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

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

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Strasbourg, 1512

THE ELEMENTS
OF
FRACTIONAL DISTILLATION

BY

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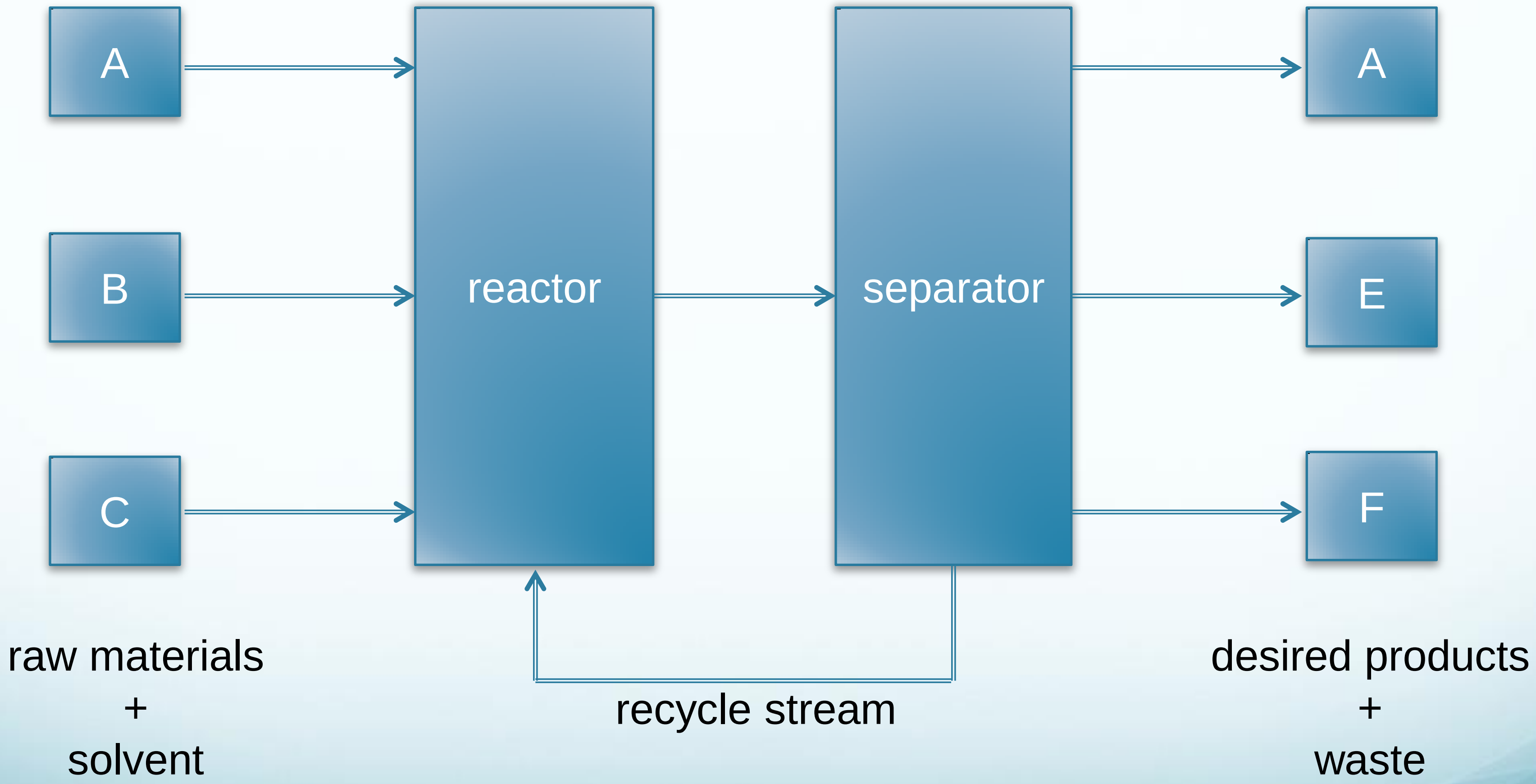
Unit Operations in Chemical Processing



Often taught without specific chemistry…

The Real World

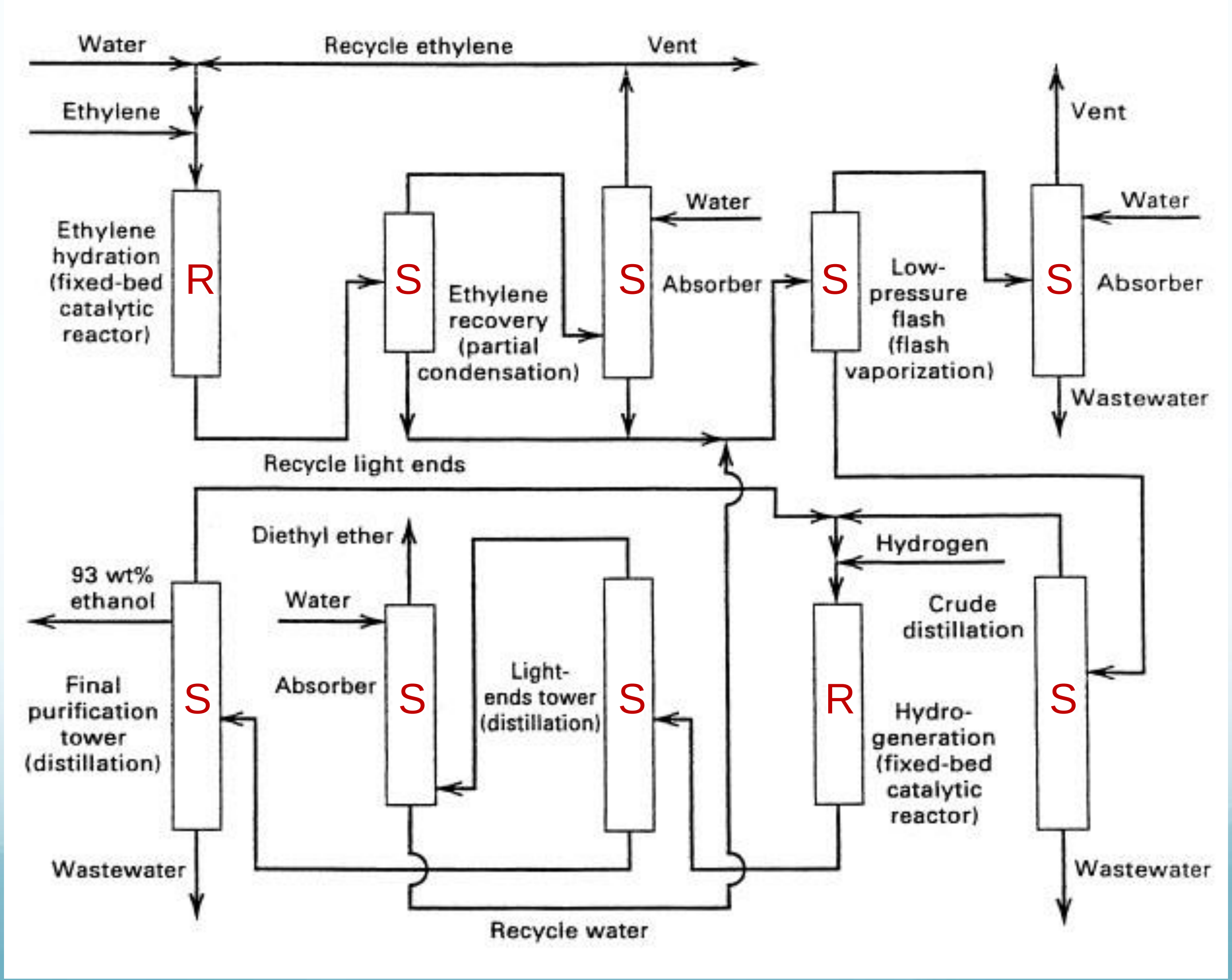
Fractional distillation columns at an oil refinery

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: $C_2H_4 + H_2O \rightarrow C_2H_5OH$



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.

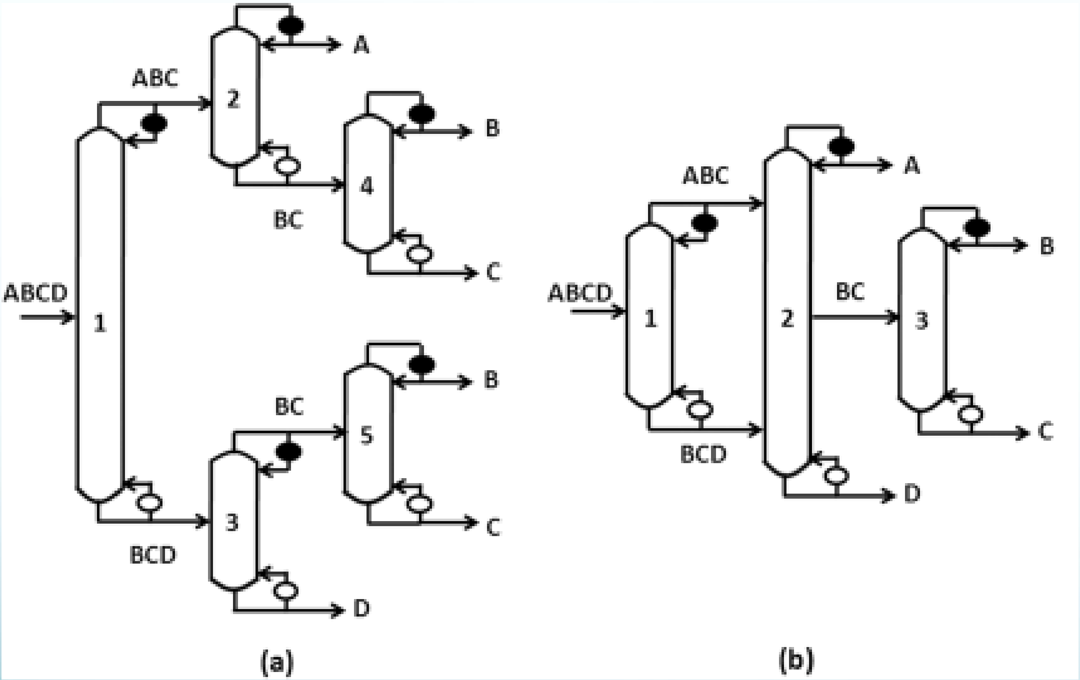
Technique	Research funding	Educational priority
Distillation	Anemic, despite dominant role in industry and importance of improved methods	Well-covered core topic
Membranes	Robust, despite slow adoption and suitability issues	Now entering textbooks
Chromatography	Modest, mainly as nanotech design and 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

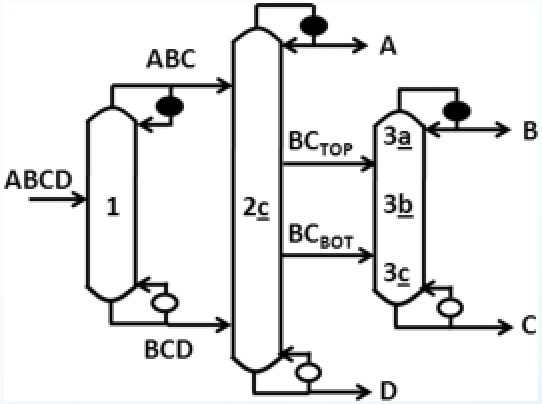
New Energy-Saving Configurations for Multicomponent Distillation

conventional

consolidation of transfer streams

multiple intermediate exchange streams





G. M. Ramapriya, M. Tawarmalami, R. Agarwal, *AIChE J.* **2014**, *60*, 191.

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

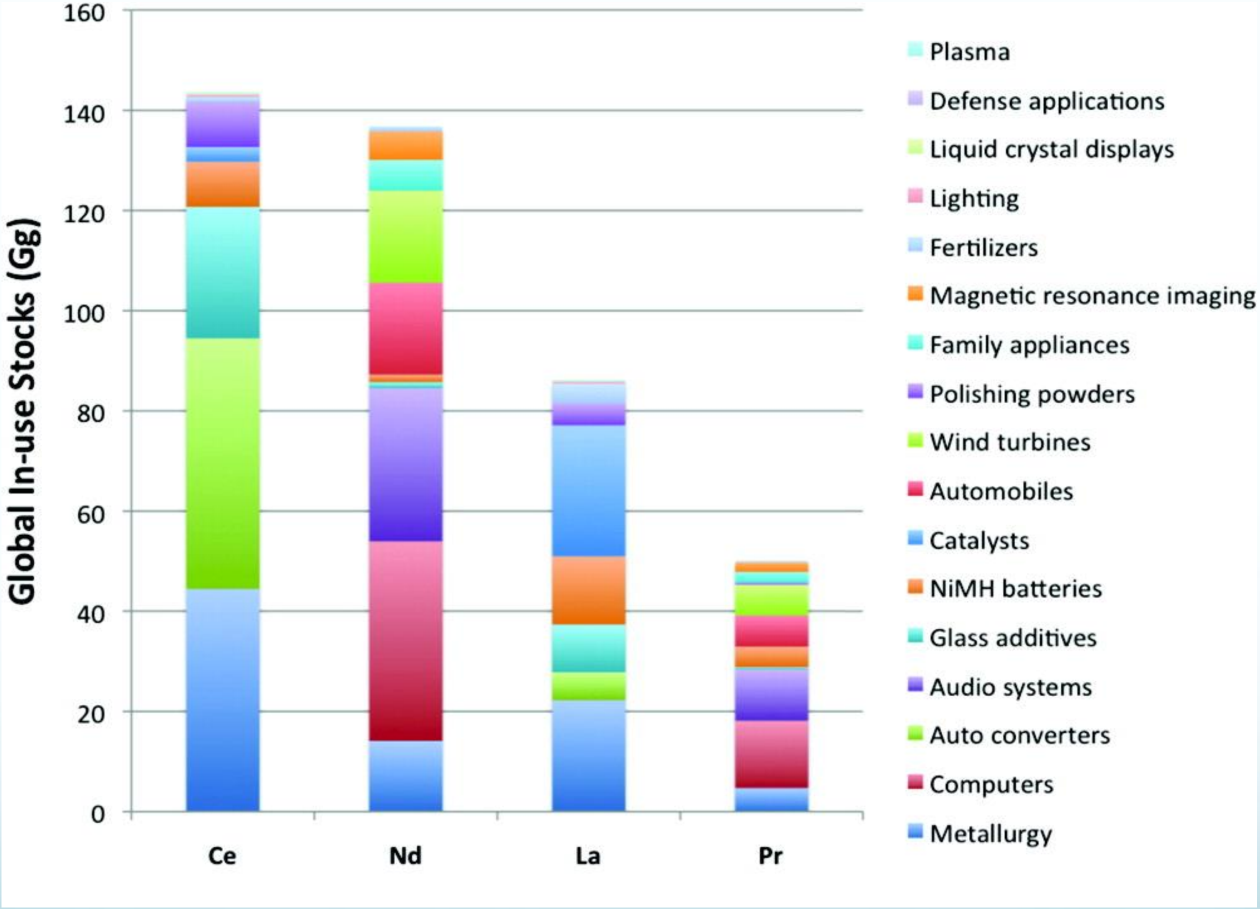
Anastas and Warner, Green Chemistry: Theory and Practice, **1998**

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

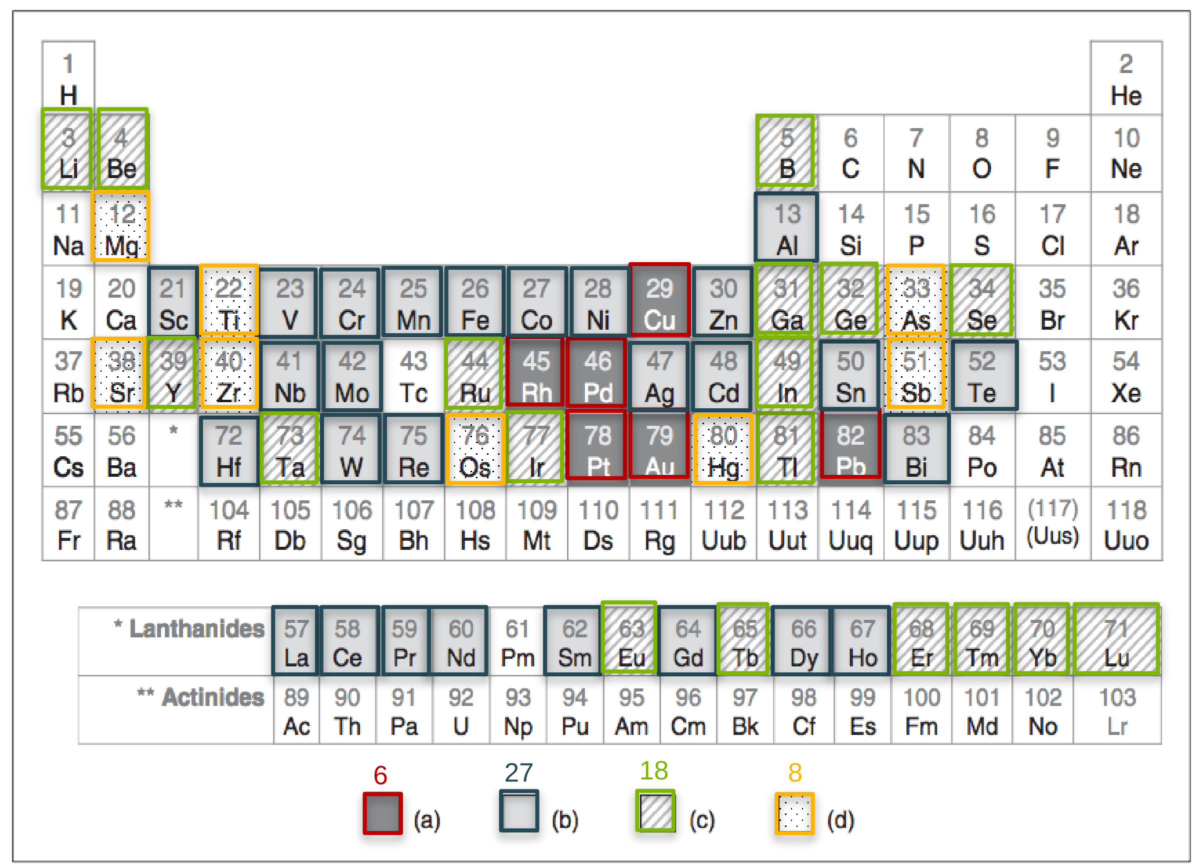
Anastas and Zimmerman, *Env. Sci. Technol.* **2003**, *37*, 94.

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;

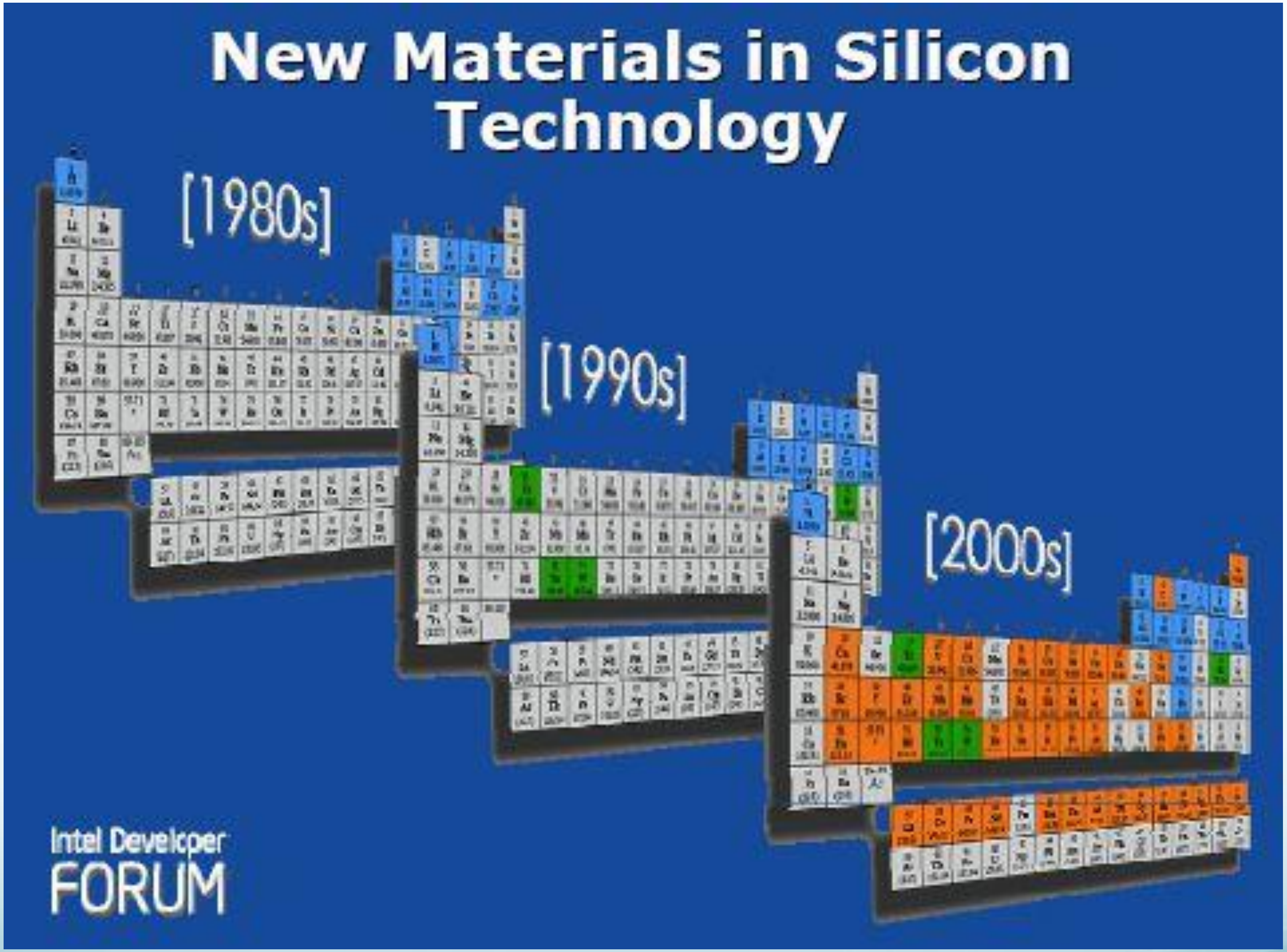
(b) used in multicomponent alloys, so recycling is likely only in alloy form;

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

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

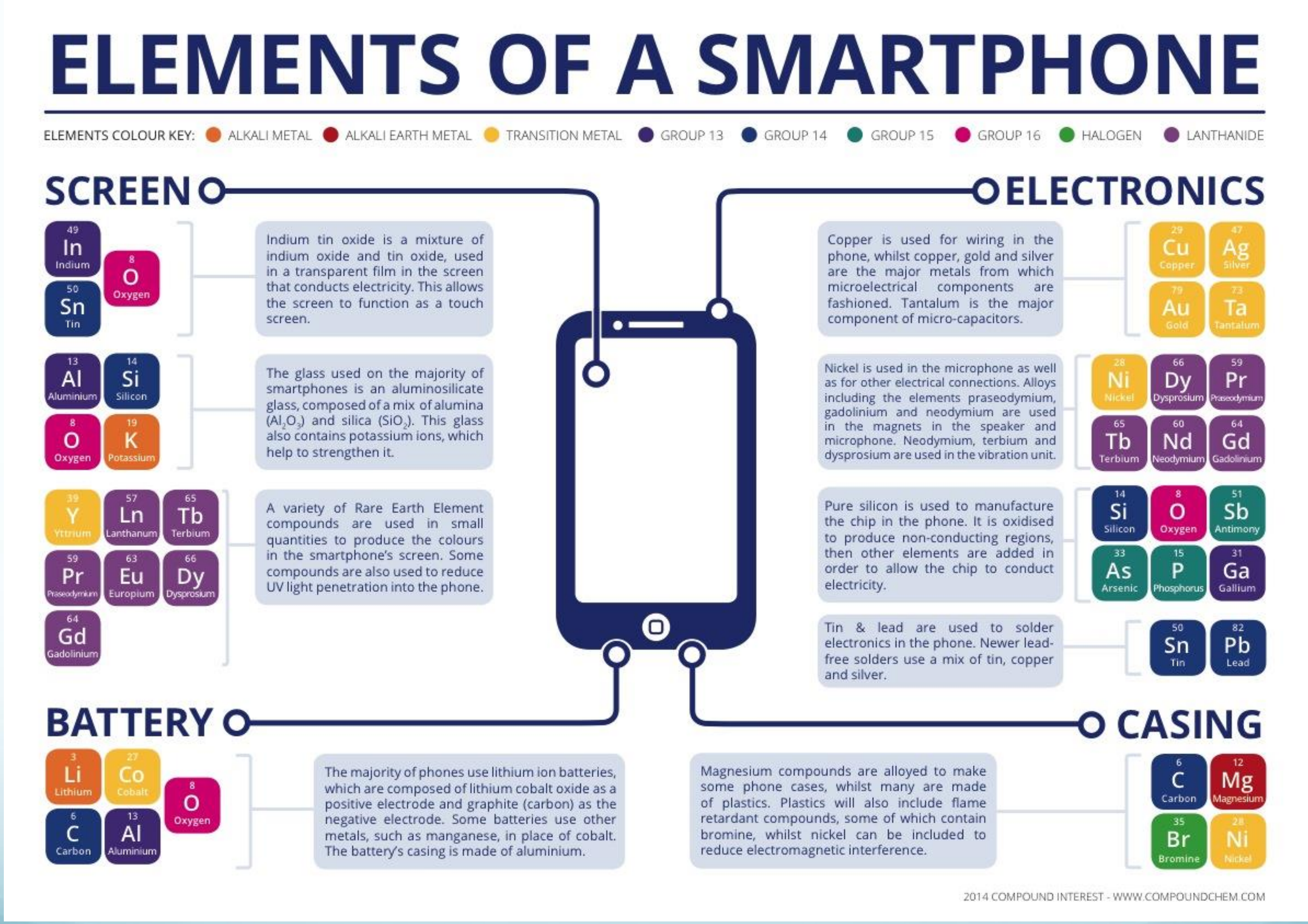
Graedel, The Bridge: Linking Engineering and Society, 2011.

Element Proliferation



http://www.digital-daily.com/cpu/intel_penryn/index2.htm

Design for disassembly



http://www.compoundchem.com/2014/02/19/the-chemical-elements-of-a-smartphone/

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)