What Is Industrial Chemistry

J.J. Siirola

Abstract

Industrial chemistry is the manufacturing art concerned with the transformation of matter into useful materials in useful amounts. Usually this transformation of available materials into more desirable ones involves some kind of process following a recipe. In turn the process may involve grinding, mixing together various ingredients, dissolving, heating, allowing ingredients to interact (chemically or biochemically react forming new compositions of matter), cooling, evaporating or distilling, growing crystals, filtering, and other physical-chemical-biological operations.

Keywords

Manufacture of Desired Materials • Class of reactions • Catalysis • Unit Operations • Large Scale Production

Industrial chemistry is the manufacturing art concerned with the transformation of matter into useful materials in useful amounts. Usually this transformation of available materials into more desirable ones involves some kind of process following a recipe. In turn the process may involve grinding, mixing together various ingredients, dissolving, heating, allowing ingredients to interact (chemically or biochemically react forming new compositions of matter), cooling, evaporating or distilling, growing crystals, filtering, and other physical-chemical-biological operations.

The practice of intentionally transforming materials dates back more than 7000 years. Some of the oldest examples include leavened bread; brewing beer; lead, tin, and copper roasting; clay brick baking; soap; charcoal; iron smelting; and salt purification. The development of bread and beer along with agriculture to raise grains to support those processes are the oldest instances of man's ability to develop technology and build civilization. The ability to produce some of the other materials proved so important that scholars divide ancient history accordingly

---

J.J. Siirola (✉)
School of Chemical Engineering, Purdue University,
West Lafayette, IN 47907-2100, USA
e-mail: jjsiirola@gmail.com

J.A. Kent et al. (eds.), *Handbook of Industrial Chemistry and Biotechnology*,
DOI 10.1007/978-3-319-52287-6_1

(Pottery Neolithic Age, Copper Age, Bronze Age, Iron Age, etc.).

In many cases, critical agents in these processes such as the wild yeasts involved in bread and beer making or the carbon monoxide involved in iron ore smelting were not known even to the practitioners. This is why successful recipes, however accidental their development, were highly valued, often kept secret, and those with custody became elevated and revered members of society. The practice of material transformation long preceded the development and understanding of the chemical science which supports it.

Of the seven metals known to the ancients (gold, silver, copper, tin, lead, iron, and mercury), gold because of its attractive appearance and relative scarcity became particularly prized. This led beginning perhaps as early as 3500 BC to alchemy, attempts to convert base metals into gold. These efforts which had significant components of symbolic mysticism and also involved other concerns such as finding a universal solvent and creating an elixir of life (eternal youth) continued throughout the centuries in Greco-Roman Egypt, the Islamic world, and medieval Europe, India, and China. Ultimately, however, alchemy was replaced in the seventeenth century by rigorous experimentalism.

Although fire (combustion) is usually cited as the first controlled chemical reaction, it was the attempt to improve the industrial processes of ore refining and smelting which led in 1605 to the development of the scientific method by Francis Bacon. In 1615, Jean Beguin described a material transformation using what we would now call a chemical equation. In 1661, Robert Boyle developed an atomic theory of matter, and a century later Antoine Lavoisier established the law of conservation of mass for chemical reactions. Chemistry is now defined as the science of the nature of matter and its transformations (the latter distinguishing it from physics) and in contrast with physics used little mathematics (until the twentieth century and quantum chemistry). Chemistry is now also understood to underlie biological transformations as well.

Over the last four centuries, many materials have been brought into contact with each other under various conditions of temperature, pressure, solvents, etc. to explore experimentally just what might happen. The science of chemistry can be exploited as a curiosity, or as an analytical or diagnostic tool, or to make materials to be used for some purpose. The first two categories are about information and knowledge, and the amount of physical material required may be as small as can be conveniently manipulated, often fractions of a gram. The last category, however, is about making materials in quantity. One handbook describes some 26,000 chemical and biochemical synthesis methods, about 10% of which have been used to make materials on an industrial scale. These materials range from natural (biological) products like cotton, wool, rubber, and paper to inorganics like steel, copper, aluminum, brick, concrete, glass, mineral fertilizer, acids, and alkalis; to fuels like methane gas, gasoline, diesel, and kerosene; to polymers like polyethylene, polystyrene, polyester, and nylon; and to fine chemicals like paints and adhesives, pigments and dyes, soap and detergents, solvents, fire retardants, explosives, pesticides, vitamins, pharmaceuticals, and many many others. The annual production of some of these materials is less than a few kilograms per year (laboratory scale). Annual production greater than that up to about 1000 tonnes per year is considered specialty scale. Annual production greater than 1000 tonnes per year is commodity scale. Some of the largest scale commodity products include the organic building block ethylene (150 million tonnes per year), gasoline (1200 million tonnes per year), steel (1700 million tonnes per year), and concrete (4200 million tonnes per year). Some of the large commodity-scale materials are manufactured because of their exact chemical composition, while many of the smaller scale materials are manufactured mostly for their ability to performa specific function rather than for their particular chemical structure. This handbook is principally about industrial chemicals manufactured at the specialty scale and at the commodity scale.

Chemical process recipes can vary widely. But in general they involve gathering available raw materials, possibly separating out specific reactants, bringing them together under particular conditions of temperature, pressure, and other factors so that they react producing new products, followed by some methods to isolate and purify the desired product. In many cases multiple reaction steps with different materials and intermediates performed consecutively are required to produce the final product, a sequence called a reaction path.

Laboratory-scale chemical methods are used for experimentation and for very-small-scale manufacture. Equipment used like beakers and flasks have volumes from a few milliliters to a few liters. Temperatures generally range from −50 °C to 250 °C at pressures around 1 bar, although specialized equipment is available for temperatures and pressures beyond these ranges. Borosilicate glass is often used because of its general corrosion resistance and ease of fabrication onto convenient shapes. This scale of chemistry is almost always executed in batch mode and often several steps of the recipe are done sequentially in the same piece of equipment. Some aspects of the laboratory scale art have evolved to help improve consistency, for example the common practice of conducting reactions in refluxing solvent which occurs at the constant temperature of the boiling solvent, thereby eliminating the need for a more complex temperature control system. Almost all laboratory-scale procedures are manually conducted by chemists and chemical technicians.

At larger than laboratory scale, many more considerations become important including consistency, reliability, environmental impact, and economics, and specialized expertise in process and equipment design and operation in addition to chemical knowledge is required. Specialty-scale industrial chemical methods are most often also conducted in batch mode, following a recipe. The equipment is larger with volumes up to a few thousand liters, but the sequence of steps may be almost identical to those used at the smaller laboratory scale. Equipment for specialty-scale production may be designed, constructed, and connected together only for the production of one specific chemical (special purpose batch), or it may be designed with more interconnection flexibility so that with some modification different chemicals may be produced at different times with the same equipment (multipurpose batch). Typical industrial batch chemical production equipment includes agitated thermally jacketed vessels for reaction, extraction, liquid blending, evaporation, crystallization, etc.; filters, centrifuges, and dryers for solid-liquid separation; stills for distillation; mills for grinding; solids blenders; packaging equipment, etc. Stainless steel and glass-lined (enameled) steel are common materials of construction, but many other materials are used including corrosion-resistant alloys, polymers, graphite, and even wood (although pure glass common in laboratory scale is only rarely used). Any temperatures and pressures needed can be designed for including ranges far outside those that would be practical or safe in a laboratory. Although some specialty-scale processes are manually operated by chemical technicians, more and more aspects are conducted under automatic recipe computer control. Much specialty chemical manufacturing technology, equipment, and operating procedures can be traced to the historic dyestuff industry largely developed in Germany in the late nineteenth century. Some of these procedures require just a few dozen steps, while the synthesis of more complicated chemical and biochemical molecules may require several hundred. Although it depends on the complexity of the recipe, a batch reactor system may be able to produce up to 200 tonnes per year.

As the industrial revolution led to increased demand for materials, some batch industrial chemical processes were converted to continuous operation reconfigured so that multiple steps in the recipe that were conducted at different times in one vessel were instead conducted in different pieces of equipment each designed to perform only one single step of the recipe but to do it and only it all of the time. Chemical manufacture began to be understood in terms of processing technologies, often expressed in the form of flow diagrams, but usually centered around a particular reaction type (oxidation, reduction, hydrolysis, halogenation, nitration, sulfonation, esterification, polymerization, etc.) or final product (sulfuric acid, caustic, soda ash, azo dyes, etc.). The different chemical industries were regarded as different industrial technologies, each with different principles and recipes.

In 1916 Arthur D. Little developed an entirely new focus on equipment functionality called unit operations. His unit operation classes included fluid flow processes, heat transfer processes, mass transfer processes, thermodynamic processes, reaction processes, and mechanical processes. These, along with a unified understanding of chemical reaction kinetics (rates) and the role of temperature, pressure, concentration, and catalysis by William H. Walker, Warren K. Lewis, and William H. McAdams, led to formalization of the principles for a new discipline of chemical engineering. And with these principles continuous processes were developed for most, but not quite all, commodity-scale industrial chemical manufacture.

With the continuous production paradigm, chemical manufacturing equipment changed dramatically. For example, batch reactors mostly look quite similar: jacketed stirred tanks. Long pipe plug flow continuous reactors behave mathematically like batch reactors, but in most instances are not used but instead have been replaced with vessels (sometimes more than one) which look quite different from each other depending on the amounts and phases of the substances being reacted, required residence time and residence time distribution, whether a catalyst (a substance which helps a reaction to proceed under more mild conditions) is present and in what phase, whether the reaction is thermodynamically endothermic or exothermic, whether the reactor is run adiabatically or isothermally, and whether any separation is inherently part of the reaction step. Multistage packed or trayed distillation became the most used separation technology for substances that could be boiled. Heat transfer equipment became specialized. Continuous or nearly continuous versions of previous batch operations such as adsorption, crystallization, filtration, centrifugation, and drying were developed. Some new continuous equipment such as thermosiphon reboilers and plug flow reactors were developed that are generally not even seen in the laboratory except in piloting situations. The industrial production of almost all materials with annual production per plant in excess of 5000 tonnes per year is now done continuously (with some notable exceptions including steel and certain polymers requiring the sharper molecular weight distribution achievable with batch reaction). Since it is difficult to run continuous processes reliably at rates less than about 10 L min^{-1} (5000 tonnes per year), commodity chemicals in the annual production range below 5000 tonnes per year may be run either batchwise in multiple plants or continuously at an acceptably high rate but for only part of the year. In either event, industrial chemicals in the awkward annual production range between about 500 and 5000 tonnes per year are more expensive than what might otherwise have been expected.

The design of continuous industrial chemical manufacturing facilities is generally performed by chemical engineers to implement at large scale a reaction system developed by chemists and to be operated by manufacturing technicians. The design task has benefitted from analogies between fluid dynamics and heat transfer developed by Osborne Reynolds and between heat transfer and mass transfer developed by Wilhelm Nusselt. Recasting fluid dynamics as momentum transfer by R. Byron Bird, Warren E. Stewart, and Edwin N. Lightfoot led to a consistent and analogous mathematical treatment at the macroscale, microscale, and molecular level for all three of these processes known collectively as transport phenomena. Finally, more recent developments in process system engineering including process design (synthesis, analysis, evaluation, optimization, and intensification of process alternatives), process control (regulatory control, statistical process control, adaptive control, model predictive control), process operations (planning, scheduling, fault diagnosis, real-time optimization), and computer tools (sequential modular simulation, equation-based simulation, dynamic simulation, and mathematical optimization) have all contributed to the viability of industrial chemical manufacture.

A facility to manufacture an industrial chemical has three primary objectives: to make the desired material, to make it completely fit for use, and to make the desired amount in a given period of time. The desired material may be for example one particular molecular structure, or an alloy or a blend of a number of particular species, or a complex mixture of ill-defined composition like gasoline. Fitness for use may involve composition (the desired chemical structure), purity (the product is at least so much of the desired composition), specification (usually limits on the amounts of other materials that may be in the product), physical properties (density, viscosity, refractive index, color, crystal structure, melting point, etc.), chemical properties (reactivity, heat of combustion, molecular weight, molecular weight distribution, etc.), or possibility performance in some use test (ability to dissolve, adhere, withstand stress or vibration, etc.).

In addition to the primary chemical objectives, the manufacturer of industrial chemicals also has objectives related to the performance of the process itself. Principal among these secondary objectives is economics as industrial chemistry has become globally competitive market. However many other considerations are also important including safety, health, waste, environmental impact, reliability, controllability, employment, social impact, and sustainability. These primary and additional manufacturing objectives have a profound impact on the practice of industrial chemistry.

Because of the focus on producing a specified material as well as minimizing wastes and environmental impacts, industrial chemistry tends to exploit reaction systems that are highly selective (that is, produce few by-products through undesired parallel or sequential side reactions). In many situations, it may be possible when reactants are brought together for more than one reaction to occur in parallel, or that some reaction may take place with the desired product to make a sequential undesired material. Reaction conditions of temperature, pressure, and especially catalysis may be selected which maximize desired reaction rates while minimizing undesired reaction rates and by-product formation. Another industrial technique may involve removing a desired product even during the course of a reaction to minimize undesirable consecutive reactions.

There are four general classes of reactions: rearrangement (the reactant and the product contain the same atoms, but the bonds among them may be different; also called isomerization), addition (two or more reactant molecules combine into a single product molecule), decomposition (one reactant molecule breaks up into two or more fragment molecules, one of which is the desired product and the other are coproducts), and substitution (two or more reactant molecules combine into one desired product molecule and one or more other coproduct molecules). All four reaction types are common but the most common is substitution. In experimental chemistry and laboratory-scale industrial chemistry, the quantities of materials are small, and there is often little concern over which type of reaction may be employed. However in specialty-scale and commodity-scale industrial chemical manufacture, coproducts from decomposition and substitution reactions represent material in the reactants that does not appear in the desired product. The amount of such coproducts is determined by stoichiometry. If these coproducts can be sold or otherwise used in some process there may not be too much of an economic penalty. However, if they cannot be recovered and used, they become wastes which must be properly and safely disposed sometimes at significant cost.

Some reactions do not spontaneously occur even if reactants are brought together. A thermodynamic property, the Gibbs free energy of reaction, which can be calculated for any proposed reaction and reaction conditions, gives an indication if this may be the case. If the Gibbs free energy is disadvantageous, it still may be possible to achieve the desired result not directly, but indirectly by devising a chain of reactions, each under different operating conditions, so that the Gibbs free energy of each separate reaction and the resulting equilibrium is advantageous. This is often achieved by employing new reactions of the decomposition or substitution type with either the product or coproduct designed to leave the reaction zone by precipitation or evolution as a gas (two conditions which result in more favorable Gibbs free energy of reaction). This indirect approach is a form of multistep reaction path synthesis, one of the first industrial chemistry examples of which was the Leblanc process for soda ash (sodium carbonate).

The desired direct reaction between sodium chloride (salt) and calcium carbonate (limestone) to form soda ash is thermodynamically unfavorable, so an indirect sequence was developed by Leblanc. Each of these new reactions involved the evolution of a gas coproduct or creation of a solid coproduct and a favorable Gibbs free energy. As it turned out, some of these coproducts were rather innocuous, but some were corrosive, toxic, and odorous; had no value; and, as production volumes for soda ash increased, became significant environmental burdens.

A clever alternative was the Solvay process for soda ash. Like the Leblanc process, the Solvay process involved an indirect sequence of several reactions, each with coproducts, and each operated under conditions of favorable Gibbs free energy. However, in the Solvay process, each of the coproducts was itself a reactant in an earlier reaction in the reaction path. After each reaction the coproduct was recovered and recycled to that earlier reaction. Only the overall desired sodium carbonate product and its stoichiometric coproduct are produced and all of the other intermediate reaction coproducts remain completely within the process, thus achieving superior environmental and economic performance, a characteristic that often dominates industrial chemistry considerations.

Some laboratory syntheses are chosen to get high conversions specifically by choosing a substitution-type reaction with a gaseous coproduct, which if it leaves the reaction zone results in a favorable reaction equilibrium. For example, amides are frequently synthesized from amines and acid chlorides because easy removal of the resulting coproduct hydrogen chloride gas results in nearly complete conversion. At small scale this is perfectly acceptable as the hydrogen chloride is easily trapped, neutralized, and safely disposed of.

However at larger scales and especially at commodity scale such environmental costs would become uncompetitive. At those scales the alternative reaction between the amine and an acid with water as the coproduct might be chosen even though the reaction equilibrium is much less favorable and the reaction conversion would be lower. Because of the poorer conversion, separation, recovery, and recycle of unreacted reactants would be necessary, but the greater cost for this is more than offset by the lesser mitigation cost of water, rather than hydrogen chloride, as the coproduct.

Almost all industrial chemistry reactions are catalyzed and therefore operate under more mild (and hence generally more selective) conditions than would otherwise be possible. Catalysts and biocatalysts (enzymes) sometimes have complicated structures or contain rare elements and therefore may be expensive. By definition, catalysts are not consumed in the reaction they are facilitating (otherwise they are called stoichiometric reagents) and generally are present in only small quantities. Again because of economics, it is important that catalysts be carefully recovered for reuse, and that if they become degraded they can be cleaned or otherwise regenerated, operations that can sometimes be more complex than the main process itself. Likewise because of economics and waste, stoichiometric reagents are to be avoided if at all possible in industrial reaction paths.

Health, safety, and environmental issues are all important industrial chemistry considerations. Oftentimes they dominate manufacturing decisions. These issues are often mitigated by considering alternatives with different chemistries involving species with fewer or less serious impacts, or by minimizing the amount of hazardous intermediates in the process, or by engineering controls to mitigate the potential impacts of such hazards. Batch processes that involve a series of consecutive reactions typically inventory one or more batches of each intermediate. Continuous processes, on the other hand, often have very little inventory of intermediates as they are sent on to the next processing step as quickly as they are formed. Minimizing inventories of dangerous intermediates (material at risk) may be a motivation for choosing continuous operation even before considerations of annual production rate.

Economics, which are rarely important in the laboratory, become critical as manufacturing scale increases and more entities compete to meet the total demand. Costs include both the manufacturing cost to make the material and the capital cost of the facility in which industrial chemistry is conducted. Principal among manufacturing costs are the cost of the raw materials that are the reactants. Also very important is energy in the form of heat, cooling, and power that may be required to drive or promote the reactions, separations, and other operations in the recipe. Additional costs include adjuvants such as solvents and catalysts which also facilitate the reactions, costs to manage wastes and protect the environment, and labor to conduct or supervise the execution of the process steps and maintain the manufacturing facility in operating order. These manufacturing costs are incurred as product is made and are largely proportional to the amount of product made. Capital costs are the costs of the chemical equipment and facilities used to make the product. Once built such equipment and facilities may perform for a very long time, even decades. Capital costs are incurred when the manufacturing facility is first built, and often exhibit economies of scale, meaning that a larger size equipment capable of producing twice as much product as a smaller size equipment costs less than twice the cost of the smaller one. The economics of sublinear capital cost scaling therefore tend to favor larger sized facilities. Optimizing the balance of manufacturing costs and capital costs often influences industrial chemistry reaction path choices.

While a batch process may be relatively more straightforward to develop from laboratory experience, there are a number of advantages for continuous processing besides reactor productivity (the amount of product made per volume of reactor over a given elapsed time, typically one or two orders of magnitude higher). The first of these is the concept of recycle. It is true that in batch processes, some of the last steps in the procedure may be the recovery and purification of solvents so that they might be used in subsequent batches. However, if a batch reaction has low conversion chemistry (not all of the reactants react), it is relatively rare for unreacted reactants to be recovered for use in subsequent batches. In continuous processes on the other hand, each step of the process is always in operation. Therefore, if unreacted reactants are isolated as part of product recovery and purification, they may be immediately sent back or recycled to the reactor for another attempt at reacting. This results in a major improvement in raw material utilization and associated reduction in raw material costs. It also means that high reaction conversion which is an important consideration in batch industrial chemistry implementation is much less of a consideration in continuous implementation (depending on the costs incurred to isolate and recycle the unreacted reactant).

In continuous industrial processes the concept of recycle is ubiquitous. Reactants, solvents, catalysts, mass separating agents, sorbents, and other adjuvants are all recovered, sometimes reprocessed, and reused in the process. Products are sometimes used as absorbents. Distillation reflux liquid is obtained from recycled overheads product while stripping vapor is boiled from recycled bottoms product. Filtrates from final crystal washings are recycled for first washes. Separations are implemented in countercurrent cascades. Reaction conversions per pass may be low, but the overall process conversion is often near unity. All of these instances of recycle conserve mass and reduce material costs.

However, material recycle in continuous processes does have some risks. No chemical reaction is perfectly selective, meaning that there are always by-products. Sometimes the amounts of these by-products are extremely small and they may not have even been detected in laboratory experiments. In batch processes, these materials might leave with the product (as long as the product meets specifications) or with coproducts that are already being disposed of as wastes. But in continuous processes with recycle, some by-products may instead be separated into streams being recycled and thus become trapped in the process building up until they causes havoc. Processes with recycle must make provisions such as small purges to control the accumulation of all such possible by-products.

Continuous processing also facilitates the recovery and reuse of heat and power. Many chemical processing operations require the introduction or removal of thermal energy at various temperatures or the addition of power as in compression and agitation. In batch processes, these requirements occur at different times in the recipe and are almost always supplied from utilities (steam at different temperatures, furnaces, cooling water, refrigeration, electric power, etc.) provided as part of the manufacturing facility for the purpose. In continuous processes, these needs may also be satisfied by utilities. However, because the needs occur all the time, it is often possible that complementary needs can be matched up within the process, a stream to be cooled used to heat a stream needing to be heated, thus saving both the heating utility and the cooling utility. This technique is called heat integration and is a very important economic feature of modern commodity-scale continuous industrial chemical manufacture. An analogous technique can also be used among gas streams being compressed and those being expanded (as frequently happens around high-pressure vapor-phase reactors and in refrigeration cycles) and is called power integration. Heat and power integration and process design modifications which increase the opportunities for such integrations can reduce process utility operating costs by more than half.

Also since the industrial revolution there has been an increased thermodynamic understanding of the concepts of heat and power. It is now better appreciated why certain operations such as the compression of gasses to higher pressure and refrigeration (which is often implemented by compressing and then expanding a gas) are particularly expensive in terms of the heat or power that will be required. These mechanical costs sometimes significantly influence which industrial chemistry route to a desired product might be selected for implementation.

Another thing that continuous processing facilitates is automatic process control. Engineers have developed two types of process control: servo control in which the system is desired to change from one condition to another as quickly as possible (some performance aircraft flight control systems work this way), and regulator control where it is desired to maintain constant operation no matter what perturbations may be imposed upon the system (automobile cruise control is in this category). In batch operation, something is always changing at each point in time. In continuous operation, on the other hand, while conditions of temperature, pressure, flow, etc. are different in each piece of equipment, they are intended at each place to be constant there all the time. This lends itself to regulator control and systems of sensors, valves, and other control elements which help maintain operational consistency and product quality from moment to moment especially for commodity-scale industrial chemical manufacture.

Some raw materials and catalyst materials are readily available on the earth while others as far as is known are relatively scarce. These facts also become more important as manufacturing scale increases. For oxidation reactions, for example, chemists are aware of many oxidizing agents, some of which are very selective for the desired oxidization while avoiding competing undesired oxidation reactions over a wide range of conditions. Such agents are often used at the laboratory scale precisely because of this selectivity. However, the selective agents may be expensive. At the commodity manufacturing scale, whenever possible the least expensive oxidation agent, air, is used with the operating temperature, catalyst, etc. precisely selected and controlled at the most selective conditions possible.

Early industrial processes for making metals, mineral acids, lime, fertilizers, cement, etc. used as raw materials inorganic ores and mineral deposits formed by geophysical processes near the surface of the earth. Early natural products were derived from plants and animals, some especially cultivated and harvested as particular raw materials for fiber, fuel, soap, dyes, drugs, and even food. The need for a purer carbon fuel for the higher temperatures required for iron ore smelting (and unknowingly also for the agent to chemically reduce the ore) led to the pyrolysis first of wood to produce charcoal and later of coal to produce coke. Both of these pyrolysis processes produced by-products (pyroligneous acid in the case of charcoal and coal tar in the case of coke). These at first were nuisance waste products, but finding reactions to convert them into useful substances gave birth to the industrial organic chemical industry. Early chemical products from plants and wood included methanol, ethanol, acetic acid, acetone, butanol, and cellulosic polymers. Early chemical products from coal tars included aromatics, phenolics, and dyes, and from coke carbon monoxide and hydrogen, and from lime and coke acetylene. In fact, in the early twentieth century, acetylene was poised to be the principal building block of industrial organic chemistry and much chemistry was developed from that starting point.

Also in the early part of the century, the popularity of the automobile drove an increased demand for gasoline. Petroleum kerosene had already replaced whale oil for illumination, and specialized chemical processing facilities called refineries were being built to supply the increasing demand for gasoline and diesel fuel. Natural gas, which was usually associated with coal seams and considered a hazardous nuisance, was also being coproduced in some oil fields. Pipelines were built to transport the lightest component, methane, to urban areas for clean household heating and cooking displacing coal while the heavier propane and butane components were liquefied and trucked for the same purpose in less densely populated rural areas. Also a technique called steam reforming was developed to turn methane into carbon monoxide and hydrogen. Within refineries new chemistries called cracking were used to break larger molecule heavier fractions in crude oil into smaller molecules in the gasoline range, and a special catalyst was developed to produce aromatics from crude which were needed for very high octane aviation gasoline.

Of all the components in natural gas and of the lightest molecules found in crude oil, ethane had virtually no known uses and no value. However chemists discovered that a variant of cracking technology called steam cracking not considered useful in refineries as it produced olefins which tended to foul carburetors could be applied to ethane to produce ethylene which was the monomer for the newly discovered synthetic polymer polyethylene. It was also discovered under what reaction conditions ethylene could make most of the products that acetylene could. Within a short period of time, other synthetic polymers were developed from ethylene-derived monomers like polystyrene, polyvinylacetate, and polyvinylchloride and from similar propylene (also produced in crackers) derived monomers including polypropylene, polyacrylonitrile, and polyacrylates. Thus within a short period of time, methane from natural gas, ethylene from steam crackers, and benzene, toluene, and xylene aromatics from refinery reformers became the principal building blocks for the industrial organic chemical industry almost completely displacing wood, coal tar, acetylene, and the reaction paths starting from them.

This is a feature of the chemical manufacturing industry. Raw materials of choice change from time to time depending on availability, price, and technology. The organic chemical industry is about one-twentieth the size of the fuel industry, and at the present moment the favored raw materials are essentially minor by-products from that industry. A few years ago there was concern that natural gas and crude oil were nearly exhausted and chemists returned their attention to more abundant coal as a possible alternative source material for chemicals and biomass as a source for ethanol fuel. However, even more recently with the development of extraction technologies for both gas and oil from shale deposits, it appears that methane, ethylene, and aromatics will remain advantaged feedstocks for industrial chemistry some decades to come until the next developments.

The purpose of industrial chemistry is manufacture. Manufacture introduces new objectives in addition to chemical identity including fitness for use, consistency, economics, reliability, health and safety, environmental protection, and social responsibility. All of these objectives play a role in what chemical reaction paths are ultimately selected for industrial implementation.