

Separation Science and
Technology Education:
*A perspective from the interface of
chemistry and chemical engineering*

Susannah L. Scott

*Dept. of Chemical Engineering, and Dept. of Chemistry & Biochemistry
University of California, Santa Barbara*

Separation Science and Technology Education as a Convergence Platform for SusChEM
248th ACS National Meeting, San Francisco, August 2014

Hieronymus Brunschwig

Liber de Arte Distillandi

Strasbourg, 1512



THE ELEMENTS OF FRACTIONAL DISTILLATION

BY

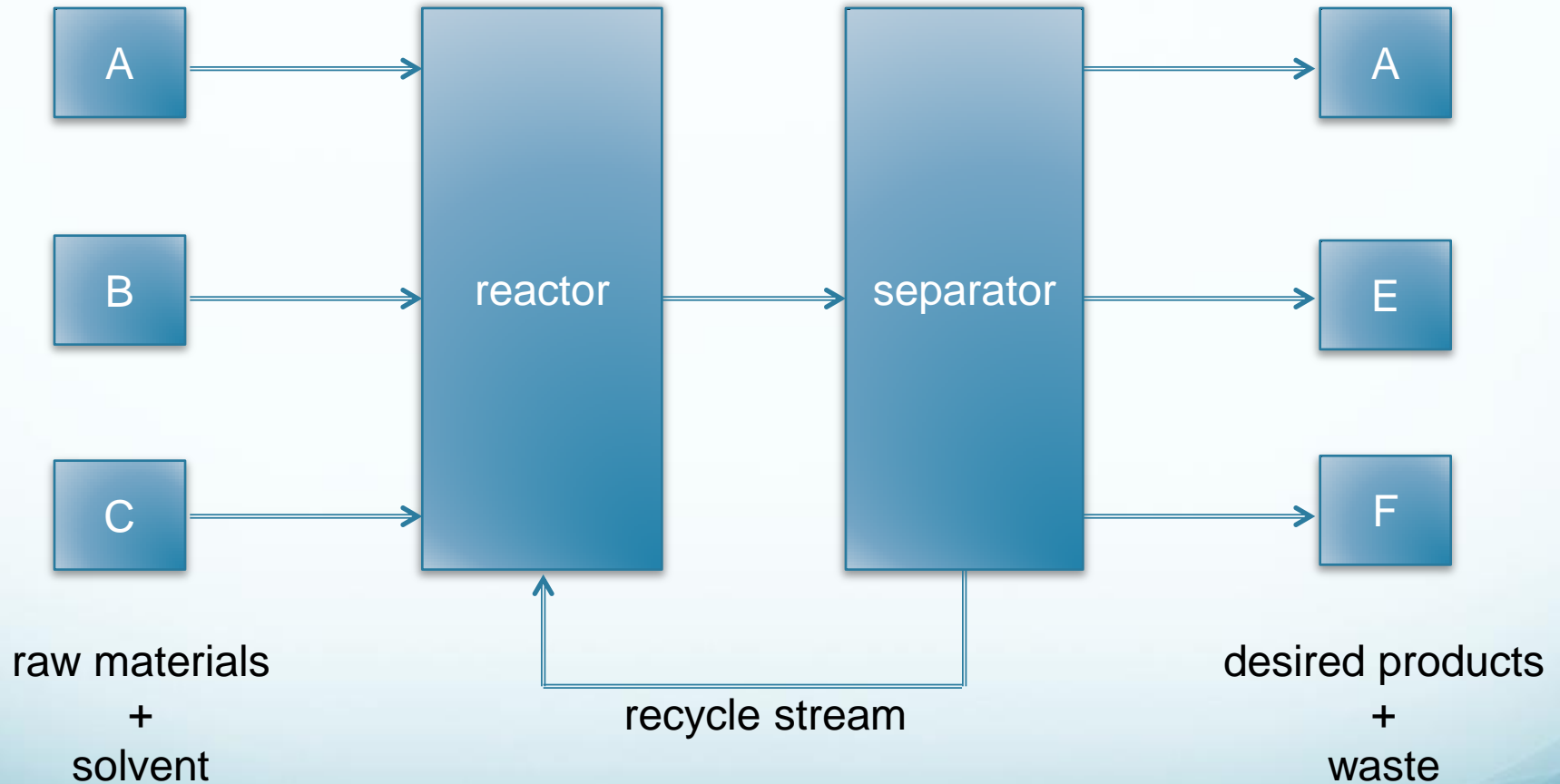
CLARK SHOVE ROBINSON

ASSISTANT PROFESSOR OF CHEMICAL ENGINEERING AT THE MASSACHUSETTS INSTITUTE
OF TECHNOLOGY, FORMERLY CHEMICAL ENGINEER WITH THE
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Unit Operations in Chemical Processing



Often taught without specific chemistry...

The Real World



Fractional distillation columns at an oil refinery

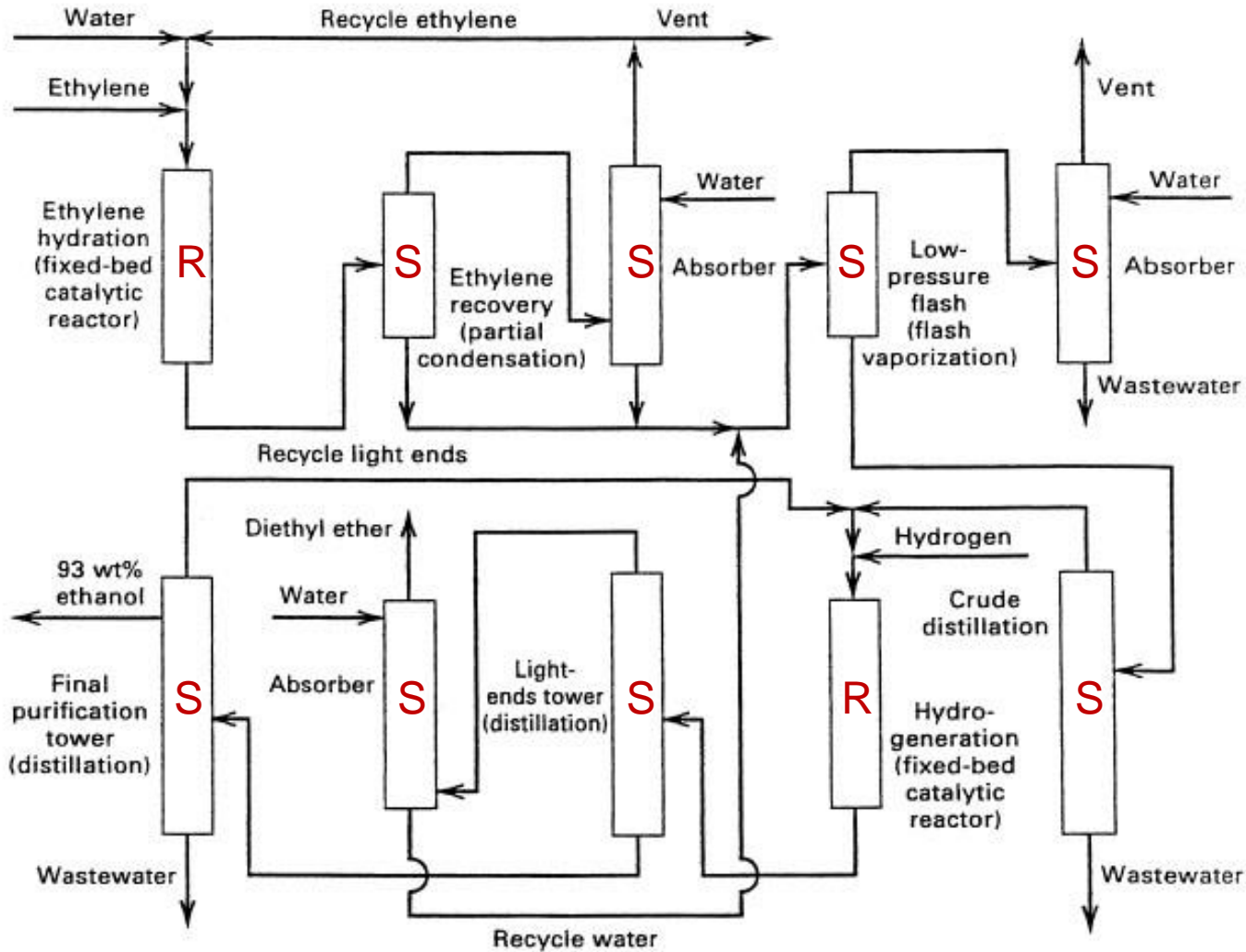


Spiral-wound membrane units at a water treatment plant

Why Is Separations Education Critical?

- Separations equipment can be **50 - 90 %** of the capital investment in a chemical plant.
- Separations can also represent **40 - 70 %** of operating costs.
- Purity requirements should meet (but not greatly exceed) user tolerance.

Process Diagram for Ethylene Hydration:



Why Are Separations Expensive?

- “Unmixing” requires a reduction in entropy; this is not spontaneous.
- It is achieved by addition of an external separating agent:
 - Energy (e.g., distillation)
 - Material (e.g., extraction)
 - Barrier (e.g., membrane)
 - Gradient (e.g., electrophoresis)

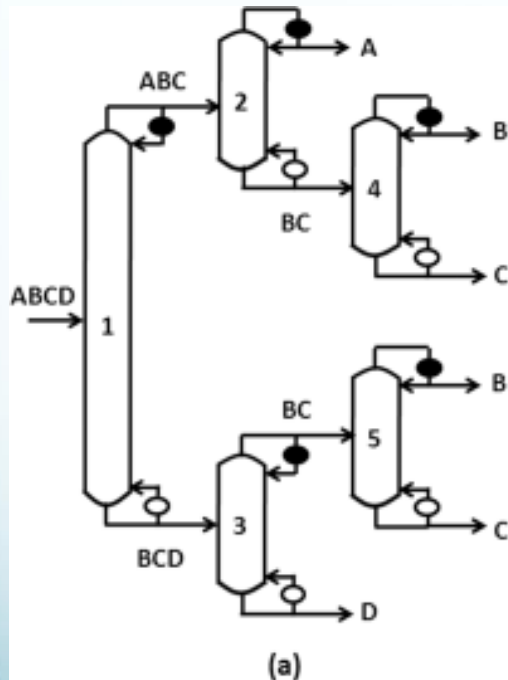
Research Funding → Educational Priorities

P. C. Wankat, "Separations: A short history and a cloudy crystal ball", *Chem. Engr. Educ.* **2009**, 43, 286.

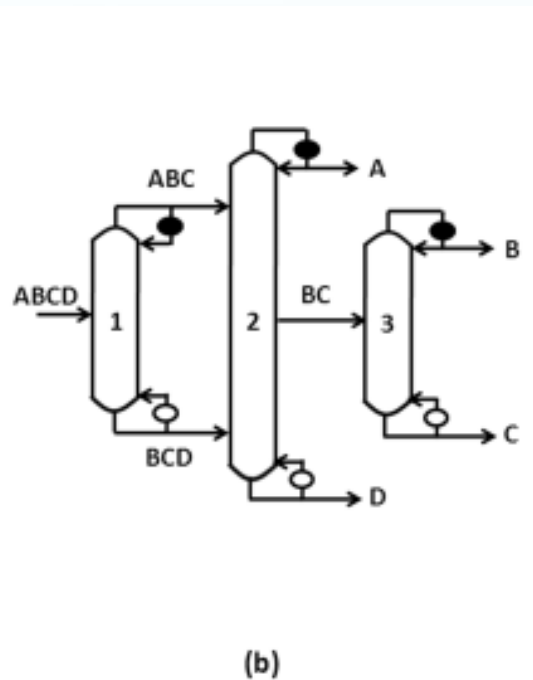
Technique	Research funding	Educational priority
Distillation	Anemic, despite dominant role in industry and importance of improved methods	Well-covered core topic
Membranes	Robust, despite slow adoption and suitability issues	Now entering textbooks
Chromatography	Modest, mainly as nanotech design and in biological applications	Weak
Mechanical separations	Very modest, mostly for particulates	Not considered core
Crystallization	Practically non-existent	Practically non-existent
Extraction	(Not described)	Not accessible in time-impacted curriculum

New Energy-Saving Configurations for Multicomponent Distillation

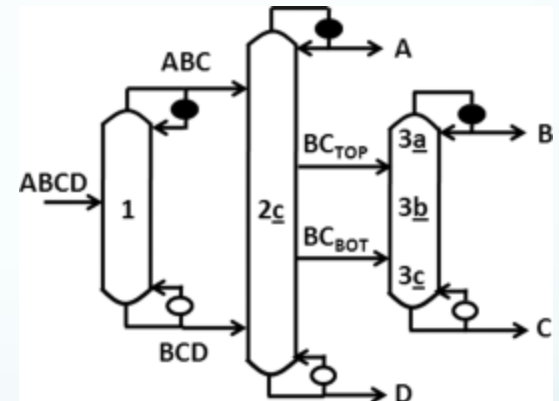
conventional



consolidation of transfer streams



multiple intermediate exchange streams



Separations in Chemistry

Best grad schools, US News and World Report, 2014

Analytical Chemistry

Purdue

UNC-Chapel Hill

UI Urbana-Champaign

UT Austin

Indiana University – Bloomington

University of Wisconsin – Madison

University of Michigan – Ann Arbor

University of Florida

University of Arizona

University of Washington

Chemistry Overall

CalTech

MIT

UC Berkeley

Harvard

Stanford

UI Urbana-Champaign

Northwestern

Scripps

University of Wisconsin - Madison

Columbia

Top Chemistry Departments Emphasize...

- **Caltech:** Chemical synthesis and catalysis, chemical dynamics and reaction mechanisms, biochemistry, bioinorganic, bioorganic, and biophysical chemistry, and materials chemistry.
- **MIT:** Biological chemistry, environmental chemistry, inorganic chemistry, organic chemistry, materials chemistry, nanoscience, and physical chemistry
- **Berkeley: Analytical & bioanalytical**, chemical biology, environmental chemistry, green chemistry, inorganic & organometallic, materials, polymers & nanoscience, nuclear, organic, physical, theoretical

Green Chemistry Principles

1. Pollution Prevention at Source
2. Atom Economy
3. Less Hazardous Chemical Synthesis
4. Designing Safer Chemicals
5. Safer Solvents and Auxiliaries
6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
8. Reduce the Use of Derivatives
9. Catalysis
10. Design for Degradation
11. Real-time Analysis
12. Inherently Safer Chemistry

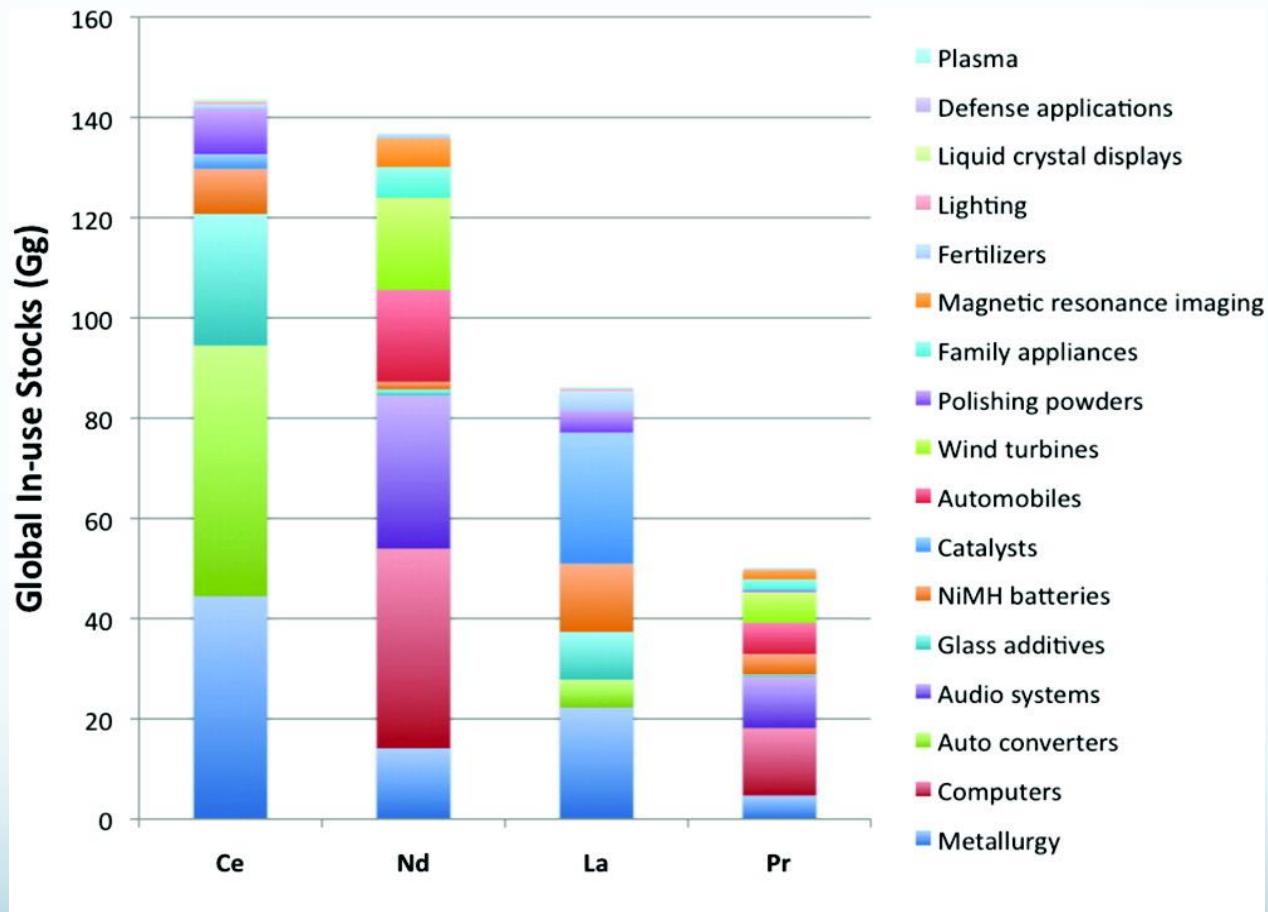
Anastas and Warner, *Green Chemistry: Theory and Practice*, **1998**

Green Engineering Principles

1. Inherent rather than Circumstantial
2. Prevention instead of Treatment
- 3. Design for Separation**
4. Maximize Efficiency
5. Output-Pulled vs. Input-Pushed
6. Conserve Complexity
7. Durability rather than Immortality
8. Meet Need, Minimize Excess
- 9. Minimize Materials Diversity**
10. Integrate Material and Energy Flows
11. Design for Commercial “Afterlife”
12. Renewable rather than Depleting

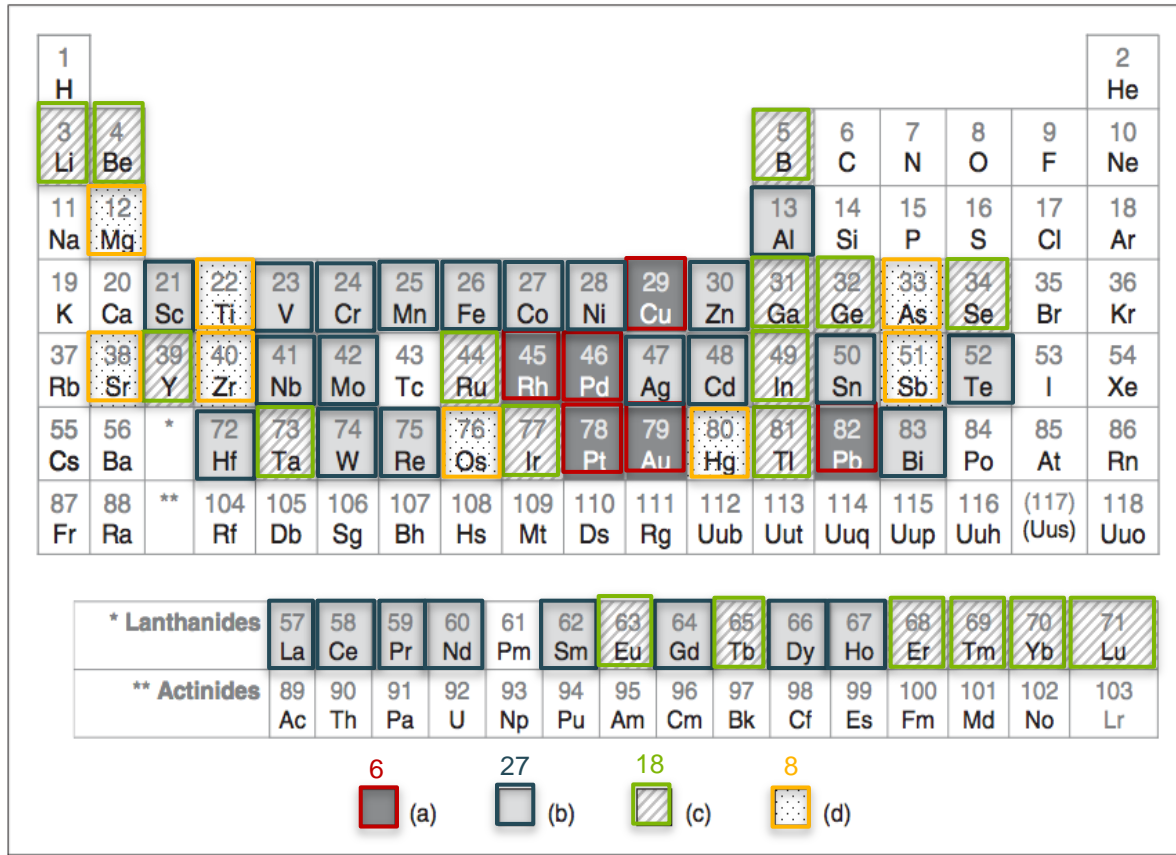
Anastas and Zimmerman, *Env. Sci. Technol.* **2003**, 37, 94.

Global In-Use Stocks of Rare Earth Elements



X. Du, T. E. Graedel, *Environ. Sci. Technol.*, **2011**, *45*, 4096

Recycling potential of metals in urban stocks



Legend:

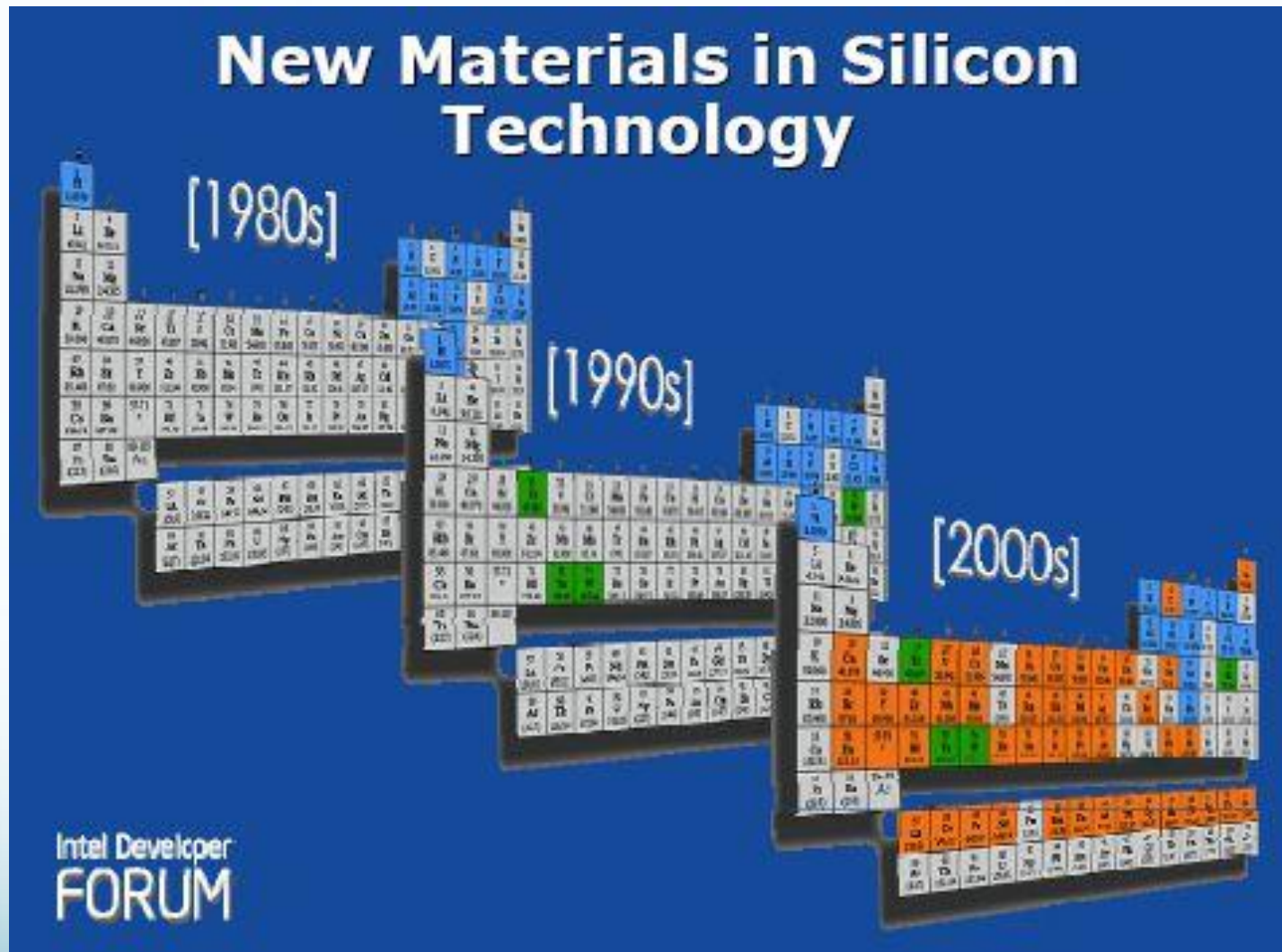
(a) relatively easy to recycle;

(b) used in multicomponent alloys, so recycling is likely only in alloy form;

(c) used in highly mixed assemblages for which recycling is difficult;

(d) predominant uses are dissipative, so little or no recovery is possible.

Element Proliferation



Design for disassembly

ELEMENTS OF A SMARTPHONE

ELEMENTS COLOUR KEY: ● ALKALI METAL ● ALKALI EARTH METAL ● TRANSITION METAL ● GROUP 13 ● GROUP 14 ● GROUP 15 ● GROUP 16 ● HALOGEN ● LANTHANIDE

SCREEN



Indium tin oxide is a mixture of indium oxide and tin oxide, used in a transparent film in the screen that conducts electricity. This allows the screen to function as a touch screen.



The glass used on the majority of smartphones is an aluminosilicate glass, composed of a mix of alumina (Al_2O_3) and silica (SiO_2). This glass also contains potassium ions, which help to strengthen it.



A variety of Rare Earth Element compounds are used in small quantities to produce the colours in the smartphone's screen. Some compounds are also used to reduce UV light penetration into the phone.

BATTERY



The majority of phones use lithium ion batteries, which are composed of lithium cobalt oxide as a positive electrode and graphite (carbon) as the negative electrode. Some batteries use other metals, such as manganese, in place of cobalt. The battery's casing is made of aluminium.

ELECTRONICS



Copper is used for wiring in the phone, whilst copper, gold and silver are the major metals from which microelectrical components are fashioned. Tantalum is the major component of micro-capacitors.



Nickel is used in the microphone as well as for other electrical connections. Alloys including the elements praseodymium, gadolinium and neodymium are used in the magnets in the speaker and microphone. Neodymium, terbium and dysprosium are used in the vibration unit.



Pure silicon is used to manufacture the chip in the phone. It is oxidised to produce non-conducting regions, then other elements are added in order to allow the chip to conduct electricity.



Tin & lead are used to solder electronics in the phone. Newer lead-free solders use a mix of tin, copper and silver.

CASING



Magnesium compounds are alloyed to make some phone cases, whilst many are made of plastics. Plastics will also include flame retardant compounds, some of which contain bromine, whilst nickel can be included to reduce electromagnetic interference.

2014 COMPOUND INTEREST - WWW.COMPOUND-CHEM.COM

Design for recycling

The polymer content of an average vehicle has more than tripled since 1970, from 32 to 114 kg today.

About 10 million vehicles are scrapped each year. The plastic parts are shredded into “fluff” which is more expensive to landfill or recycle (\$10-35 per ton) than to buy new (\$7 per ton).

A major technical obstacle to plastics recycling is a quick and inexpensive way to identify and separate them.

Hopewell, J., Dvorak, R., & Kosior, E.. Plastics recycling: challenges and opportunities. *Phil. Trans. Roy. Soc. B*, 2009.



Critical Educational Needs

- Funding agencies need to support core research areas to promote expert teaching
- Universities need to re-engage chemists in separations, and promote dialog between chemists and chemical engineers through cross-teaching
- Instructors need to promote systems-level thinking about materials and processes in design courses
- Curriculum needs to include life-cycle assessment (to encourage design for recycling)