

A LOOK BACK AT THE AMUNDSON REPORT

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Abstract

The Amundson Report, published in 1988, emphasizes the need for chemical engineering research to make significant efforts in what is referred to as the frontier areas (new and emerging areas of investigation). At the same time, the Report does not fail to re-establish the importance of continuing research in what is called the core areas (the fundamental topics of chemical engineering). It is shown that much of the suggestions made by the Report are taken seriously by the chemical engineering community. Nonetheless, some data indicate that though the overall chemical industry is making tremendous profits, areas such as education and employment still have concerns that need to be addressed. Overall, the chemical engineering discipline is a profession with vitality, innovation, and robustness. All present indications point to chemical engineering having the staying power to contribute to the nation's future and well being.

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The Amundson Report, formally known as ‘Frontiers in Chemical Engineering: Research Needs and Opportunities’, is originally published in 1988 by the National Research Council. The Report is showcased at the 1987 National Meeting of the American Institute of Chemical Engineers in New York City. Though the Report is sponsored by a variety of organizations (American Chemical Society, the American Institute of Chemical Engineers, the Council for Chemical Research, Inc., the U.S. Department of Energy, etc) and is written by a committee made up of many individuals from both industry and academia; the chairman of the overall project is Neal Amundson, who is then and now a professor of chemical engineering at the University of Houston. For this reason, the report is known as the Amundson Report.

The Report investigates opportunities for research at the frontiers of chemical engineering. Research at the frontiers, the Report alleges, is necessary to keep the discipline alive and vigorous; not only for its survival as a field of study, but also such that it is capable of stepping up to meet the challenges of the future. In addition to research at the frontiers, research in the core areas is also emphasized. The Report claims that the chemical industry is an extremely profitable sector of the national economy. Thus, continued research in existing areas is required to take advantage of the powerful economic advantage the chemical industry has in the world economy.

This work intends to make an analysis of the state of the chemical engineering discipline since the release of the Amundson Report. Criticisms of the Report by the chemical engineering community are also addressed. The positive effects of the Report on chemical engineering research are reviewed. Finally, the state of the chemical industry is analyzed using the latest economic data. The evidence shows that the Amundson Report is well received by the chemical engineering community. And though much of the Report's suggestions are followed, the economic data reveals some disturbing trends – to be discussed later in detail. Nevertheless, for the most part, chemical engineering is strong enough to weather any storm in the conceivable future and is certainly capable of thriving for many years to come.

THE AMUNDSON REPORT

The Amundson Report is, without a doubt, a body of work that makes recommendations for leading edge research, primarily in the area of chemical engineering, with the sole purpose of keeping the discipline current and viable for the future. The intention is to create more opportunities for chemical engineers as the state of the world economy changes. Specifically, the core principles of the chemical engineering practice are applicable to new and emerging fields. Chemical engineering must make itself available to novel areas of technology and science by applying chemical engineering principles to frontier areas in the form of ground breaking research. Research leads to application, and likewise, the employment of chemical engineers in these emerging disciplines.

It is important to note that the Amundson Report does not suggest a complete revamping of the chemical engineering curriculum. Rather, the Report maintains that subjects such as transport phenomenon, thermodynamics, and kinetics are still the core of chemical engineering

education. That is, chemical engineers are still concerned with heat and mass balances, application of the first and second law of thermodynamics, and the prediction of chemical reaction rates. What must change are the types of applications to which these subjects are applied. Amundson calls this changing the “flavor” of the curriculum.

“While the report does not lay out a detailed, new curriculum for chemical engineering, it points out that the changes needed are more in the nature of highlighting new applications as part of the fundamentals currently at the heart of the curriculum. The changes should be in flavor and point of view, focusing on different production scales and product chemistries and new product development.” (Chemical Engineering Progress, 1987).

“Amundson insists that the basic nature of chemical engineering will not change much, ‘but its flavor must change.’ In the past, he says, ‘we have prepared graduates as if they all were going to work for the Du Pont Co. In the future, that will have to change, for the market will require that students be trained more broadly. This may require, in some cases, options at the undergraduate level and a change in the kinds of applications and problems in the standard courses undergraduates are offered’.” (Caruana, 1987)

Amundson’s recommendations for chemical engineering education are summarized by a few distinct points:

- The core of chemical engineering must stay the same, only the “flavor” must change.
- Design courses must steer away from the traditional ammonia type projects and incorporate applications in the frontier areas.
- Interdisciplinary or multidisciplinary study must be enhanced. The goal is to obtain broad knowledge for the student since frontier areas require understanding from a wide span of disciplines.
- Recruitment of new faculty whose strengths are in the frontier areas. They are to serve in teaching new applications for chemical engineering principles and spearhead research in the frontier areas.

Having made it clear that chemical engineering education is to remain essentially unchanged, it is important to note that the main focus of the Amundson Report is research. The Report intends to explore the application of chemical engineering principles to emerging areas of study and technology. It is aimed primarily at research agencies in the government and private industry. The Report hopes to generate interest in government and corporations for funding projects that are at the frontiers of chemical engineering research. The goal is to increase research activity in the frontier areas, develop new technologies, and literally “beat a new path” for the future of the chemical engineering profession. In essence, new research creates new opportunities for chemical engineering graduates.

“The report stresses chemical engineering research in those areas where chemical reactions play a significant role. Since chemical engineers are the only engineers who have a knowledge of chemistry, that is an advantage that the Amundson Report believes should be exploited to the fullest change has always been necessary for the growth and good health of the profession. What is important is to anticipate the nature of the change so that the necessary support can be marshaled from industry, academic circles, and government.” (Chemical Engineering Progress, 1987)

“For the young academic chemical engineers starting their careers, Amundson hopes the report will serve as a guide for pertinent research. ‘For funders, of course, the report should serve as a guide on where they should place their bets To make the United States more competitive in the industrial scene, the people who can enable research to be carried on – congressmen and legislators – need to be convinced that tax credits and other incentives for research expenditures should be allowed and more money for academic research should be

authorized’.” (Caruana, 1987)

The Amundson Report makes suggestions in four distinct areas of chemical engineering research (Chemical Engineering Progress, 1987):

- New Technologies – biotechnology (biology, biochemistry, molecular biology, biomedical devices) and materials (ceramics, polymers, composites, superconductors).
- Established Technologies – continue research in areas of energy, gasification, minerals, liquid fuels.
- Environmental Protection – this refers, of course, to the treatment and disposal of pollution and waste products; but also includes safety (emergency relief systems, risk analysis, etc.).
- Computers and Process Technology – specifically process simulation, catalysis, and interfacial science (coatings, films, adhesives, etc)

GIANNI ASTARITA

Shortly after the release of the Amundson Report, Gianni Astarita publishes an article entitled, “Frontiers in Chemical Engineering and 1992”. (Astarita, 1990) This work is a scathing criticism of the Amundson Report. Essentially, Astarita claims that by pursuing the frontier areas of chemical engineering with such vigor, chemical engineering loses its focus on the core areas. He predicts that such activity makes chemical engineering a hollow shell of a discipline that may lead to its demise.

It is important to note that the criticisms which Astarita makes are understood properly only in light of his European background. This point is highlighted because Astarita alludes to this fact himself, “As a European relying on 3,000 years of cynicism”. (Astarita, 1990) Once his viewpoint is examined, based on his European roots, one finds that Astarita is mainly condemning the American university research system, and not so much the Amundson Report. To do this, first one must look at the historical and cultural foundation of his statements.

The European Backdrop

To understand European culture, one has to take into account the history of that continent. Though Europe is much different from 3,000 years ago, the present culture cannot be understood in a vacuum that excludes its historical realities.

In the centuries after the fall of the Roman Empire, Europe builds its culture based on values handed down from Rome and ancient Greece. Greek philosophy is the foundation of Christian theology. The Church adopts Latin as its official language and builds its organizational structure on the Roman model of government.

In those early centuries, Church is the guardian of education. Latin is the language of learning. The Church is linked to the monarchy; and the Church approves the appointment of kings and presides over royal weddings. The cultural, political, and religious elites are taught at monasteries or religious centers – the forerunners of today’s universities.

George M. Marsden, in his book, “The Soul of the American University”, makes this vividly clear. “Christian scholars, who earlier had been situated primarily at cathedral schools, established themselves in the twelfth century as self-governing guilds. They were licensed by the pope to grant degrees, meaning that only they could determine who was qualified to be a master, or teacher. Despite the major achievement of some autonomy, these scholars’ guilds or universities were ultimately under the control of the church. Masters had to take holy orders as clerics and hence were subject to church control. Their conduct could be a matter of church concern and, very important, their teachings could be condemned.” (Marsden, 1994)

Marsden continues, “Latin and Greek were the very languages of education. All the

practical elements (the trivium of grammar, rhetoric and logic and the quadrivium of arithmetic, music, geometry, and astronomy) had been established by the ancients.” It is essential to note that the trivium and quadrivium are the basic elements of the Liberal Arts. The Liberal Arts are central to early European education and still are today in some places. The point to underscore, however, is that the goal of the Liberal Arts is to improve the quality of living through broad understanding of many subjects; rather than make an individual more employable by emphasizing long, focused study in a narrow discipline. Implicit in the Liberal Arts is the importance of concentrating on fundamentals like reading and writing (core areas), as opposed to computer aided design or wireless networking technology (frontier areas).

The European Communist Block

It is highly possible that as Astarita sits down to write his article, Europe is still under the shadow of the Communist Block and the Iron Curtain. Though Eastern Europe is communist, the ties with the West are not broken. England makes a good sum of money by building chemical plants in the USSR. East Germany never loses its identity with West Germany. Poland remains very Catholic and ultimately breaks free from Soviet control with help from the Pope. The United States under the Reagan Administration ships huge quantities of American grain to the USSR.

It should be noted that most of free Europe is socialist at the time Astarita writes his article. Socialism is sort of a midpoint between pure capitalism and communism. Socialism is akin to communism in that it promotes government sponsored education and health care, but allows the individual to engage in capitalistic enterprise (at a very high tax margin). Understanding this is even harder when one considers that some socialistic systems have monarchs and others do not. Nevertheless, certainly there are shared values between the East and West during this time.

Another interesting note is that Astarita is not only European; but specifically, Italian. This is important because the greatest theorist and interpreter of Karl Marx is Antonio Gramsci. Gramsci is the founder of the communist party in Italy, 1921.

Malachi Martin in his book, “The Keys of This Blood”, describes Gramsci: “When Pope John Paul II reckons up the major forces against him and his Church in the millennium endgame, the geopolitical strength of Soviet-led world Communism at the end of the twentieth century rests in his view on the contributions of one man, who stands second only to Marx and Lenin. The historic events that have been gathering momentum since the end of World War II, and that have reached a pitch of euphoric fever at the opening of the 1990s, have proved Antonio Gramsci the worthiest, the most farsighted and, in practical terms, the most successful of all the interpreters of Karl Marx.” (Martin, 1990)

Another interesting bit of information is that Communism has a fair degree of success in Italy. The Italian communist party has a history of winning a significant number of seats in parliament. The party captures a large percentage of total votes in national elections since its creation. Italy is even the first Western European country to elect a former communist to head of state, Massimo D'Alema, 1997.

It is now time to look at what is at the core of communist ideology. At the core of communism, is a disdain for what is at the core of capitalism: money. The communist message is centered on becoming free from a capitalistic system where professions are measured in terms of money. Communism, in fact, sees Capitalism as translating all aspects of life into money – all being forced to bow down and worship the money God.

T. Z. Lavine, in the book, “From Socrates to Sartre”, describes the communist view point in stunning color: “The bourgeoisie, these ‘leaders of whole industrial armies,’ have changed the

face of human life by destroying the traditional hierarchical and patriarchal human relationships of feudalism, leaving no other relationship 'between man and man and the naked self-interest, than callous cash payment'. Capitalism has destroyed the feudal aristocratic culture, it has drowned its religious piety, its chivalry, its sentimentalism in the 'icy waters of egotistical calculation'.” Lavine adds, “Capitalism, says Marx, has stripped the halo from every profession which had been previously honored – physician, lawyer, priest, poet, scientist – and made their practitioners into wage laborers.” (Lavine, 1994)

Lavine’s statements, regarding money and wage laborers, lead perfectly into Astarita’s criticism of the Amundson Report.

Astarita’s Objections to the Amundson Report

Astarita opens the discussion with what is in actuality a condemnation of the American university research system as a whole – not really a condemnation of the Amundson Report. Astarita points out that the entire American university research system is focused on money: money for research, money for the university, soft money for the investigator, money for promotion in the professorial ranks, and money making opportunities for students when they graduate.

He describes how professors have become slaves to the “almighty dollar”. Scholarship has fallen by the way-side. Researchers are pressured to pursue trendy, novel, and sometimes superficial areas of research for the sake of attracting grant money. Concepts and scientific principles are no longer in vogue. Rather, the goal is to market ones research in the best possible light to win funding in the celebrated research field of the day.

“A good portion of academic life is spent writing research proposals; there is incredible pressure to bring in money by any conceivable means, and how much money one does bring in is an important criterion in promotion discussions (even if not openly acknowledged). In many schools, a sizable percentage of every salary is based on soft money, and the pressure to generate that money is not only a question of advancement but of survival; the success or failure of a research program is based on monetary terms, not on educational values. Engineering schools are regarded often by administrators as money-making institutions that should contribute to general university welfare because they are able to do so. Forget about scholarship and related values; those are things that the humanities are supposed to cultivate.” (Astarita, 1990)

Astarita continues, “Thirty years ago, chemical engineers were contributing concepts, not solutions to problems trivial enough to have a fair chance of being funded before the solution is found. Contributing concepts comes from research efforts that are more than occasionally totally fruitless, which does not go over well with funding agencies.”

“The abstracts of many of the theses sound something like ‘I have done with rhenium what previously had been done with palladium.’ That result may be quite useful to the sponsoring industries, but it hardly contributes anything to the education of the graduate students. In the meantime, their advisor is so busy writing proposals, traveling to Washington to lobby for them, and keeping good public relations with industrial sponsors that he or she has no time left for the task of teaching something to the graduate students (let alone be inspired by them into some intellectual endeavor or vice versa). But everyone is perfectly happy with the situation: the department sees good money coming in and the dean is happy about the overhead, as are the provost and the president; the graduate students know that they have a good chance of entering academia because they are in a money making area, and that is all that matters. If not interested in an academic career, they know they’ll have good industrial opportunities because they know how to use the latest fluorescence apparatus (and how many people are there who can do that?). They are even spared the painful experience of producing one original thought.”

These comments by Astarita must be interpreted in the context of his European roots. He comes from an educational culture that has its roots steeped in antiquity. The Liberal Arts focus on fundamentals like reading, writing, and arithmetic. Astarita believes that the fundamental duty of a university is to educate, not pursue research dollars. The Liberal Arts is concerned with teaching concepts, not vocational arts. Astarita emphasizes that the university's role is to focus on teaching fundamentals and concepts, even if they are engineering fundamentals and concepts; this applies to the classroom and the research laboratory as well (since research is a form of teaching).

In all of Astarita's comments, there can be no doubt that there is a slight hint of resentment as regards the engineering teaching profession being reduced to a commodity – defined solely in monetary terms. He is certainly a part of that European culture that believes there is more to life than just money. That honor, duty, social responsibility, teaching, and knowledge have their intrinsic value outside of money and that somehow they are all intertwined. A person is still defined by what he does, and not necessarily on how much money he makes

Astarita makes this clear by quoting Albert Einstein: “Engineering science cannot be pursued under the pressure of bringing in money; to quote Albert Einstein (referring to his years as an employee of the Swiss Patent Office), ‘A practical profession is a salvation for a man of my type; an academic career compels a young man to scientific production, and only strong characters can resist the temptation of superficial analysis.’ Unfortunately, there just aren’t enough strong characters around, particularly when so much time is spent writing proposals and quarterly reports that one is lucky if there is a enough time left over for even superficial analysis.”

He also quotes Humphry Davy: “When he invented the mine safety lamp, Humphry Davy refused to patent it because, in the words of S. Ruben, he ‘believed that the duty of men of science was to contribute their discoveries to the benefit of mankind.’ Today, Davy would be fired by any ‘right-thinking’ department of engineering.”

This leads nicely into an examination of Astarita's exact criticisms regarding the Amundson Report. Remember that Astarita is European and he holds true to his European roots – the adherence to engineering fundamentals, and the commitment to core areas in a university teaching/research system.

Firstly, Astarita acknowledges that the Amundson Report is in favor of maintaining a fidelity to preserving the chemical engineering core areas in the university. The problem is that the Amundson Report is stressing frontier areas, not core areas. Thus, in the present research environment, the core areas are doomed since there is no money for them. Money is absolutely essential to any university research program, as has been previously described. However, since the Amundson Report emphasizes funding in the frontier areas that leaves the core areas to wither since no right minded researcher is to put energy into a field that does not yield funding.

Secondly, Astarita again agrees that the Amundson Report is in favor keeping the core curriculum in chemical engineering intact – heat and mass balances, thermodynamics, transport phenomenon. The problem is that the Report promotes the substantial hiring of faculty that have expertise in the frontier areas. Astarita claims that a mechanism is required to specifically protect the core areas, especially when new faculty is hired who bring new subjects of study in the frontier areas. Without a specific mechanism to preserve the core areas, the frontier areas stand a chance of superceding them.

Thirdly, since the Amundson Report is in favor of pouring money into the frontier areas, the drive to hire new faculty in the frontier areas is surely to be based on the money that can be derived from these trendy research specialties. Scholarship and ability takes a secondary place to

the prerequisite of securing research funds. “. . . this means that people will be hired not because of how good they are but because of the subject they are interested in; the average quality of faculty is thus bound to go down, if perhaps only marginally.” (Astarita, 1990)

Fourthly, since most of the money and attention is going to frontier areas, no right minded student wants to study core areas. Thus, in the future, the core areas suffer because no one is around to study and teach those areas. Astarita adds, “Specialists in frontier areas will be poor teachers of core courses because they matured in an atmosphere where expertise in the core area was seen as the kiss of death”.

Astarita closes his article with a haunting fact. He states that The European Federation of Chemical Engineering (EFChE) conducted its own report and came to completely opposite conclusions as did the Amundson Report. The EFChE recommends concentrating research on core areas, not frontier areas. In light of the European tradition, it is not a surprise that the EFChE supports the promotion of fundamentals.

“Starting with the same data that lead to the Amundson report, the EFChE reached a quite different conclusion: in order to efficiently continue to work in the frontier areas, one needs to strengthen research and teaching in the core areas. The argument is that the concepts developed in the core areas form the basis for working in both existing and future frontier areas.” (Astarita, 1990)

THE AFTERMATH

Looking at the state of chemical engineering and the chemical industry in 2004, one must conclude that the Amundson report is taken seriously. At the time of the Amundson report, and even before, departments around the country steadily increase the representation of researchers in the area of biological science and engineering. The announcements for new positions in the area of biochemical engineering proliferate throughout the nation's chemical engineering departments in the 80s and 90s. Recalling a private conversation, while a graduate student in the mid-80s, a professor comments that the department is getting a new faculty member: “He is our Bio-Man . . . I guess every department has to have one of them these days”.

Research in the 80s, 90s, and beyond certainly follow the spirit of the Amundson Report, if perhaps unconsciously. Now it is time to review the state of chemical engineering in academia and industry; and determine how the Amundson Report affects them. The following discussion is an analysis of the state of chemical engineering research and the chemical industry in light of the Amundson Report's recommendations.

Research in Core and Frontier Areas

The proceeding is a summation derived from 20 years of observation within the chemical industry. These observations are collected from several different reference points: student, researcher, practicing engineer, technical writer and professor. They are by no means complete nor all encompassing; rather they serve simply as highlighted examples of how research in the chemical engineering discipline incorporates the suggestions made by the Amundson Report.

- **The Design Institute for Emergency Relief Systems (DIERS)** DIERS is a users group sponsored by AIChE. It has its origins in the 1970s and the research is funded primarily by chemical corporations. However, around 1990, the chemical industry faces a wave of new regulations addressing the environment and occupational safety. The Houston section of AIChE responds by holding the 1992 Process Plant Safety Symposium to address concerns brewing in the chemical industry as relate to the new regulations. At this tremendously successful event, members of the DIERS community showcase their research to a very receptive audience. Companies around the country start applying

DIERS technology to their new and existing designs, particularly in the area of 2-phase pressure relief systems. In 1992, DIERS publishes the 538 page handbook: "Emergency Relief System Design Using DIERS Technology". Today, DIERS continues to do research in the field of emergency relief systems: flow characteristics, flow properties, computer modeling.

- **Supercritical Fluids** Supercritical fluids is an area of research that continues to attract investigators. Several major universities are presently doing work in this subject: University of Texas (Austin), Texas A&M University, University of Illinois (Chicago), and University of Connecticut, just to name a few. Supercritical fluids are valuable because they have the unique ability to absorb hydrocarbons with great propensity. Applications include pollution abatement, decaffeination, flavor extraction, and equipment fouling.
- **Fuel Cells** This is definitely one of the most notorious topics being discussed at research laboratories and conference hallways. Fuel cell research is highly focused on seeking alternative sources of energy for automobile power. The federal government expresses high interest in this research and indicates that fuel cell technology frees the US from dependence on foreign oil. Having attended presentations at Argonne National Laboratory, it is clear that Argonne is highly interested in the investigation of fuel cells. Research at Argonne is linked closely to the Department of Energy. Private discussions with researchers at Engelhard Corporation reveal that Engelhard is putting a significant amount of resources into the area of fuel cell research. They are particularly interested in how catalysts make fuel cell operation more efficient.
- **Mary K. O'Conner Process Safety Center** The Center, located on the campus of the Texas A&M University, is established in 1995. Current research includes review of the effectiveness of current safety regulation, the effect of aerosols on flames and explosions, vapor dispersion modeling, viscous 2-phase flow in relief systems, and runaway reactions. The Center also hosts a safety symposium every year. This conference is previously known as the Process Plant Safety Symposium.
- **Refinery Fouling Mitigation** Argonne National Laboratory is doing research in the area of refinery fouling. In 1998, Argonne hosts a workshop to discuss the future of refinery fouling research. Representatives from such organizations as Department of Energy, HTRI, University of Illinois (Chicago), Exxon, and Chemical Processing Magazine are in attendance. Research avenues include the use of supercritical fluids, antifouling chemical additives and reaction mechanisms to predict fouling. Today, Argonne continues this research and the results are often presented at AIChE conferences.
- **Bioengineering** It is no secret that bioengineering at Rice University is a vital area of research, even before the Amundson Report. Much of the support for research is spurred by the University's close proximity to the Houston Medical Center. Research at Rice progresses such that Bioengineering separates from the Department of Chemical Engineering to form its own academic department in 1996. Research areas include biochemical engineering, biotechnology, tissue engineering, and biomedical devices.

The State of the Chemical Industry

The purpose of the Amundson Report, as is mentioned earlier, is to secure the future of the chemical engineering profession by encouraging research in the core and frontier areas. In the words of Amundson himself, if "chemical engineering as an academic discipline is to prosper and not disappear as metallurgical engineering did 30 years ago, we must find new avenues of endeavor." (Caruana, 1987)

So the question begs to be asked, “How is the state of the chemical engineering profession?” An attempt to answer this question is made by looking at statistics describing various aspects of chemical engineering: education, industry, etc. As is shown above, the state of research looks very good. The discussion moves now to examine other factors that indicate whether chemical engineering is to go the way of metallurgical engineering.

- **Oil Prices** Traditionally, it is believed in the chemical industry that oil prices drive the market for chemical engineers in every way. Figure 1 is a plot of oil prices for West Texas Intermediate oil. Previous to 1973, oil prices can be described as “boring”. However starting in 1973, with the Arab Oil Embargo, oil prices are volatile and nearly unpredictable. The first energy crisis of 1973 corresponds with the embargo initiated by the Organization of Petroleum Exporting Countries (OPEC). OPEC stops selling any oil to countries that help Israel in the Yom Kippur War. The second oil crisis of 1979 is due to several factors: Iranian oil production hits a low due to an Iranian revolution that deposes the Shah, OPEC launches a series of oil price hikes, and the Iranian hostage crises forces the USA to place an embargo on Iranian oil. Prices get a boost when, Houstonian and former oilman, George Bush enters the presidency. Finally, oil prices surge in the face of Operation Iraqi Freedom. The key dates here to remember are 1973, 1979, 1989, 1993, 1996, 2000, 2001. Other industrial statistics are now presented and interpreted in light of these dates.
- **Chemical Employment** Before jumping into the employment data, an important point must be made. In 2003, the federal government changes the basis on which it compiles statistical data. Previous to 2003, the government uses the Standard Industrial Classification System (SIC). However, in 2003, the federal government changes to the North American Industry Classification System (NAICS). SIC data are revised to use the NAICS system; but only back to 1990. The problem is that one needs at least 30 years of data to properly observe business cycles. Therefore, this work only uses SIC data from 1972 to 2002, unless otherwise noted. The main difference between how the chemical industry is defined by SIC and NAICS is that NAICS transfers chemical managers and researchers out of the chemical industry and into “professional services”. William Storck in his article, “NAICS REDUX”, states, “This means that, according to BLS (Bureau of Labor Statistics), all sorts of managers, from company CEOs to branch office heads, no longer work in the chemical industry. And the industry, no longer employees research chemists. They now work in the professional and technical services industry”. (Storck, 2004)^a Though the differences between the two systems are not gigantic, they are big enough to make a significant difference, as Stock’s chart points out in his article. It is best to just stick with SIC and leave NAICS to a later time, when more data has been compiled. Such being the case, Figure 2 is a plot of chemical employment between 1972 and 2002. It is clear that chemical employment sky rockets during the periods of oil crisis in the 1970’s. The reason is that higher oil prices abroad favored oil production domestically. Domestic production creates domestic jobs. Furthermore, oil usually provides the feedstock for chemical production. Higher oil prices normally mean higher chemical prices. Higher prices generate higher revenues. Though this scenario may not necessarily flow in reality as is here indicated, it is the customary belief in the industry that higher prices for a chemical, take ethylene, means a bonanza. Thus, higher production levels, plant upgrades, expanded facilities, etc are necessary to capitalize on the favorable economic situation. As such, employment in the chemical industry is usually significantly increased, though the prospect of higher prices does not necessarily mean higher profits. Around 1981, OPEC can no longer keep prices elevated and so oil

prices began to fall and likewise so does domestic chemical employment. However there is a definite upward swing while George Bush is in the presidential office. After this period, chemical employment plummets. All indications from industry analysts point to the chemical industry having a continual decline in employment into the near future. William Storck, in his article, "Job Losses Forecast", says, "But if anyone thinks that an economic recovery will halt the contraction (of employment), the BLS has bad news: Total employment in the industry will continue to fall". (Storck, 2004)^b Nevertheless, if one takes a broad and objective look at Figure 2, one sees that on average the overall employment for the chemical industry really is not changed since 1972. Chemical employment averages 1.054 million. It can be argued that chemical employment is not really changed in 30 years. It has a down turn in the recent past but overall employment it is still in good shape.

- **Chemical Engineering Degrees Awarded** When viewing the statistics regarding the number of chemical engineering degrees awarded over the past 30 years, one must keep in mind that student interest in chemical engineering usually lags employment by 2 or 3 years. Figure 3 is a plot of the total number chemical engineering bachelor degrees awarded in the United States between 1972 to 2002. As oil prices rise in 1973 (Figure 1) and employment (Figure 2) rises to meet demand, the number of degrees in chemical engineering is slow to respond. It is not until 1977 that that number of chemical engineering graduates increases to meet the demands imposed by industry. Luckily, the second oil shortage of 1979 sustains chemical employment and accomadates the increase in chemical engineering graduates. Unfortunately, the number of chemical engineering degrees awarded hits an all time high in 1982 – exactly coinciding with the first year that chemical employment begins to see a definite decline. Oil prices are also falling from their all time high in 1980. Oil prices, chemical employment and degrees awarded all continue to fall for several years after 1982. During the period that former Texas oilman, George Bush, is in the presidential office, 1989-1993, oil prices and chemical employment both rebound nicely. But, as usual, it takes the educational sector time to respond. Degrees awarded do not start to increase until 1994. By that time, the "party" for chemical engineers in the chemical industry is over and done. In 1994, both oil prices and employment are falling significantly. In 1997, degrees awarded hit a high, while chemical employment continues to fall. Oil prices are falling also, but have an unusual spike in 1996. Nevertheless, shortly after this sudden high, oil prices continue their downward spiral and hit a 20 year low in 1998. The record indicates that in 2002 oil prices are rebounding to their former highs of the late 70s and early 80s. Degrees awarded appear to be moving upward in response to oil prices. Beyond 2002, it is predicted that employment continues to drop, as has been previously mentioned. Bethany Halford, in the article, "Chemical Engineering Education in Flux", states, "The oil crisis of the mid-1970s inspired many youngsters to study chemical engineering as a way to manage the nation's energy woes. That boom, in turn, led to a glut of chemical engineers, fewer job openings, and declining enrollment in the early 1990's". Halford adds, "When asked to attribute the enrollment slump to one particular factor, chemical engineering educators hesitate. For the past 30 years, they say, chemical engineering enrollment has never been on a constant upward or downward slope. Instead it tends to rise and fall sharply over the course of a decade". In the final analysis, its is safe to say that, for the most part, the quantity of degrees awarded in chemical engineering remains unchanged over 30 years. When inspecting Figure 3, one can see that the plot takes a rough sinusoidal pattern (assuming that the data for 1982 is a statistical anomaly). The number

of degrees awarded in chemical engineering do not deviate too far from 4742.4 over 30 years. The number of degrees awarded in 2002 is essentially that same as that awarded in 1980. These observations put chemical engineering education in a favorable light. Degrees awarded remain steady, all is well. But, this is not the case, as is shown in the next section.

- **Chemical Economics** As is stated before, the goal of the Amundson Report is to secure the future of the chemical engineering profession. A good indicator of the state of the chemical engineering profession is the state of the chemical industry, economically speaking. Figure 4 is plot of the nation's GDP per year (source: Bureau of Economic Analysis, 2004 Economic Report of the President, Statistical Abstract of the United States: 2004). It also indicates that portion of the nominal GDP which is attributable to the chemical industry. In either nominal or real terms, there is no doubt that the country's economy is steadily expanding. In real terms, there have been a few years of slowdown, but the over all trend is an upward trend. For 30 years, the value added by the chemical industry (the portion of the GDP that is contributed by the chemical industry) is consistently between 1.5 to 2.0 percent of the total GDP. Figure 5 is a year by year plot of profits for the chemical industry. It is at this point where a very disturbing discovery is made. During the years from 1986 to 1988, chemical profits surge to all time highs; but at the same time, employment is slogging along at one of its lowest points. From 1989 to 1993, chemical profits wane as chemical employment soars to heights not matched by any year following that time. Chemical profits then hit all time highs between the years of 1994 and 1999 while chemical employment stampedes towards a 30 year low. On one hand, it is not surprising that chemical profits are increasing. The national economy is steadily increasing and the percentage of the economy that represents the chemical industry is holding steady. Thus, as the output of the nation is increasing, so is the output of the chemical industry. It is not surprising then that the profits in the chemical industry are also rising. What is surprising is that the employment in the chemical industry is falling. If output is rising, should not employment at least hold steady; if not rise as well? In economic terms only one explanation is plausible: the chemical industry is becoming more efficient. Remember that near the time of 1994 a new business sweeps America - "re-engineering". This new service to the business sector of the American economy is known by many other names as well. It is also known as streamlining, reorganization, downsizing, and layoffs. Though it is true that the chemical industry is more efficient due to enhancements in work scheduling, automation, computer control and computer design; it is also true that the 80s and 90s are the years of the MBAs and years that take cost control very seriously. While working in the manufacturing field during the early 90s, conversations take place that make one thing clear: by far the largest cost in the fabrication of pressure vessels is labor. During the 90s firms are very conscious of their stock price. Many CEOs are payed primarily in the form of stock options. Employee incentives and retirement funds are tied to the stock market. High value is placed on sizable profits that translate into more retained earnings/stock dividends; and likewise translate into higher stock prices. In light of all this, one must conclude that chemical profits do increase to reflect an industry that is growing simultaneously with an expanding economy; but, that this increase in profits is due substantially to increased cutbacks, layoffs and hiring freezes.

THE FUTURE OF THE CHEMICAL ENGINEERING PROFESSION

As has been stated previously, the Amundson Report makes the recommendation that, if

chemical engineering is to survive as a viable profession, research must be encouraged in the frontier areas. Any reasonable person dare not disagree with this recommendation. It is only reasonable that chemical engineering make every effort to expand its horizons in every endeavor of engineering where chemistry is essential.

The only problem is that chemical engineering may have come to this realization too late. At the present time, and even at the time of the Amundson Report's publication, many areas of research that are inline with the chemical engineering discipline are migrating to other branches of engineering or specific departments are sprouting to meet the challenge. Areas such as water treatment, air pollution, and environmental engineering typically associate with civil engineering. While a graduate student in chemical engineering, private discussions with other graduate students in civil engineering reveal that the civil engineering department is doing significant work in the area of catalysis. The civil engineering student explains that the research entails using catalysts in the study of air pollution. Again while a graduate student, a guest speaker from Austin, Texas presents a talk on chemical engineering in the microelectronics industry. He states that there exists a tremendous amount of reaction engineering at microelectronic surfaces and interfaces. However, since chemical engineers do not work in that field, the electrical engineers simply devise their own terms for what chemical engineers call diffusion, adsorption, etc. Moreover, polymers and materials engineering are usually housed as completely different entities apart from chemical engineering, as is done at the University of Massachusetts (Amherst) in the field of polymers and the California Polytechnic State University for materials. And lastly, as mentioned previously, some universities are simply establishing completely new departments in bioengineering.

Now, turn to the statements made by Gianni Astarita. It is inconceivable that he is opposed to chemical engineering placing such subjects as materials, polymers, and environmental engineering under its umbrella. Therefore, he is not condemning the Amundson Report for promoting research in frontier areas; rather, he is condemning the entire American academic research system for putting money ahead of education. He feels that too much emphasis is placed on obtaining research funds; thus, this leads to superficial analysis, and likewise research as a form of education is undermined – the research is superficial, no concepts; and therefore, no learning. Astarita's fear is that the Amundson Report causes the problem to proliferate since money primarily is earmarked for frontier areas (encouraging a stampede of superficial research coupled with superficial analysis) and not devoted to the core areas where the fundamentals of chemical engineering are easily found.

Anyone having the experience of university research certainly acknowledges that academic investigation can be extremely routine and superficial. It is so easy to get caught up in the circular pattern of writing proposals, procuring equipment, taking the data, performing the regression analysis, publish the paper, using the previous work to support a new proposal, buy more equipment, etc, etc, etc. Jokes and cartoons echoing this endless cycle are often placed on departmental bulletin boards.

As a graduate student, a discussion is overheard between a professor and his graduate student in the office next door. For the sake of example, the student's hypothetical name is "John". The professor states, "that is what research is all about, John: take the data and write the paper, take the data and write the paper" It is easy to see how one can get stuck in this cyclic routine; but university educational research is and must be more than just that.

And lastly, the economic data relating to the chemical industry present a haunting picture. On the surface, the casual observer notices that employment in the chemical industry is nearly constant over the past thirty years. The same can be said for the number of degrees granted in chemical engineering. A closer look, however, reveals that the national economy is steadily

expanding over this time. Likewise, the chemical industry is increasing output such that it has maintained a fraction of the national GDP that is nearly constant. In other words, chemical output grows while employment and degrees granted in the chemical engineering are flat. What is even more disturbing is that profits in the chemical industry surge higher, particularly during periods of high chemical unemployment.

Despite the evidence here presented, it is unrealistic to predict that chemical engineering is in a tail spin, spiraling towards unavoidable destruction. The world, for perpetuity, needs energy; and all energy involves chemical reaction: gasoline combustion, ATP cycle, the sun (nuclear reaction), even electrical energy has its roots in chemical reactions.

The recommendations of the Amundson Report are firm and sound. And as is seen in this study, chemical engineers are making significant advances in the core and frontier areas of research: safety, fouling, bioengineering, etc. However, one can retort by saying that the state of the chemical engineering profession does not reflect the value of research in the core nor the frontier areas of research. That is, the level of employment and the number of graduating chemical engineers are unchanged in 30 years. It is further predicted that the numbers in employment and graduates are to see a significant drop in the next few years.

As true as this is, it must be stated that the Amundson Report could not have possibly predicted the type of geopolitical and economical changes the world has seen since its publication: the fall of communism, the flight of the US manufacturing sector to developing nations, the rise of the service industry, the Tech Boom of the late 90s, the notoriety of Dolly (the cloned sheep) and the Human Genome Project. All of these events pull research money, students, jobs and public focus away from the chemical industry. Nothing can insulate the chemical engineering profession from these radical changes.

Yet, it is safe to predict that as long as chemical engineering continues efforts in the frontier areas of research, there will always be a need for chemical engineers. Everyone in the business certainly agrees that the profession sees its ups and downs. One buzz phrase in the industry is “these things are cyclical”. Certainly, the chemical engineering profession is cyclical. Things might get better or things might get worse, but either way, chemical engineers will still be here. One way or the other, they will have “their place in the sun” again.

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FIGURES

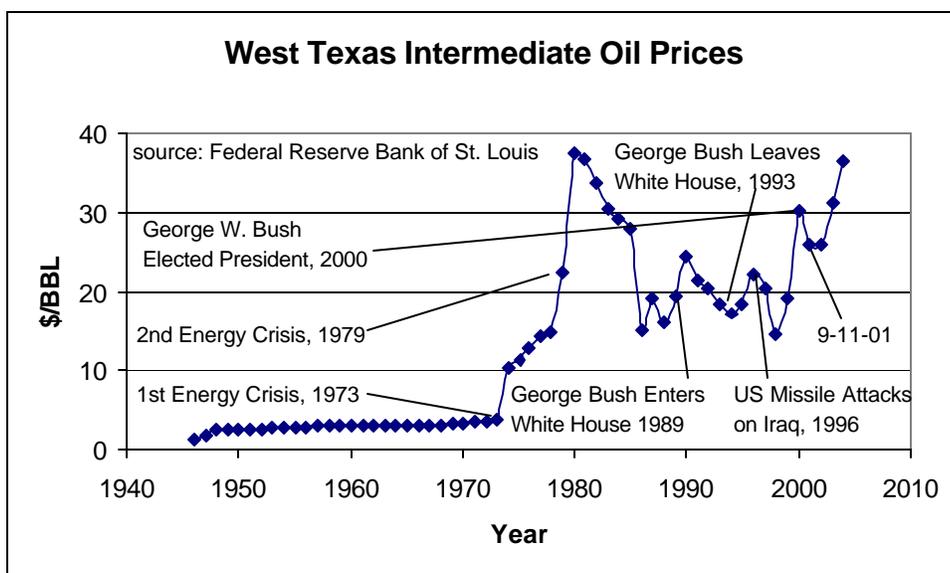


Figure 1. West Texas Intermediate Oil prices since 1946.

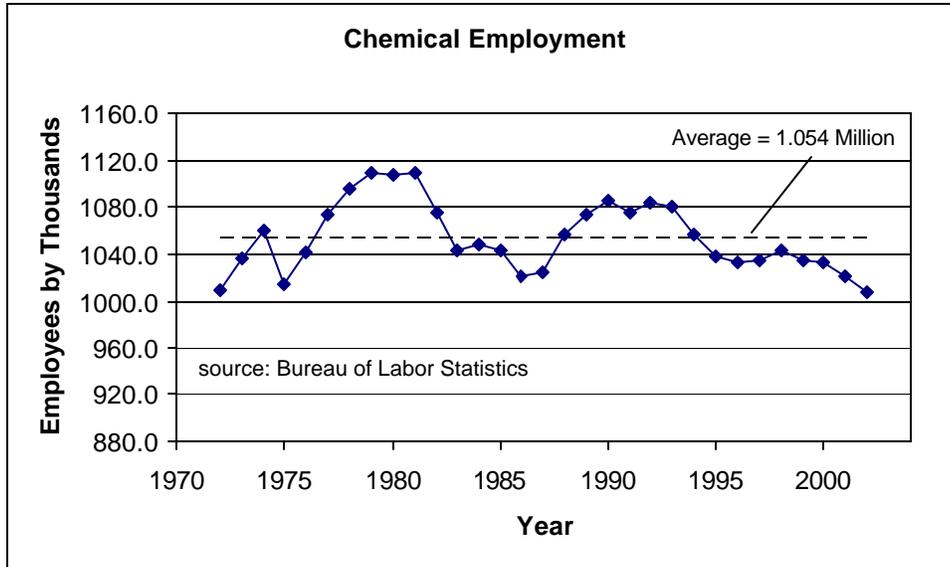


Figure 2. Chemical employment from 1972 to 2002, SIC basis

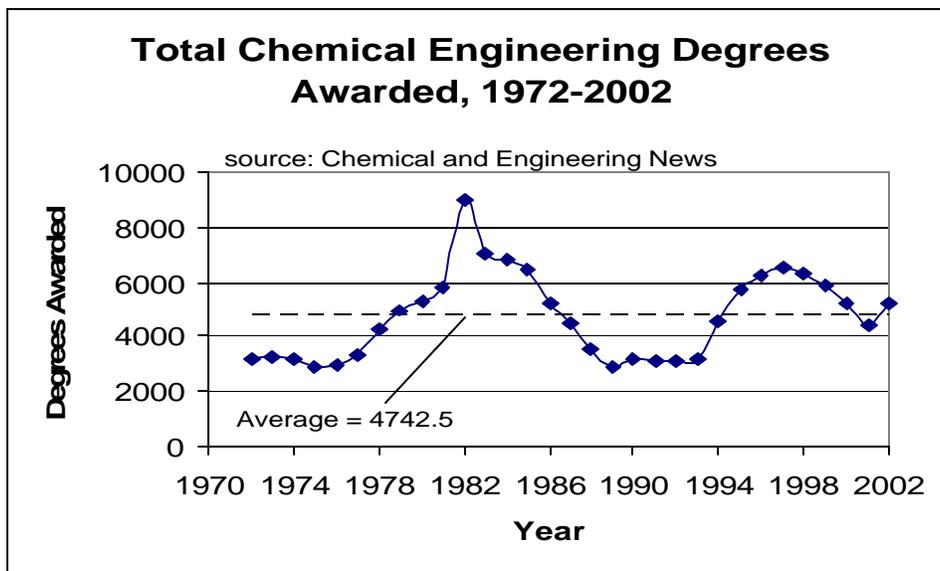


Figure 3. Total number of bachelor degrees awarded over 30 year period.

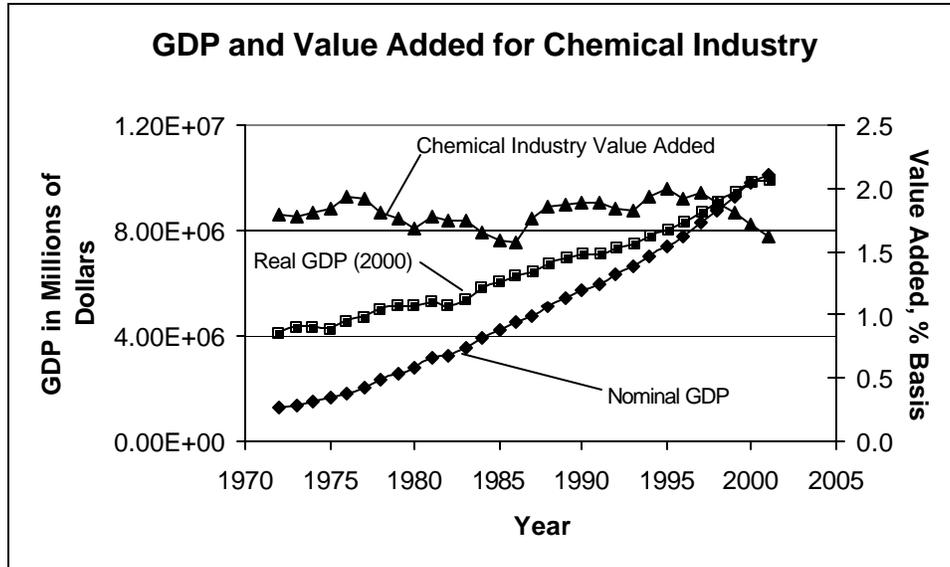


Figure 4. National GDP in nominal and real terms, value added by the chemical industry, 1972-2002.

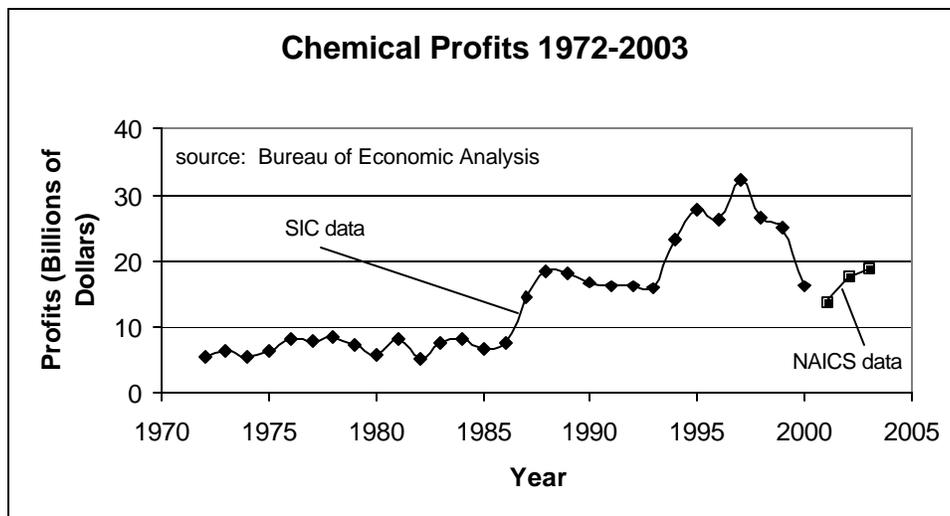


Figure 5. Chemical profits covering a 30 year span with mixed SIC and NAICS data.

