

As we dig our heels into the 21st century...

Where is the Chemical Engineering Industry Headed?

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The chemical enterprise is already global — a trend that is almost certain to continue. What does this trend mean for the chemical engineering profession and for the practicing professional?

The answer to the question posed above reveals itself through the chemical enterprise. With over 70,000 products in its portfolio and global sales exceeding \$2.2 trillion/yr, the chemical industry is large and lucrative (1). Globally, it employs approximately 10 million people, enables indirect employment of over 50 million people and, according to the Bureau of Labor Statistics (BLS; Washington, DC; www.bls.gov), has a domestic industrial population of engineers that is 31,000 strong (slightly more than 2% of the 1.4 million engineers working in the U.S. today are chemical engineers).

While the enterprise is global, its market distribution (measured by sales volume) is dominated by three regions. The single largest market is Europe with 38%, followed by Asia Pacific with 28%, and North America with 25%, leaving just 9% for the rest of the world. China accounts for 13% of the global market, and is the fastest growing segment today. Of the 39 mega cities around the world today, each of which has a population of more than 5 million, 23 of them are in Asia. It is therefore not surprising that the highest growth rates in chemical consumption during the last ten years were in Singapore (+13.6%) and China (+12.4%), according to Alfred Oberholz, chairman of DECHEMA e.V. (www.dechema.de). Between now and 2010, chemical consumption will increase by 7%/yr in Asia compared to only 2.5%/yr in Europe.

On the production side, the global distribution of manufacturing sites has fluctuated noticeably, especially in the recent years, while the total number of new, large chemical plants has remained fairly constant — in the range of 300-400 new projects per year. Figure 1 shows the increasing globalized nature of the chemical industry through the geographical distribution of new plants (2). Comparing 2005 to 2000, the

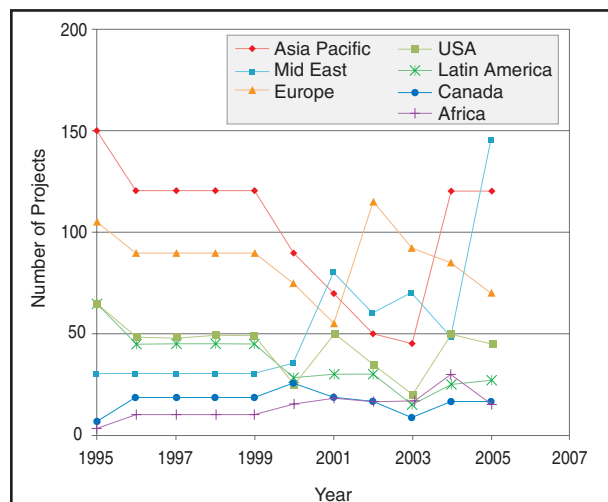


Figure 1. Location of new chemical plants.

sharpest increases in number of new plant projects have occurred in Asia Pacific (up 33%) and in the Middle East (up 314%) — clearly, the industry is migrating to regions with the fastest growing markets and/or with proximity to petroleum feedstock — a strong global trend that is almost certain to continue.

So what does this all mean? It seems unavoidable that the profession must mirror this globalization development. But it's not just this geographic change to which the profession must adapt. In recent years, many new industries have come to appreciate the need for process engineering and have realized the potential benefits to new products of molecular engineering coupled with multiscale analysis and process design. This leads naturally to the broad range of interactions between and among chemical engineering and essentially all other engineering and science disciplines. Hence, there is a need for well-educated, well-rounded chemical engineers, who are depicted

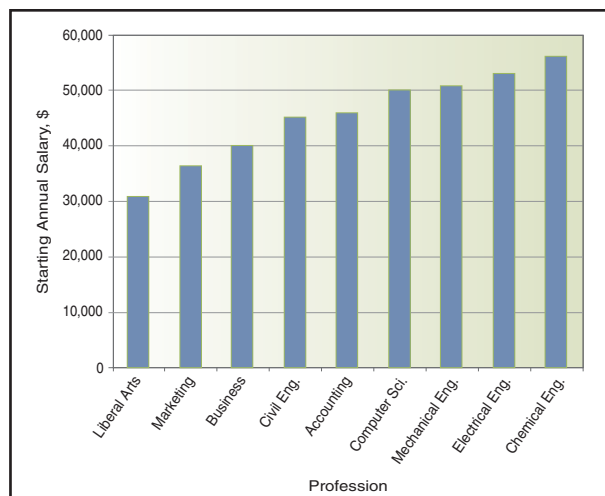
as “the successful chemical engineers of tomorrow.” These are the individuals who have obtained an education at the best international level, and then pursued the profession globally, as needs and opportunities arise. The usual past experience of life-long careers in the country of one’s origin and/or education will be replaced by this new paradigm.

This has been occurring in recent years, though we lack firm data to document the trend. A hint of this can be seen in the results of a survey conducted in 2004 by the World Chemical Engineering Council (WCEC; www.chemengworld.org) on chemical engineers with at least 5 years of practical/industrial experience. The survey indicates which nations have a more “globalized” approach to the chemical engineering profession (3). The data represent the percentages of individuals who work abroad, based on responses from 63 different nations. In China, Mexico and the U.S., less than 3% of young chemical engineers work abroad; whereas in Australia and France, the numbers are 16% and 23%, respectively; and in the U.K. and Germany, 7-8%, work abroad. It seems that the practice of chemical engineering is already global for many young professionals.

Another sign of the times is the industries into which chemical engineers find their way. Traditionally, chemical process and oil/gas industries have been the major employers. In recent decades, increased emphasis on life sciences has highlighted biological, medical, and pharmaceutical firms as good opportunities for young chemical engineers. This trend has gained much attention, to the extent that over 18% of the chemical engineering departments at U.S. universities have altered their names to include the “bio” term — *e.g.*, “chemical engineering and biotechnology,” — and many more have increased bio subjects in their curriculum. It is interesting to compare this expectation with actual employment data.

In a 2005 survey conducted by AIChE, the three dominant industries where chemical engineers are employed are still the traditional ones of chemicals, engineering, and oil/gas, which together employ almost half (45%) of all chemical engineers (4). The combined employment in pharmaceutical, biological and medical industries totals 12.8%, almost equal to that of the oil and gas industry. Another combination of note is the broader “energy” sector — the sum for the oil/gas, energy, and half of the engineering industries, which comes to 25%.

Market forces indicate that the chemical industry has a high regard for the chemical engineering profession. The National Association of Colleges and Employers (NACE; www.nacweb.org) posted chemi-

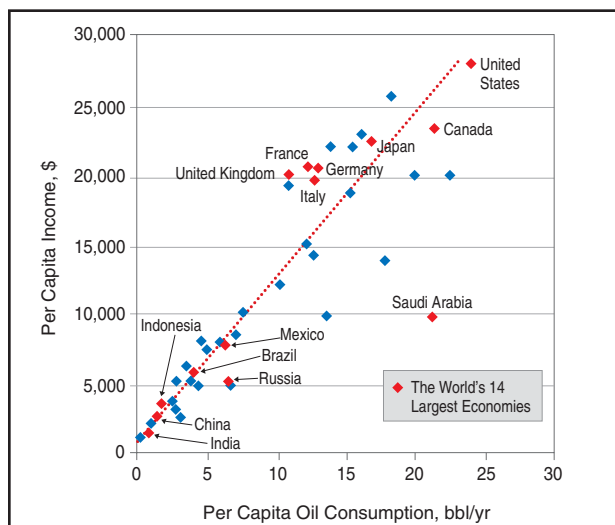


■ Figure 2. Starting salaries in the U.S. for various professions from NACE (5).

cal engineers’ starting salaries at \$56,335/yr, up 4.7% compared to last year, and roughly \$3,000 higher than that of the second highest-paying engineering disciplines, electrical and mechanical engineering (Figure 2). Petroleum and coal products manufacturers (which made the largest number of offers to chemical engineers) paid top dollar — an average \$58,456/yr.

The industry often looks to the Engineering Workforce Commission’s (EWC; www.ewc-online.org) salary survey, which breaks out the salaries of each engineering discipline according to degree, experience, level of responsibility, geographic location, and more. According to the latest data reported, chemical engineers earn a discipline-leading \$79,230/yr. This salary leadership status prevails throughout their careers, and chemical engineers typically average higher salaries than their counterparts in other engineering disciplines. The top paying industries for this occupation are reported by the BLS as scientific research and development services (\$88,670); management of companies and enterprises (\$84,280) and petroleum and coal products manufacturing (\$83,440) (5).

While we face geographic and technical challenges, the chemical engineering profession remains strong, well regarded, well compensated and in demand. But, when we think about the future of the profession, it helps to examine more than the current state. It is important to take a look at the past, specifically to identify the core developments that collectively define the field. Where the core technology will go in the future is anyone’s guess. Biotechnology, nanotechnology, microtechnology and the exploitation of new energy and raw material sources are some of the key sectors that are driving innovation in the industry. Process intensification, biorefineries, water recycling and gas-to-liquid technologies are also attracting a



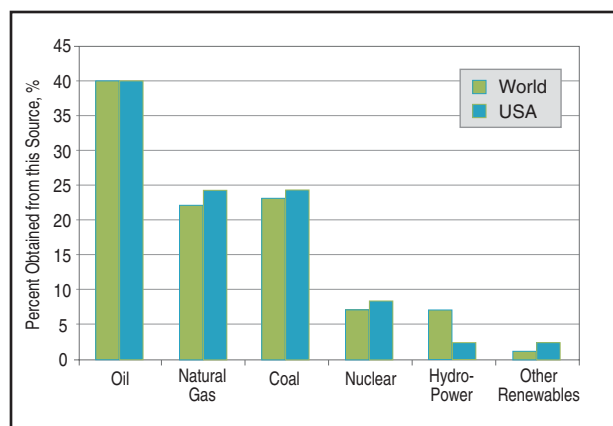
■ Figure 3. Correlation between per capita income and energy consumption (6).

good deal of interest.

But, by and large, ensuring the security of raw material supplies, increasing energy efficiency and reducing the environmental impact of products and processes are the primary challenges that we will face in the future.

The transition from fossil raw materials to renewables will be one of our biggest missions for the next 50 years. Without fulfilling this basic need, other innovative technologies will not be brought to fruition (e.g., energy for water purification systems in third-world countries). The search for alternatives to the fossil-based economy will not be limited to fuels that give us mobility and energy. Renewable raw materials are also at stake.

There is a strong correlation between nations' energy usage (as reflected by oil consumption) to per-capita income (PCI; a reasonable measure of average quality of life), as depicted in Figure 3. The inverse derivative of the curve is ~0.8 bbl/yr oil consumption increase for every \$1,000 improvement in income, per capita. To a large extent, the driving force of countries moving up the curve is what leads to the anticipated large increase in world energy demand. For example, more recent data show China's PCI at \$5,300 and increasing at rate of 7–9% annually. This extrapolates to a PCI of \$11,400 by 2015, with a corresponding increase in oil consumption to ~9.5 bbl/yr, per capita. Even without a net increase in its population of 1.3 billion, China's need for oil by 2015 would be roughly 12 billion bbl/yr, or 33 million bbl/d. A similar scenario exists for India, the population of which is expected to exceed that of China by 2030. This increase in oil consumption is startling when compared to the current



■ Figure 4. Sources of primary energy for U.S. and the world (6, 7).

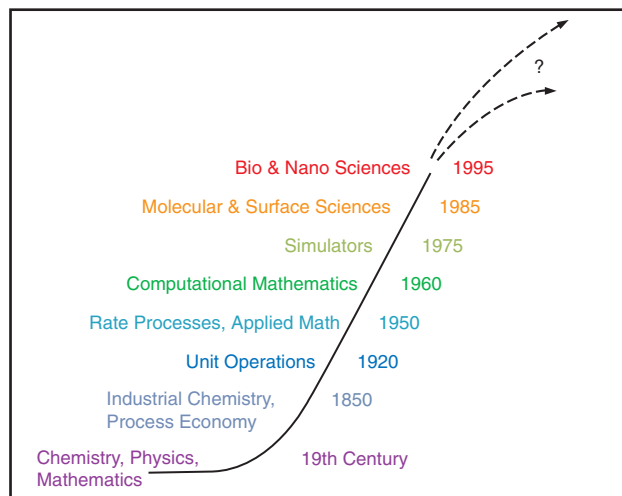
world oil production of ~79 million bbl/d.

Currently, oil and natural gas supply 62% of the world's energy, and together with coal, feed 85% of this demand (Figure 4). All other sources, including hydropower, nuclear energy and renewable resources, contribute the balance of 15%. The luxury of reliance on readily available fossil fuels can last only for a limited number of decades. With fossil fuel usage at current rates, oil reserves will last 35 years; at projected usage, these oil reserves will last 25 years. Natural gas reserves will last 60 years at our current usage, but only 45 years at the projected rate. Coal will last 400 years at our current usage; data are not available for projected usage (6).

Part of the energy problem is its enormous scale. Consider this — from 2000 to 2050 the world demand for energy will increase 1,500 quads/yr (1 quad = 10^{15} Btu) (7). Most of the increase is tied to improvements in living standard and population growth in Asia, Africa and Latin America. If we continue to use 33% of our supply to produce electricity, an additional 12 terawatts of generating capacity would be needed by 2050. If 33% of this additional energy were to be derived from nuclear reactors, then 3,300 nuclear power plants at 1,200 MW each would have to be built worldwide — that is an average of 67 plants/yr over the next 50 years.

Complicating matters further is the concern for environmental sustainability. Take the issue of CO₂ emissions and its contribution to global warming. Presently, CO₂ concentration in the atmosphere is approximately 360 ppm, which represents 1.5×10^{15} lb of carbon. If the recoverable fossil fuels, such as oil, coal and gas were to be combusted without hindering the release of CO₂, roughly 2.2×10^{15} lb of carbon would be added to the atmosphere — more than doubling the current concentration (8).

To prevent this scenario, the U.S. Dept. of Energy's



■ Figure 5. Major developments in chemical engineering technology.

(DOE; www.doe.gov) FutureGen program is underway. It involves the gasification of coal, followed by water/gas shift reaction and H_2/CO_2 separation. CO_2 is sequestered and H_2 is used as the product fuel in energy conversion devices (e.g., combustors, fuel cells, etc.). Much detailed technology needs to be developed, proven, and implemented for such systems.

The above discussion leads to the conclusion that the intertwined objective of satisfying the world's energy requirement and maintaining environmental sustainability is a huge and complex challenge. The technological solution of FutureGen obviously requires the traditional expertise of the chemical engineering profession. But, what about other societal needs and other potential technical solutions; would the chemical engineering profession be pertinent? While impossible to completely predict future developments, one can postulate that the challenges and potential solutions are unavoidably complex and multi-scaled. How does our profession measure up against these needs?

Indeed, chemical engineering is well suited to take on such challenges. Engineering approaches will need to be flexible and able to build upon scientific discoveries from all fields. And, the curriculum must engage students in the subject matter of chemical engineering and its use, and cultivate along the way that mix of attributes that characterizes the engineer. To accomplish these goals we envision a four-year structure that emphasizes the qualities of a global chemical engineer.

The evolution of chemical engineering is punctuated by technological landmark events, such as the 1985 biotechnology and biomedical infusion; the 1992 proliferation of personal computing and communications, including microelectronics, sensors, advanced computing; and the 2000 nanotechnology revolution (Figure 5). These waves have been cumulative, increasingly globalized, driving chemical engineering from macroscopic

towards microscopic, to nano-scale, and eventually to molecular dimensions. "Chemical engineers have a much different responsibility, namely, the discovery and implementation of new products and processes that are useful and economical. Sometimes, in the previous five decades of pursuit of chemical engineering science, we have forgotten this central aspect of our charter and at times become excessively preoccupied with scientific questions, out of proportion to the significance of these questions to the applied goals of the profession." These were the words of James E. Bailey, a chemical engineering visionary.

Bailey's historical caveat to chemical engineers was that our profession will condemn itself to a perpetual supporting role, and one that assumes less and less significance in a highly dispersed process industry producing high-value products, if we restrict our efforts to improving existing technologies and scaling-up laboratory developments. His words capture the essence of what the chemical engineer's role in this progressively global enterprise. "Particularly in the era already upon us, which rapidly creates new product and process possibilities, chemical engineering can only justify its place as a premier engineering profession by actively engaging not only in the synthesis of known knowledge, but also in the creation of new technology. We must seek a new and more constructive balance of analysis, synthesis and invention in order to achieve the greatest success for our profession and for society in the 21st century.

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