

Eliminating Supply Risks, Enabling Energy Technologies

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1 H Hydrogen 1.00794																	2 He Helium 4.003						
3 Li Lithium 6.941	4 Be Beryllium 9.012182																	5 B Boron 10.81	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050																	13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.06	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938045	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80						
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29						
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98039	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)						
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (264)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 Ds Darmstadtium (269)	111 Rg Roentgenium (272)	112 Cn Copernicium (277)												

From Mines Through Science To Manufacturing

58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.05	71 Lu Lutetium 174.967
90 Th Thorium 232.0381	91 Pa Protactinium 231.03688	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

CMI Overview

- What: Research to reduce supply risks for materials essential to clean-energy technologies; up to \$120 million over 5 years
- Why: To remove impediments to technology development and deployment, to accelerate innovation
- How: Develop technologies to (a) increase & diversify supply and (b) reduce demand
- Who: A consortium of 18 institutions

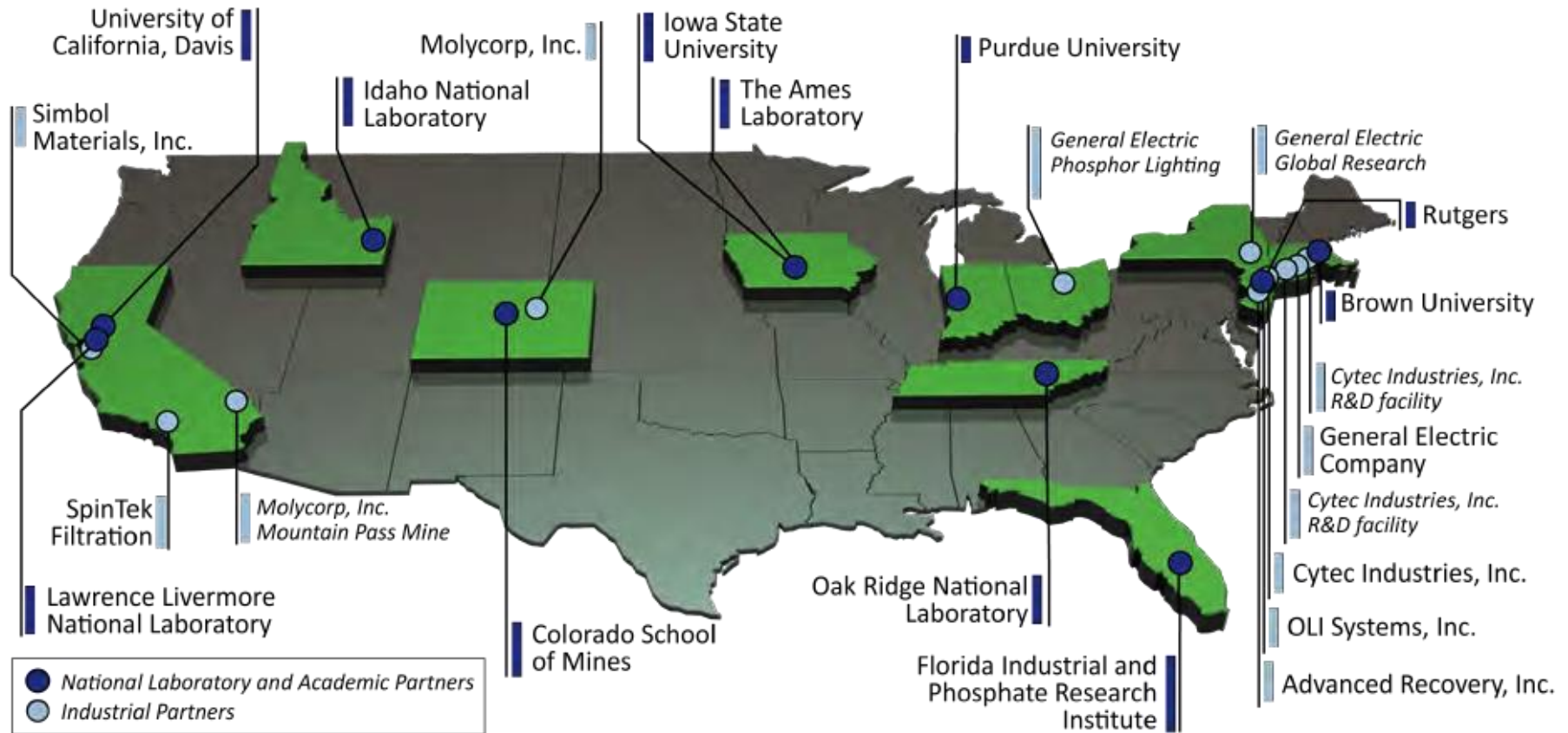


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The CMI Partnership



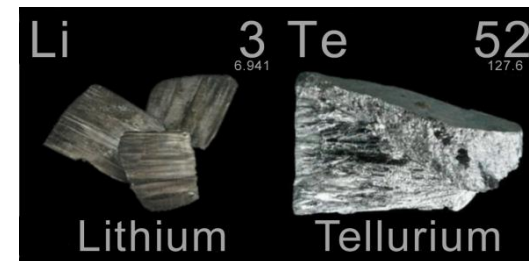
What is a “Critical Material”?

- Any substance used in technology that is subject to supply risks, for which there are no easy substitutes
- Or, stuff you really need but can't always get
- What is 'critical depends on who, where and when you ask
- For CMI: clean-energy technologies, in the U.S., over the next 10 to 15 years

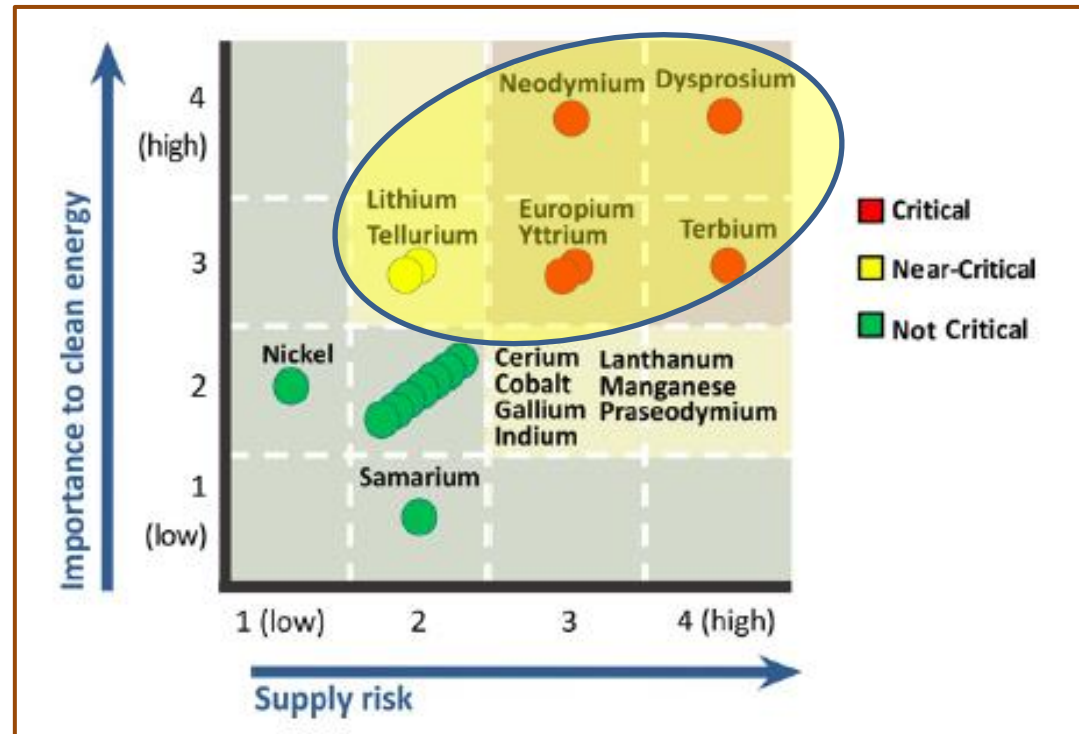
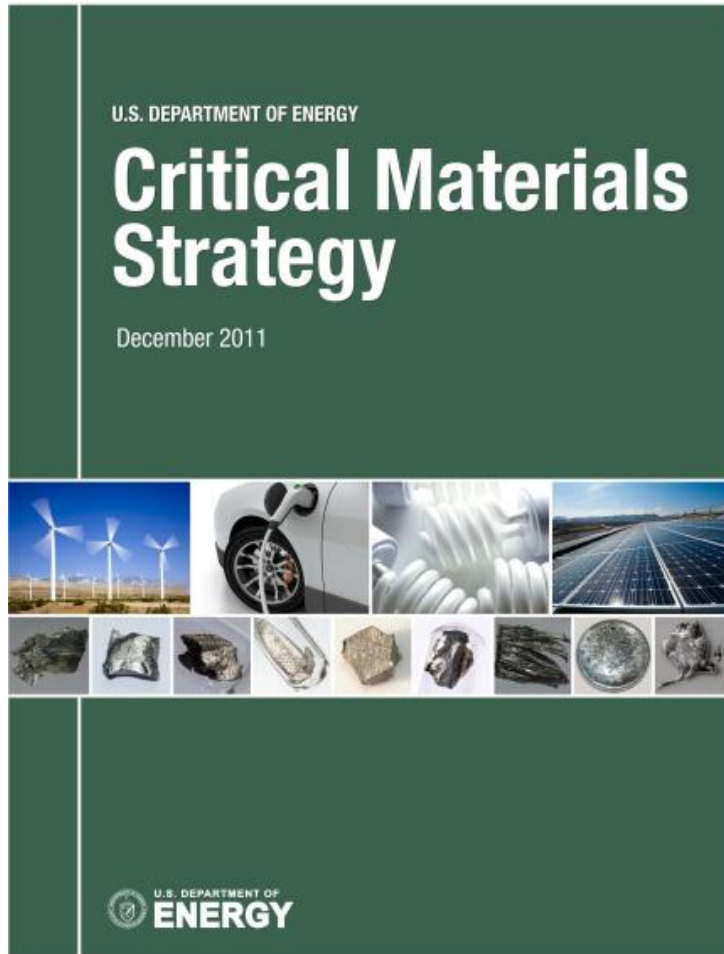


Initial CMI Focus

- 7 elements
- 4 technologies
 - magnets
 - phosphors
 - batteries
 - photovoltaic materials



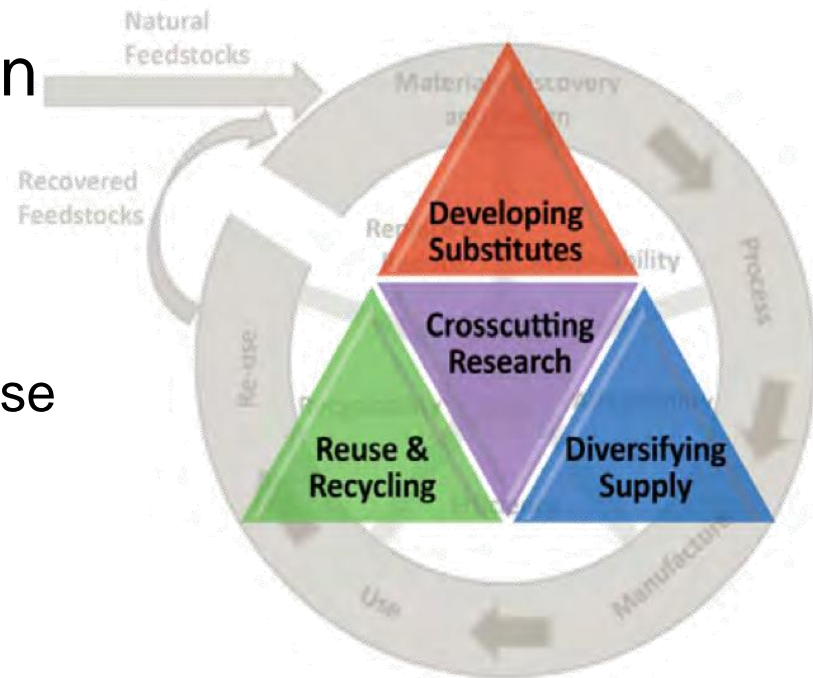
Implementing DOE's *Critical Materials Strategy*



Medium Term: 2015 – 2025

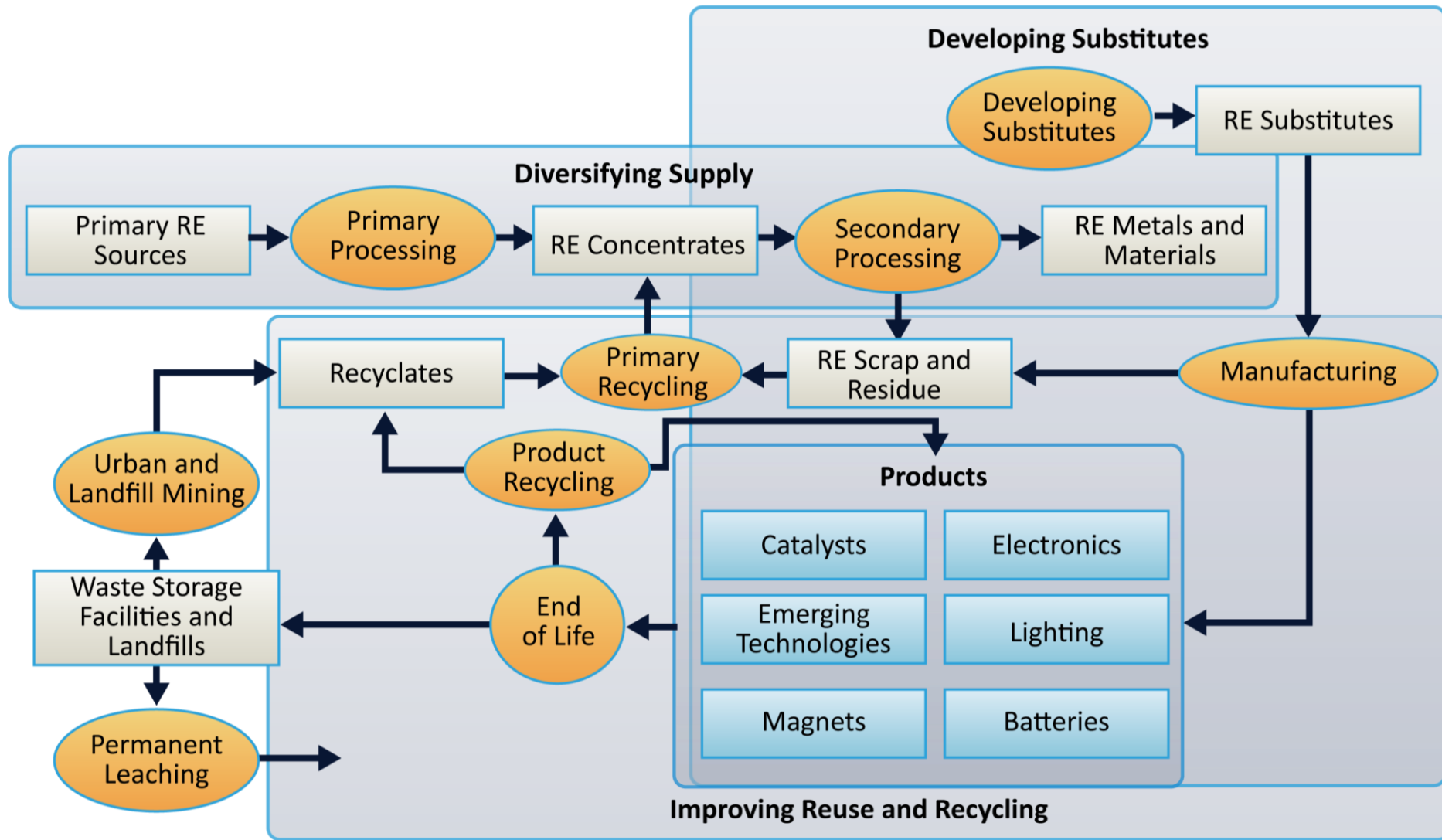
“Produce more, use less”

- Research across the supply chain to:
 - Diversify global supply chains
 - Develop substitute materials
 - Enhance recycling, reuse and efficient use of materials
 - Support the activities above



...but not *ALL* of these in *EVERY* case!

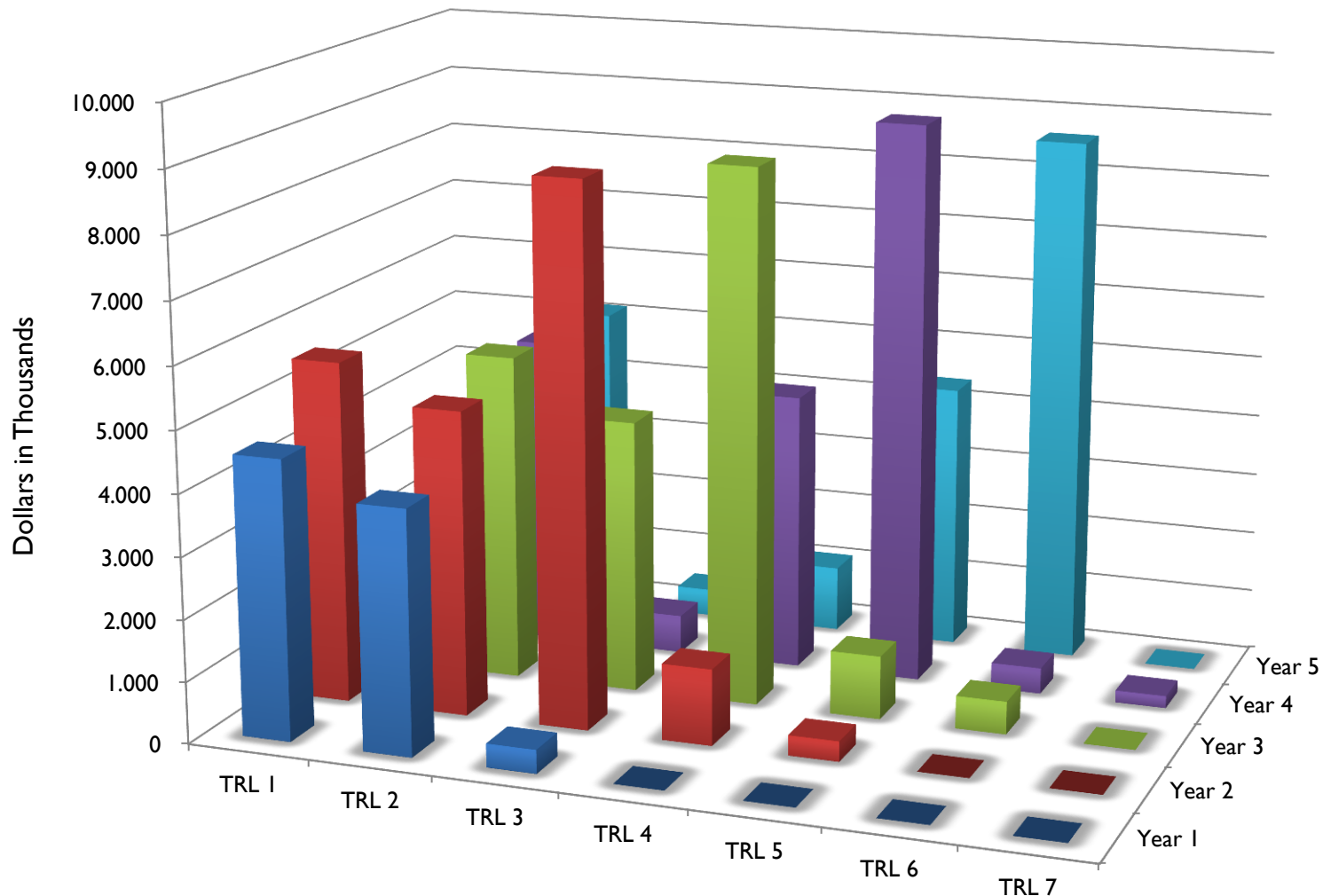
Supply Chain and Economic Analysis



Project selection & management

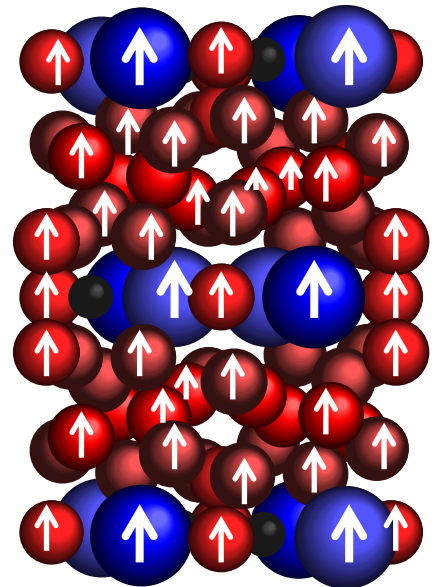
- 35 initial projects, selected on the basis of . . .
 - Industry need
 - Realistic timeframe
 - Opportunities for multi-institution collaboration
 - Clear path to deployment
- Annual evaluation (milestones, deliverables)
- Projects will be terminated (failure to meet milestones, or the world changes)

Progressing Toward Deployment: Budget Distribution by Technology Readiness Levels

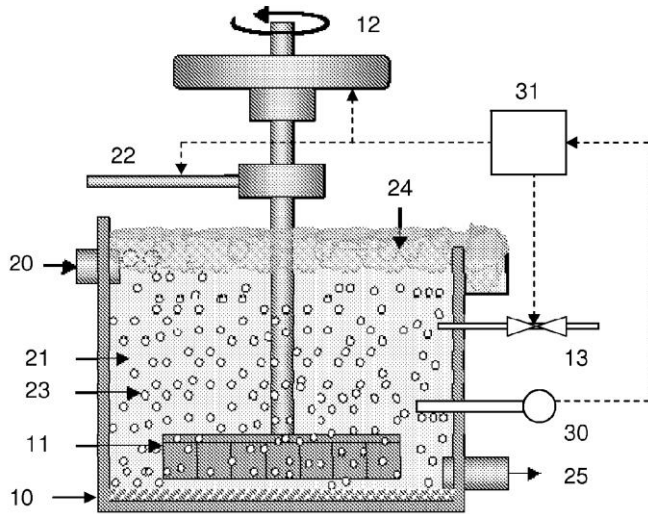


Neodymium

- Used for high-performance magnets
- Traditional uses:
 - Hard disk drive spindle motors
 - Portable electronics - loudspeakers & microphones
 - Small motors in vehicles
- Emerging uses:
 - Traction motors in electric vehicles
 - Wind turbine generators



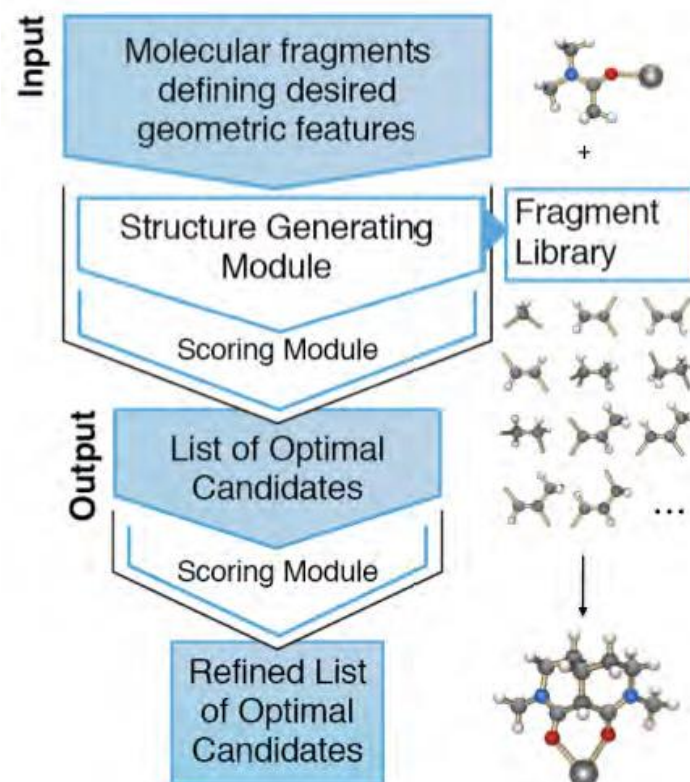
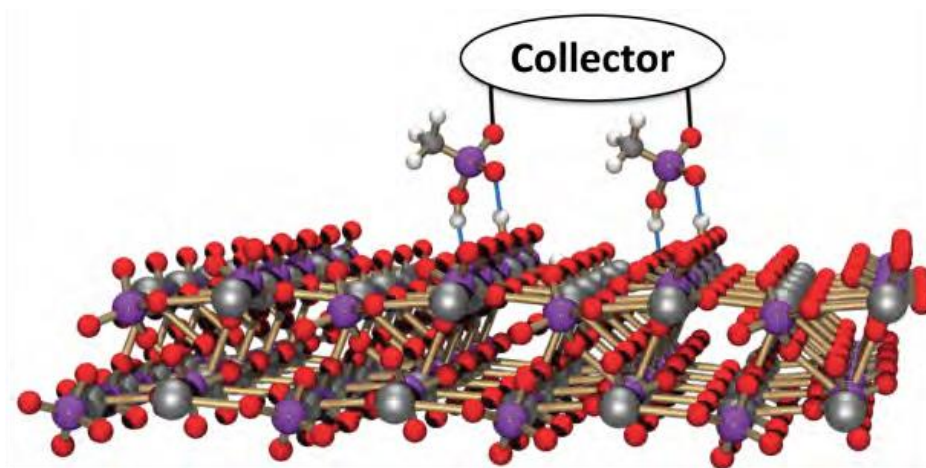
Classical Froth Flotation



- Separates valuable ore from the associated gangue.
- Concentrates bastnaesite, but not monazite.
- Monazite contains more of the higher-value heavy rare earths, but currently goes to the tailings heap.

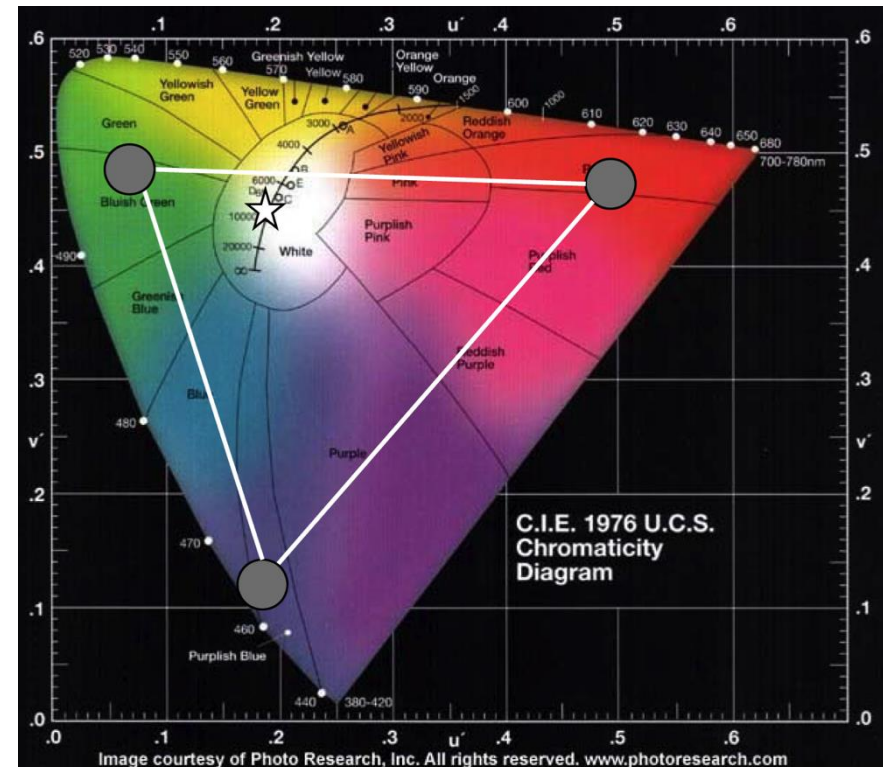
Quantum Froth Flotation

- Solution: find collector molecules that bind monazite to air bubbles
- Quantum chemistry computations at Ames and Oak Ridge
- Pilot-scale testing at Idaho
- US-based chemical manufacturers
- Deployment to US mines

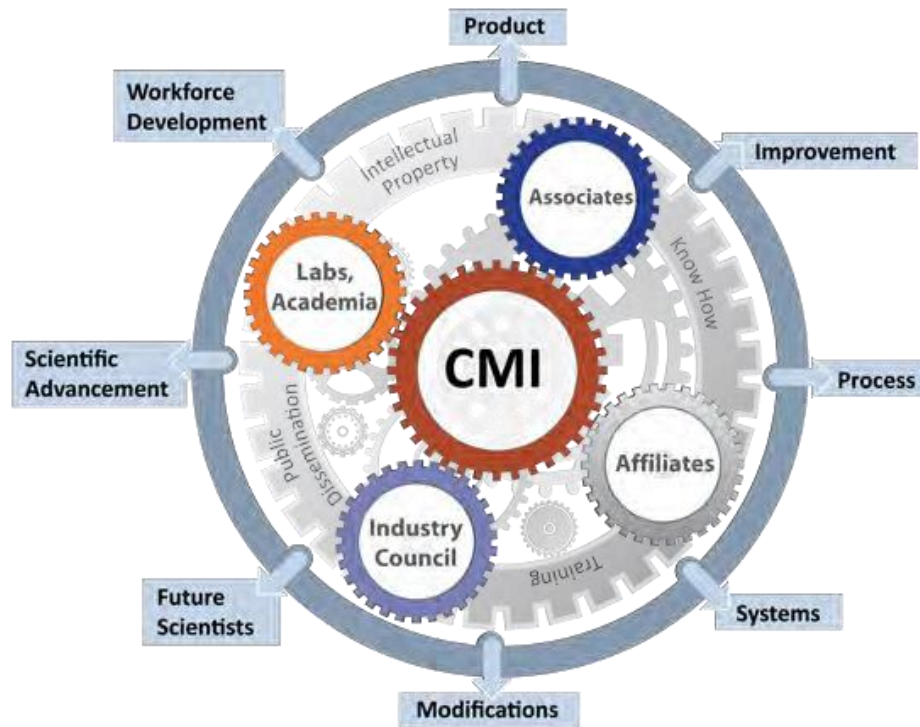


Terbium & Europium

- Provide green and red light emission
- Traditional uses:
 - CRTs
 - Long-tube fluorescent lamps
 - Flat panel color displays and TVs
- Current uses:
 - Compact fluorescent lamps
 - Personal electronics
- Future uses:
 - LED lighting
 - OLED displays

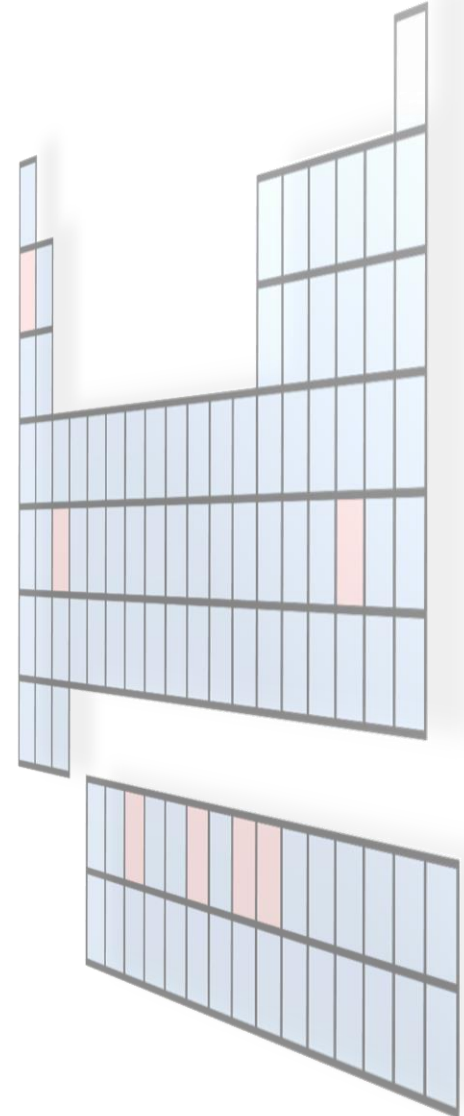


CMI's Integrated Approach



CMI Today and in the Future

- Mantra: eliminate supply risks, enable energy technologies
- How?
 - Innovate to produce more, use less
 - Develop the next generation of scientists and technical experts
 - Anticipate rather than respond to material-supply crises
- Finally: develop mutually beneficial international collaborations





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