition of **surfactant** allows even more oil to be recovered by preventing much of it from getting trapped in nooks and crannies. Yet, it is **impossible to get all of the oil out of a well**.

Transportation

Because **crude oil** is a liquid it is much **easier to move** than natural gas or coal. **Coal** is nice and dense, so it does not require large holding containers, but it **cannot be pumped**. Conveyor belts and cranes cannot compete with pipelines for economic efficiency. **Natural gas** can be pumped using expensive compressors, but it requires **enormous holding tanks**. A recent trick has been to inject huge amounts of water into salt strata. The water dissolves the salt, leaving truly enormous caverns. The natural gas is then pumped in and stored until needed. The **ease in transporting oil** is one of the reasons we have become so **dependent upon it**. Pound for pound natural gas and coal just cannot compete.



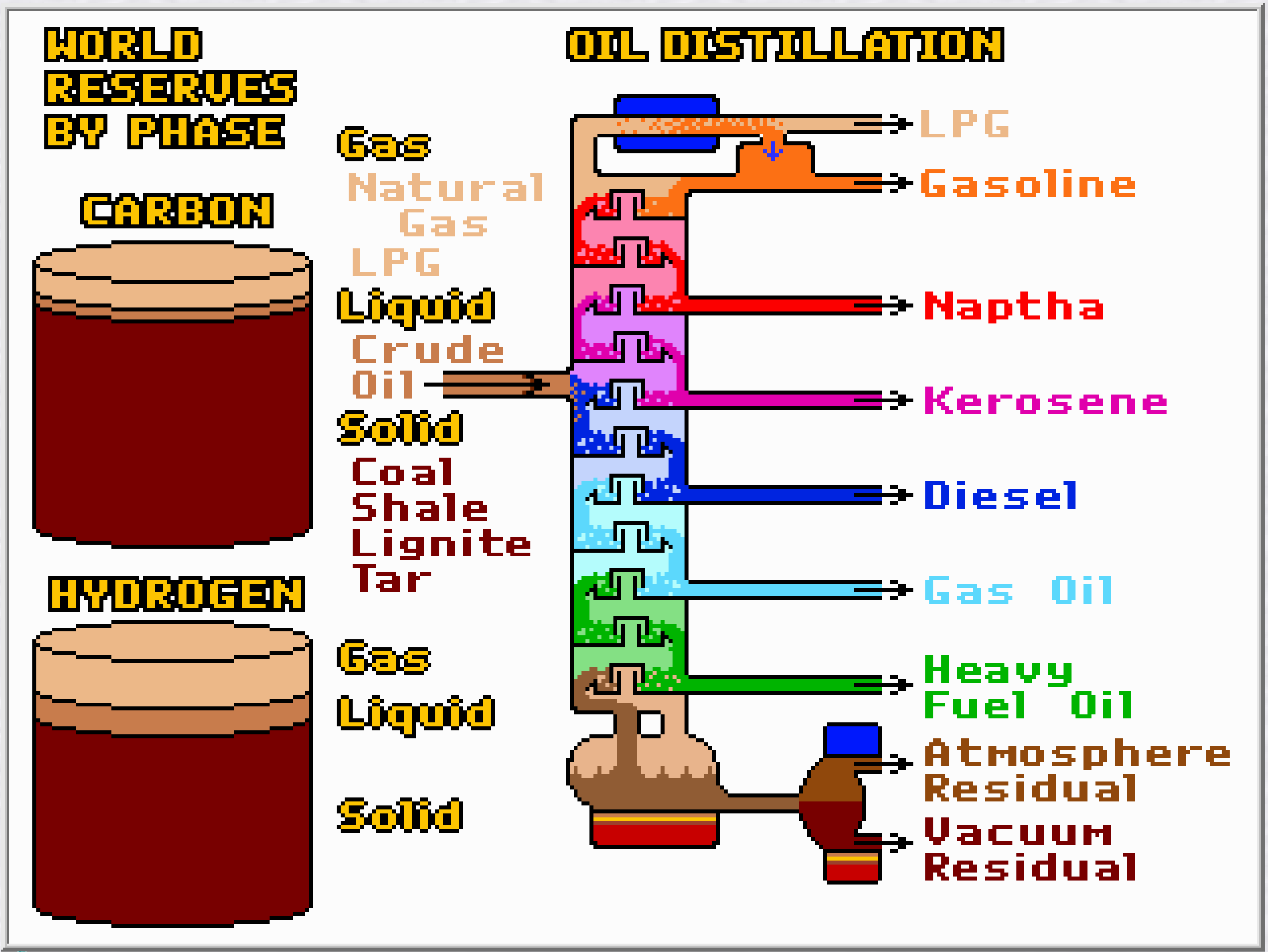
Reserves

The **proven reserves** of crude oil within the **U.S.** are about **3.9 billion cubic meters**. This could **cover** the state of **Minnesota** with a layer **one half inch thick**. A reasonable value for the **total amount of crude oil** obtainable using current methods from around the **world** is **350 billion cubic meters**. This could **cover Minnesota** with a layer of oil **four and a half feet thick**. Yet, at the rate we are consuming oil, the **nation's reserves** will be **depleted by 2010**, and the **world's reserves** will be depleted by the **end of the 21st Century**.

Yet, oil is not the only source of hydrocarbons. **Natural gas** and **coal** are both available in much greater amounts (see Distillation Figure). However, we may decide that it is not such a good idea to burn all of these hydrocarbons. **Carbon dioxide** is a **strong greenhouse gas** (along with water and methane), and the results to the global environment could be catastrophic to human life. Nuclear fission, solar power, hydroelectric power, and geothermal power offer immediate **alternatives**, however energy produced by these methods would be more expensive than burning oil, coal, or natural gas. The holy grail of power production, nuclear fusion, continues to elude scientists and engineers. In any case, **refining techniques** will **remain vital** to produce not only **fuels** but raw **materials** for petrochemical industries (plastics, pharmaceuticals, agrochemicals, etc.).

"The Kingdom of Heaven runs on righteousness, but the Kingdom of Earth runs on OIL!"

Quote by **Ernest Bevin** at the British Parliament during a heated discussion concerning the Middle East.



Distillation

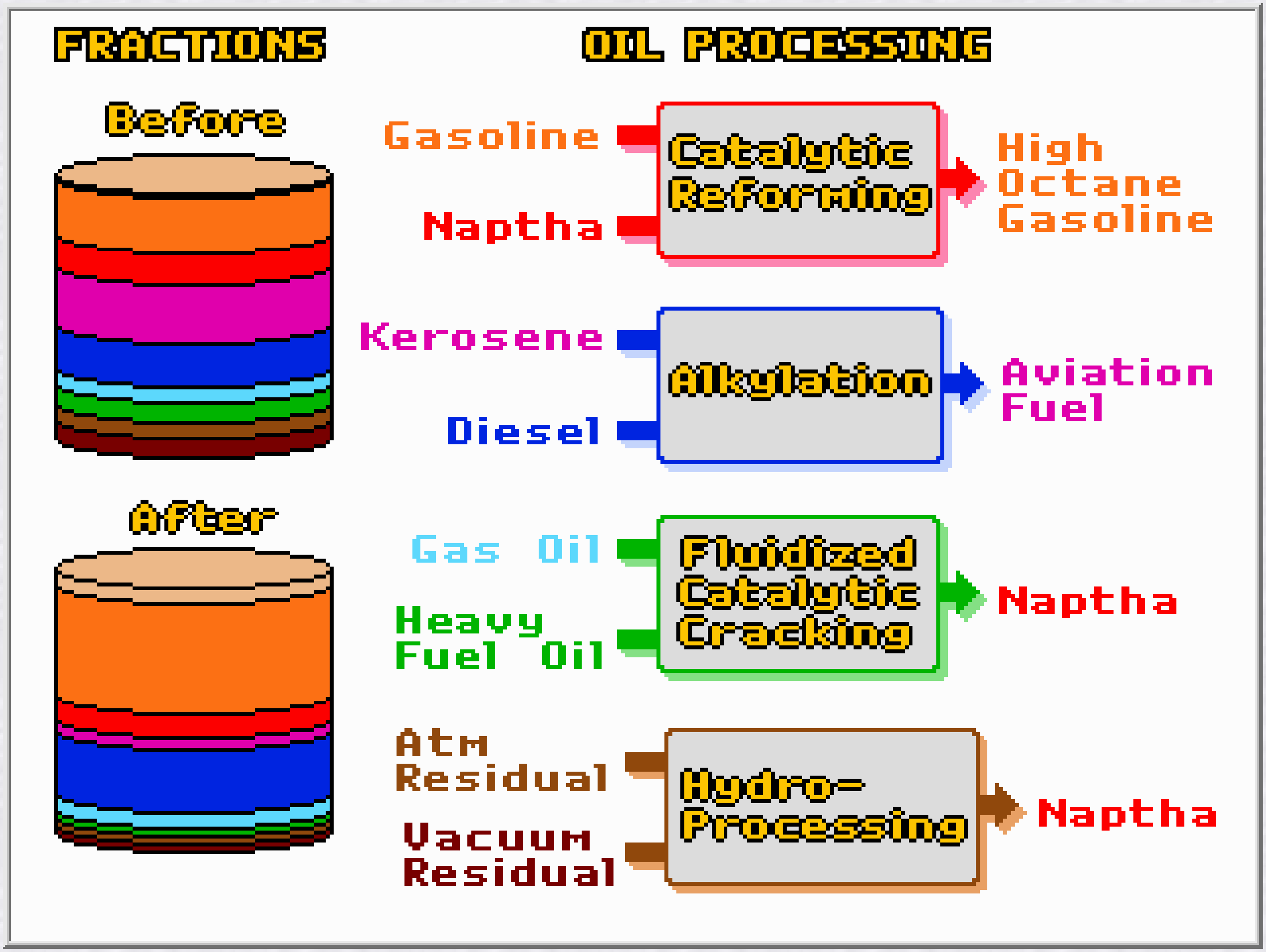
Oil contains a **complex mixture** of hydrocarbons. The first step in obtaining something of value from this muck is to **de-salt** and **de-water** it. Then the oil is heated and sent into a huge **distillation column** operating at **atmospheric pressure**. Heat is added at the reboiler, and removed at the condenser, thereby **separating the oil into fractions based upon boiling point**. A typical atmospheric column can separate about 4,000 cubic meters (25,000 barrels) of oil per day. The bottom fraction is sent to another column operating at a pressure of about 75 mm Hg (one tenth of an atmosphere). This column can separate the heaviest fraction without thermally degrading (cracking) it. Whereas atmospheric columns are thin at tall, **vacuum columns** are **thick and short**, to minimize pressure fluctuations along the column. Vacuum columns can be over 40 feet in diameter!

Crude Oil Refining

Distillate Fraction	Boiling Point (°C)	Carbon Atoms per Molecule
Gases	below 30	1-4
Gasoline	30-210	5-12
Naphtha	100-200	8-12
Kerosene & Jet Fuel	150-250	11-13
Diesel & Fuel Oil	160-400	13-17
Atmospheric Gas Oil	220-345	
Heavy Fuel Oil	315-540	20-45
Atmospheric Residue	over 450	over 30
Vacuum Residue	over 615	over 60

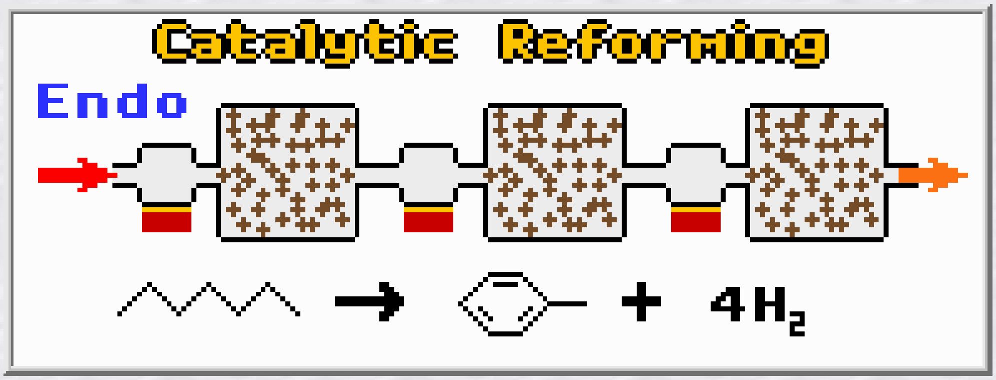
Which Fraction to Make?

Various **fractions** are more **important** at different **times of year**. During the **summer driving months**, the public consumes vast amounts of **gasoline**, whereas during the **winter** more **fuel oil** is consumed. These demands also vary depending upon whether you live in the **frigid north**, or the **humid south**. Modern refineries are able to **alter the ratios** of the different **fractions** to **meet demand**, and maximize profit.



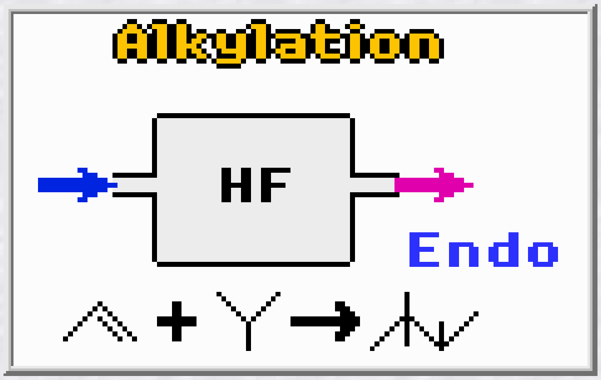
The Five Pillars of Refining

While distillation can separate oil into fractions, **chemical reactors** are required to create more of the **products** that are in **high demand**. Refineries rely on four major processing steps to alter the ratios of the different fractions. They are; **Catalytic Reforming**, **Alkylation**, **Catalytic Cracking**, and **Hydroprocessing**. Each of these methods involves feeding **reactants** to a reactor where they will be **partly** converted into **products**. The unreacted reactants are then separated from the products with a **distillation column**. The unreacted reactants are **recycled** for another pass, while the products are further separated and mixed with existing streams. In this way **complete conversion** of reactants can be obtained, even though not all of the reactants are converted on a given pass through the reactor. The **four processing methods**, along with **distillation**, are the **pillars of petroleum refining**.



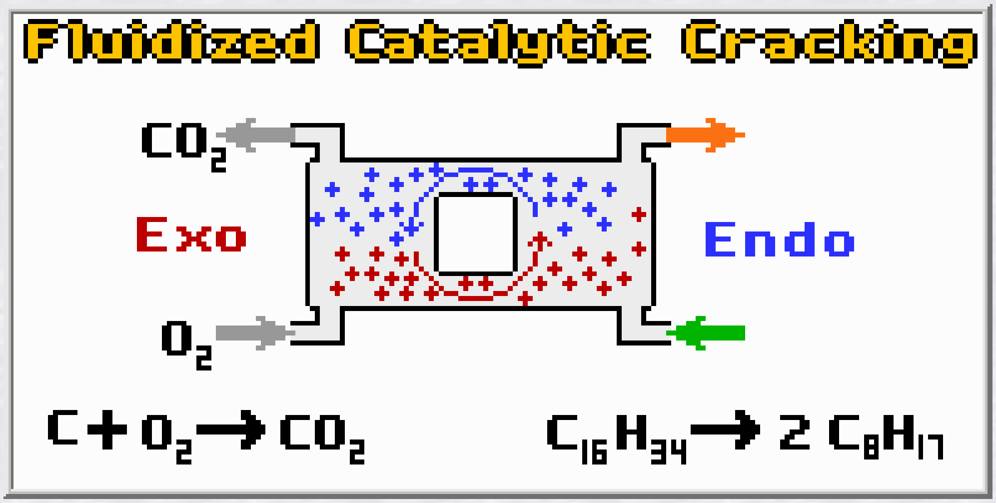
Catalytic Reforming

Catalytic Reforming produces **high octane gasoline** for today's automobiles. Gasoline and naphtha feedstocks are heated to **500 degrees Celsius** and flow through a series of **fixed-bed catalytic reactors**. Because the reactions which produce higher octane compounds (aliphatic in this case) are **endothermic** (absorb heat) additional **heaters** are installed between reactors to keep the reactants at the proper temperature. The **catalyst** is a platinum (Pt) metal on an alumina (Al2O3) base. While catalysts are never consumed in chemical reactions, they can be **fouled**, making them less effective over time. The series of reactors used in Catalytic Reforming are therefore designed to be disconnected, and swiveled out of place, so the catalyst can be **regenerated**.



Alkylation

Alkylation is another process for producing **high octane gasoline**. The reaction requires an **acid catalyst** (sulfuric acid, H2SO4 or hydrofluoric acid, HF) at **low temperatures** (1-40 degrees Celsius) and **low pressures** (1-10 atmospheres). The acid composition is usually kept at about 50% making the mixture **very corrosive**.



Fluidized Catalytic Cracking

Catalytic Cracking takes **long molecules** and **breaks** them into much **smaller molecules**. The **cracking** reaction is **very endothermic**, and requires a large amount of heat. Another problem is that reaction quickly **fouls** the Silica (SiO2) and alumina (Al2O3) **catalyst** by forming **coke** on its surface. However, by using a fluidized bed to slowly carry the catalyst upwards, and then sending it to a **regenerator** where the coke can be **burned off**, the catalyst is **continuously regenerated**. This system has the additional benefit of using the large amounts of heat liberated in the **exothermic regeneration** reaction to heat the cracking reactor. The FCC system is a **brilliant reaction scheme**, which turns two negatives (heating and fouling) into a positive, thereby making the process extremely economical.

Hydroprocessing

Hydroprocessing includes both **hydrocracking** and **hydrotreating** techniques. Hydrotreating involves the addition of hydrogen atoms to molecules without actually breaking the molecule into smaller pieces. **Hydrotreating** involves temperatures of about **325 degrees Celsius** and **pressures of about 50 atmospheres**. Many catalysts will work, including; nickel, palladium, platinum, cobalt, and iron. Hydrocracking breaks longer molecules into smaller ones. **Hydrocracking** involves temperatures **over 350 degrees Celsius** and pressures up to **200 atmospheres**. In both cases, very **long residence times** (about an hour) are required because of the slow nature of the reactions.

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Petroleum: Distillation

"The end already...go back to the top."

We always welcome COMMENTS, SUGGESTIONS, OR REACTIONS.

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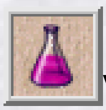
Case Study: Petroleum

Distillation

The **chemical engineer** is often faced with **complex mixtures** of chemicals. In these mixtures **some** chemicals are **valuable** while others may be **worthless** or even **hazardous**. The trick is to separate the good from the bad without spending too much money along the way. While there are quite a few separation techniques in a chemical engineer's bag of tricks, **distillation** is the **workhorse of the chemical industry**. It is fairly inexpensive and can produce **very high purity** products. Because of this the petroleum industry has adopted it as their separation method of choice. The **towers** pointing skyward at **oil refineries** are in fact **distillation columns**, and their vast numbers reveal just how frequently this unit operation is used.

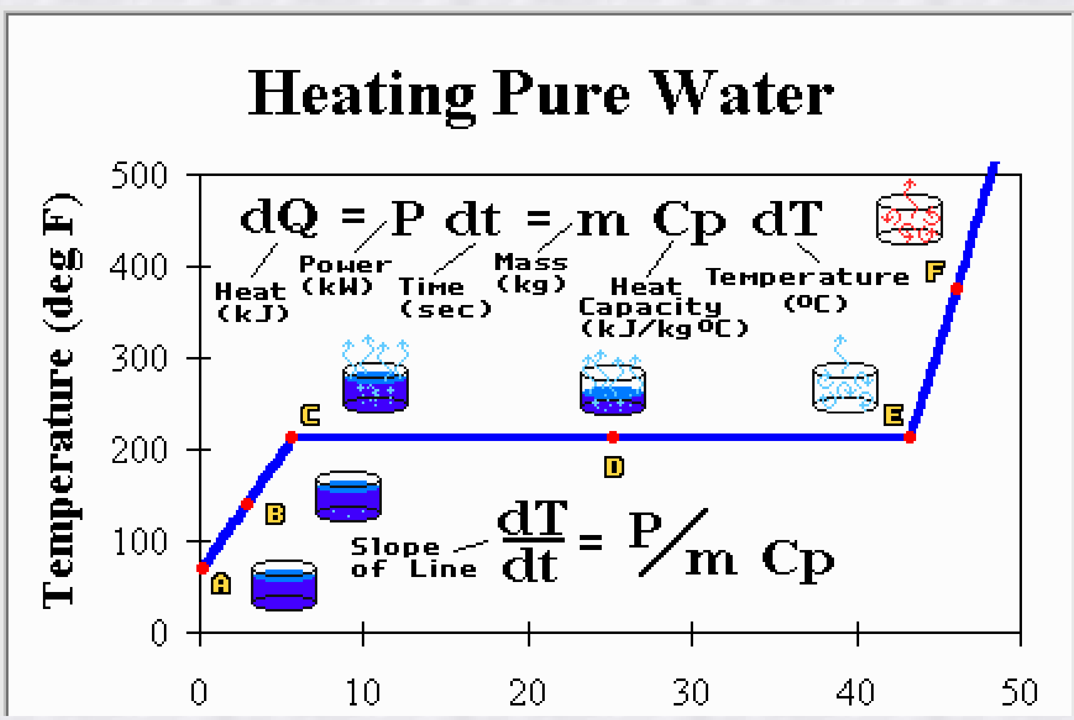
"Enough already...go to the end."

But how does a distillation column work? To answer this we will first **observe** how the world behaves, then try to **understand** why it works the way it does. Finally we must figure out how we can use this knowledge for our **benefit**. Following are descriptions of two experiments which will hopefully illuminate the physical principles governing distillation.



Vaporization of pure components

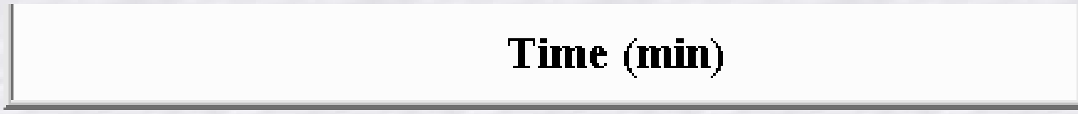
Imagine **filling a pot full of water** (1 kg or 2.2 lbs) and placing it on the **stove**. We turn on the burner (power of about 5 kW) and start heating the water, hoping to eventually bring it to a **boil**. While it is still cold lets stick a **thermometer** into the water so we may watch how the temperature changes during the process. Here is what happens (ignore the math if you like):



Point A: The water has just been **placed on the burner**. It is at the temperature of the tap (70 degrees Fahrenheit), but with the addition of heat from the burner it will not stay there long. Because the temperature is below the boiling point the liquid is called "**sub-cooled**".

Point B: The water is slowly **warming up**. The water obviously has a **capacity to absorb heat** and displays a temperature increase while absorbing that heat (heat capacity of 4.2 kJ/kg C).

Point C: The **first bubble** (of



water vapor) appears at the bottom and rises to the surface. The bubble rises because steam is less dense than water. This is to say that a given volume of vapor is always lighter than the same volume of liquid. Gravity assures that the heavier fluid will displace the lighter fluid, and a good thing or filling a drinking glass with water would be a challenging process indeed.

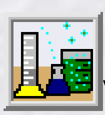
Point D: More and more of the **water is boiling off**, being converted from water to steam. No surprise there, however something unusual has happened to our thermometer. It seems to have stopped rising, and hovers at 212 degrees Fahrenheit (100 degrees Celsius). The steam boiling off is also at 212 degrees Fahrenheit. Yet, the burner is still on, and is still much hotter than the water, so heat is still flowing into the water. It seems as though when a compound transforms from a liquid to a vapor some additional heat is absorbed. This heat does **not raise the temperature**, instead it causes some water to change to steam. Joseph Black observed this behavior in 1765 and called it "hidden heat". Today it is called "**latent heat**" but the idea is the same. Some heat, in fact a very large amount as evident by the long time needed to finish boiling, is required to turn water into steam (2257 kJ/kg). Similarly, steam gives off the same amount of heat when it is converted back to water. But enough talk, lets continue to watch the pot and see what happens as we add more and more heat.

Point E: The last drop of water boils away leaving us a **pot full of steam** and air. The temperature now begins to increase once again and the steam becomes "**super-heated**". The temperature grows rapidly because steam has a lower heat capacity than water and most of the vapor has left the pot so there is less material to heat up. Most cooks would remove the pot to prevent damaging it, but let's leave it on the burner to see what happens.

Point F: The temperature of the vapor within the pot continues to **rise**. It will increase until the pot, and vapor within it, finally reach the same **temperature as the burner**. At this point, no more heat will flow and the temperature will remain at a steady state.

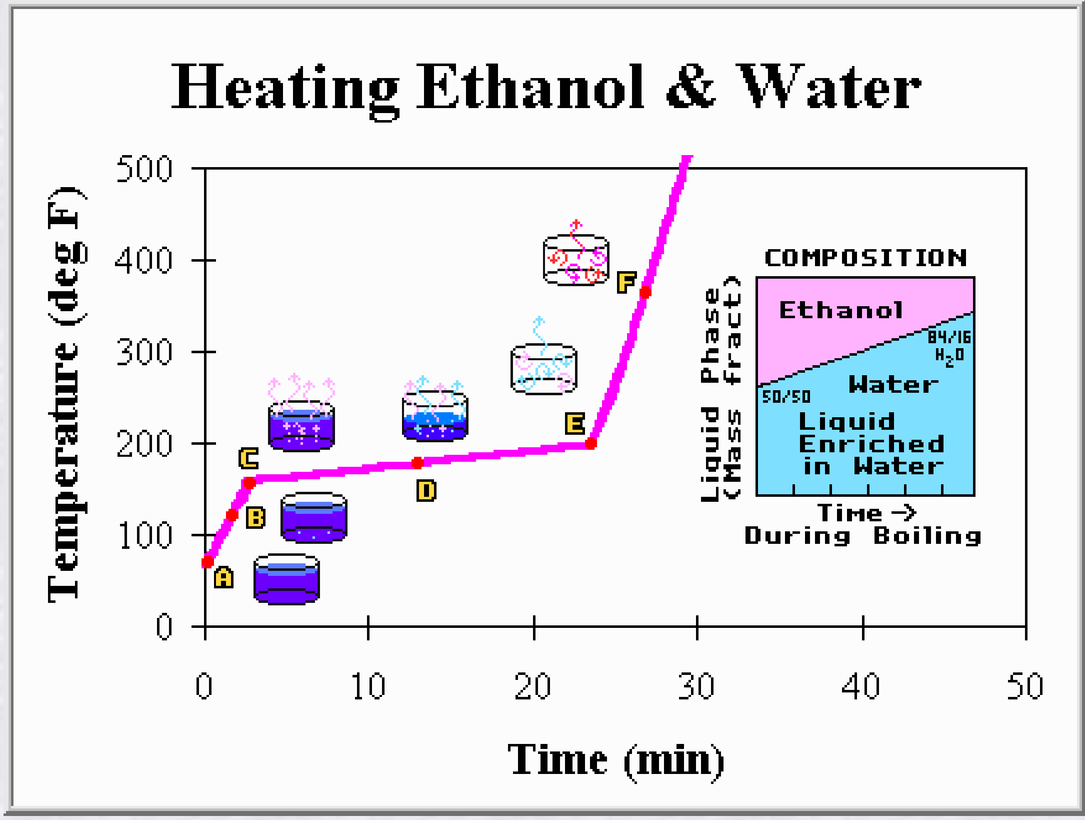
Summary of our findings:

- **Pure compounds** have a **capacity to absorb heat**, and in the process warm up.
- **Pure compounds** boil when they reach a temperature called their **boiling point**. The **temperature then remains constant**, even though heat is still being added, until all the liquid is boiled away.
- While boiling, heat is absorbed, but no temperature increase is observed in the liquid or the vapor. This hidden heat is called **latent heat**.
- Once all the liquid is boiled off the **temperature** of the **steam** will again **increase**, until the heat source and the steam are at the same temperature.



Vaporization of mixtures

Well, that was mildly amusing. We are now standing in a hot humid room and have a warped pot laying upon the burner. But, on the bright side, we understand the universe a little better and are one step closer to setting up a distillation column. Now, lets put a **mixture** of liquids in a pot and repeat the same experiment. We choose a bottle of whiskey, and pour it into the pot. The whiskey is made of half **ethanol** (ethyl alcohol) and half **water**. However, it is not entirely clear what is going to happen when we heat the mixture, because **pure ethanol boils at 173 degrees Fahrenheit** (78.3 degrees Celsius), **not 212 degrees like pure water**. **Will the temperature remain constant while the mixture boils off?** With this question in mind we eagerly turn on the burner and watch the thermometer. Our findings are summarized below:



Point A: The mixture of **ethanol and water** has just been **placed on the burner**. The liquid is still cool, and for a moment we consider stopping the experiment to take a sip.

Point B: The mixture is **warming up faster** than the pure water did. This is not too surprising as we know that pure ethanol would warm up much faster than pure water. Ethanol's heat capacity (2.8 kJ/kg C) is smaller than that of water, and we expect the ethanol-water mixture to have properties somewhere between that of the pure components.

Point C: The **first bubble** appears at the bottom and rises to the surface. If we could catch this bubble we would find that it is **enriched in ethanol**. While the liquid is 50% ethanol and 50% water, the first bubble of vapor is over 65% ethanol. This may come as a surprise, but makes some sense... Because ethanol has a lower boiling point it has a tendency to boil off first. This temperature (about 176 degrees Fahrenheit) is called the **bubble point**, because it is the temperature at which the first bubble forms.

Point D: **Ethanol, and water,** continues to be **boiled off**. However, the **temperature is not remaining constant**. Instead, it has slowly been increasing. The **latent heat is still present**, and is responsible for slowing the temperature rise, but its presence is not nearly as obvious as when we had only pure water. The temperature is rising because the **liquid phase** is being **enriched in water**, which has a higher boiling point. This liquid enrichment occurs because the first vapors were mainly ethanol, and so a larger fraction of water was left behind.

Point E: The **last drop** of liquid is very **rich in water**, and it too eventually boils away. This is called the **dew point** because if we were condensing the vapor instead of boiling the liquid this would be the temperature at which the first drop of liquid would form (about 185 degrees Fahrenheit). That first drop of liquid condensed would be mostly (84%) water.

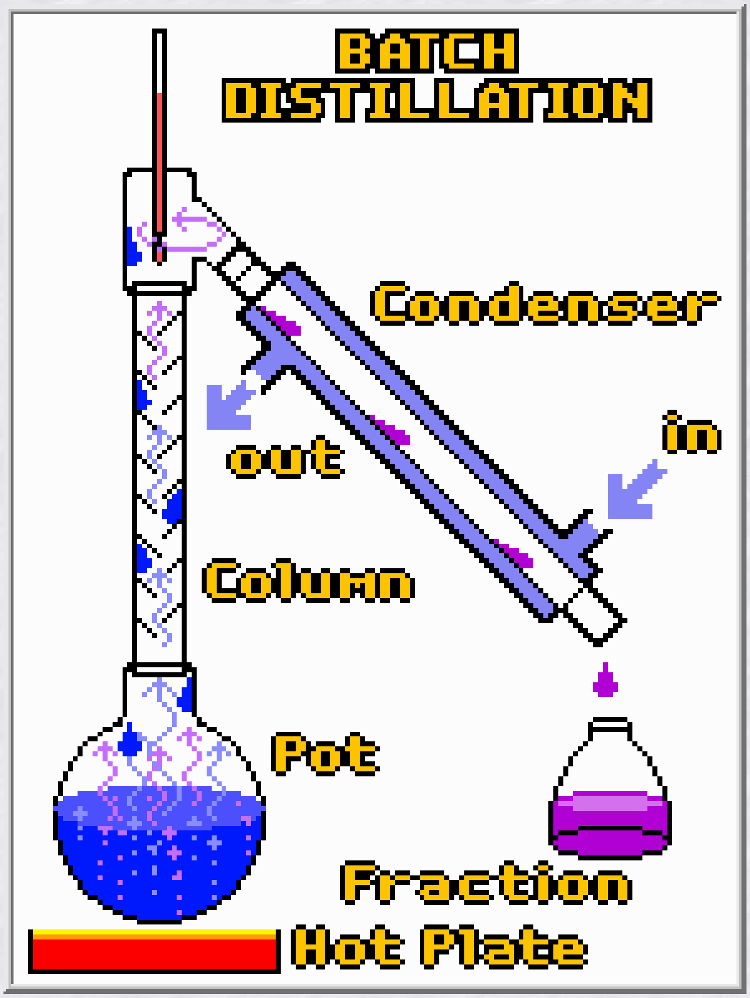
Point F: The **temperature** of the **vapors** within the pot continues to **rise** until they are as hot as the burner.

Summary of our findings:

- **Mixtures** have a **capacity to absorb heat**, and in the process become warmer.
- **Mixtures boil** when they reach a temperature called their **bubble point**. Afterwards the temperature slowly rises, even though latent heat is still present, until the **last drop of liquid vaporizes** at the **dew point**.
- The **vapor produced** at the **bubble point** is **rich in the lower boiling compound** (in this case ethanol).
- The **last** little bit of **liquid** is **rich in the higher boiling compound** (in this case water).

- Once all the liquid is boiled off the **temperature** of the **vapor mixture** will again **increase**.

Batch distillation

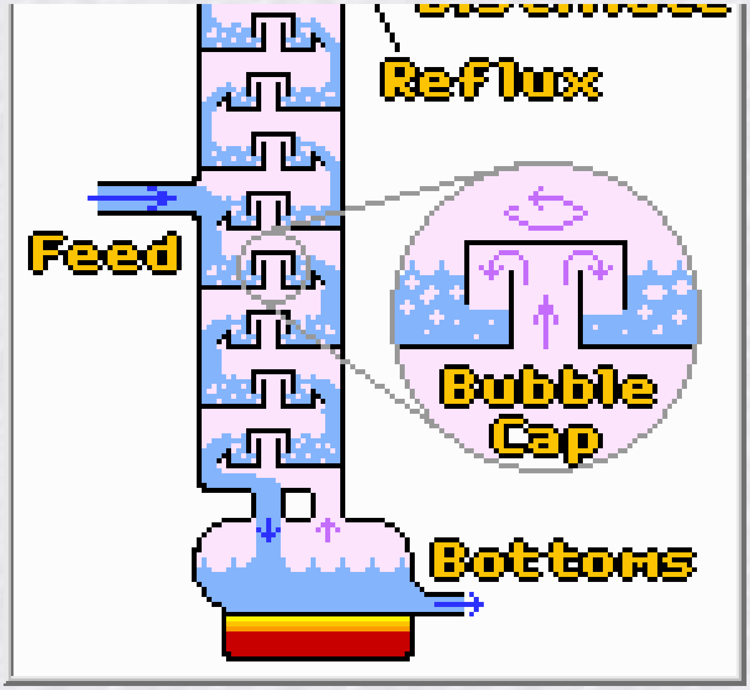


It is fairly easy to turn **pots and burners** into a **batch distillation** apparatus. A **condenser** is required to turn the vapors back to a **liquid** so they can be easily collected. A **tall column** is also desirable because it greatly improves the separation by giving high boiling compounds **another chance to condense** before they reached the top and are collected. Finally, by using **different collection vessels**, the original mixture can be separated into **fractions**. However, despite these bells and whistles the principle is the same; by **applying heat a distillation column separates** compounds in a mixture **based upon their boiling points**.

Continuous Distillation

One of the **characteristics** of the Industrial Revolution has been a **shift from** small scale **batch** (craft like) operations **to** large scale **continuous** (plant based) mass production. Ford's automotive **assembly line** is the typical example of **mass production**, but the same kinds of changes also occurred in the **chemical industry**. Labor intensive **batch distillation** was **replaced** with **continuous distillation** which allowed a much **greater chemical throughput**. Just as mass production techniques greatly **reduced the price** of a "**Model T**" automobile, it also greatly reduced the price of the **gasoline** which powered that machine.

There are two major types of continuous distillation columns, but both operate in basically the same way. In both cases **liquid** is **continuously fed** into the column, and at least **two streams** (**distillate** and **bottoms**), together containing the same amount of total material, are **continuously removed**. **Heat** is **added** to the **re-boiler** (pot) and **removed** at the **condenser**. The re-boiler



vaporizes some of the liquid, which then follows a treacherous path to the top of the column where it is re-condensed. Along the way most of the high boiling compounds will been left behind, and the **distillate will be quite pure**. To further aid the separation process some of the liquid distillate is often returned to the column where it flows back to the bottom. Along the way this **reflux** condenses some of the higher boiling liquids out of the vapor phase helping to purify the vapor. The two types of columns are:

- **Tray Columns** (shown above): Such columns consist of physically separated pools of liquid which are in intimate contact with a vapor. Bubble columns are often used to force the upward flowing vapor through these pools of downward flowing liquid. Each of these trays operates as an equilibrium stage (like the pot and water examples above).

- **Packed Columns**: Such columns are filled with a saddle shaped packing that resembles Styrofoam peanuts. This packing provides a lot of surface area for the vapor to condense upon and assures that the liquid and vapor are in intimate contact.

Whereas the **composition** of the distillate and bottoms in **batch** distillation **changes over time**, a **continuous** column operates under steady conditions where the **composition at a given location does not change over time**. This **steady state operation** is desired in almost all continuous unit operations. Because the composition **only** depends upon the **position in the column**, additional product steams can be easily tapped at different heights (not shown) and each tray will have a different composition of compounds. The trays at the top of the column are rich in light boiling compounds while those at the bottom are rich in compounds that only boil at high temperatures.

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Timeline

"The end already...go back to the top."

We always welcome COMMENTS, SUGGESTIONS, OR REACTIONS.

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pafko.com/history/h_distill.html

A Chemical Engineering Timeline

(Please forgive my digression into other topics)

TIMELINE KEY

Topics Relating to Chemical Engineering.

A Digression into Miscellaneous Topics (often Chemistry)

Concerning the Rise and Fall of Nations (Wars & Such)

"Enough already... go to the end."

~440 BC: **Democritus** proposes the concept an of **atom** to describe the indivisible and indestructible particles that were thought to compose the substance of all things.

~250 BC: **Archimedes** deduces the law of the **levers** and could evaluate the relative density of bodies by observing their **buoyancy force** when immersed in water.

~240 BC: **Eratosthenes of Cyrene**, director of Alexandria library, calculates the **size of Earth** by measuring the sun's shadow at noon in Siena (Egypt) and Alexandria.

~70: **Pliny the Elder** writes his Historia Naturalis, a 39 volume **universal encyclopedia**, compiling all that was known about the science of his day. Pliny died in Pompeii during the eruption of the volcano the year 79.

~130: **Claudius Ptolemaeus** (Ptolemy) writes a mathematical and geographical treatise describing all ancient knowledge concerning distances and locations on the earth. He also developed a **star catalogue** with 1022 entries. The Ptolomeic model placed the earth as the center of the universe; the sun, stars and planets revolved around the earth in circular orbits. This model remained the standard interpretation for more than a millennium, until the time of Copernicus.

230: **Romans create life expectancy table** for selling "annuities." Average life expectancy is only **20-30 years**.

1347: **William Occam** enunciates the principle now known as **Occam's Razor**; "entities must not be multiplied beyond what is necessary."

1492: Cristoforo Colombo (**Christopher Columbus**) arrives on the shores of a new continent. The continent was later called America in honor to the Italian cartographer **Americo Vespucci**.

1500: **Leonardo da Vinci** points out that animals could not survive in an atmosphere that could not support combustion.

1540: **Johann Gutenberg** receives from Johann Fust an advance of 800 guilders to develop his **printing press**. Probably the first book printed was a dictionary called Catholicon and then later the Latin Bible.

1543: **Copernicus**' **heliocentric model** of the universe was a revision of the Ptolomeic model which had become too complex and inaccurate to accommodate the known movement of celestial bodies.

1546: **Hieronymus Francastorius** wrote on Contagion, the first known discussion of the phenomenon of **contagious infection**.

1616: **William Harvey** demonstrates his findings on the **circulation of blood**. In 1628 he published Exercitacio Anatomica Motu Cardis et Sanguinis in Animalibus, in which he describes the function of the circulatory system, including the notion of the **heart as a mechanical pump**.

1635: **John Winthrop**, Jr., opens **America's first chemical plant** in Boston. They produce saltpeter (used in **gunpowder**) and alum (used in **tanning**).

1644: **Evangelista Torricelli** devises the **barometer**.

1647 **Blaise Pascal** determines the **pressure of air**. He also invents a machine to perform **addition and subtraction;** the Pascalina, a remote precursor of calculating machines.

1660: **Nicaise Le Febvre**, in Traité de la Chymie held that the function of **air in the respiration was to purify the blood**.

1662: **Robert Boyle** found that the volume occupied by the same sample of any gas at constant temperature is inversely proportional to the pressure. This statement is known as **Boyle's law**.

1666: **Fire destroys 3/4 of London**. Prompts introduction of fire insurance and municipal fire departments.

1683: **Antoni von Leewenhoek** discovers **bacteria**.

1687: **Isaac Newton** publishes his "Philosophiae Naturalis Principia Matematica". The whole development of modern science begins with this great book. Newton set the foundations of **mechanics**, the theory of **gravitation**, a theory of **light**, and also concurrently, with **Leibnitz**, invents the **calculus**.

1720's: **Newcomen's steam engine** comes into general use.

1722: **Réamur** publishes "L'art de covertir le Fer Forgé en Acier" solving the **guarded secret of steel-makers**; that steel is iron containing just the right amount of carbon.

1749: England begins a **Lead-Chamber Method** to produce **sulfuric acid**.

1750's: **Classic British Industrial Revolution** begins (often said to last until 1830's, however in many ways it continues to this day).

1760's: **James Watt** improves on the Newcomen Engine.

1761: **Joseph Kölreuter** publishes reports in **artificial hybridization**.

1766: **Henry Cavendish** discovers "inflammable air" (**hydrogen**), which he concluded to be a combination of water and phlogiston (oxygen), since its combustion yielded water.

1770: **John Priestley** discovers **oxygen** and showed that is **consumed by animals and produced by the plants**.

1772: **Daniel Rutherford** describes "residual air", the first published description of **nitrogen**.

1772: **Joseph Priestley** and **Jan Ingenhousz** investigate **photosynthesis**.

1773: **Stephen Hales** makes the first measurement of **blood pressure**.

1775: **Antoine Lavoisier** shows that **fire** is due to the **exothermic reaction** between combustible substances and oxygen. He named a gas discovered by Cavendish, that burned to produce water, hydrogen (Greek, water producer). Also demonstrated that CO_2, nitric acid, and sulfuric acid contained oxygen.

1776: The **United States** declares its **independence** from England.

1780: **Antoine Lavoisier** and **Pierre Laplace** publish their Memoire on Heat, in which they reach the conclusion that **respiration is a form of combustion**.

1781: The **Americans defeat the British** in the last major battle of the War of Independence at **Yorktown, Virginia**.

1781: **Tobacco snuff linked to cancer** of nasal passage.

1783: **Lazaro Spallanzani** performs experiments demonstrating that **digestion is a chemical process** rather than a mechanical grinding of the food.

1785: **Charles de Coulomb** measures the attractive and repulsive forces of electrically charged particles, and discovered that these **forces are inversely proportional to the square of the distance**.

1787: **Jacques Alexandre César Charles** studies the **volume changes** of gases with changes in temperature.

1787: The **U.S. Constitution** is written.

1789: **Nicholas Le Blanc** develops his process for converting **common salt into soda ash**.

1795: **Alessandro Volta** shows how to produce electricity by simply putting two different pieces of metal together, with liquid or damp cloth between them, and he thus produced the **first electrical current battery**.

1798: **Thomas Robert Malthus** publishes his **Essay on the Principles of Population**.

1800: **Karl Friederich Burdach** coins the term "**Biology**" to denote the study of human morphology, physiology and psychology.

1802: **Louis Joseph Gay-Lussac** announces the **ideal gas law**.

1802: **Jean Baptiste Lamarck** elaborates a theory of **evolution based on heritable modification of organs**.

1802: The **E. I. du Pont de Nemours and Company** (Du Pont) is founded and builds a **gunpowder factory** along the banks of the Brandywine River near Wilmington, Delaware.

1804: **Nicholas Theodore de Saussure** publishes experiments on **photosynthesis**, and described the **balanced equation** of the process.

1805: **Geoges Cuvier** publishes his **Lessons in Comparative Anatomy**.

1806: **Louis Nicolas Vauquelin** and **Pierre Robiquet** first isolated an amino acid, **asparagine**, from asparagus.

1807: **Humprey Davy** utilizes **electric current to prepare metals** from molecules such as; sodium, potassium, magnesium, calcium, strontium and barium.

1809: **Jean Baptiste Lamarck** investigates the **microscopic structure** of plants and animals and perceived that cellular tissue is the general matrix of all organization. He also published his Philosophie Zoologique, where emphasized the fundamental unity of life.

1809: **Nicolas François Appert**, inventor and bacteriologist, demonstrates a procedure for preservation of foods by **canning**.

1810: **Joseph Louis Gay-Lussac** deduces the equations of **alcoholic fermentation**.

1811: **Amadeo Avogadro** demonstrates that equal volumes of all gases under the same temperature and pressure contain the same number of molecules, and that a fixed number of molecules of any gas will weigh proportional to its molecular weight. Presently the accepted value for the **Avogadro number is 6.023 x 10^23 molecules per gram-mol**.

1824: **Sadi Carnot** publishes his Reflexions sur la Puissance Motrice du Feu, setting various outstanding principles that constitute the basis of actual **Thermodynamics**.

1827: **J. B. Fourier** outlines atmospheric process by which **earth's temperature is altered**, using a hothouse analogy.

1828: **Friederich Wöhler** synthesizes the first **organic compound from inorganic compounds**, preparing Urea by reacting lead cyanate with ammonia.

1828: **Robert Brown** first describes **Brownian motion**.

1830-40: **Justus von Liebeg** develops techniques in quantitative analysis and applied them to biological systems, and the concept that vital activity could be explained in physicochemical terms.

1831: **Michael Faraday** shows the **relation between magnetism and electricity is dynamic.** He showed that not only was magnetism equivalent to electricity in motion but also, conversely, electricity was magnetism in motion. Later, Clerk Maxwell summarized in concise form the electromagnetic theory.

1833: **Jean Baptiste Boussingnault** recommends the use of **iodized salt to cure goiter**.

1835: **Ralph Waldo Emerson** writes the essay *Nature*.

1835: **Jöns Jacob Berzelius** demonstrates that the **hydrolysis of starch** is catalyzed more efficiently by malt diastase than by sulfuric acid. He published the first general theory of **chemical catalysis**.

1837: **René Dutrochet** recognizes that **chlorophyll** was necessary for photosynthesis.

1838: Congress passes act requiring **boiler inspection and testing** because of frequent **steamboat explosions**. This is the **first US legislation regulating a technology**.

1839: **Pierre François Verhulst** develops the logistic model of **population growth**.

1840: Publication of **Justus von Liebig's Thierchemie** which united the field of chemistry and physiology. He pointed out that that organic compounds in plants are synthesized from **carbon dioxide** in the atmosphere while **nitrogenous compounds** are derived from precursors in the soil.

1842: **Julius Robert Mayer** enunciates the **Law of Conservation of Energy** (1st Law of Thermodynamics), after establishing the work equivalent of Heat.

1845: **Herman von Helmoltz** and **Julius Robert Mayer** formulate the **Laws of Thermodynamics**.

1845: **Alfred Kolbe** synthesizes **acetic acid**.

1846: **Joule** demonstrates the **equivalence for various forms of energy** (heat - electrical - mechanical).

1846: An **ether-soaked sponge** became the first successful **surgical anesthetic** helping to remove a **tumor** at the Massachusetts General Hospital in Boston.

1848: The **American-Mexican War** comes to a close.

1850's: The first **petroleum refinery** consisting of a **one-barrel still** is built in Pittsburgh by Samuel Kier.

1853: **Kerosene** is extracted **from petroleum**.

1854: The **Pennsylvania Rock Oil Company** becomes the **first oil company** in the US

1854: **Colera epidemic in London** linked to contaminated water by Dr. John Snow. The removal of the **pump-handle at the Broad Street well** prevented people from drinking the contaminated water and stopped the epidemic.

1855: **Benjamin Silliman**, of New Haven, Connecticut, obtains valuable products by **distilling petroleum**. They include; **tar**, **naphthalene**, **gasoline**, and **various solvents**.

1856: **Bessemer** devises a process to make **cast steel** on a large scale by blowing air through melted pig iron to burn the carbon and maintain the resulting steel melted.

1856: Seeking to make a substitute for quinine, the first artificial aniline **coal tar dye** is developed by **William H. Perkin**.

1858: **Friederich August Kekulé von Stradonitz** proposes that **carbon atoms can form chains**.

1859: The **first** commercially successful US **oil well** is drilled by **E. L. Drake** near Titusville, Pennsylvania. This 70 foot well **launches the petroleum industry**.

1860: During the **First International Congress of Chemistry** in Karlsruhe, **Canizzaro** presented new methods determine **atomic weights**; Oxygen weight of 16 was adopted as measuring basis of element weights, thus setting Hydrogen's weight, the lightest known element, to approximately 1.

1860: **Louis Pasteur germ theory** of disease revolutionizes concepts of Medicine and public health.

1863: **Ernest Solvay** perfects his method for producing **sodium bicarbonate**.

1863: The **British government** passes the "**Alkali Works Act**" in an attempt to control environmental emissions.

1864: **Ernst Haekel** outlines the essential elements of modern **zoological classification.**

1864: **Louis Pasteur's demolition** of the doctrine of **spontaneous generation**.

1864: **Ernst Seyler** performed the first **crystallization** of a protein: **hemoglobin**.

1865: The **Civil War** (1861-65) **ends**.

1865: **Friederich August Kekulé** devices a **ring model** for the structural formula of **benzene**.

1865: The first US **petroleum pipeline** is built from an oil field near Titusville, Pennsylvania to a nearby railroad.

1866: **Dynamite** is developed by **Alfred Nobel**.

1866: **Celluloid** is invented by a British entrepreneur named **Alexander Parkes** ("The Father of Plastics").

1866: **Gregor Mendel** published his investigations on plant hybrids and the **inheritance of "factors"**.

1866: **Ernst Heinrich Haekel** hypothesizes that the **nuclei of a cell transmits its hereditary information**. He was the first using the term "ecology" to describe the study of living organisms and their interactions with other organisms and with their environment.

1867: The **Typewriter** is invented.

1868: **Charles Darwin** elaborated the theory of pangenesis.

1868: **Jean Baptiste Boussingnault** pointed out that plants require **oxygen** for the **photosynthesis**.

1869: **Dmitri Mendelejeff** published a chemical elements arrangement table. This is the basis of the well known **periodic table**.

1869: The **Transcontinental Railroad** is completed as the Golden Spike is driven in at Promontory Point, Utah.

1869: **Celluloid** was produced by **John Hyatt** in Albany, New York. The breakthrough came about because of a search for an **ivory substitute that could be used to make billiard balls**. Celluloid was the **first synthetic plastic** to receive **wide commercial use**.

1870: **Justus von Liebeg** proposed that all ferments were **chemical reactions rather than vital impulses**.

1871: **Johan Friederich Miescher** isolated a substance which he called "nuclein" from the nuclei of white blood cells. This substance came to be known as **nucleic acid**.

1872: **Carl Friederich Wilhem Ludwig** and **Eduard Pfünger** studied the gas exchange process in the blood and showed that **oxidation occurs in the tissues rather than in the blood**.

1872: **Lodygin**, produced the first **incandescent** lamps in Russia.

1873: **Barbed wire** is introduced. Meat becomes plentiful as the cattle population doubles between 1875 and 1890.

1873: **Anton Schneider** observed and described the behavior of nuclear filaments (**chromosomes**) during cell division, providing the first accurate description of the process of **mitosis** in animal cells.

1873: **London fog kills 1,150 people**; similar incidents repeated in the following 20 years.

1874: German graduate student **Othmar Zeider** discovers the chemical formula for **DDT**.

1875: **Oscar Hertwig** showed that the head of the spermatozoon becomes a pronucleus and combines with the female pronucleus as the zygote nucleus, thus establishing the concept that **fertilization** is the conjugation of two cells.

1876: The **Telephone** is patented by **Alexander Graham Bell**.

1876: **Nikolaus August Otto** designed the **first four stroke piston engine**. It is nicknamed the "Silent Otto".

1876: The **American Chemical Society** (ACS) is formed.

1877: **Wilhelm Friederich Kühne** proposed the term **enzyme** (meaning "in yeast") and distinguished enzymes from the microorganisms that produce them.

1877: **Thomas Edison** patented the **phonograph**.

1878: **Josiah Willard Gibbs** developed the theory of **Chemical Thermodynamics** introducing fundamental equations and relations to calculate multiphase equilibrium, the phase rule, and the free energy concept. His work remained unknown until 1883, when **Wilhelm Ostwald** discovered his work and translated it to German.

1879: **First electric train** is presented at the international exposition in Berlin.

1879: **Thomas Edison** and **Sir Joseph Swan** independently devise the **first practical electric lights**.

1879: **Saccharin** is discovered by Constantin Fahlberg, a chemist at Johns Hopkins University. The **calorie free sweetener** is 300 times stronger than sucrose and has been sold commercially since about 1900.

1880: **Andrew Carnegie** develops his first, large, **steel furnace**.

1880: **George Davis** proposes a "**Society of Chemical Engineers**" in England.

1881: **Billy "the Kid"** is **shot** by **Pat Garrett**.

1881: **Louis Pasteur** gave a public demonstration of the effectiveness of his **anthrax vaccine**.

1882: **Thomas Edison** builds the first **hydroelectric power plant** in Appleton, Wisconsin.

1882: Robert Koch discovers the rod-like tubercle bacillus responsible for **tuberculosis** (TB).

1883: **Osborne Reynolds** published his paper on the **Reynolds' Number**, a dimensionless quantity which characterizes **laminar and turbulent** flow by relating **kinetic** (or inertial) **forces** to **viscous forces** within a fluid.

1884: The World's **first Skyscraper** begins to be erected in **Chicago**.

1884: **Patent** granted for **chemical-coagulation filtration** process.

1884: The **Solvay process** is transferred to the **United States** and the Solvay Process Co. begins making soda ash in Syracuse.

1884: **Svante Arrhenius** and **Friederich Ostwald** independently **defined acids** as substances which release hydrogen ions when dissolved in water.

1884: **Christian Joachim Gram** invented his staining method for **classification of bacteria**.

1884: **Viscose Rayon** is invented by the French chemist Hilaire Chardonnet.

1885: The **gasoline automobile** is developed by **Karl Benz**. Before this, gasoline was an unwanted fraction of petroleum which caused many house fires because of its tendency to explode when placed in Kerosene lamps.

1886: The **first** modern **Oil Tanker**, the *Gluckauf*, was built for Germany by England.

1887: **August Weismann** elaborated a theory of chromosome behavior during cell division and fertilization predicting the occurrence of **meiosis**.

1887: **Emil Fischer** elaborated the structural patterns of **proteins**.

1888: **George Davis** provides the blueprint for a new profession as he presents a series of **12 lectures on Chemical Engineering** at the Manchester, England.

1888: **Jack "the Ripper"** kills six women in London.

1888: The **Massachusetts Institute of Technology** begins "**Course X**" (ten), the first four year Chemical Engineering program in the United States.

1888: **Heinrich Hertz** performed the first experiments with a receptor to "hear" herzian radio waves.

1889: **Francis Galton** formulated the law of ancestral inheritance, a statistical description of the relative contribution to heredity made by ancestors.

1890: **Theodor Boveri** and **Jean Louis Guignard** established the numerical equality of paternal and maternal chromosomes at **fertilization**.

1890: **Emil Adolf von Behring** discovered **antibodies**.

1891: **Heinrich Wilhelm Weldiger** proposed the **neuron theory** of the nervous system.

1891: **Marie Eugene Dubois** discovered Java man and named it Pithecanthropus Erectus, now known as **Homo erectus**.

1892: **Diesel** develops his **internal combustion engine**.

1892: **Pennsylvania** begins its **Chemical Engineering curriculum**.

1893: **Sorel** published "La rectification de l'alcool" were he developed and applied the mathematical theory of the **rectifying column for binary mixtures**. **William Ostwald** proved that **enzymes are catalysts**.

1894: **Karl Pearson** published the first of a series of contributions to the mathematical theory of **evolution** and methods for analyzing statistical frequency distribution.

1894: **Emil Fischer** conducted investigations which form the basis of the notion of **enzyme specificity**.

1894: **William Maddock Bayliss** and **Henry Sterling** studied the electric currents in mammalian heart.

1894: **George Oliver** and **Eduard Albert Sharpey-Schaeffer** first demonstrated the action of a specific hormone; the effect of an extract of adrenal gland on blood vessels and muscle contraction, upon injection in normal animals it produced a striking elevation of blood pressure.

1894: **Tulane** begins its **Chemical Engineering curriculum**.

1895: The German physicist **Wilhelm Konrad Roentgen** discovered a new kind of radiation working with the vacuum tube discharge. This radiation was called **X-rays.**

1895: **Linde** develops his process for **liquefying air**.

1895: The first professional **US football game** is played in Pennsylvania.

1897: Badishe produces **synthetic Indigo** on a commercial scale in Germany.

1898: The US defeats Spain in the **Spanish-American War**.

1899: The first bottle of **Aspirin** goes on **sale to the public**.

1899: **Max Plank** introduced the concept that light and all other kinds of electromagnetic radiation, which were considered as continuous trains of waves, actually consist of individual energy packages with well defined amounts of energy **quanta**, proportional to its vibration frequency.

1900: **John Herreshoff**, of the Nichols Chemical Co., develops the first **contact method for sulfuric acid production** in the United States.

1900: **Automobile** is welcomed as bringing **relief from pollution**. New York City, with 120,000 horses, scrapes up 2.4 million pounds of manure every day.

1901: **J.P. Morgan** organizes the **US Steel Corporation**.

1901: **George Davis** publishes a "**Handbook of Chemical Engineering**."

1901: **Oil Drilling** begins in **Persia**.

1903: **Orville & Wilbur Wright** fly the **first powered aircraft** at Kitty Hawk, North Carolina.

1903: The **Ford Motor Company** is founded.

1903: **Arthur Noyes**, a prominent MIT professor, established a **Research Laboratory of Physical Chemistry**.

1905: **Einstein** has his "**miracle year**" as he formulates the **Special Theory of Relativity**, establishes the **Law of Mass-Energy Equivalence**, creates the **Brownian Theory of Motion**, and formulates the **Photon Theory of Light**.

1906: The **San Francisco Earthquake** kills hundreds and destroys the city.

1906: **Ludwig Boltzman dies**. He has the equation: **"S=k ln(W)" carved** on his **tombstone** in Vienna. Today it is known as the **Boltzman Principle**, and provides a **statistical relationship** between **entropy** (S) and the **number of ways** a system can be configured (W).

1908: The **American Institute of Chemical Engineers** (AIChE) is founded.

1908: **Cellophane** is discovered by a Swiss chemist named Jacques Brandenberger.

1908: New Jersey starts **chlorinating water supply**.

1908: **Svante Arrhenius** argues that the **greenhouse effect** from coal and petroleum use is warming the globe.

1908: The **General Motors** Company is founded.

1908: The first "**Model T**" rolls of the **Ford assembly line**.

1908: **Dr. Leo Baekeland** ("The Father of the Plastics Industry") discovers **Bakelite** in his laboratory in Yonkers, N.Y.

1910: **Bakelite production begins** at the General Bakelite Company. The plastic finds widespread use in; electric **insulation**, electric **plugs and sockets**, **clock bases**, **iron handles**, and **jewelry**.

1910: **Synthetic Ammonia** is first produced by the **Haber Process** in Ludwigshafen, Germany.

1910: A US **Rayon plant** is constructed by the American Viscose Co.

1911: **Sir Ernest Rutherford** proposes his theory concerning the **atomic nucleus**.

1912: The **Titanic sinks**, killing 1513 people, after striking an iceberg.

1912: **Piltdown Man** is proven a **hoax**.

1912: **Wilson's cloud chamber** allows the detection of **protons and electrons**.

1913: The Standard Oil Co. (Indiana) begins the **thermal cracking of petroleum** in "**Burton Stills**".

1913: **Niels Bohr** proposes his "solar system" **model of the atom**.

1914: **Robert Goddard** begins his **rocketry experiments**.

1914: **World War I begins in Europe**.

1915: The **unit operations** concept is articulated by **Arthur Little**.

1915: **Ford** Motor Co. develops a **farm tractor**.

1915: **Toxic gas** (Chlorine Gas) is used in **World War I** at the battle of Ypres. **Fritz Haber**, primarily known for his ammonia production process, **supervises these deadly "experiments"**. Later, his **wife** pleads with him to stop his work concerning poison gases. After he refuses she **commits suicide**.

1915: The **Corning Glass Works** begins marketing **Pyrex glass**.

1916: **William H. Walker** and **Warren K. Lewis**, two prominent MIT professors, established a **School of Chemical Engineering Practice**.

1916: **German saboteurs blow up the US munitions arsenal** at Black Tom Island, New Jersey.

1917: The **US enters World War I**.

1917: A full-sized plant, producing **nitric acid** from ammonia, is built by the Chemical Construction Co.

1918: **Fritz Haber** receives the **Nobel Prize** for his work on **Ammonia synthesis**. However, the **award is highly protested** because of his prominent role in developing and delivering **poison gas in WWI**. Ironically, Haber is **forced to leave his beloved Germany** in 1933 because he is **part Jewish**

1918: **Acetone** is produced for the British in Terre Haute, Indiana.

1920's: **Cellulose acetate**, **acrylics** (Lucite & Plexiglas), and **polystyrene** can finally be produced in large quantities.

1920: The **18th Amendment**, **prohibiting** the **sale of alcoholic** beverages, goes into effect. Many cases of **blindness** and death result as people mistake **wood alcohol** (methanol) for **ethanol**.

1920: The **Massachusetts Institute of Technology** starts an independent **Department of Chemical Engineering**.

1920: **Ponchon** and **Savarit** developed and presented the famous **Enthalpy-Concentration diagram** useful to solve distillations calculations.

1920: The Standard Oil Co. (New Jersey) produces **Isopropyl Alcohol**, the first commercial petrochemical.

1921: A 4,500 metric ton stockpile of **ammonium nitrate** and ammonium sulfated **exploded** at a chemical plant in **Oppau, Germany**. The blast and subsequent fire **killed 600**, injured 1500, and left 7000 people homeless.

1922: Thomas Midgley uses **Tetraethyl lead** as an **antiknock additive** in **gasoline**.

1922: Albert Calmette and Camille Guerin develop a **tuberculosis vaccine**, BCG.

1922: The first human **diabetes** patient is injected with **insulin.** Mass production of this “wonder drug” soon follows.

1923: **Louis de Broglie** demonstrated that **radiation** has corpuscular properties, and that matter particles such as **electrons** present ondulatory **wave characteristics**.

1925: The **AIChE** begins **accreditation** of chemical engineering programs.

1925: **Rubber antioxidants** begin to be used.

1925: **McCabe and Thiele** present a graphical method for computing the number of equilibrium plates required in a fractionating column for binary mixtures.

1926: **Du Pont** and Commercial Solvents begin **synthetic methanol production** in the US

1927: **Hermann Miller** used X-rays to cause **artificial gene mutations** in Drosophila.

1929: The **stock-market crash** on "Black Thursday" brings ruin to thousands of investors.

1929: **Alexander Fleming** observes the effect **Penicillin** has on bacteria. The breakthrough occurred when he returned to his laboratory after a **four week vacation**. An improperly sealed bacteria culture had been accidentally **contaminated** by a number of **molds and yeast**. One of the molds had killed the bacteria in the culture.

1930's: The Wisconsin duo of **Hougen & Watson** stress the importance of **thermodynamics** in Chemical Engineering **Education**.

1930's & 40's: Michigan's **Katz**, **Brown**, **White**, Kurata, Standing, & Sliepcevich help lay down some foundations in **phase equilibria**, **heat** transfer, **momentum** transfer, and **mass transfer**.

1930's: The US suffers through the **Great Depression**.

1930's & 1940's: **Systematic analysis of chemical reactors** begun by; **Damkohler** in Germany, **Van Heerden** in Holland, and **Danckwerts** and **Denbigh** in England. They explore **mass transfer**, **temperature variations**, **flow patterns**, and **multiple steady states**.

1931: **Neoprene synthetic rubber** is produced by **Du Pont**.

1933: The Imperial Chemical Industries in England discover **Polyethylene**.

1933: Du Pont begins production of **Rayon tire cord fabrics**.

1934 Perry's first edition of the **Chemical Engineers Handbook** is published.

1935: **Wallace H. Carothers**, of **Du Pont**, discovers **Nylon**.

1936: Rohm & Haas begins marketing **Methyl Methacrylate plastics (PMMA)**.

1936: The **Houdry Process** is used in the **Catalytic Cracking of Petroleum**.

1937: **Polystyrene** is offered to consumers in the US by **Dow Chemical**. It finds uses in **radios**, **clock cases**, **electrical equipment**, and **wall tiles**.

1938: **World War II** begins in Europe.

1939: Enrico Fermi, Otto Hahn, F. Strassman, Lisa Meitner, and Otto Frish discover **Nuclear Fission**.

1939: **Nylon** used for **women's stockings**.

1940's: **Polyethylene** (electrical insulation and food packaging), **silicones** (lubricants, protective coatings, and high-temperature electronic insulation), and **epoxy** (a very strong adhesive) are developed.

1940: Standard Oil Co. (Indiana) develops **Catalytic Reforming** to produce **higher octane gasoline** and create **toluene for TNT**. Higher octane gasoline helped the American and British fighters outperform their German counterparts.

1940: First **tire** from **synthetic rubber** produced in US

1941: The **United States** enters **World War II**.

1941: **Styrene-Butadiene Rubber** first produced in the US

1942: **Polyester resins** introduced.

1942: **Enrico Fermi**, and a team of scientists, operated the **first man-made nuclear reactor** under a **football field** at the **University of Chicago**. A **cadmium control rod** was suspended over the **pile** with a **rope**. Should something have gone wrong, a scientist was to cut the rope with an ax, thereby dropping the rod into the reactor, hopefully solving the problem. Ever since then an emergency shutdown has been called a **SCRAM**, which stands for "**safety control rod ax man**".

1942: New York State grants Hooker Chemical Company **permission to dispose of waste** in clay-lined abandoned **Love Canal**.

1943: **Government owned synthetic rubber** plants help boost war time production.

1943: **DDT**, a powerful pesticide, first produced in the US

1944: **Teflon,** Tetrafluoroethelene resins, marketed by **Du Pont**.

1944: Selman Waksman discovers **streptomycin**, the first effective **anti-tuberculous drug**.

1945: The US ends World War II by detonating the **Atomic Bomb** over **Hiroshima, Japan**.

1945: After World War II, the US broke Germany's enormous **I.G. Farben** into; **BASF**, **Bayer**, and **Hoechst**.

1947: A **barge**, the *Grandcamp*, loaded with **fertilizer grade ammonium nitrate** catches fire and **explodes** destroying a nearby city and **killing 576** in what would later be known as the "**Texas City Disaster**".

1947: The formation of **hydrocarbons from synthetic gas** by the **Fischer-Tropish Process**.

1947: **ENIAC** computer uses **Monte Carlo methods** to solve neutron diffusion problem in atomic bombs.

1947: The first **off shore oil** is drilled.

1948: A **deadly smog** settled over the **small steel mill town of Donora, PA**. The noxious air **killed 19** and caused thousands to become ill.

1948: Müller awarded **Nobel Prize for inventing DDT** (dichlorodiphenyltrichloroethane).

1950's: **Television** enters American homes.

1950: The **Korean War** begins.

1950's & 1960's: **Minnesota's mathematical marvel** of **Amundson & Aris** stress the importance of **mathematical modeling** in **Chemical Reactor Engineering**. Their work helps **encourage greater mathematical competence** in Chemical Engineering Education.

1950's & 1960's: **Wisconsin's triumvirate** of **Bird, Stewart, & Lightfoot** reveal the unifying concepts of **mass, momentum, and energy transport**. Their textbook, "***Transport Phenomenon***" continues to be a phenomenon in Chemical Engineering Education.

1950: **Benzene** produced from petroleum.

1951: The first **Fusion Bomb** is tested.

1952: **Du Pont** introduces **Mylar** polyester film.

1952: 4,000 die in a **London smog.**

1953: Production of **soap** exceeded by **synthetic detergents**.

1953: Francis Crick solved the three-dimensional structure of **DNA** molecule disclosed by James Watson and discovered in 1950 by Erwin Chargaff.

1953: After an extremely strong storm the **North Sea floods southern Holland**. More than **1800 people di**e.

1954: **Polyisoprene rubber** developed.

1955: **General Electric** produces **synthetic diamond**.

1955: **Government sells synthetic rubber plants** to private industry.

1957: The Russians launch **Sputnik I**, the first man-made satellite.

1957: **Windscale graphite nuclear reactor burns** for 42 hours in England. Releases I-131. Residents curtail milk consumption for safety reasons.

1957: **General Electric** develops **polycarbonate plastics**.

1959: The **computer control** of **chemical processes** gains credibility.

1959: A large scale **hydrogen plant**, to produce **rocket fuel**, is completed by Air Products.

1960: **Theodore Maiman** builds the first **LASER** based upon the proposal of Arthur Schawlow.

1961: **Alan Shepard** becomes the **first American into space**.

1961: **William McBride**, an Australian obstetrician, discovers that **thalidomide**, a mourning sickness drug,

causes birth defects. Twenty years later he similarly "discovers" that **debendox**, another mourning sickness drug, also causes birth defects. However, this time his McBride had altered his data. Debendox produces no ill effects. In 1993, he was **found guilty of scientific fraud by a medical tribunal**.

1962: The **Russians remove** their **missiles from Cuba**.

1962: The **smog** in London kills 1,000.

1962: Rachel Carson's book, "**Silent Spring**", presents an emotional plea for **protecting human health** and the **environment** from **chemical pesticides**.

1965: American Troops enter the **Vietnam War**.

1965: **Bottles** made from **polyvinyl chloride** gain market share.

1965: **NutraSweet** is discovered by a researcher, Mr. James Schlatter, at the G.D. Searle & Co. The calorie free sugar replacer is 200 times sweeter than common sucrose.

1966: Fist attempt to **control organic solvent emissions** made by Los Angeles' Rule 66.

1968: Consumption of **man-made fibers** tops natural fibers in US

1969: The **Apollo 11** mission succeeds by **landing Man on the Moon**.

1969: The horribly **polluted Cuyahoga River**, running through Cleveland, actually **caught on fire**.

1970's: America's heavy **dependence on foreign oil** results in an **Energy Crisis** as the Arabs stop shipment to countries which supported Israel in the **Arab-Israeli Wars**.

1970: America holds its first "**Earth Day**" on April 22.

1970: The Environmental Protection Agency (**EPA**) is **formed**. It consists of 6,000 employees and has an annual budget of $1.3 billion.

1970: Congress passes the "**Clean Air Act**" establishing national air quality standards.

1972: Congress passes the "**Clean Water Act**" to confront water pollution.

1973: The last **American Troops leave Vietnam**.

1973: Stanley Cohen & Herbert Boyer perform the first experiment in **Genetic Engineering**.

1973: Construction on New York's "**World Trade Center**" and Chicago's "**Sears Tower**" are completed.

1974: **Richard Nixon resigns** from office.

1974: **Cyclohexan vapor** from ruptured makeshift bypass pipe **explodes killing 28 workers in Flixborough, England**, prompting legislation for risk studies in British chemical plants.

Mid 1970's: **Toxic** releases including: the **Kepone** tragedy at **Hopewell**, VA; the **PCB** contamination of the **Hudson River**; and the **PBB** poisoning of **cows in Michigan** keep environment issues in the headlines.

1975: **Catalytic converters** are introduced in many **automobiles** to meet emissions standards established by the US government.

1975: **Cable fire at Browns Ferry nuclear reactor** in Alabama almost leads to disaster. It was **caused by an electrician who used a candle to check for air leaks** below the nuclear plant's control room.

1975: Du Pont recognizes the contributions of Nathaniel C. Wyeth. He was responsible for introducing the **plastic soda bottles** made from **polyethylene terephthalate (PET)** which quickly **replaced** their **glass predecessors**.

1975: **McDonald's** fast food chain starts using **Polystyrene** to package its **hamburgers**.

1976: Congress passes the "**Toxic Substances Control Act**" regulating toxic chemicals.

1976: Seymour Cray, of **Cray Research**, makes the Cray-1 **super-computer**

1976: The US National Academy of Sciences reports that **chlorofluorocarbons** (Freons) can deplete the **Ozone Layer**.

1976: The US **bans** the use of **chloroform** in drugs and cosmetics.

1976: **Viking 1** lands on **Mars**, becoming the first man-made object to ever soft-land on another planet.

1977:The **FDA** moves to **ban Saccharin**, a calorie free sweetener, because it has been found to cause **cancer in rats**.

1977: Raymond Damadian builds his **first Magnetic Resonance Imager (MRI)** used to generate **3-D images** of the **human body** using the principles of **Nuclear Magnetic Resonance spectroscopy (NMR)**.

1978: Due to considerable grass roots pressure, the **FDA** decides to merely require an **information label on Saccharin**, despite being shown to cause cancer in laboratory animals.

1978: **Chlorofluorcarbons** (Freons) are **banned** as spray propellants in the US because of fears over the **Ozone Layer**.

1978: The **US Government begins limiting** the amount of **lead permitted in gasoline**. The action is taken to **prevent deterioration** of the **platinum catalysts** in catalytic converters, **not to protect the public's safety**.

1979: No one is injured, but many are terrified, by an **nuclear reactor incident** at **Three Mile Island**, Pennsylvania.

1979: **Soviet** troops **retreat** from **Afghanistan**.

1979: **Genetic Engineering** succeeds in **synthesizing human insulin**.

Late 1970's: **Love Canal** (in New York) and the **Valley of Drums** (10,000 leaking hazardous waste drums near West Point, KY) keep environmental issues in the news and are described as "**ticking time bombs**."

1980: The US Supreme Court rules that **General Electric** can **Patent** a **microbe** used for **oil cleanup**.

1980: The "**push through tabs**" used on today's **pop and beer cans** are first introduced.

1980: The **US Government bans** the sale of **lead based paints**.

1980: The **Superfund**, containing $1.6 billion, is formed to be used by the **EPA** in cleaning up **pollution sites**.

1981: **Microsoft** develops **MS-DOS** for the IBM PC.

1981: **Chemical Process Simulation software** is released for the PC. Soon packages like DESIGN II, ASPEN, SIMSCI (PROII), HYSIM, & CHEMCAD start appearing on engineering desktops.

1981: **John Darsee**, a former Harvard researcher, was found to be **faking heart study data**. His fraud had been propagated in almost 100 published research studies.

1981: Gerd Binnig & Heinrich Rohrer develop the **Scanning Tunneling Microscope (STM)** which is capable of **resolving individual atoms on a surface**.

1981: NASA's **"Columbia" Space Shuttle** becomes the world's **first reusable space craft**.

1983: **Carl Sagan**, and a group of scientists, publishes an alarming report concerning the **long term climatic impacts of nuclear war**.

1984: **AT&T is broken** into "**Baby Bells**" by the US government.

1984: **Apple** introduces the **Macintosh** personal computer.

1984: An accidental **toxic gas release** by Union Carbide **kills over 2000 and disables 10000 in Bhopal, India.**

1985: Richard E. Smalley and Harold W. Kroto discover "**Buckyballs**", a **soccer ball** like molecule made of **60 carbon atoms**.

1985: Low petroleum prices lead to the **cancellation** of the US Government sponsored **"Synfuels" project**, designed to develop **alternative energy sources based on coal or oil shales**.

1986: **Chernobyl Nuclear Reactor #4 explodes**, releasing large amounts of radiation near Kiev, USSR.

1986: NASA's Space Shuttle, **Challenger**, **explodes** shortly after take off.

1986: K. Alex Muller and George J. Bednorz discover a **superconductor** that operates at **30 degrees Kelvin**. This sets off an explosion in "high" temperature superconductors.

1987: Japan's "Nipon Zeon" company develops a **plastic with "memory**". At **low temperatures** it can be **bent and twisted**, however when **heated** above 37 degrees Celsius it **returns to its initial shape**.

1988: A **Scanning Tunneling Microscope** produces the first picture of a **Benzene Ring**.

1988: **North Sea oil platform explodes** prompting England to require risk assessments in oil industry.

1988: **McDonald's** fast food chain **stops** using the "**clamshell**" to package its **hamburgers** because of fears over the CFC's used in manufacturing Polystyrene.

1989: An **Exxon Oil Tanker**, the ***Valdez***, **runs aground** in of the coast of Alaska.

1989: The fall of **Berlin Wall**.

1989: "The New Yorker" magazine raises the possibility that **electromagnetic fields might cause cancer**. Over the next decade, US taxpayers spend $25 billion funding studies which find no link between power lines and cancer. Similar epidemiological studies in Canada and Britain also find **no link**.

1989: The **Human Geonome Project**, designed to map all the genes in a human being, is launched.

1989: Stanley Pons & Martin Fleischmann boldly announce the "invention" of **cold fusion**. Results have never been duplicated and are agreed to have been faulty.

1990: **Lithuania declares independence** from Soviet Union in March 11. As response USSR sends troops and blocks gas and oil supplies.

1990: Federal Trade Commission **opens antitrust probe of Microsoft**.

1991: The **Soviet Union** formally dissolves.

1991: Washington D.C. has a **victory parade**, celebrating the decisive **US success against Iraq in the Gulf War**.

1992: The **Australian Government** begins a three year plan to introduce **plastic $5, $10, $20, $50, & $100 bills**.

1993: New York's "**World Trade Center**" is bombed by terrorists. The explosive was created by a 26-year-old **chemical engineer** educated at **Rutgers University**.

1993: The high price of replacing a **corroding heat exchanger** causes the **Portland General Electric Company** to **retire, rather than repair**, its **Nuclear Power Plant** in Rainier Oregon.

1994: **More computers than television sets** are sold.

1994: **Eurotunnel opens**. The 50 kilometer long tunnel connects England with France.

1995: The **Shinri Kyo cult** uses **Sarin nerve gas** in the deadly **Tokyo subway attack**.

1995: A **bomb** made from **ammonium nitrate** fertilizer and **fuel oil** destroys the **Federal Building** in **Oklahoma City**, OK.

1995: **Dow-Corning files bankruptcy** after being sued by 19000 women over "faulty" breast implants.

1996: **Dolly**, a female sheep, becomes the first mammal to be **cloned** from an adult mammal's cells. This incredible work was carried out at Edinburgh's Roslin Institute, and its announcement sparked a rash of discussion and legislation concerning the morality of cloning human beings.

1996: **Olestra**, a fat-free fat replacer, is approved for use in salted snacks by the FDA after 10 years of deliberation. Olestra is a novel lipid made from sucrose and soybean oil. With up to 8 fatty acids attached to the sucrose molecule, instead of the 3 fatty acids typically found in fat, enzymes are unable to break down Olestra. The Procter & Gamble company has been studying the safety of Olestra for nearly 30 years.

1996: Britain announces that 10 people have contracted **mad cow disease**, or Bovine Spongiform Encephalopathy (BSE), from contaminated beef. In response, **3.7 million cattle are slaughtered**.

1996: A **NASA** funded team finds evidence that suggests microbial **life may have existed on Mars** more than 3.6 billion years ago. The evidence consists of traces of **organic compounds** and **mineral features** characteristic of biological activity.

1996: **Troll offshore platform** begins collecting natural gas off the Norwegian coast. At 369 meters tall (most submerged) and 656,000 tons it is one of the worlds largest structures.

1997: **Mar's Pathfinder** becomes the first spacecraft to land on Mars in more than two decades. Its **automated rover** provides close-up views of "Barnacle Bill" and other Martian rocks while its novel **airbag** landing demonstrates NASA's commitment to more numerous, less expensive missions.

1998: Government begins antitrust trial of Microsoft.

2000: **Y2K bug** costs $100 billion to fix. Doomsday scenarios averted.

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Don't forget to VIEW OUR GUESTBOOK.

Special thanks to Luis Klemas & Murugan Selvan for their contributions...

Last updated on September 18, 2000 by Wayne Pafko...

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Working Bibliography

This history has only scratched the surface of a **vast, varied, and interesting history** concerning **chemical engineering**, **applied chemistry**, and **chemical technology**. Below is a sampling of some works on this subject. If you are interested in reading more I recommend:

1) Isaic Asimov who discusses the **future** of chemical engineering (and why not, he wrote about everything else!)

2) John Servos who does an excellent job examining the **beginnings at MIT** (all programs should have such a detailed and well written exploration of their past!)

3) William Walker who discusses the "modern" (1911) **alchemists** in industry who keep their discoveries to themselves (some things never change!)

4) Terry Reynolds who describes the scene in the American industry, at the turn of the century, that helped chemical engineers gain **prominence and prestige** (hopefully to never be lost).

"Enough already...go to the end."

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See what our fine institute has to say in defense of itself...

CEMS

University of Minnesota Chemical Engineering and Materials Science (CEMS) department. See what the best department in the country has to say (modesty is their thing).

Local AICHE Chapter

See what our University of Minnesota AICHE chapter has to offer.

WWW Chemical Engineering Virtual Library

Lotsa links.

AIChE's National Home Page

Explore what the American Institute of Chemical Engineers has to say about our profession.

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