Appendices

A. Biomolecular Engineering

Rationale for a *Biomolecular* Engineer (Comments from M. J. McCready, 11/25/01)

While BS chemical engineers have long found employment in a diversity of industrial sectors, chemical and petroleum have been the industries that have been the drivers for attracting people into the chemical engineering profession. Chemical engineers enjoy a special status in these industries in the sense that many of these companies are "run" by chemical engineers. However, evidence exists that this era is over or at least rapidly coming to an end. *Accenture* was the single largest new employer of chemical engineers for the year 1999-2000. While Exxon-Mobil has had record profits and the chemical industries endure as one of the few with a positive balance of trade for the US, there is little doubt that the CPI has become a mature industry and the prospects of future growth, at least in the US, are slim. Tangible evidence of the maturation is given in figure 1, which shows the capital productivity of the CPI. It is seen that there is a considerable downward trend from a peak in the late 1960's. Based on these data, it is understandable why the CPI would be reluctant to engage in *any* capital investment that was not necessary to meet changing laws or existing business commitments. The many mergers are indicative of both some overcapacity as well as a need to gain *business* efficiency to remain profitable, because the traditional way, which was to improve technology is not longer generally viable. It does not need to be pointed out that the lack of capital investment will translate into no job growth and difficulty in making a case for investment in research in these areas.

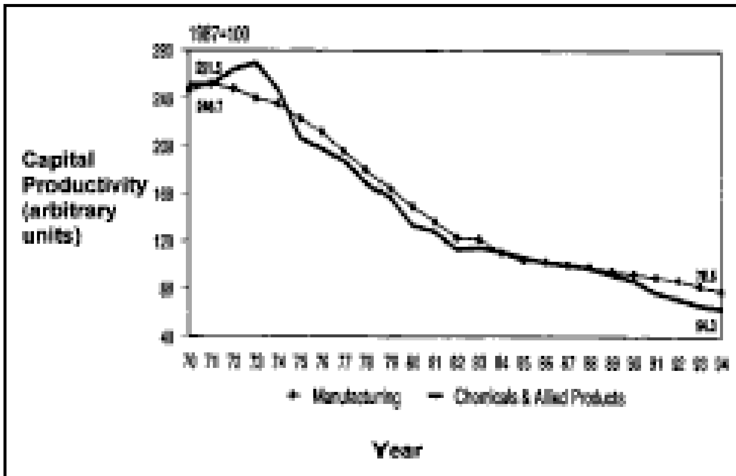

Figure 1. Data from the U.S. Chemical Manufacturers Association indicates a gradual decline in capital productivity, defined as the ratio of the revenues to the cost of the assets (U.S. Chemical Industry Statistical Handbook, 1996).

Figure 1. Referenced in Harold et al. (2000)

Of course, because the CPI were the drivers for the development of chemical engineering, they were also the reason that chemical engineering undergraduate curricula have developed into their present form. While there is some variation among different schools owing to differences in mission, student background and interest and expertise of the faculty, essentially all programs have a set of courses that cover: mass and energy balances, equilibrium thermodynamics, heat, mass and momentum transfer, chemical reaction engineering, separation processes, chemical process dynamics and control and chemical process design -- in line with ABET requirements prior to the new EC2000 rules. The basic science requirements include physics, math and extensive study of chemistry.

Perhaps quite independent from the (inevitable) maturation of the CPI, advances in molecular understanding of living systems, has provided a fertile scientific framework on which new engineering achievement s can be expected to occur. We can expect wonderful new treatments for disease, engineered crops to expand the world food supply and even remedies to help reverse past transgressions against the earth's environment and lead humanity into a new age of sustainable development. It is not crass to state or realize that considerable industrial growth and creation of new jobs will occur in these areas and thus a need for people who can direct and participate in this process.

There has already been some response by engineering colleges in the US to the emerging realization of the potential of *molecular biology* as a foundation science for engineering. Just to give a few examples, new bioengineering or biomedical engineering departments have been started at Minnesota and Rice, greatly expanded at Washington University and Rutgers and there are plans for a new department at UIUC. New multidisciplinary research efforts at MIT, Penn and Stanford in the form of research institutes have also sprung up. The response to the specific focus on *molecular* biology has led to formation of new biology departments and programs with the specific titles of molecular biology or molecular and cellular biology.

The question of interest to chemical engineers, given the decline of the CPI and the emergence of biology, is <u>what should the response be</u>? Should bioengineering activities within chemical engineering be split off and merged with other bioengineering activities from other departments to form new bioengineering departments? If this is done, what will be left? Alternatively, is there a way to fully integrate molecular and cellular biology into the chemical engineering to the same extent that chemistry has traditionally been. Molecular biology is quantitative and by definition "molecular" and thus possesses many similarities to chemistry. Can we envision chemical engineers, who for about 100 years have been the people who brought the inventions of chemistry to society, become the engineers who bring the products of biology to society?

The plan at Notre Dame developed over the past 5 years has been the integration of biology into the chemical engineering curriculum. Two new faculty (AEO, AFP) have been hired with this effort in mind and some progress has been made at this integration process. We are developing our vision for a chemical engineering curriculum that could possibly be called *chemical and biological* engineers, *molecular* engineers, or *chemical and biomolecular* engineers. The specific curricular work that will be done is the development of laboratory modules on drug delivery, to augment one elective course and several core courses in the new curriculum, development of a biomaterials laboratory technique course which would prepare undergraduates and first year graduate students for research in this field and development of life-science oriented, web-based courseware and example problems for several core courses. Both the overall effort and the specific materials to be developed are intended to serve as a model for other chemical engineering programs around the country that choose *integration of life sciences* as an evolutionary pathway in the coming years.

Bioengineering course material to be integrated to make the bio-molecular engineering component

As mentioned above, there is a common set of core courses that virtually all chemical engineering programs in the US offer. The connection with the chemical process industries is extremely strong. For readers from other disciplines, it is worth noting that chemical engineering is more homogeneous than other engineering fields as there are no standard, universal specializations that produce graduates who are missing significant coverage of this core. The table below shows only a sampling of how *chemistry*, generally through an understanding of molecular structure and energetics, is integrated into the current chemical engineering curriculum. The last column shows how we intend to integrate bio-molecular understanding into each of these core courses. It is expected that by addressing topics on a sufficiently fundamental level, that integration of biology will improve students' understanding of the tools contained in different subject area course. It should be noted that we realize that further evolution of the curriculum may require more dramatic changes, but we think that for the period of this project and for a transition period (which nationwide could last a decade or more) this approach is viable and efficient.

Course	Molecular understanding of matter	Bio-molecular understanding
Mass and Energy Balances	Constitutive equations are described as necessary because molecular level of detail is not included in the conservation law equations.	Constitutive equations for cellular and bacterial culture phenomena
Molecular thermodynamics	Excess Gibbs free energy models and equation of states are described to students based on enthalpic and entropic arguments. Molecular simulation is used a tool to predict simple fluid properties. Phase splitting is explained with reference to molecular structure	Thermodynamics of protein folding, crystallizatio ligand binding Solubility of drugs, toxin and biomolecules in flui and tissue
Computer Methods in Chemical Engineering	Numerical analysis techniques are used to model small molecule diffusion through various geometries	The same techniques used to solve the diffusion equation can be coupled with compartmental analysis to model drug distributions in an animal
Transport phenomena	Stress-strain relations for nonNewtonian fluids are explained based on molecular structure. Surface tension as a force is explained based on molecular understanding, how surfactants influence this is also described Knudsen diffusion, and facilitated transport are often topics in this course sequence and are discussed based on molecular structure.	Cellular membrane transport mechanisms ,Fluid mechanics of living systems Role of diffusion in determining cell size and metabolism rate Cell motility
Separation Processes	Chromatographic separations are explained based on chemical and physical adsorption differences	Facilitated transport, kidney and liver functions, a in terms of fundamental biochemistry
Reaction Engineering	Molecular basis for rate laws is explained, catalysis is described in terms adsorption sites and energetics of bond activation	Cell metabolism, Metabolic engineering
Process Design	Students are shown how molecular structure of the desired product dictates very significantly choices of synthesis and separation processes that are used for flow sheeting.	Biosensors, tissue engineering Prosthetic devices Drug delivery, Gene therapy

While not part of this proposal, we expect to further incorporate life sciences by including biochemical cycles and cellular process as examples of integrated "systems" -- similar to controlled, dynamical chemical processes -- into our curriculum

A. Biomolecular Engineering Option

Integration of the life sciences into Chemical Engineering at Notre Dame

Overview

To develop a world class bioengineering teaching and research program, the department of chemical engineering at Notre Dame is following a strategic plan to *integrate* an understanding of Life Sciences throughout the curriculum, and to create new elective courses in fundamental topics of bioengineering that emphasize a rigorous application of engineering analysis and design principles. The goal is to train engineers who are prepared to manufacture for the public, exciting new *life-science inspired* products, just as chemical engineers have done for chemical compounds for the past century.

The chemical engineering department will initiate a *Biomolecular Engineering* Option that fits within the fully accredited Bachelor of Science in Chemical Engineering degree. The details of this option are given on the next page. Students who complete this program, *Biomolecular Engineers*, will have a strong understanding of <u>structure</u> and <u>function</u> of biologically active molecules and how they interface with both living systems and inanimate chemical systems. The application of chemical engineering mathematics, analysis, and computation will enable graduates in this field to develop new products using molecular biology, analyze and design process systems ranging from the microscopic to macroscopic scale, and integrate their new bioproducts into existing materials. Such products include artificial skin, blood, organs, and tissues, advanced delivery systems for essential pharmaceuticals, new drugs based on knowledge obtained from the human genome, revolutionary sensors that rapidly and sensitively detect bacteria, in people and in products designed for human use and consumption. A key part of this program, that is not discernable from just the curricular sheet, will be the incorporation of life science example problems into many of the core chemical engineering courses.

Biomolecular Engineering Option

FIRST YEAR

First Semester	Cr.	Second Semester	Cr.
MATH 125, Calculus I	4	MATH 126, Calculus II	4
CHEM 117, Gen Chem	4	BIO 118, Intro toCell/Mol Bio	3
Arts and Letters (A&L,I)	3	Univ. Sem180/ENG110 (A&L, III)	3
EG111	3	EG112	3
ENGL 110/Univ. Sem. 180 (A&L II)	3	PHYS 131, Gen Phys I	4
	17		17

SOPHOMORE YEAR

First Semester	Cr.	Second Semester	Cr.
MATH 225, Calculus III	3.5	MATH 228, Linear Algebra & ODE's	3.5
CHEM 223,Org Chem I	3	CHEM 224, Org Chem II	3
CHEM 223L, Organic Chem Lab I	1	Arts and Letters V	3
PHYS 132, Gen Phys II	4	CHEG 258, Computer Mtds	3
CHEG 255, Intro Chem Eng	3	CHEG 256, Thermodynamics	4
Arts and Letters IV	3		
	17		16.5

JUNIOR YEAR

First Semester	Cr.	Second Semester	Cr.
MATH 325, Diff Eqns	3	CHEM 324, Physical Chem	3
CHEM 333, Analytical Chem	2	CHEG 356, Transport Phen II	3
CHEM 333L, Analytical Chem Lab	2	CHEG 438, Chem Proc Control	3
Arts and Letters VI	3	CHEG 358, Chem Eng Lab I	3
ChEg 225, Materials	3	CHEM 420 Biochemistry	3
CHEG 355, Transport Phen I	3	Arts and Letters VII	3
	16		18

SENIOR YEAR

First Semester	Cr.	Second Semester	Cr.
CHEG 473/573 Biomaterials engineering@	3	CHEG 448, Proc Design	3
CHEG 459, Chem Eng Lab II	3	Engineering elective	3
CHEG 443, Separation Proc	3	CHEG 474 Bioprocess Eng.@	3
CHEG 445, Chem Rxn Eng	3	Advanced Biology Elective	3
Advanced Biology Elective+	3	Arts and Letters VIII	3
	15		15

total:132 credits
The 8 Arts and Letters slots are for: 2 Phil, 2 Theo, 1 Hist., 1 Soc. Sci, 1 Fine Arts/Lit., ENGL 110.
A list of courses that fulfill the Advanced Science elective is available in chemical engineering advising handbook
+ Suggested biology electives are Cell biology [341], Developmental biology[342], Molecular biology[501], Microbiology[401] and Genetics[303].
@ Or other bioengineering electives in chemical engineering such as ChEg 471, Biomedical transport.
Draft: January 17, 2002

Current Chemical Engineering Department Bioengineering electives

ChEg 471/571 Biomedical Engineering Transport Phenomena CRH: 3.0

Course Instructor: Andre Palmer, offered every Fall

Level: senior undergraduate students/graduate students

Description:

This course brings together fundamental engineering and life science principles, and provides a focused coverage of key concepts in biomedical engineering transport phenomena. The emphasis is on chemical and physical transport processes with applications toward the development of drug delivery systems, artificial organs, bioartificial organs, and tissue engineering.

ChEg 473/573 Biomaterials Engineering CRH: 3.0

Course Instructor: Agnes Ostafin, offered every other Spring

Level: senior undergraduate students/graduate students

Description:

Biomaterials Engineering is the application of engineering principles to design, develop, and analyze materials that involve biological molecules. These may be materials of biological origin that are used in medical, biological, or chemical applications, and materials of chemical origin that are used with biological systems or their components. In this course you learn about the basic principles involved in the choice of material properties, the nature of the interaction of biological materials with their surroundings, and modern applications in science, medicine and engineering. Issues relating to marketing, packaging and storage, regulation, and ethics will also be discussed. Students will have an opportunity to apply mathematical-based engineering analysis of complex biomaterials systems.

ChEg 474/574 Bioprocess Engineering CRH: 3.0
Course Instructor: AgnesOstafin, offered every other Spring
Level: senior undergraduate students/graduate students

Description:

Bioprocess Engineering is the application of engineering principles todesign, develop, and analyze processes that use biocatalysts. These may be in the form of a living cell, its substructures, or their chemical components. In this course you learn concepts of cellular biology, and be introduced to mathematical-based engineering analysis of complex biological systems. By the end of this course you should be able to understand basic structure and function of cells, homogeneous and heterogeneous enzyme kinetics, the regulation of cell growth, the design and operation of bioreactors, recovery and characterization of products, and methods in genetic engineering and molecular cloning.

Research

Research activities in the area of bioengineering are detailed on the chemical engineering web site at http://www.nd.edu/~chegdept/Bioengineering.html. Professors Agnes Ostafin (http://www.nd.edu/~chegdept/Ostafin.html),and Andre Palmer (http://www.nd.edu/~chegdept/Palmer.html), both of whom have joined the department in the past 3 years, have initiated extensive research activities, primarily in the synthesis and characterization of new biomaterials.

Several other faculty have growing interests in bioengineering areas. Professor Leighton has been working on separation of mixtures of proteins, Dr. Chang has worked on blood flow-blood pressure modeling and Professor Miller has continuing efforts on the development of biosensors. Dr. Hill is looking at the properties of artificial cartilage. Professor Varma is making new orthopaedic implant materials using combustion synthesis. Dr. Saddawi is looking at growth behavior of "Sulfur-Eating" bacteria. Professor Strieder has conducted theoretical studies of cell communication and cell growth.