Frontiers in Chemical Engineering Education

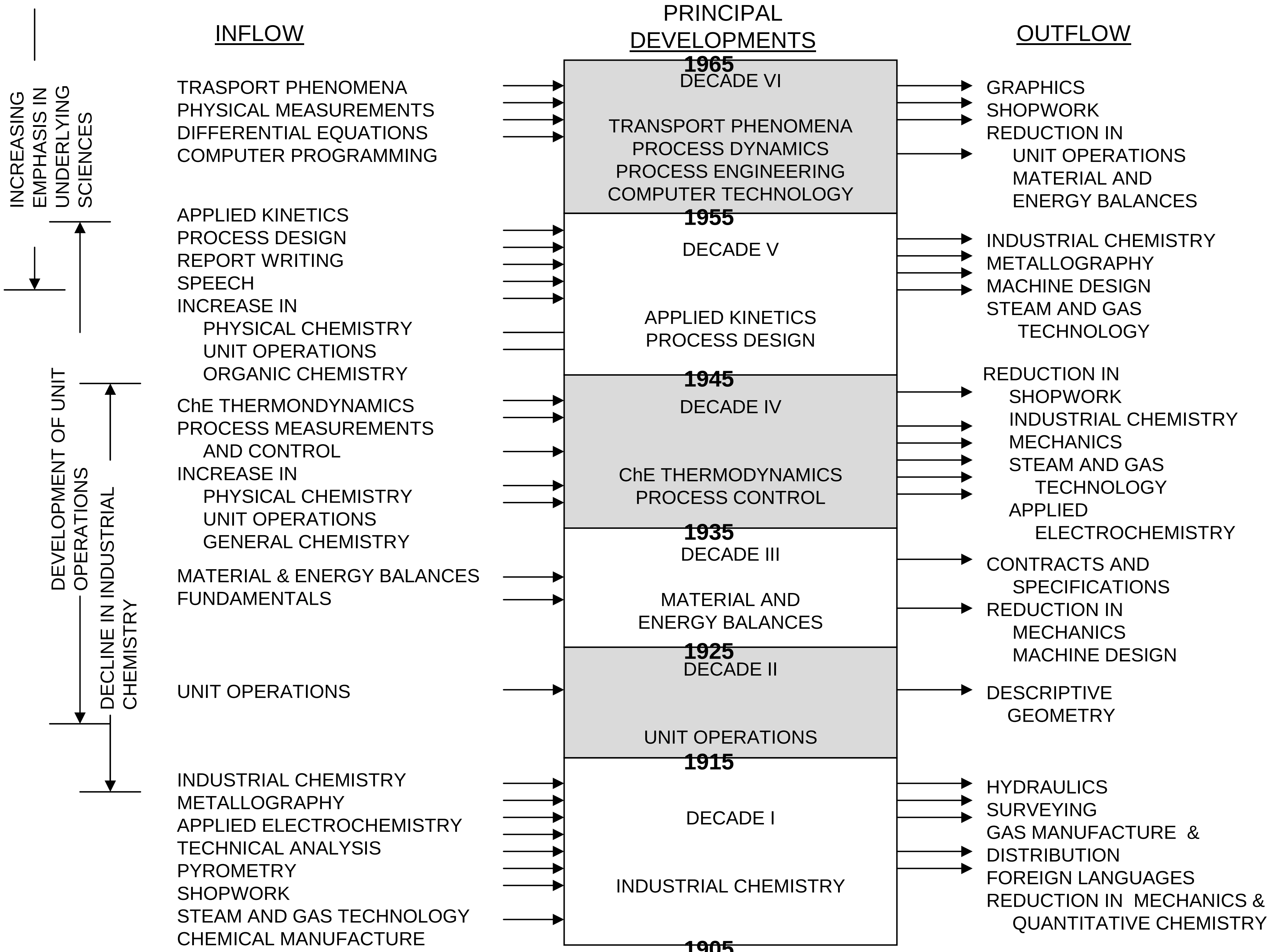
New Directions and Opportunities – Creating the Future

Discipline Wide Curriculum Workshops

Welcome

- It has been 40+ years since chemical engineering curriculum underwent major change
- During this period the profession has experienced major change
- The intellectual opportunities and career paths for the profession are exciting
- We have the opportunity to create a future chemical engineering curriculum that will produce graduates for the world ahead

… why is this important?



Changes in a typical undergraduate chemical engineering curriculum during 60 years. The initial curriculum in 1905 consisted of separate courses in chemistry and conventional engineering.

Changing Nature of Chemical Engineering

- Our industry
- Career paths
- Research opportunities
- Underlying science

Chemical Industry Observations

- The industry is global
- Mergers of companies and product lines
- Chemical companies are becoming life science companies and spinning off chemical units
- Virtual companies - out-sourcing of services - incl. research
- The chemical industry is cyclical
- Time to market for new products has dramatically decreased
- Graduates can expect to have multiple professional jobs
- Chemical engineering no longer is dominated by petrochemicals/bulk chemicals

Trends in the Chemical Industry

- Historically, a Larger Contributor to the GDP than any other Manufacturing Industry (OECD)
- Chemical Sciences and Engineering are the Largest Contributors to Technology
  - All industries create chemical technology
  - The underpinning of all industries' technology relies on chemical technology
  - The cross industry technology spillovers are highest from the electrical and chemical industries
  - Chemistry is an important part of the science base of all industries
- Growth Rates in of the Chemical Industry
  - 1993-2003: 3.9% per year
  - 2004-2014: 2.5 to 2.7 %. Below the GDP growth rate (3.0 to 3.3%)
- Geographic Allocation of Growth (2002-2014)
  - US and EU, ~ 2% per year; Japan, <1% per year…Below GDP Growth
  - Asia, 10% per year

Where Do the Companies See the Future Growth? (2004-2015)

- Commodities:
  - Primarily in Asia…….. 9-10 % per yr
- Product-Oriented Chemicals and Materials:
  - "Solutions-to-the-Customer" ……………………....... 10-15% per yr
    - Integration of technological services, chemicals, materials
  - Information/Electronics/Telecommunications...........10-15%
    - Semiconductors; Displays; Inks; Specialty polymers; Energy devices
  - Medical …………………………………………...……. 6-10 %
    - Diagnostic, Packaging, Fabrics, Surgical supplies
  - Safety, Security, Protection ……………………..…… 6-10%
    - Diagnostic, Protective Materials
  - Life Amenities (Home, Office) ……………………..…. 5-8 %
    - Materials/Components for cleaner, healthier environment; Personal care
  - Transportation………………………………………..…… 5-6 %
    - Material components and energy devices for automobiles & airplanes

Highlights---Trends in Industry

1. The Valuation of Chemical Companies by the Financial Markets has been rather low, and the Chemical Industry has not been perceived as a Knowledge-Intensive industrial sector

Response of the Chemical Companies: Increase the Knowledge Content of their Operations

Phase-1 (Mid-Term):

Increase the Knowledge-Content and Knowledge Integration in Marketing, Customers Needs, New Products through Synthesis of Technologies

Phase-2 (Longer-Term):

Increase the Knowledge Content through New Cutting-Edge Technologies

Implications for Chemical Engineering: Intensify the Differentiation in Knowledge-Content

- New and Interesting Positions for BS, MS, and PhD chemical engineers come in a large variety of activities, characterized by an Expanding Emphasis on
  - Increased emphasis on research skills;
  - Interdisciplinarity in research; teams with cutting edge technologies
  - Personal attributes: Communication; Leadership; Teamwork; Entrepreneurship
  - Appreciation of the integration: R&D-Marketing-Business Strategy
- MS and PhD degrees will be higher-value professional degrees (?)

Highlights---Trends in Industry

2. Chemical Companies shift Manufacturing Operations for Commoditized Chemicals and Materials to Low-Cost Raw Materials Areas and Areas of High Growth Rate, coupled with Strong Trends to establish R&D and Technical Services Centers to areas where the market growth is

   Implications for Chemical Engineering:

   - The growth of BS and MS positions for manufacturing operations and process engineering (pharmaceuticals excluded) may be lower than GDP in the US.
   - The growth of MS and PhD positions for new Product Development, Technical Services, and "Solutions-to-the-Customer" will be at GDP growth or possibly higher.
   - Superior educational programs will not have a problem in placing their graduates
   - Educational preparation with emphasis on the integration of R&D, Marketing, and Product Development will receive a premium

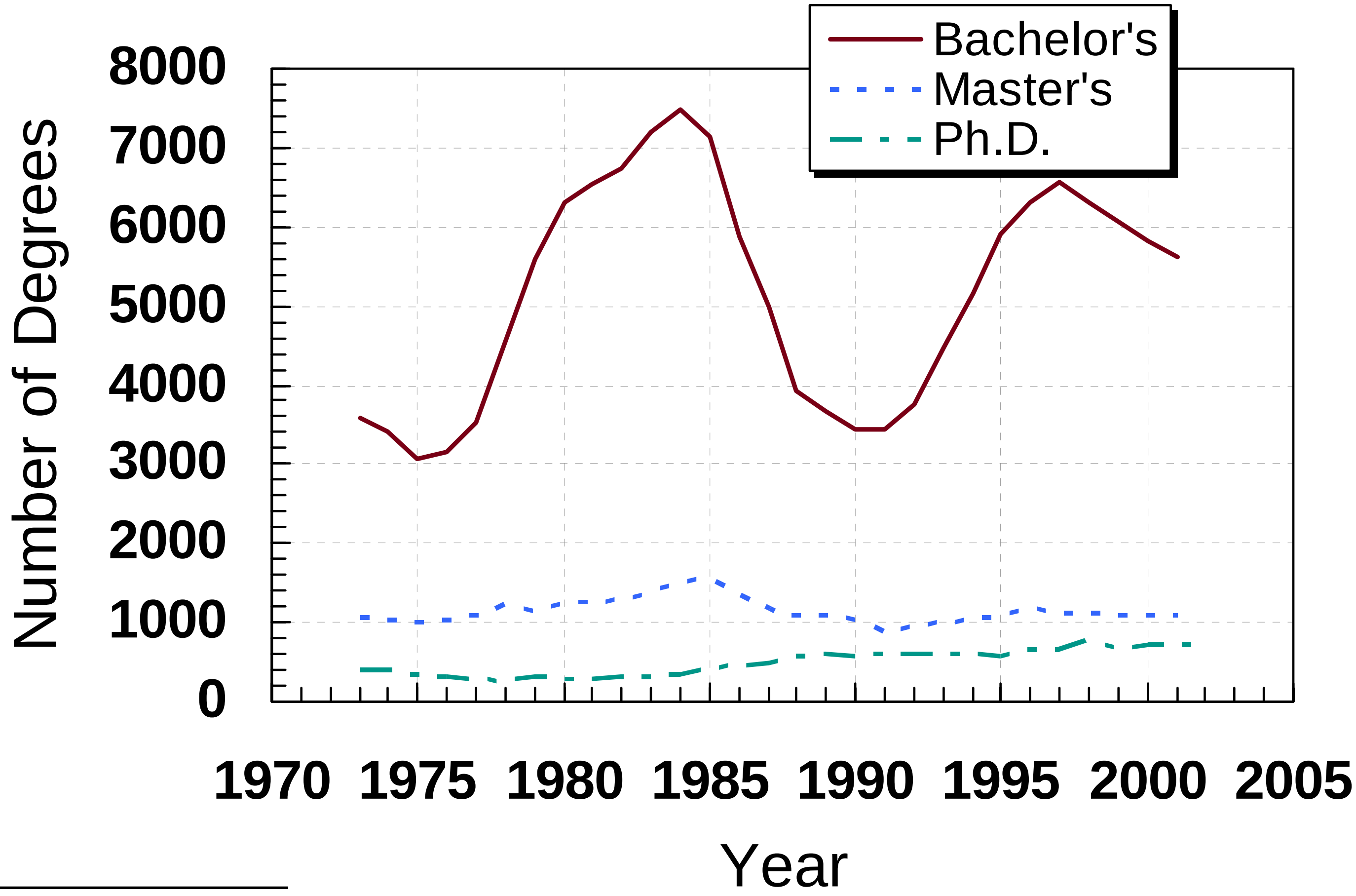
Highlights---Trends in Industry

3. High Expectations for new PhD (primarily) and MS (secondarily) positions from Technology Trends in Biotechnology, Nanotechnology, and their Integration.
   - Most of these opportunities may be created by Start-Ups
   - Significant uncertainty on the time-scale of industrial developments at major manufacturing scales
   - Significant uncertainty on the number of positions that will be created
4. The industrial sectors of Energy, Advanced Materials (biodegradable from biomass, materials for automobiles, electronics and telecommunications) offer significant promise for MS and PhD positions
   - Significant uncertainty on the time scale of significant-scale commercial developments in the energy sector and biodegradable materials from biomass
   - Specs for Advanced Materials are set by companies in Asia or with significant manufacturing base in Asia.
5. Pharmaceutical Industry is expected to exhibit growth above GDP. However, lingering questions cloud the prospects:
   - Will the role of chemical engineers expand or remain within the same scope?
   - What % of the growth will come with new positions in the US? R&D? Process Development? Manufacturing?

Manpower Issues

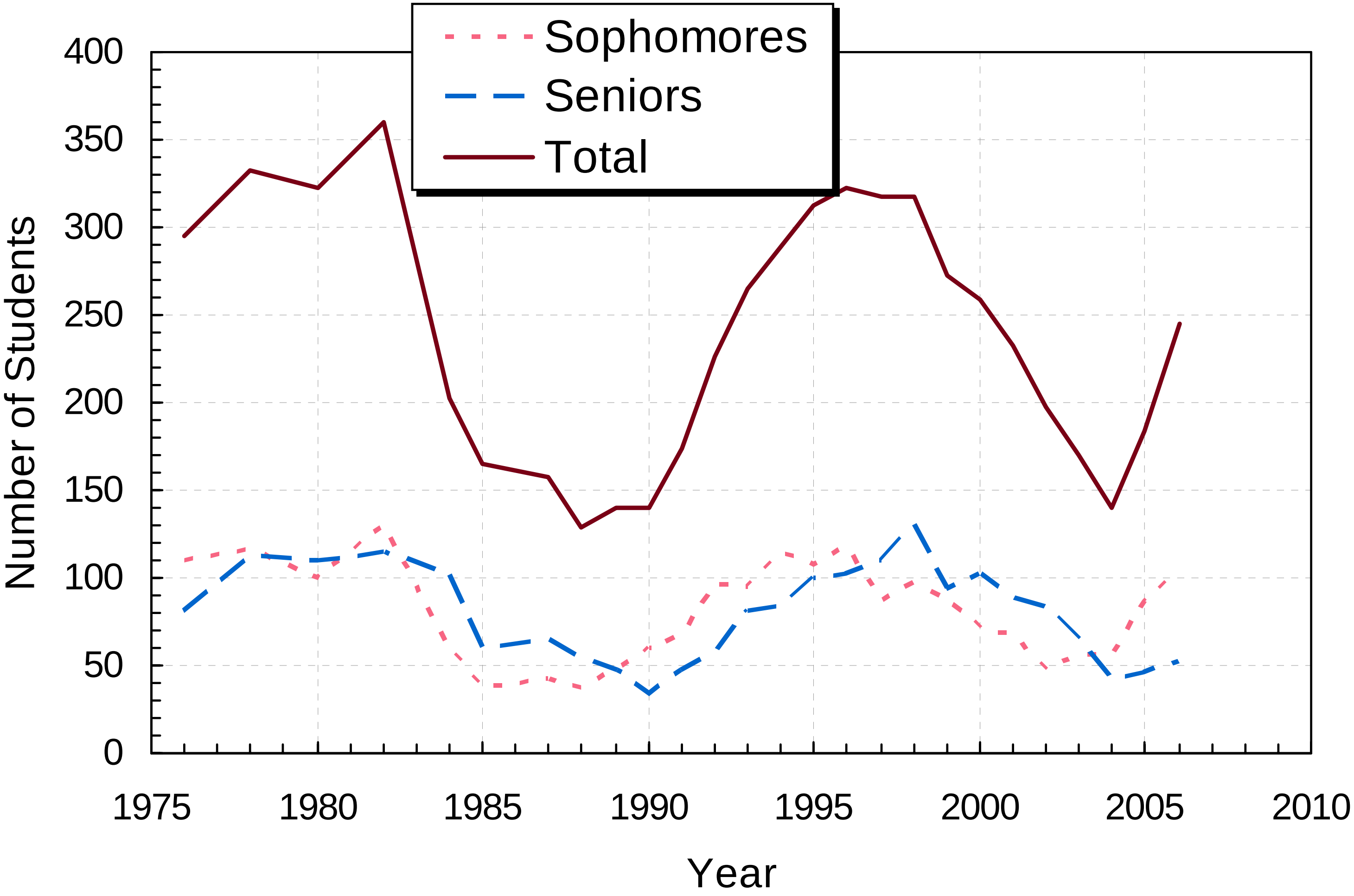
- Public perception of "chemical" is negative
- Consumers (potential students) do not know what we do in emerging technologies such as biotechnology and nanotechnology
- Enrollments are small relative to other engineering disciplines
  - Not necessarily bad, but we want the best
- Employment opportunities are diverse
  - Reflects research opportunities in our departments
- Enrollments appear to be cyclic
  - Are they really?
  - Do they need to be?

U.S. Chemical Engineering Degrees 1973-2002

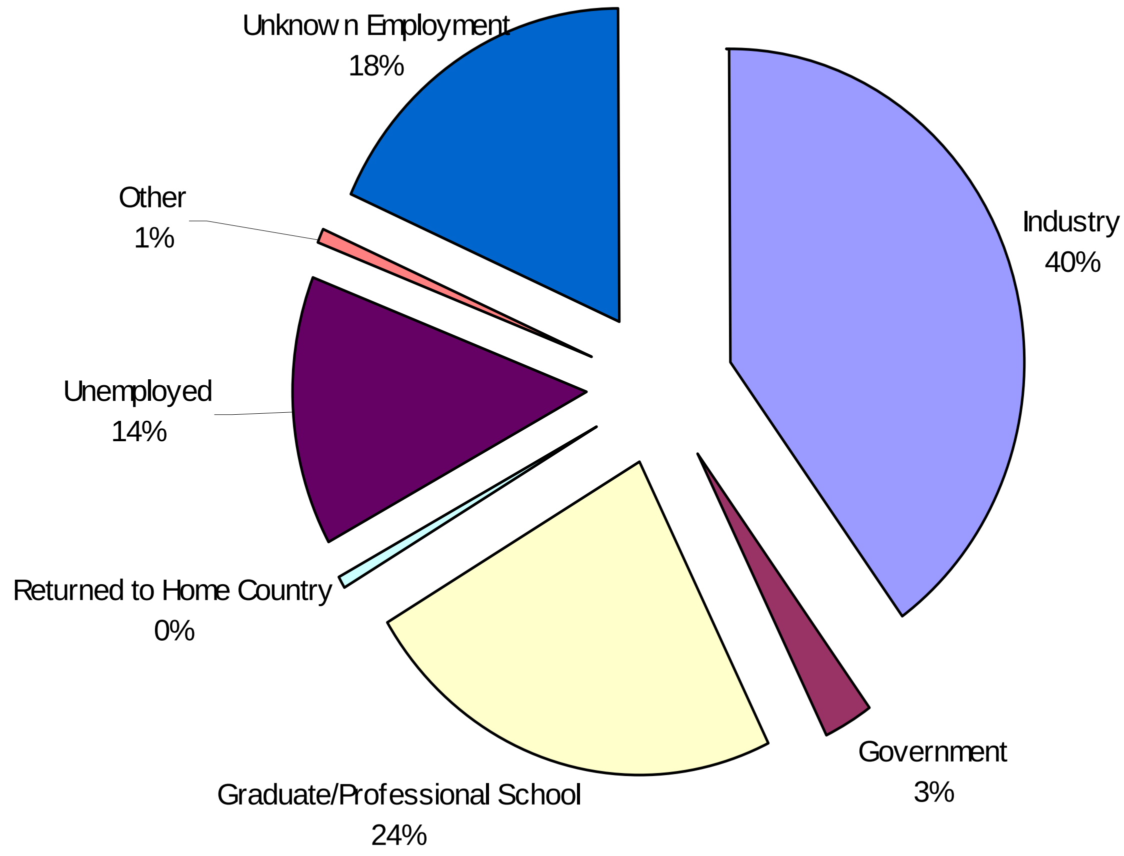


Chemical & Engineering News (November 24, 2003)

Undergraduate Class Size

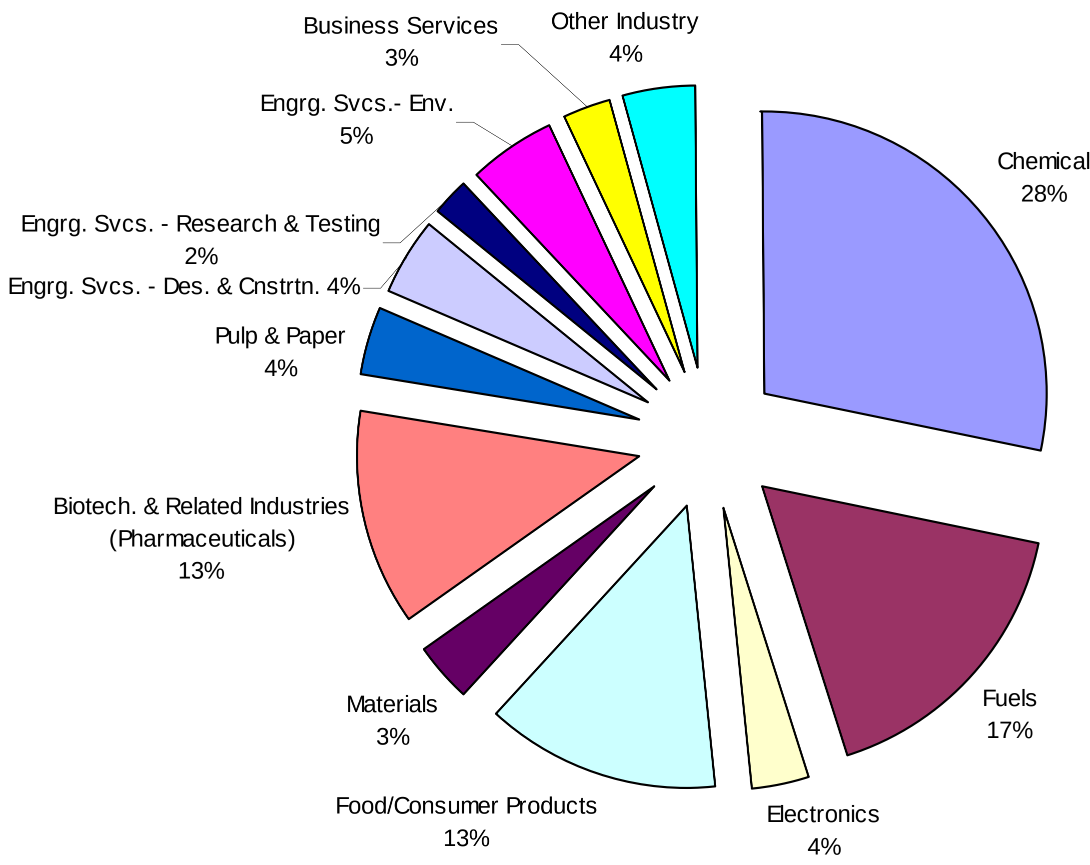


Initial Placement for BS 2002-03



AIChE Department of Career Services
December 2003

Industrial Employment for BS



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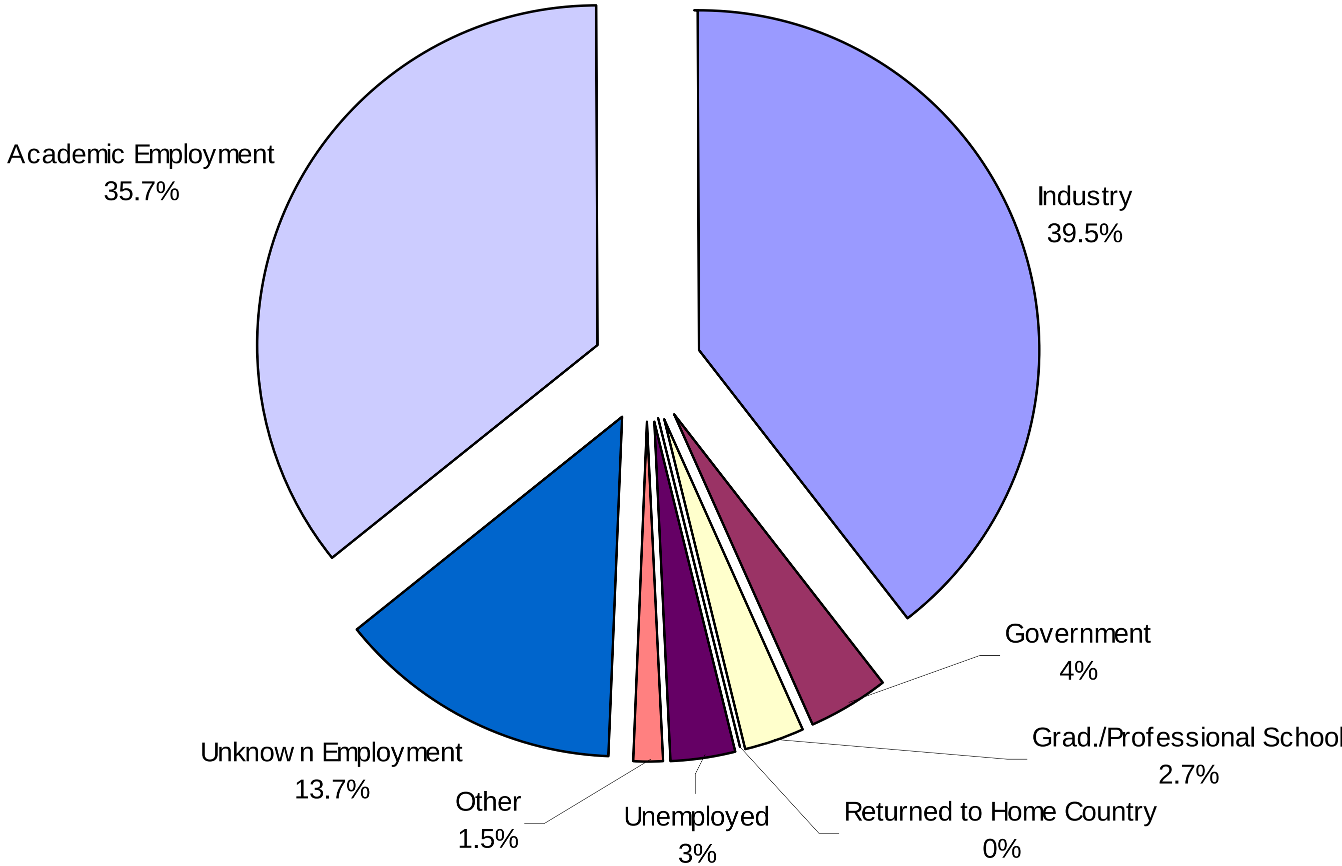
Initial Placement for PhD 02-03



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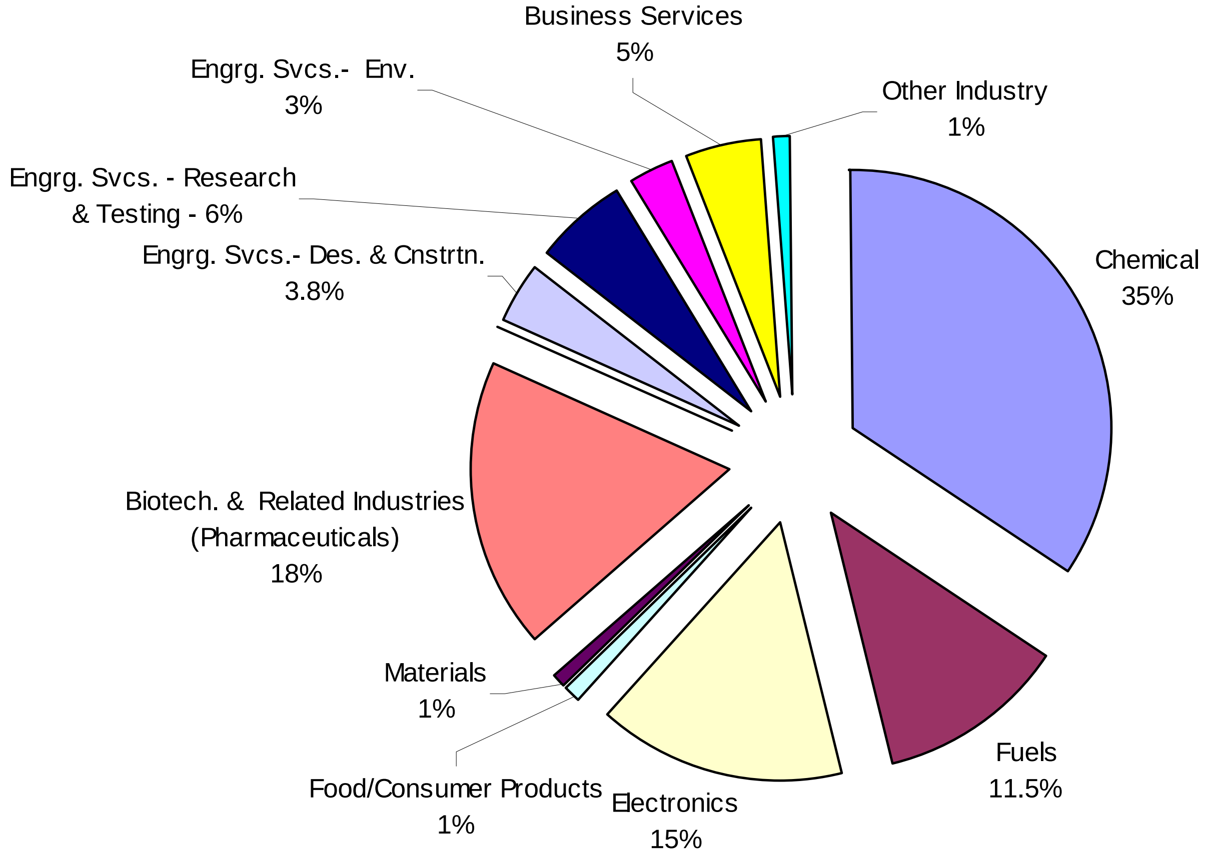
Industrial Employment for PhDs



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BS Starting Salaries*

Chemical engineering leads all fields

Field	Starting salary	Pct change from 2003
Business administration	$38,258	6.2
General accounting	$41,058	1
Marketing	$34,712	2
Computer science	$49,036	4.1
Information science and systems	$42,375	10.7
Civil engineering	$42,056	0.9
Electrical engineering	$51,124	2.7
Chemical engineering	$52,539	0.3
Chemistry	$37,618	- 0.3
Mechanical engineering	$48,578	0
Biology and life science	$29,629	0.6
Math and statistics	$43,567	7.5

*Salary Survey, National Association of Colleges and Employers, Fall 2004, Volume 43, Issue 4

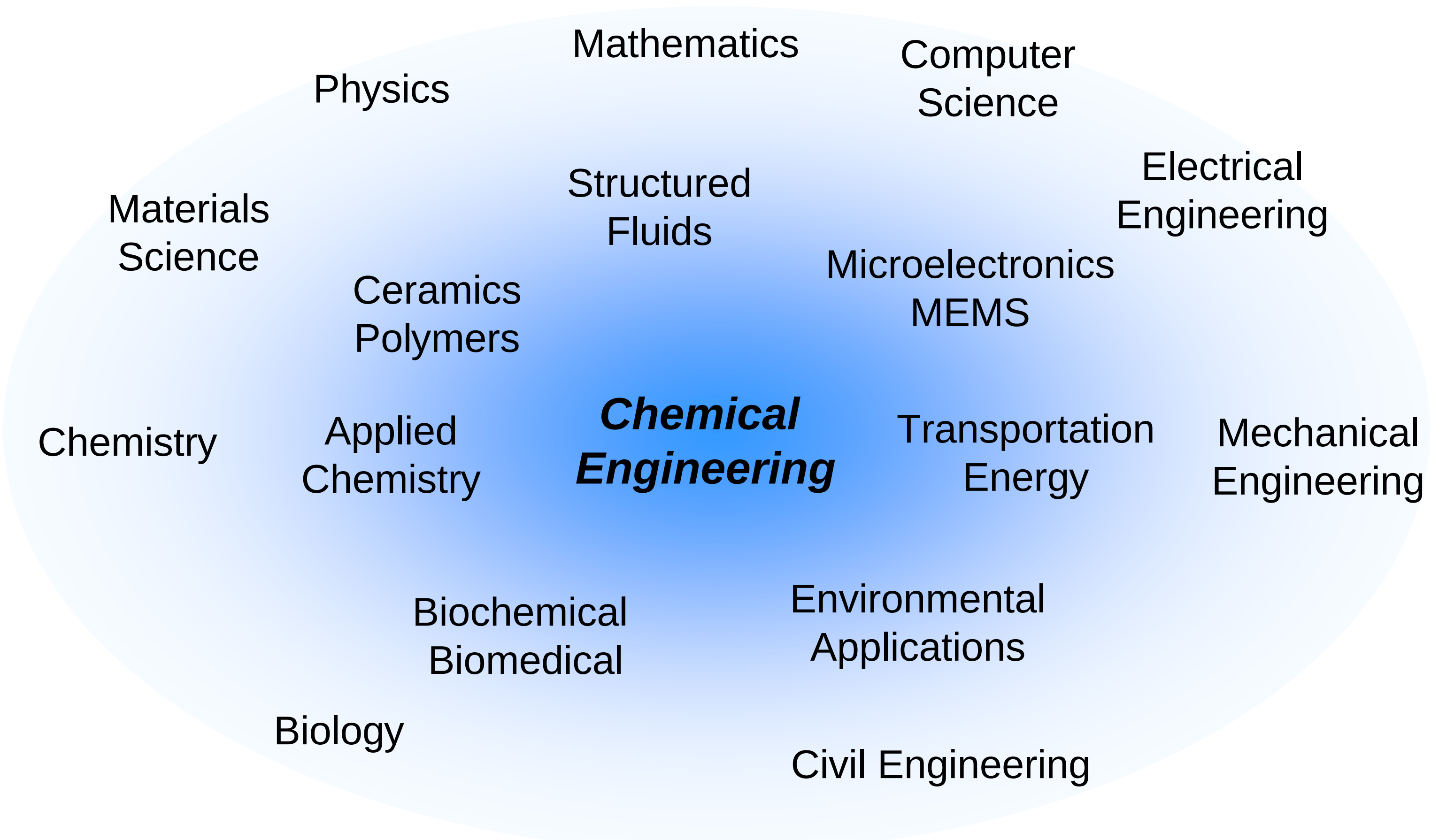
Opportunities

- Chemical engineering is a uniquely positioned at the interface between molecular sciences and engineering with many exciting opportunities, including:
  - Life sciences (genetics, pharmaceuticals ….)
  - Energy - fuel cells, catalysis,
  - Sustainable systems
  - Molecular control of processes and devices
  - …
- Other disciplines have opportunities in these areas as well and are beginning to have interest in process, synthesis, analysis issues traditionally addressed within chemical engineering
- We need to have a clear vision of chemical engineering in order to function effectively in multidisciplinary research

Vision

- Chemical engineering is a vibrant discipline with a central role in many new and emerging technologies - specifically in the translation of molecular information and discovery into products and processes
- We have evolved from a discipline closely tied to a single industry, the petrochemical industry, to one which interacts with many different industries across a broad spectrum of biological and chemical applications
- We must continue to hold a well defined core that defines the discipline and provides the basis for quantification, integration, and relevance in problem solutions
- A close, broad coupling to sciences – physics, chemistry, and biology – is essential to the discipline, enabling the chemical engineer to impact across all scales - systems, processes, products, and molecules - at different levels of focus and providing interdisciplinary perspectives on technology innovation and development

Chemical Engineering at the Center



Chemical engineering has a unique position at the interface between molecular sciences and engineering

NSF/CCR Curriculum Workshops

- A series of three planning workshops have led to a vision and model for a dramatic change in undergraduate chemical engineering education
- Why discipline wide?
  - The opportunities/frontiers are too broad for any one or several departments to address effectively
  - The costs – time and money – of developing new educational materials are too high for any of us to absorb alone
  - The coherence resulting for a joint effort will serve the discipline well
    - Maintain clear identify to the world (potential students, industry, government)
    - Ensure good manpower supply to industry and to our graduate programs
    - Ensure that curriculum developments are used

This Workshop

- Industry engagement
- Curriculum definition

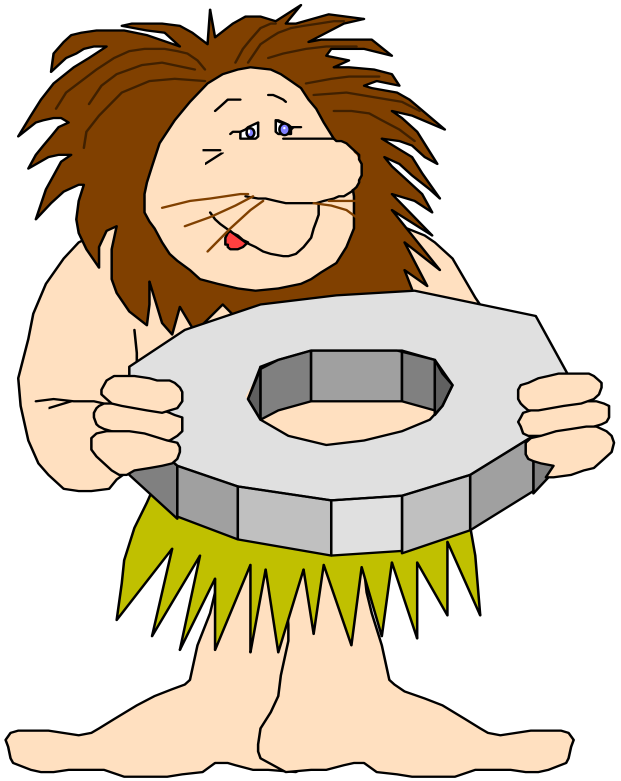
Our identity crisis

- Paradigm shift
- Industry shift
- Drift towards a broad research agenda
- Basic science shift
- …

- … Is this a shift to the center?

Evolution of Chemical Engineering

Major Paradigm Shifts	
1915	Unit Operations*
1960	Engineering Science
2015	Molecular Engineering of Products and Processes



*First articulated in the Visiting Committee Report of 1915, written by Arthur D. Little to the MIT President.

Who Are We?

- Molecular transformations
- Multiscale understanding
- Quantitative approach
- Systems view

- There is a set of attributes that we value
- We are professionals
- We are problem solvers

Drivers for Change

- Biology represents a new frontier for us as a discipline
  - Not just an application
- Our close connection with basic science makes our graduates very versatile
  - We have failed to articulate this clearly to our stakeholders
  - We have failed to imbed this in our curriculum
- Attributes are not well taught
- Our traditional industry has shifted
- Separation of research and education
- Our student base is at risk

Where Do We Go From Here...

Integration of the Curriculum: New Core Organizing Principles

- Molecular Scale Transformations
  - chemical & biological
  - physical: phase change, adsorption, etc
- Multi-Scale Descriptions
  - from sub-molecular through "super-macro"
  - for physical, chemical and biological processes
- Systems Analysis & Synthesis
  - at all scales
  - tools to address dynamics, complexity, uncertainty, external factors

Old core does not integrate molecular concepts

Old core covers only macro to continuum, physical and chemical

Old core primarily tied to large scale chemical processes

The Frontier

Increasing emphasis in biology and integration

INFLOW	PRINCIPAL DEVELOPMENTS	OUTFLOW
Molecular engineering Systems analysis Biology Product …	**2015** DECADE XI Molecular transformations Multi-scale analysis Systems view **2005**	? …

2015

- The future is open – there is currently NO content in decade XI
- How do we chose to fill it?
  - Roll forward the engineering science paradigm
    - This is reductionist … no synthesis
    - Poor integration
    - Skills and attributes taught poorly or not at all
    - Schizophrenic faculty
    - A completely full curriculum
  - What new problems could our students solve and address with molecular engineering skills?
    - Is this a future worth pursuing?

Out of the Box Thinking

- Can we continue to take a bold look at the curriculum of the future
- Principles:
  - Education is preparation for life: it is more than intellectual development;
  - The value of fundamentals: a technical or professional education should be based on the fundamental principles;
  - Excellence and limited objectives: fit to needs of society, fit to concern with science and technology.

B.F. Skinner: “Education is what survives when what has been learned has been forgotten.”