

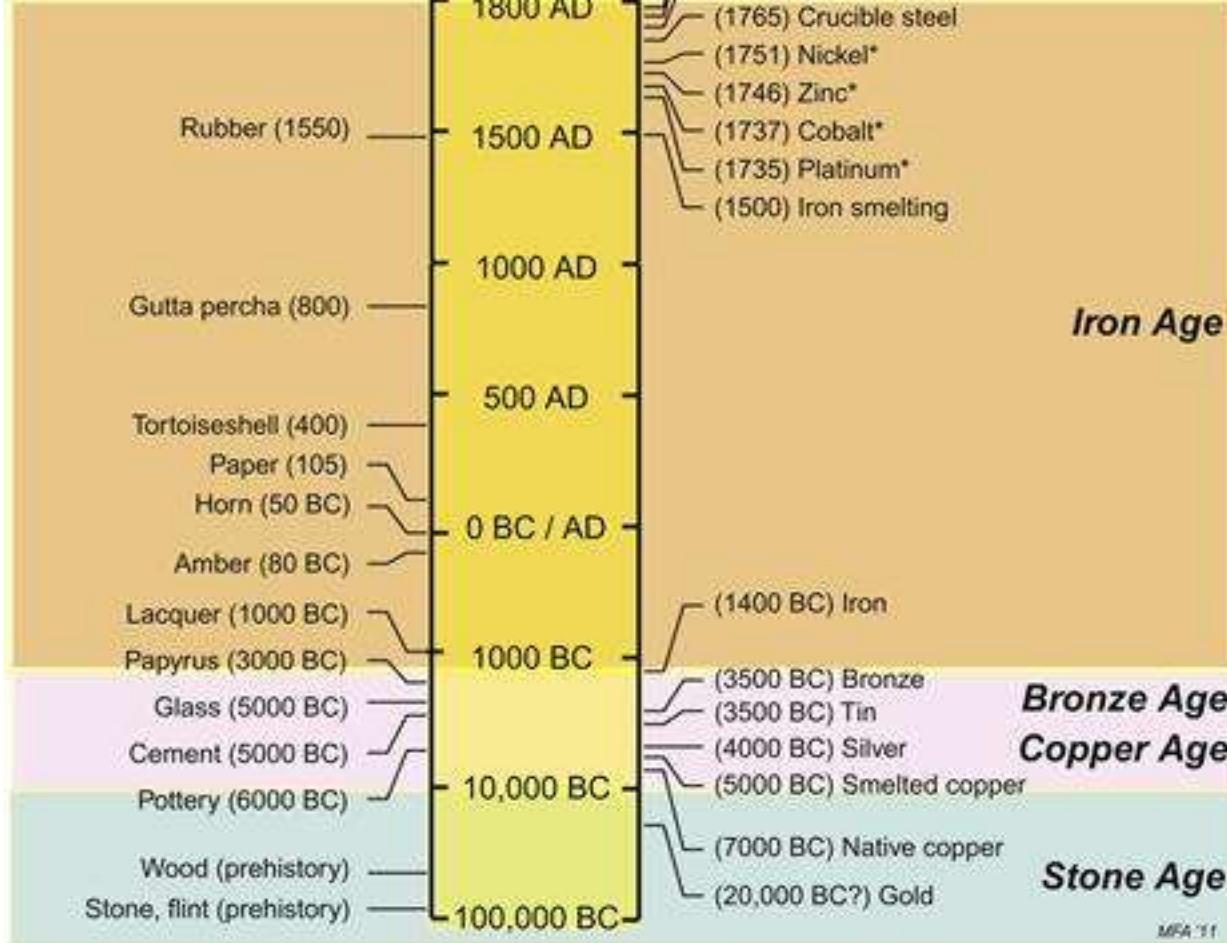
Materials Unit: Critical Materials

CEE 1610/2610: Engineering and Sustainable Development

Special THANK YOU to Cassie Thiel!

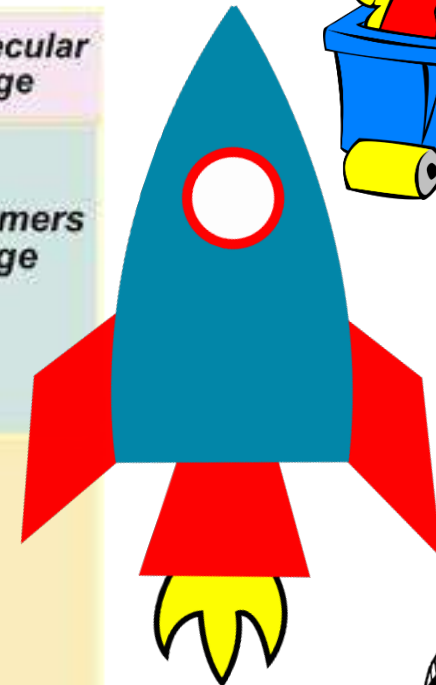
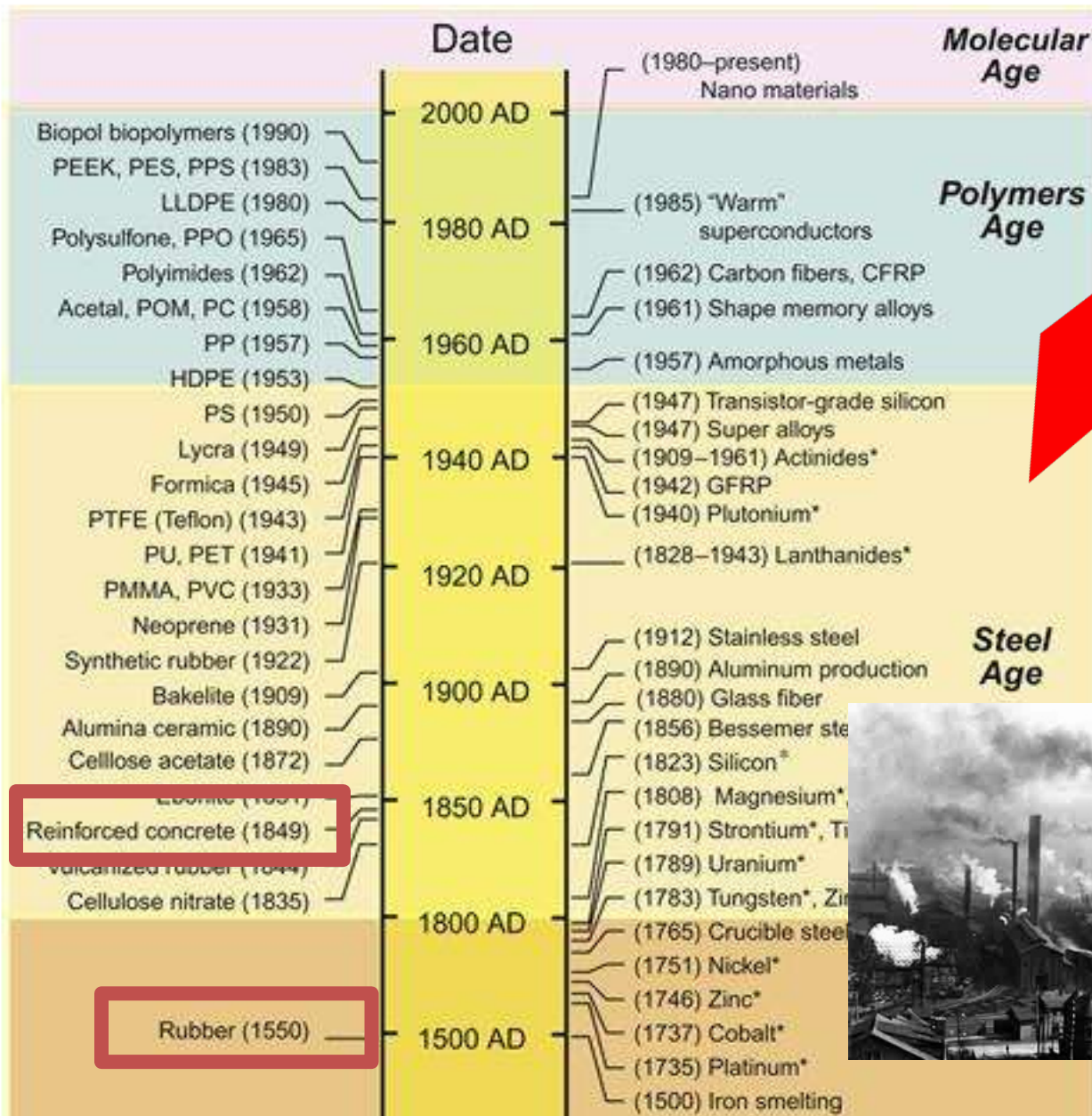
How do we

USE MATERIALS?

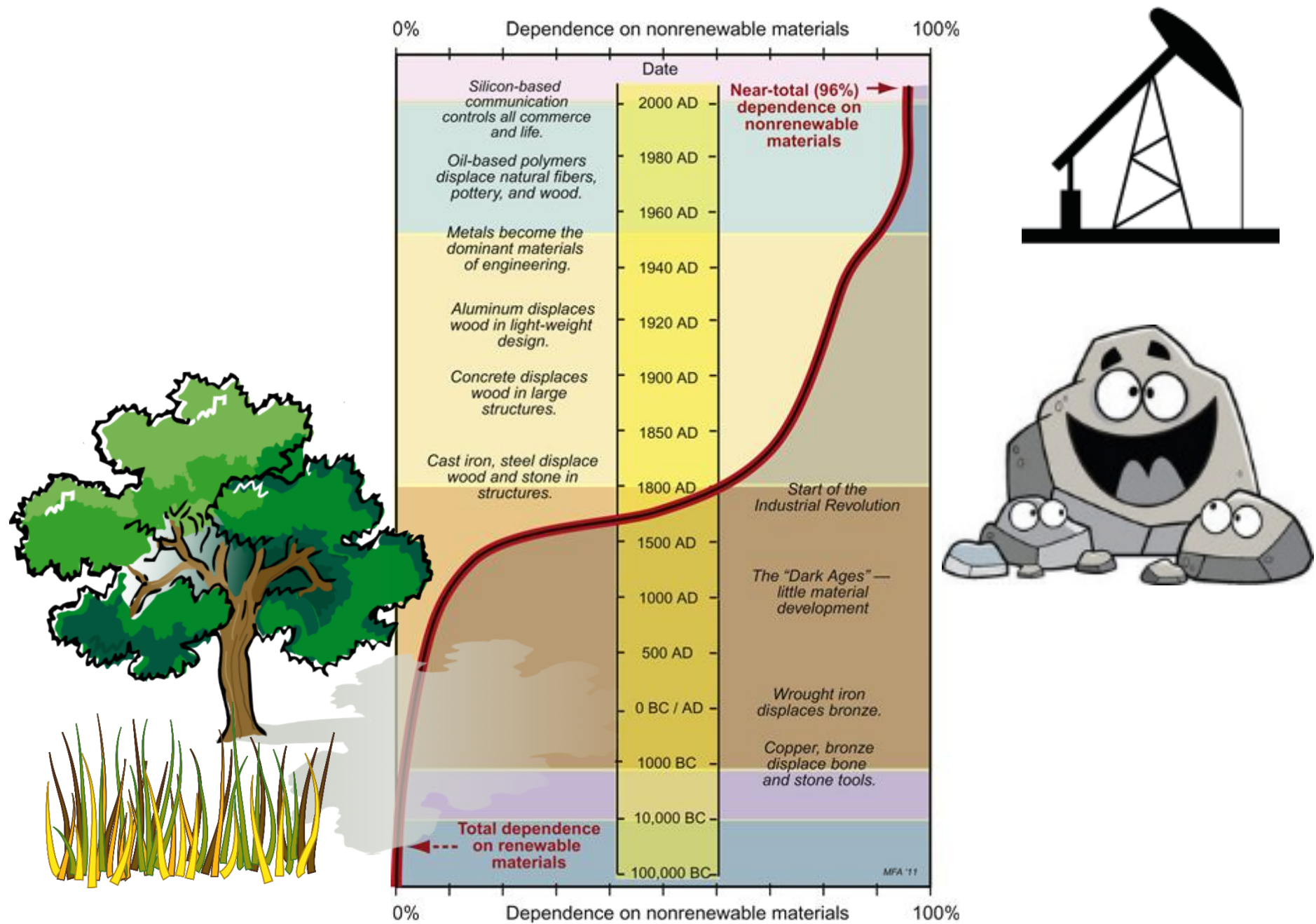


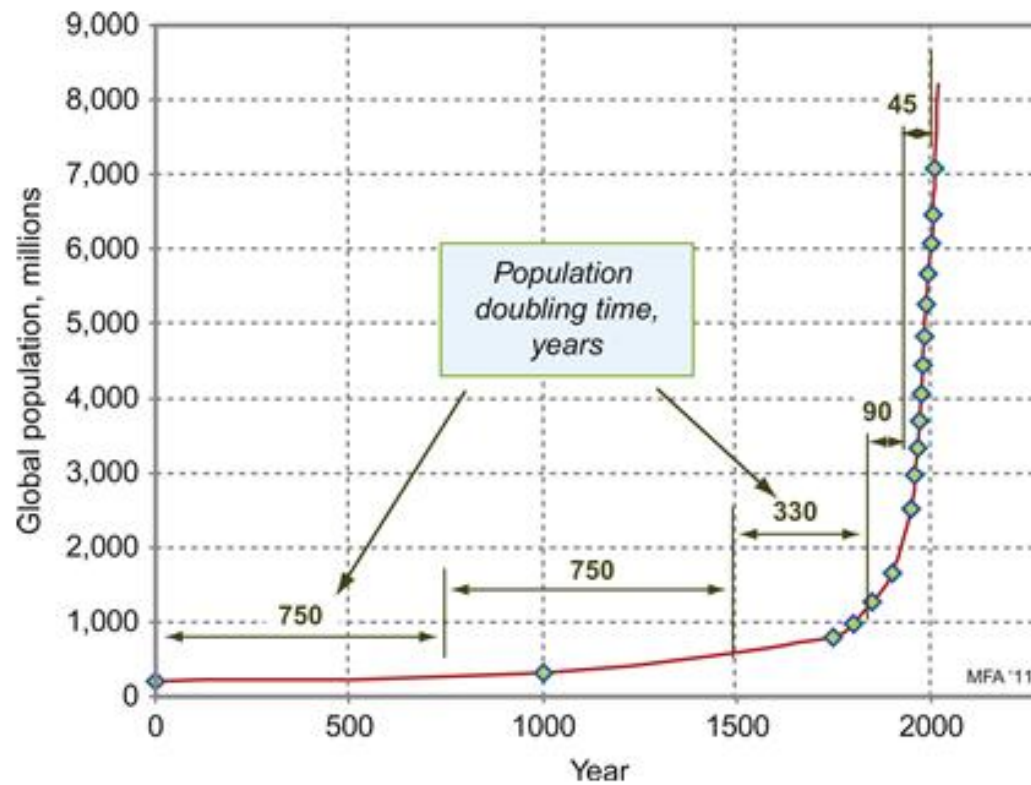
SOURCE: *Materials and the Environment: Eco-Informed Material Choice* Book by Michael F. Ashby

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SOURCE: battleofhomestead.org





What We'll Cover in the Materials Unit

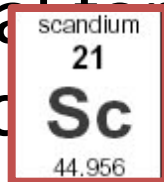
- Critical Materials (in the molecular age)
- Material Flow Assessment
- Life Cycle Thinking
- Perspective and Summary

What is a

CRITICAL MATERIAL?

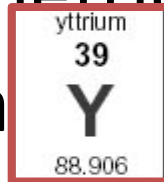
Rare Earth Elements (REEs)

- Critical for functionality in a wide variety of applications (not a large market volumetrically)

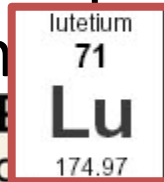


Make up <0.1% of earth's crust

- China produces 95% of the world's REEs, just widely dispersed
 - China produced 130,000 tons of rare earth minerals in 2010 (USGS)



Actually quite common, just widely dispersed



China, the largest producer of rare-earth minerals, is accused of unfairly restricting its exports. Top countries by reserves:

lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
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U.S.	13		0
India	3.1		0.003
Australia	1.6		0

Note: U.S. and Australia plan to boost production; Source: USGS

The Wall Street Journal

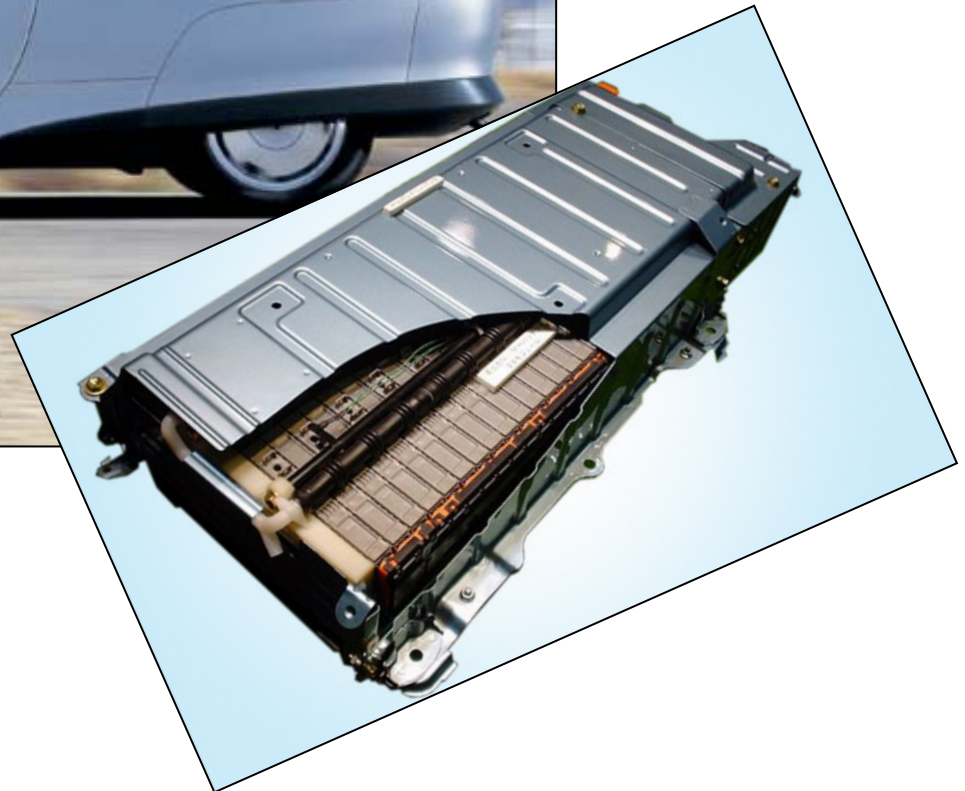
<http://online.wsj.com/article/SB10000872396390443437504577546772533972202.html>

Why do

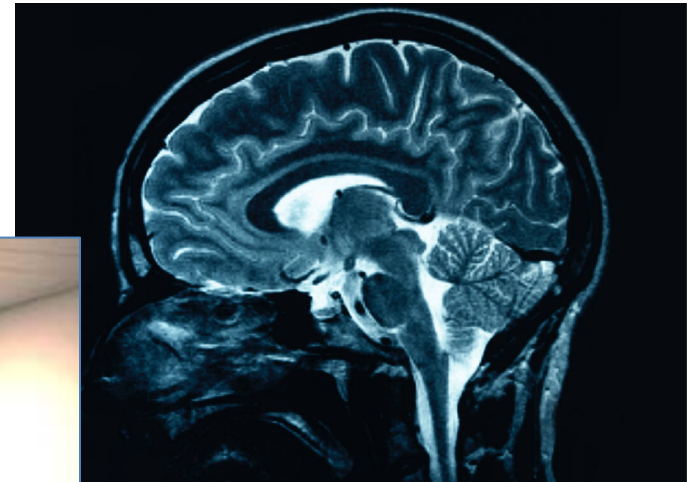
CRITICAL MATERIALS

matter?











Most of the new technologies we rely on
to improve our energy consumption and live more sustainably

CONTAIN CRITICAL MATERIALS.

Beyond that, they are
present in many everyday objects.

What are the

CONCERNS

with critical materials?

Let's Look at TWO Examples

Neodymium (Viewpoint: USDOE)

Helium (Viewpoint: Scientists)

Neodymium (Viewpoint: USDOE)												Helium (Viewpoint: Scientists)						
hydrogen 1 H 1.0079												helium 2 He 4.0026						
lithium 3 Li 6.941	beryllium 4 Be 9.0122											boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180	
sodium 11 Na 22.990	magnesium 12 Mg 24.305											aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948	
potassium 19 K 39.098	calcium 20 Ca 40.078	scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80	
rubidium 37 Rb 85.468	strontium 38 Sr 87.62	yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29	
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 ★	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 ★ ★	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnium 110 Uun [271]	ununium 111 Uuu [272]	ununbium 112 Uub [277]	ununquadium 114 Uuq [289]					

lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

* Lanthanide series

** Actinide series

Viewpoint: US Department of Energy

- In their “2011 Critical Materials Strategy” report, the DOE identified 16 elements as critical for future energy technologies
- They are especially concerned about: dysprosium, terbium, europium, yttrium, and neodymium

Table 1. Materials in Clean Energy Technologies and Components

	Photovoltaic Films	Wind Turbines	Vehicles		Lighting
MATERIAL	Coatings	Magnets	Magnets	Batteries	Phosphors
Rare Earth Elements	Lanthanum			•	•
	Cerium			•	•
	Praseodymium	•	•	•	
	Neodymium	•	•	•	
	Europium				•
	Terbium				•
	Dysprosium	•	•		
	Yttrium				•
	Indium	•			
	Gallium	•			
	Tellurium	•			
	Cobalt			•	
	Lithium			•	
	Manganese			•	
	Nickel			•	

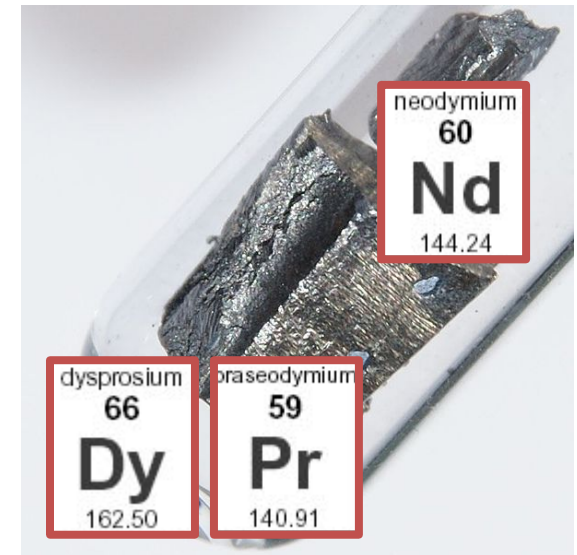
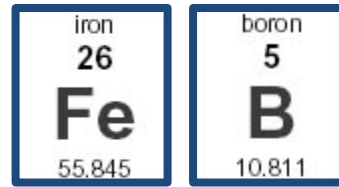
DOE, 2011

Example:

Permanent Magnets

Compact, high-strength magnets made of rare earth elements

- Developed in 1970s and 80s
- Strongest type of permanent magnet (1.4 teslas)
 - Compared to 0.5 – 1.0 teslas of ferrite or ceramic magnets
- Strongest PM is made of **NEODYMIUM**
 - “Neodymium-iron-boron” NIB magnets
 - Substitute **DYSPROSIUM** and **PRASEODYMIUM** for the neodymium
- Used in
 - Hard drives, speakers, electric generators (wind turbines), and motors (power tools to cars – **ESPECIALLY electric cars**)



<http://www.hitachi.com/environment/showcase/>

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Environmental Activities

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[Site Top](#) > [Eco-Highlights](#) > [Products and Services](#) > [Materials](#) > NEOMAX® Neodymium Rare Earth Permanent Magnet

NEOMAX® Neodymium Rare Earth Permanent Magnet



**NEOMAX® Boosts Performance and Lower Weight of Electric Motors
A Significant Factor for Reducing CO2 Emissions**

Magnets play an essential role in the modern world, being used in our applications such as the speakers in mobile phones and the electric motors in hybrid cars, air conditioners and washing machines. The NEOMAX® rare earth neodymium magnets first released in 1982* have become world leader magnets with magnetism approximately ten times that of a ferrite magnet. They help electric motors smaller and more efficient, and help reduce CO2 emissions.

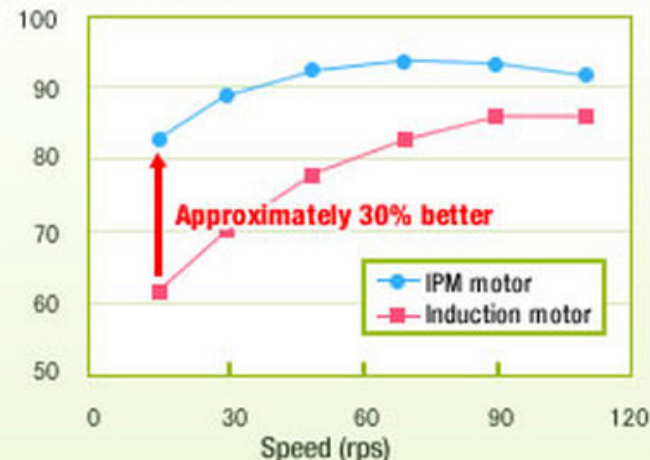
* Developed by Sumitomo Special Metals Co., Ltd. in 1982. Merged with Hitachi in April 2007.

(Updated in

Comparison of Efficiency of IPM Motor and Induction Motor *3

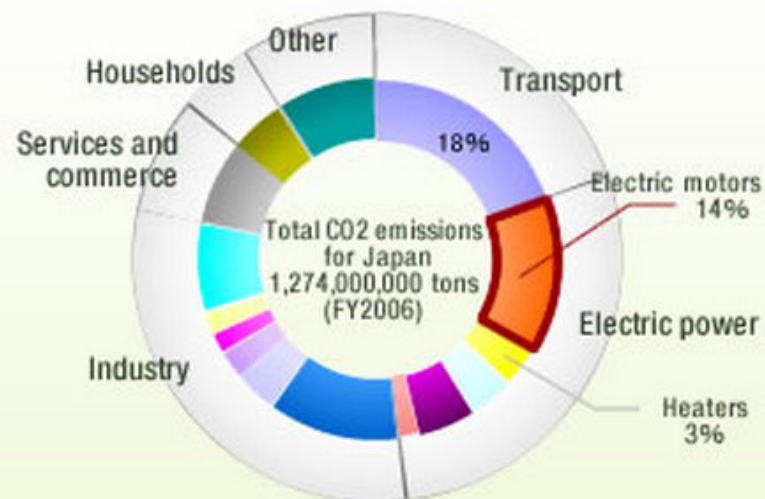
IPM = Interior Permanent Magnet

Motor Efficiency(%)



*3 Journal of the Institute of Electrical Engineers of Japan D, Vol.118-D, No.6 p.813 (June 1998)

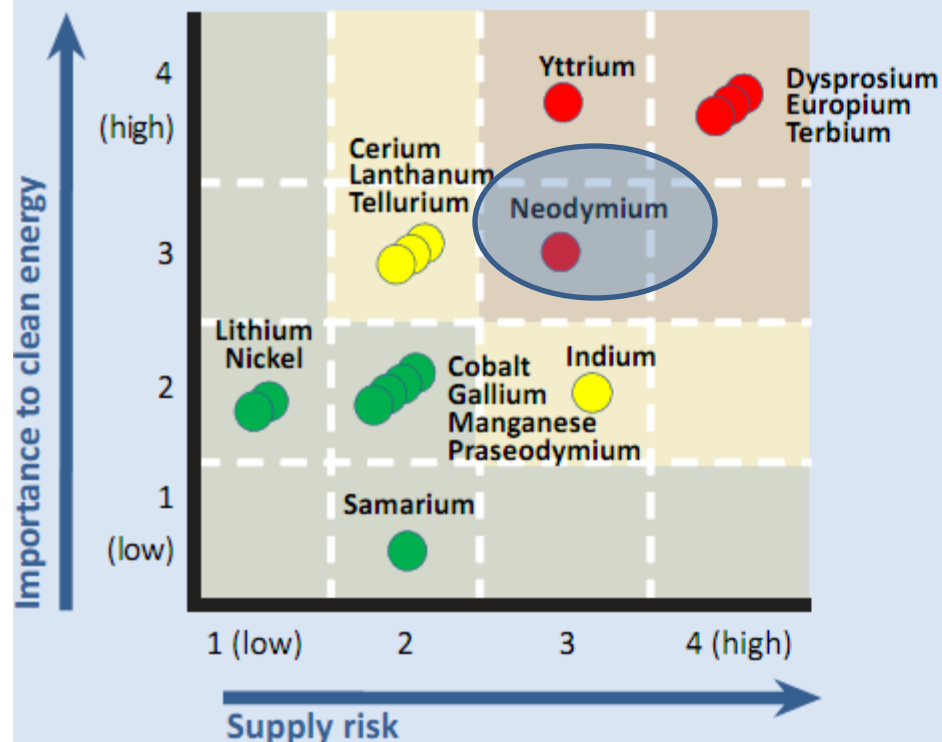
Emissions of Greenhouse Gases by Japan



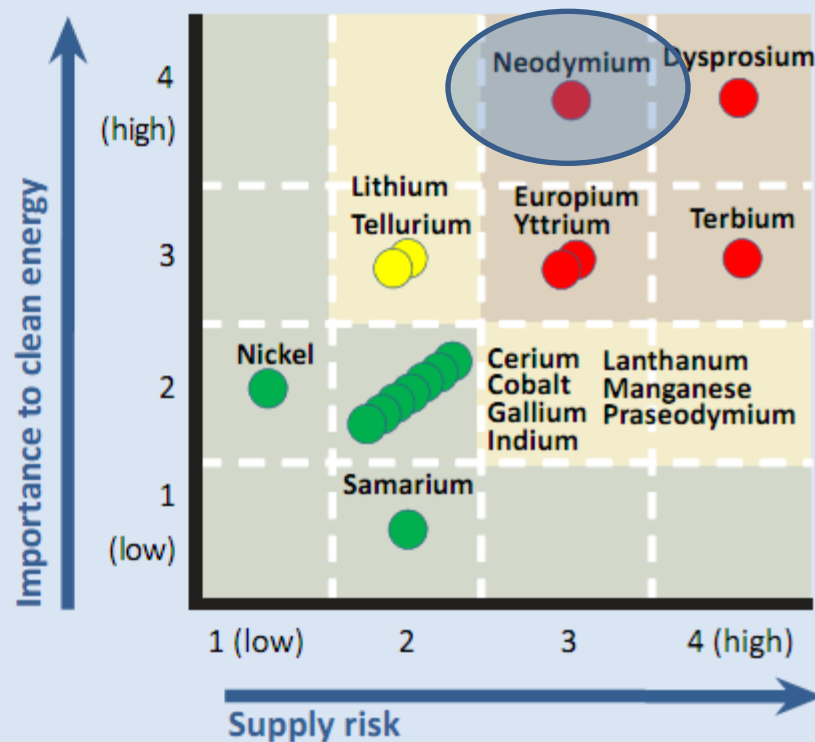
Prior to electricity distribution (GIO 2008.7.9, etc.)

Short and Medium Term Criticality

*Figure 1. Short-Term (present-2015)
Criticality Matrix*



*Figure 2. Medium-Term (2015-2025)
Criticality Matrix*



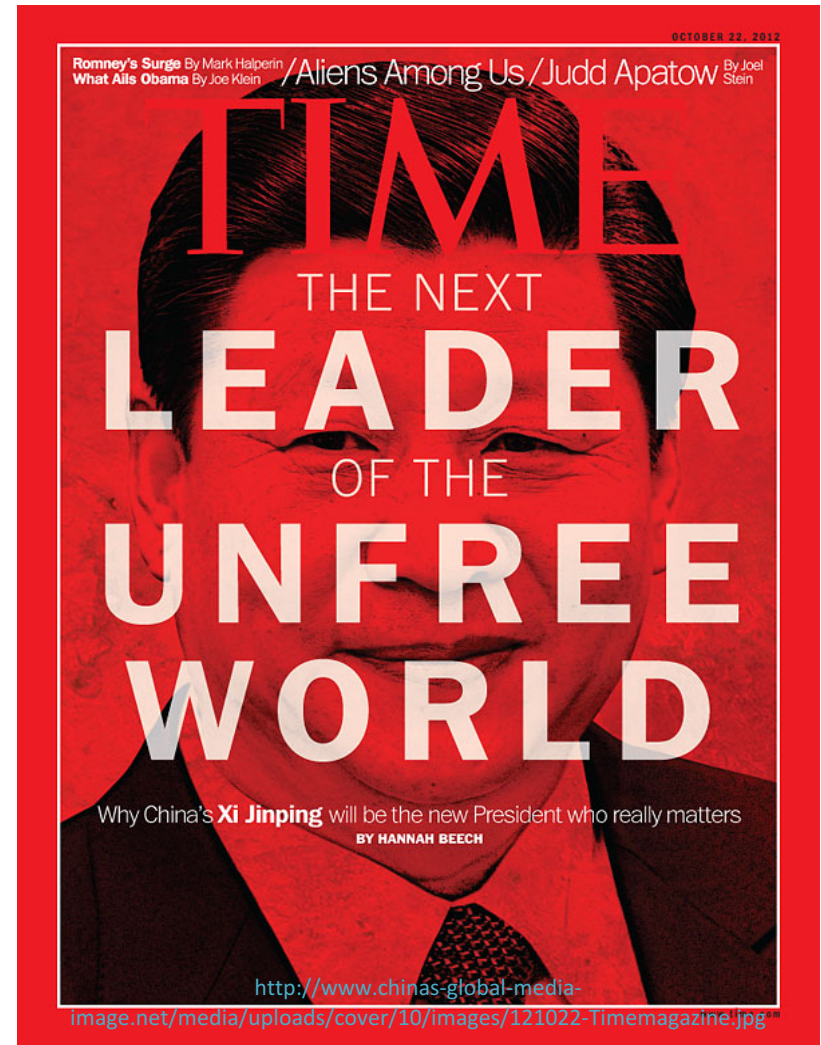
■ Critical ■ Near-Critical ■ Not Critical

Concerns with Neodymium Supply

- China has reduced REE exports

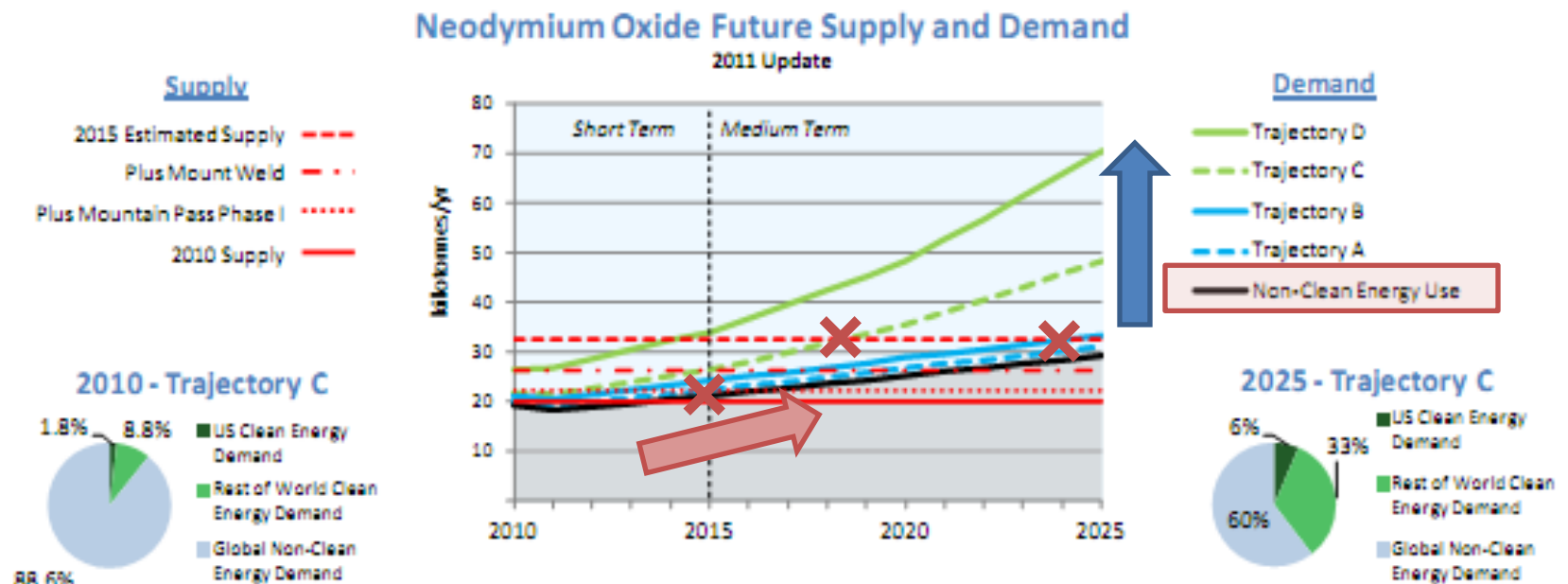
In 2010, China suspended REE exports to Japan over a territorial dispute.

Prices jumped from \$50/kg (early 2010) to \$500/kg by summer 2011



Concerns with Neodymium Supply

- China has reduced REE exports
- Global demand to increase (PHEVs, EVs, and wind turbines) with slow supply response



Small Groups (3-5 people)
BRAINSTORM
5 Minutes

What can we do

TO SECURE

critical materials (neodymium specifically)
for the future?



Alternative Materials

1	2																	18	19	20																	36	37	38																	54	55	56																	72	73	74																	88	89	90																	106	107	108																	124	125	126																	152	153	154																	172	173	174																	190	191	192																	210	211	212																	238	239	240																	258	259	260																	286	287	288																	304	305	306																	322	323	324																	340	341	342																	358	359	360																	376	377	378																	394	395	396																	412	413	414																	430	431	432																	448	449	450																	466	467	468																	484	485	486																	502	503	504																	520	521	522																	538	539	540																	556	557	558																	574	575	576																	592	593	594																	610	611	612																	628	629	630																	646	647	648																	664	665	666																	682	683	684																	700	701	702																	718	719	720																	736	737	738																	754	755	756																	772	773	774																	790	791	792																	808	809	810																	826	827	828																	844	845	846																	862	863	864																	880	881	882																	898	899	900																	916	917	918																	934	935	936																	952	953	954																	970	971	972																	988	989	990																	1006	1007	1008																	1024	1025	1026																	1042	1043	1044																	1060	1061	1062																	1078	1079	1080																	1096	1097	1098																	1114	1115	1116																	1132	1133	1134																	1150	1151	1152																	1168	1169	1170																	1186	1187	1188																	1204	1205	1206																	1222	1223	1224																	1240	1241	1242																	1258	1259	1260																	1276	1277	1278																	1294	1295	1296																	1312	1313	1314																	1330	1331	1332																	1348	1349	1350																	1366	1367	1368																	1384	1385	1386																	1402	1403	1404																	1420	1421	1422																	1438	1439	1440																	1456	1457	1458																	1474	1475	1476																	1492	1493	1494																	1510	1511	1512																	1528	1529	1530																	1546	1547	1548																	1564	1565	1566																	1582	1583	1584																	1600	1601	1602																	1618	1619	1620																	1636	1637	1638																	1654	1655	1656																	1672	1673	1674																	1690	1691	1692																	1708	1709	1710																	1726	1727	1728																	1744	1745	1746																	1762	1763	1764																	1780	1781	1782																	1798	1799	1800																	1816	1817	1818																	1834	1835	1836																	1852	1853	1854																	1870	1871	1872																	1888	1889	1890																	1906	1907	1908																	1924	1925	1926																	1942	1943	1944																	1960	1961	1962																	1978	1979	1980																	1996	1997	1998																	2014	2015	2016																	2032	2033	2034																	2050	2051	2052																	2068	2069	2070																	2086	2087	2088																	2104	2105	2106																	2122	2123	2124																	2140	2141	2142																	2158	2159	2160																	2176	2177	2178																	2194	2195	2196																	2212	2213	2214																	2230	2231	2232																	2248	2249	2250																	2266	2267	2268																	2284	2285	2286																	2302	2303	2304																	2320	2321	2322																	2338	2339	2340																	2356	2357	2358																	2374	2375	2376																	2392	2393	2394																	2410	2411	2412																	2428	2429	2430																	2446	2447	2448																	2464	2465	2466																	2482	2483	2484																	2500	2501	2502																	2518	2519	2520																	2536	2537	2538																	2554	2555	2556																	2572	2573	2574																	2590	2591	2592																	2608	2609	2610																	2626	2627	2628																	2644	2645	2646																	2662	2663	2664																	2680	2681	2682																	2698	2699	2700																	2716	2717	2718																	2734	2735	2736																	2752	2753	2754																	2770	2771	2772																	2788	2789	2790																	2806	2807	2808																	2824	2825	2826																	2842	2843	2844																	2860	2861	2862																	2878	2879	2880																	2896	2897	2898																	2914	2915	2916																	2932	2933	2934																	2950	2951	2952																	2968	2969	2970																	2986	2987	2988																	3004	3005	3006																	3022	3023	3024																	3040	304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 - Risk management
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The Supply Problem

- China has cheap extraction and manufacturing
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What It's Like To Take Photos Of A Dying Man

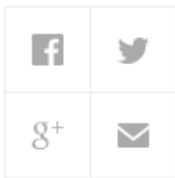
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<http://www.npr.org/sections/goatsandsoda/2015/10/04/439241698/what-its-like-to-take-photos-of-a-dying-man>



SHARE



Arriving at a hospital seven hours' drive from his remote village in the mountains, former gold miner He Quanguai is finally put in a ward. The doctors proceed to puncture his lungs with a needle to remove syringe after syringe of air. In pain, He Quanguai tries to clasp the drip pulley hanging from the ceiling; his brother-in-law Mi Shiliang is at a loss for how to comfort him.

Sim Chi Yin/VII

The Supply Problem



(1) Molycorp, (2) Lynas, (3) Indian Rare Earths/Toyota Tsusho/Shin-Etsu, (4) Kazatomprom/Sumitomo, (5) Great Western Minerals, (6) Vietnamese Govt./Toyota Tsusho/Sojitz, (7) Stans Energy, (8) Alkane Resources, (9) Arafura Resources, (10) Greenland Minerals and Energy, (11) Great Western Minerals, (12) Avalon Rare Metals, (13) Rare Element Resources, (14) Pele Mountain Resources, (15) Quest Rare Minerals, (16) Ucore Uranium, (17) US Rare Earths, (18) Matamec Explorations, (19) Tasman Metals, (20) Montero Mining/Korea Resources, (21) Namibia Rare Earths, (22) Frontier Resources/Korea Resources, (23) Hudson Resources, (24) AMR Resources, (25) Neo Material Technologies

Figure 4-2. Current and Projected Rare Earth Projects Outside China⁸⁷

The Supply Problem



**2012: REE mine owned by Molycorp Minerals LLC
reopens in California.**

Estimated annual production capacity: 19,050 mt of rare earth oxides

Molycorp 2013 Annual Report

What the DOE proposes for Nd

1. Diversify global supply chains

- Risk management
- Facilitate extraction, processing, and manufacture in the US

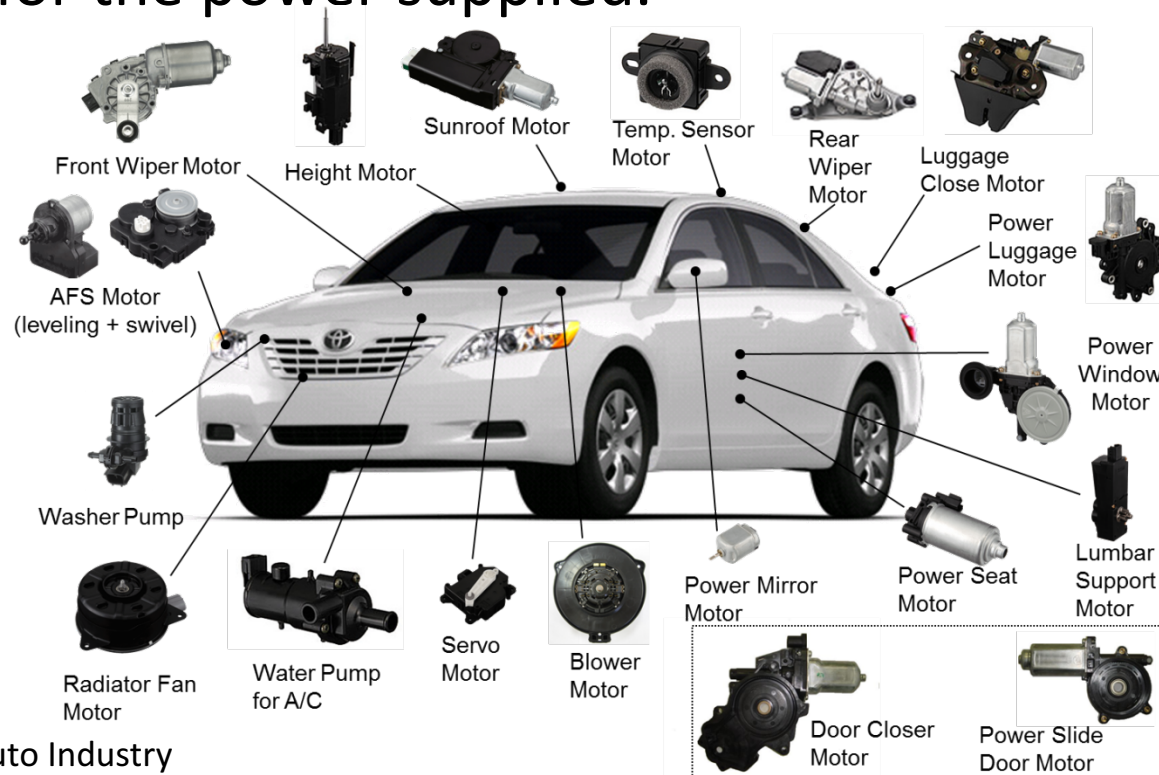
2. Develop substitutes

- Material and technology substitutes
- DOE's ARPA-E research agency introduced "Rare Earth Alternatives in Critical Technologies program"

The Wicked Problem

“70 to 120 motors are used in a luxury car”

- Cars need lower weight, maximum passenger volume, and better fuel economy (CAFE standards)
- Neodymium-based motors are smaller and lighter weight for the power supplied.



Featured Product

Home > Featured Product

Flux Multiplier Best Washing Performance

- Flux Multiplier™ motor technology
- Widest speed range was
- Industry's highest energy
- No Rare- Earth magnets

Energy C
(kWh)

400

300

200

100

0



Search

NEWS

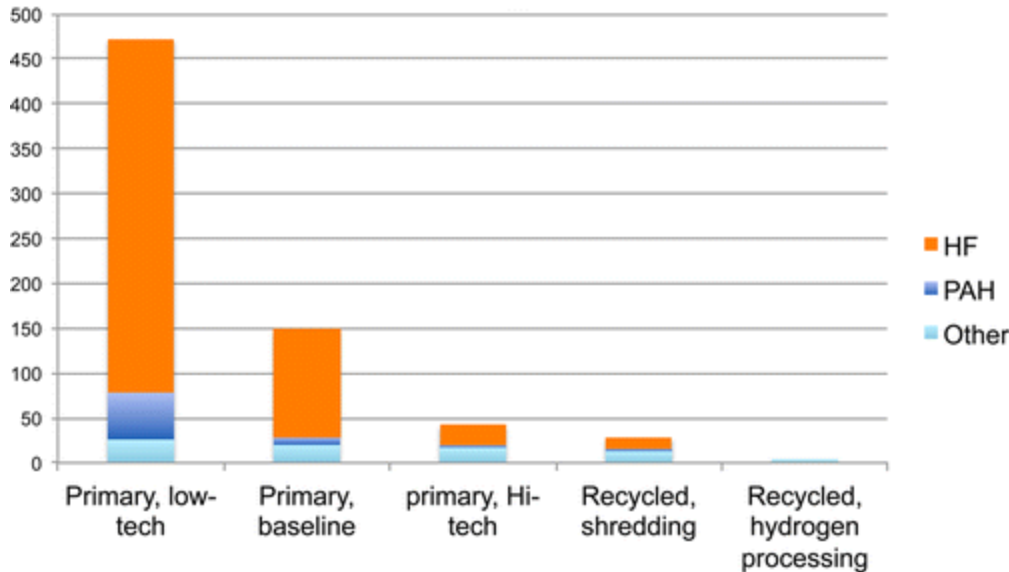
CAREER



What the DOE proposes for Nd

1. Diversify global supply chains
 - Risk management
 - Facilitate extraction, processing, and manufacture in the US
2. Develop substitutes
 - Material and technology substitutes
3. Recycling, reuse, and efficiency
 - Research and policy for recycling economically
 - Honda has started a recycling program

Human Toxicity, kg 1,4-DCB-Eq



We conclude that **recycling of neodymium**, especially via manual dismantling, **is preferable to primary production**, with some environmental indicators showing an order of magnitude improvement.

- Sprecher, et. al (2014) ES&T

ENVIRONMENTAL
Science & Technology

Article
pubs.acs.org/est

Life Cycle Inventory of the Production of Rare Earths and the Subsequent Production of NdFeB Rare Earth Permanent Magnets

Benjamin Sprecher,^{*,†,‡} Yanping Xiao,[§] Allan Walton,^{||} John Speight,^{||} Rex Harris,^{||} Rene Kleijn,[‡] Geert Visser,[⊥] and Gert Jan Kramer[‡]

Waste **flows from permanent magnets will remain small** relative to ... growing global REE demand... During the next decade *recycling is unlikely to substantially contribute to global REE supply security*. In the **long term, waste flows will increase sharply** and will meet a substantial part of the total demand for these metals.

- Rademaker, et. al (2013) ES&T

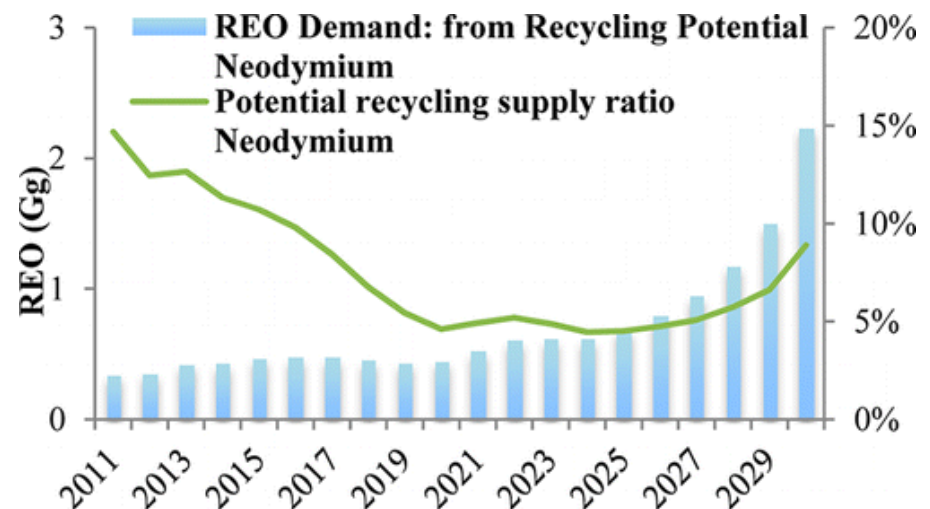
ENVIRONMENTAL
Science & Technology

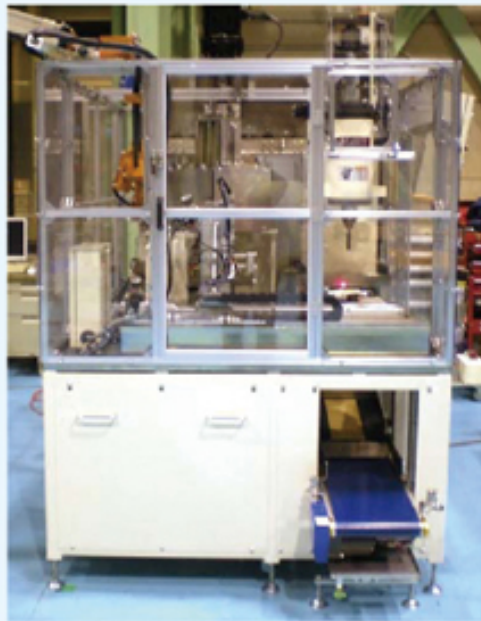
Policy Analysis
pubs.acs.org/est

Recycling as a Strategy against Rare Earth Element Criticality: A Systemic Evaluation of the Potential Yield of NdFeB Magnet Recycling

Jelle H. Rademaker,^{*,†} René Kleijn,[‡] and Yongxiang Yang[§]

[†]Green Academy, De Groene Grachten, Utrechtsedwarsstraat 11, 1017 WB Amsterdam, The Netherlands





Automatic dismantling equipment

Neodymium Magnet Recovery Process

- 1 Remove rotor from partially disassembled air conditioner compressor



- 2 Degauss magnets from the rotor at ambient temperature



- 3 Separate magnets



Partially disassembled room air conditioner compressor



Rotor extracted from the compressor



Recovered magnets (after degaussing)

Mitsubishi Electric Develops Automatic Dismantling Equipment; Removes and Recovers Rare Earth Magnets from AC Compressors in Just 30 Seconds

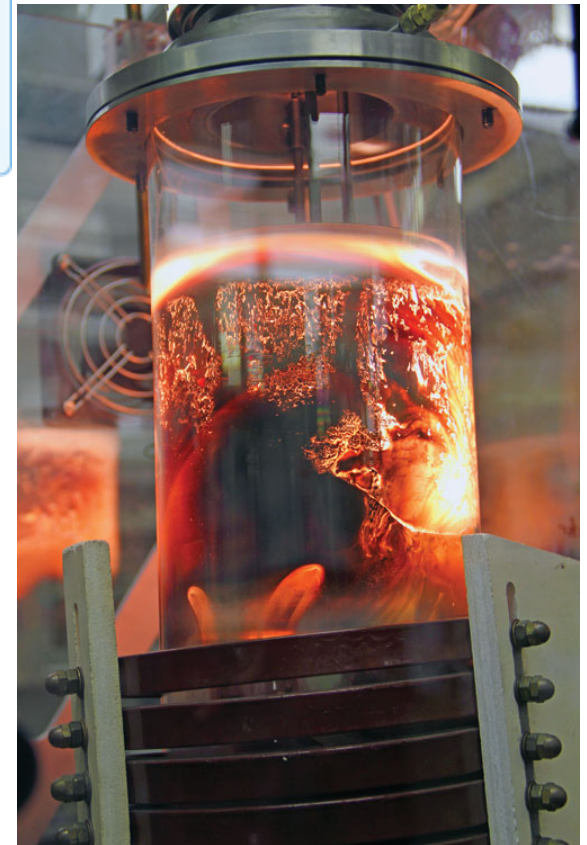
<http://www.mitsubishielectric.com/company/environment/ecotopics/rareearth/how/index.html>

Ames Laboratory and USDOE Develop Process to Remove Rare Earths from NIB Magnet Scrap

Process: Mill magnets into small pieces, add magnesium, heat material, REEs enter molten magnesium leaving behind iron and boron, molten magnesium cast into an ingot, cooled, then magnesium is boiled off.

Results: REE properties very similar to unprocessed materials

<https://www.ameslab.gov/news/inquiry/rare-earth-recycling>



Let's Look at TWO Examples

Neodymium (Viewpoint: USDOE)

Helium (Viewpoint: Scientists)

Neodymium (Viewpoint: USDOE)										Helium (Viewpoint: Scientists)									

lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

* Lanthanide series

** Actinide series

Viewpoint: Scientists

- We often think of earth as a closed system for materials. Here's a secret:

Helium will run out in less than 300 years.

Based on US Geological Survey

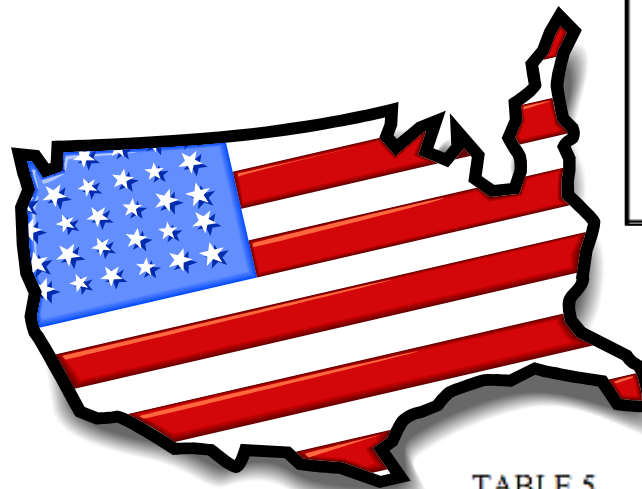


Example:

Helium

(<http://minerals.usgs.gov/minerals/pubs/commodity/helium/myb1-2010-heliu.pdf>)

- Lowest melting point of any element (-452 degrees Fahrenheit) & inert
- Second most abundant element in the universe (produced when hydrogen atoms fuse together in stars' cores)
- Rare on earth
 - Generated through radioactive decay in Uranium and Thorium atoms (generates 3.4L/km of earth/year)
 - Exists as an impurity in natural gas fields and is extracted when it's concentration is >0.3% (economical)
- Produced (and consumed) mostly in the US – 78% of world's He supply comes from the US
- Other production locations: Algeria, Canada, China, Qatar, Poland and Russia



helium
2
He
4.0026

TABLE 5
WORLD GRADE-A HELIUM
ANNUAL PRODUCTION
CAPACITY AS OF
DECEMBER 31, 2010

(Million cubic meters)

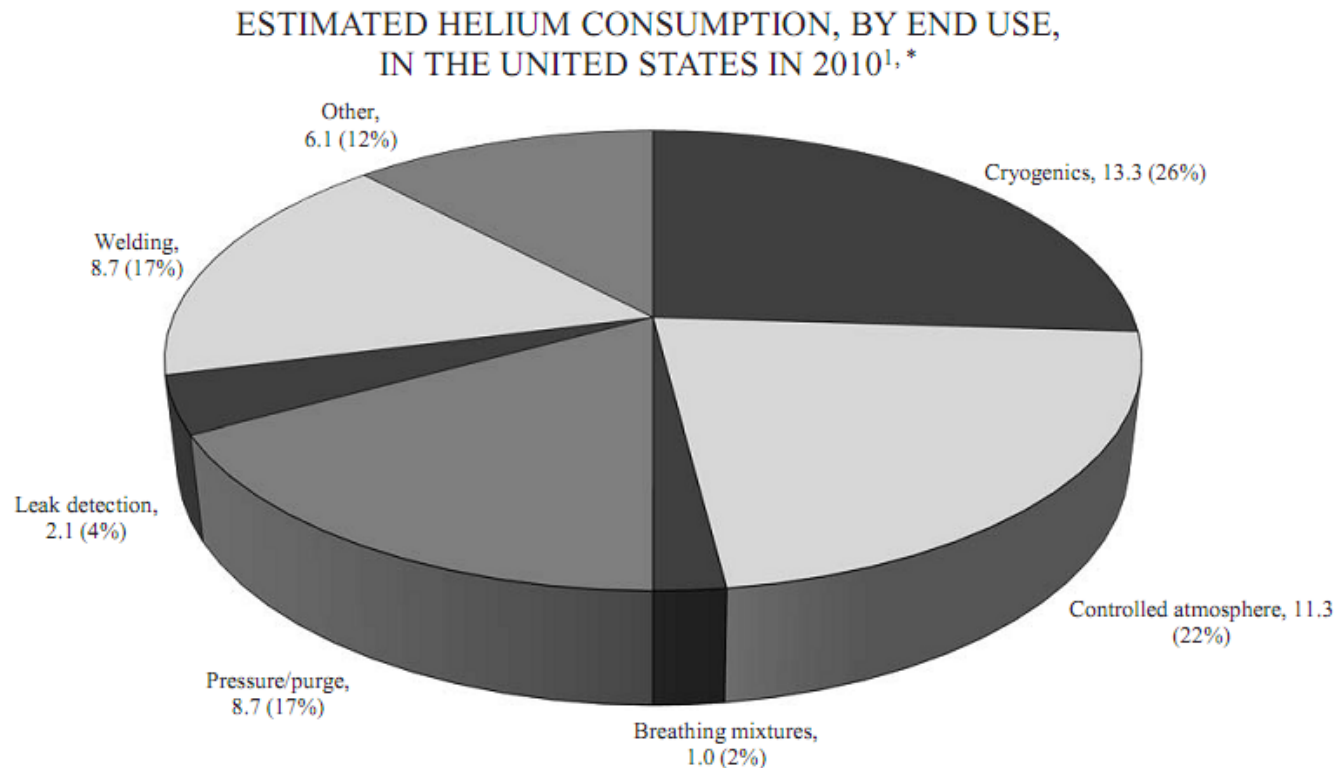
	Capacity
United States ¹	177
Rest of world ^e	70
Total ^e	247

^eEstimated.

¹Includes plants on standby as well as operating plants.

US Geological Survey

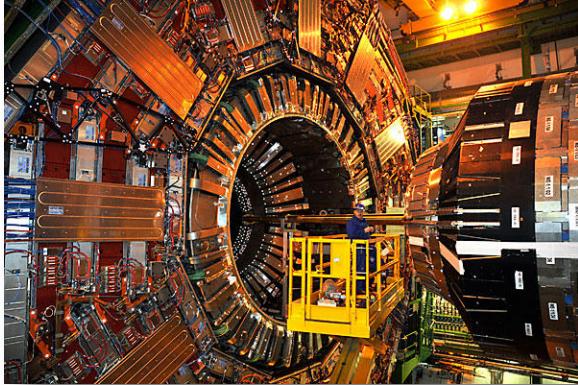
How Is He Used?



¹Total helium used in the United States in 2010 was estimated to be 51.2 million cubic meters.

*Correction posted on January 13, 2012.

How Is He Used?



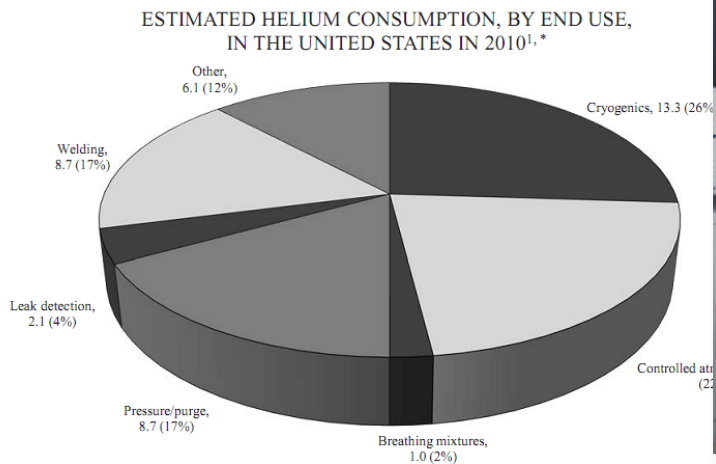
Particle Accelerators



Superconductors
(Superconducting Magnets)



Future Renewable
Energy Generation



¹Total helium used in the United States in 2010 was estimated to be 51.2 million cubic meters.

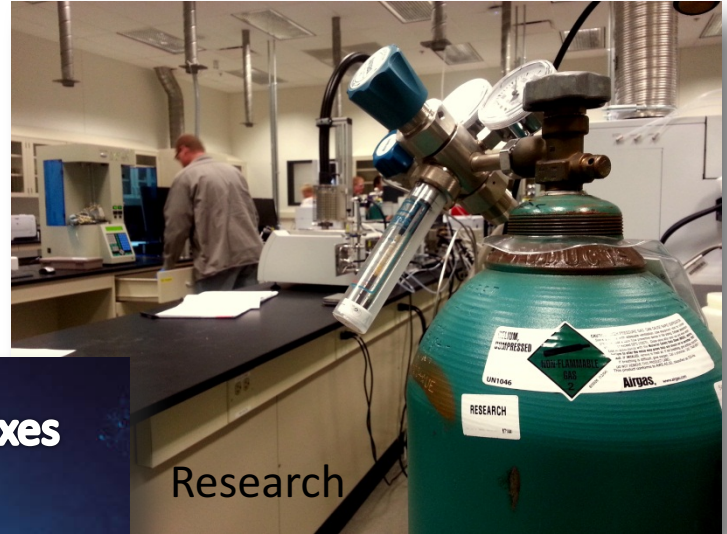
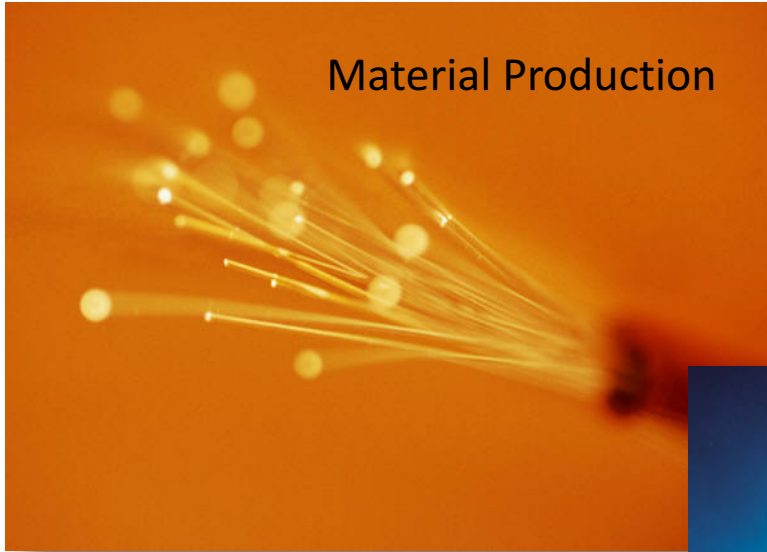
*Correction posted on January 13, 2012.



Medical Testing - MRI Machines

How Is He Used?

Material Production

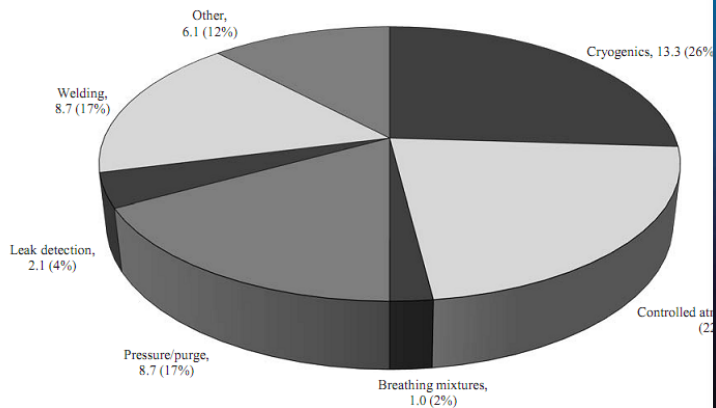


Research

Diving Air Mixes



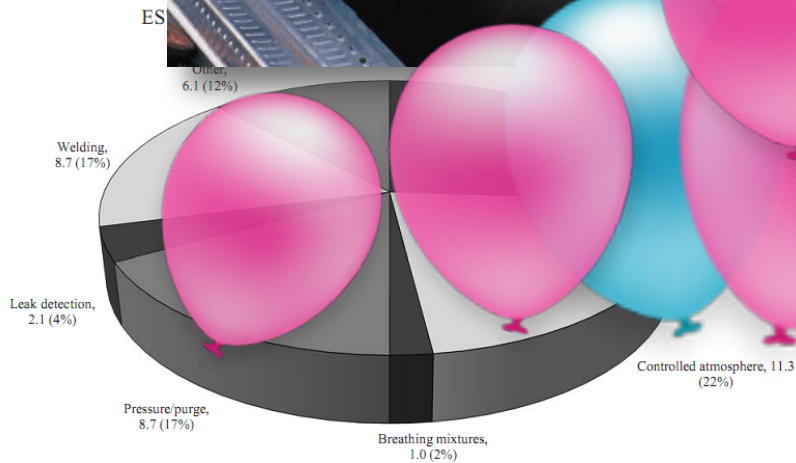
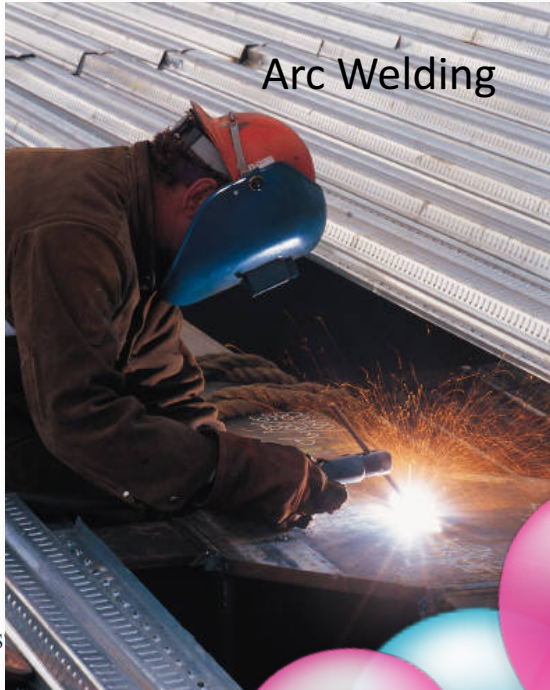
ESTIMATED HELIUM CONSUMPTION, BY END USE, IN THE UNITED STATES IN 2010^{1, *}



¹Total helium used in the United States in 2010 was estimated to be 51.2 million cubic meters.

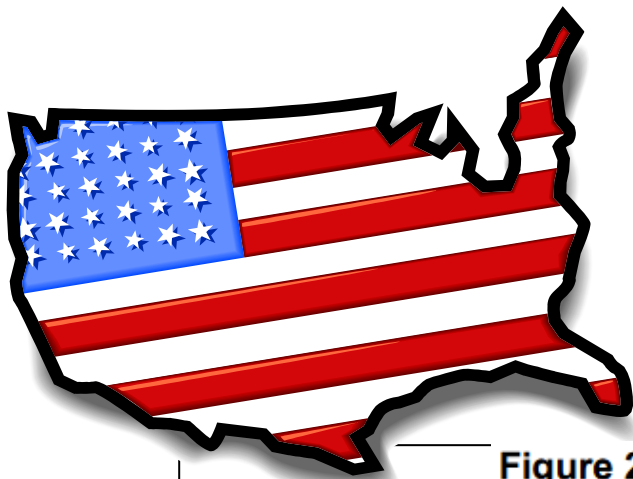
^{*}Correction posted on January 13, 2012.

How Is He Used?



¹Total helium used in the United States in 2010 was estimated to be 51.2 million cubic meters.

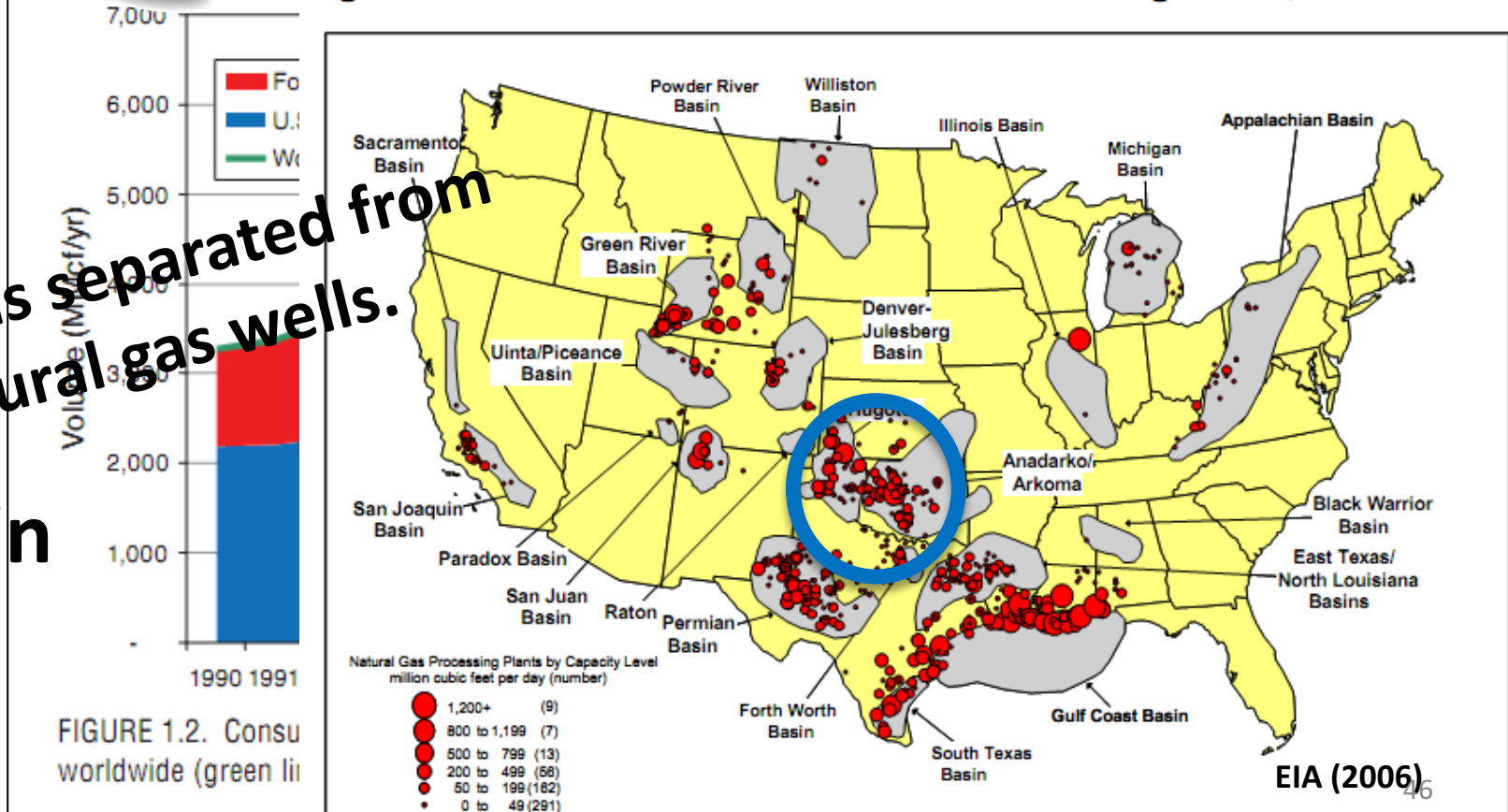
*Correction posted on January 13, 2012.



78% of world's helium supply comes from the US

Helium is separated from natural gas wells.
 ^
 certain

Figure 2. Concentrations of Natural Gas Processing Plants, 2004



Federal Helium Reserve

- In 1996, approximately 1 billion cubic meters
- Cost of \$1.4 billion
- 1996 Helium Privatization Act
- Sales of nearly all stored He between 2005-2015
- Non-market rates



While government prices for crude helium have not quite doubled over the last 10 years, the price for privately-held, grade-A helium has nearly tripled in the same time period.

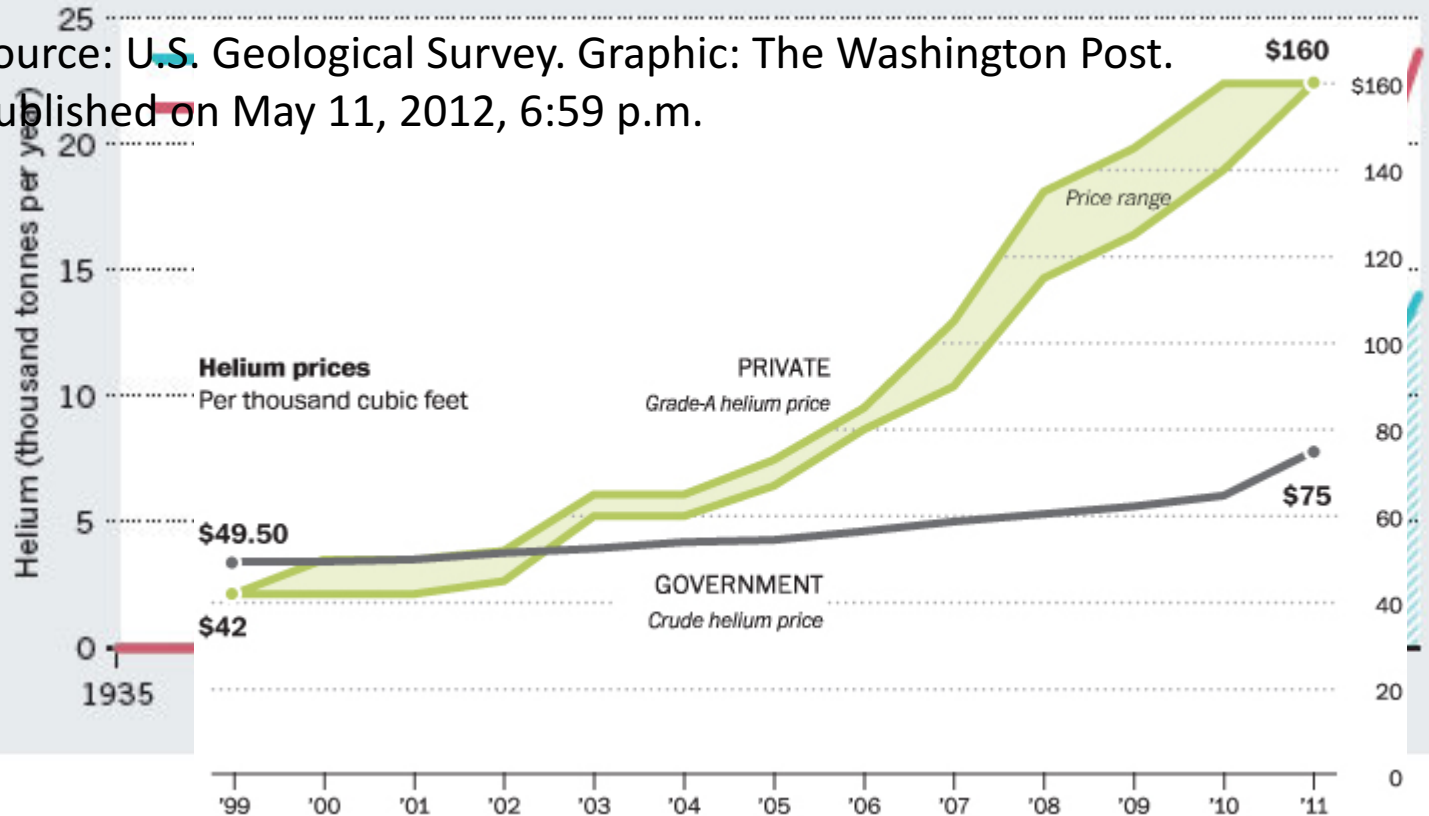
Source: U.S. Geological Survey. Graphic: The Washington Post.

Published on May 11, 2012, 6:59 p.m.

SOURCE: US BUREAU LAND MGMT/S.J. MAIONE

HELIUM SALES ON THE RISE

Annual production and sales of helium from the US federal reserve in Amarillo, Texas. After building up the reserve in the 1960s, legislation in 1996 required the nation to sell off its helium stockpile.



While government prices for crude helium have not quite doubled over the last 10 years, the price for privately-held, grade-A helium has nearly tripled in the same time period.

Source: U.S. Geological Survey. Graphic: The Washington Post.
Published on May 11, 2012, 6:59 p.m.

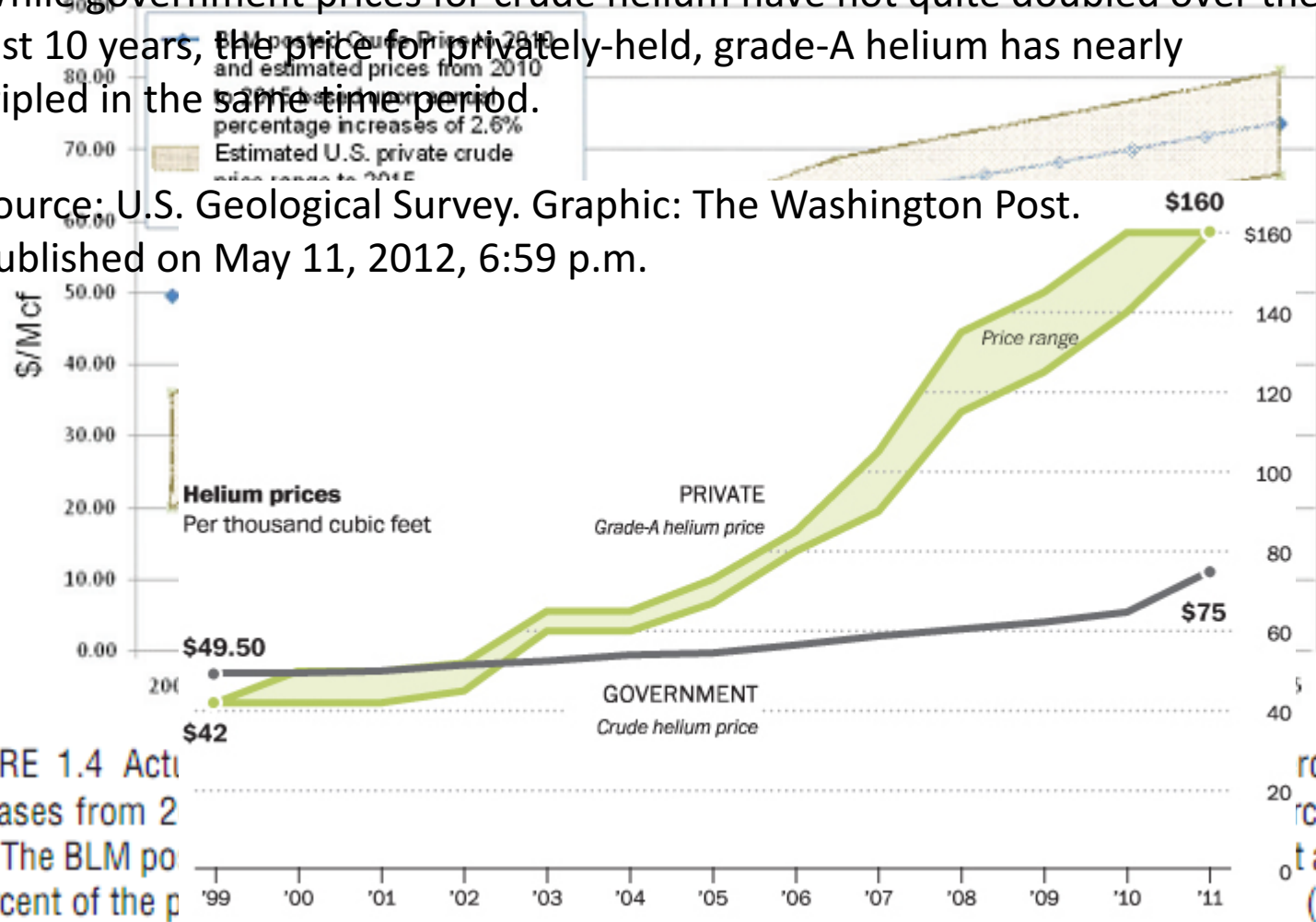


FIGURE 1.4 Actual increases from 2000 to 2011. The BLM posted crude prices in 2010 and estimated prices from 2010 to 2011 based on annual percentage increases of 2.6% (shaded areas). See text for discussion.

What can we do?

Politicians signed a bill (IT'S TRUE!) in 2013 that slowly ended the Helium Reserve's below-market rates.

Helium is now auctioned off to highest bidder (ending price distortion)



Market-driven He may ensure it's efficient and proper use,
but we may still need new sources.

Volatility is expected to increase as the federal reserve is depleted.

Short Term



2014: Qatar becomes 2nd largest helium producer with a plant that can produce 60 million m³ of He per year

2015: New plant in Colorado set to remove He from a natural CO₂ reserve (CO₂ being used in Texas for enhanced oil recovery)



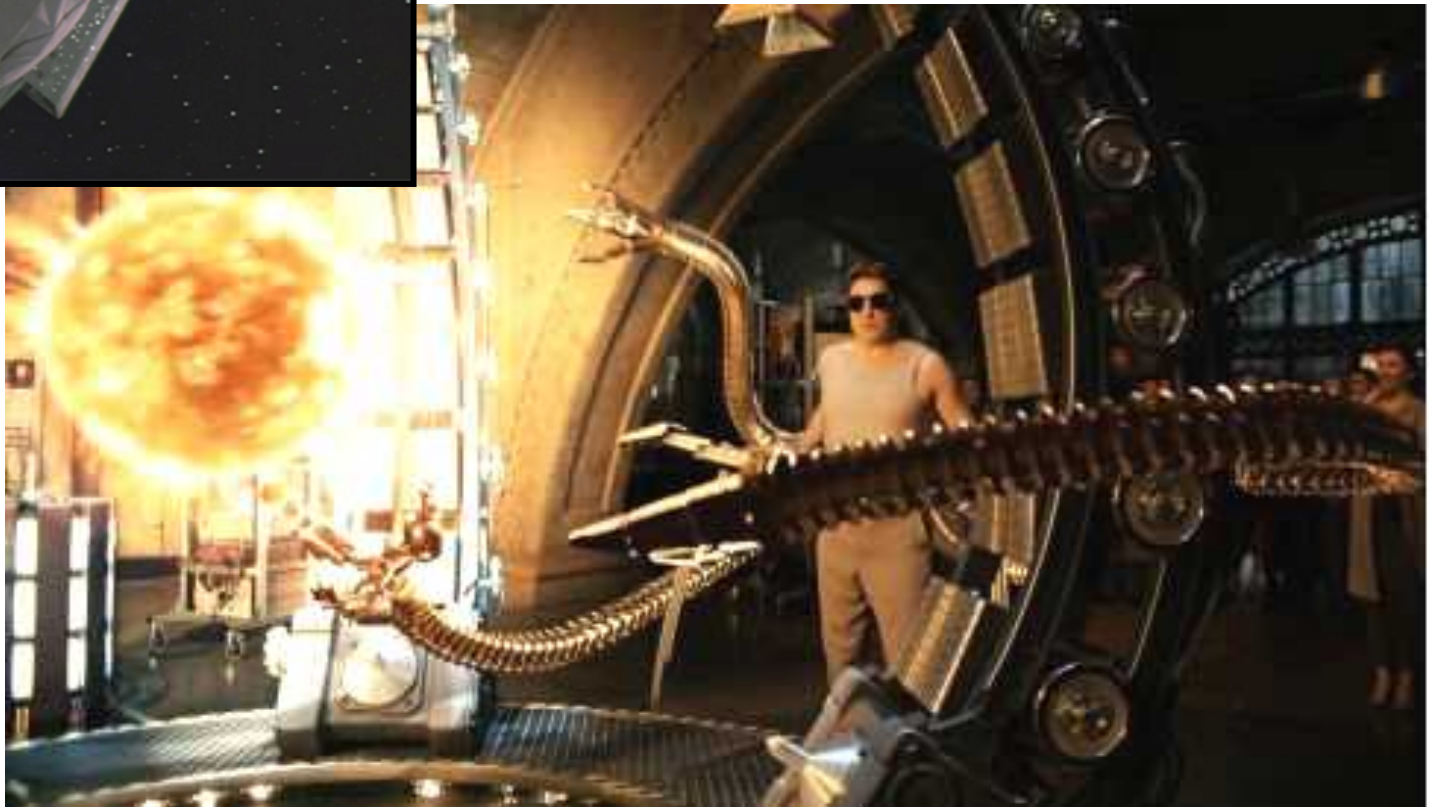
There is likely to be continued helium shortages and price spikes. Highly recommended to recover and reuse He, or find alternatives.

Options



Deuterium-Tritium fusion could generate about 8 million m³, 1/10 of our usage.

Future atmospheric gas harvesting equipment could also become more cost-effective.



Options



He News Articles for You

- <http://www.wired.com/2015/07/feds-created-helium-problem-thats-screwing-science/>
- <http://www.npr.org/blogs/itsallpolitics/2013/09/30/227772534/congress-reaches-compromise-deal-on-inert-gas>
- <http://www.washingtonpost.com/blogs/wonkblog/wp/2013/09/27/good-news-congress-just-averted-a-global-helium-crisis/>
- <http://www.nature.com/nature/journal/v485/n7400/full/485573a.html>

Your Friendly Periodic Table

Your Friendly Periodic Table																																			
hydrogen 1 H																		helium 2 He 4.0026																	
lithium 3 Li 6.941																																			
boron 5 B 10.811		carbon 6 C 12.011		nitrogen 7 N 14.007		oxygen 8 O 15.999		fluorine 9 F 18.998		neon 10 Ne 20.180																									
aluminium 13 Al 26.982		silicon 14 Si		phosphorus 15 P 30.974		sulfur 16 S 32.065		chlorine 17 Cl 35.453		argon 18 Ar 39.948																									
potassium 19 K 39.098		calcium 20 Ca 40.078		scandium 21 Sc 44.956		titanium 22 Ti 47.867		vanadium 23 V 50.942		chromium 24 Cr 51.996		manganese 25 Mn 54.938		iron 26 Fe 55.845		cobalt 27 Co 58.933		nickel 28 Ni 58.693		copper 29 Cu 63.546		zinc 30 Zn 65.39		gallium 31 Ga 69.723		germanium 32 Ge 72.61		arsenic 33 As 74.922		selenium 34 Se 78.96		bromine 35 Br 79.904		krypton 36 Kr 83.80	
rubidium 37 Rb 85.468		strontium 38 Sr 87.62		yttrium 39 Y		zirconium 40 Zr 91.224		niobium 41 Nb 92.906		molybdenum 42 Mo 95.94		technetium 43 Tc		ruthenium 44 Ru 101.07		rhodium 45 Rh 102.91		palladium 46 Pd 106.90		silver 47 Ag 107.87		cadmium 48 Cd 112.41		indium 49 In 114.82		tin 50 Sn 118.71		antimony 51 Sb 121.76		tellurium 52 Te 127.60		iodine 53 I 126.90		xenon 54 Xe 131.29	
caesium 55 Cs 132.91		barium 56 Ba 137.33		lanthanum 57 La 138.91		hafnium 72 Hf 178.49		tantalum 73 Ta 180.95		tungsten 74 W 183.84		rhenium 75 Re 186.21		osmium 76 Os 190.23		iridium 77 Ir 192.22		platinum 78 Pt 195.08		gold 79 Au 196.97		mercury 80 Hg 200.59		thallium 81 Tl 204.38		lead 82 Pb 207.2		bismuth 83 Bi 208.98		polonium 84 Po [209]		astatine 85 At [210]		radon 86 Rn [222]	
francium 87 Fr [223]		radium 88 Ra [226]		actinide series		actinide series		actinide series		actinide series		actinide series		actinide series		actinide series		actinide series		actinide series		actinide series		actinide series		actinide series		actinide series		actinide series		actinide series		actinide series	
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“NOW WE UNDERSTAND THAT THE EARTH IS FINITE, AND WE CAN’T JUST PICK WHATEVER OFF THE SHELF AND BUILD A TECHNOLOGY WITHOUT UNDERSTANDING THE CONSEQUENCES.”

- Frances Houle, Lawrence Berkeley National Laboratory
(Berkeley Lab)

<http://www.rdmag.com/News/2012/08/Materials-A-Long-Term-View-Of-Critical-Materials/>

Assessing Critical Materials: New Technologies Example

8

Energy Design Update®

June 2013

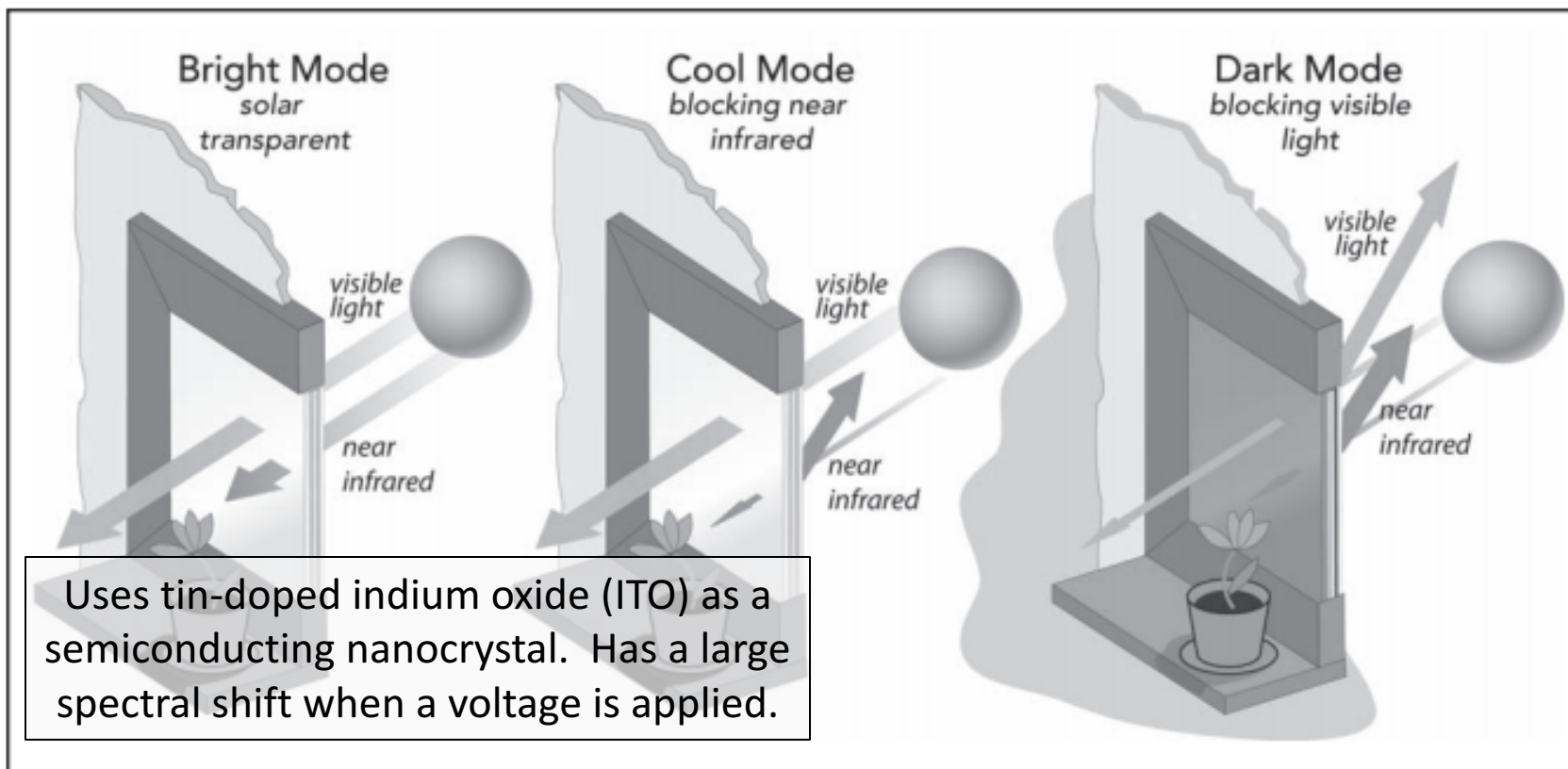
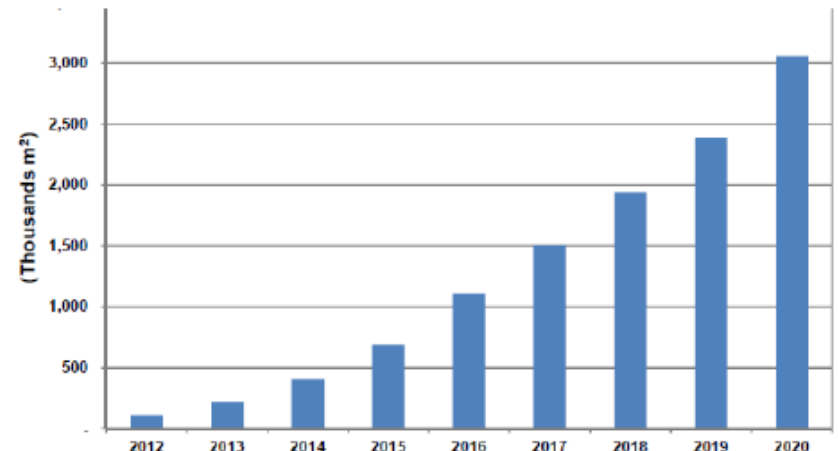


Figure 11. Milliron's team will also investigate coatings that combine the near infrared-selective plasmonic electrochromic effect with conventional electrochromic materials that can also modulate visible light, on demand. Photo courtesy Delia Milliron and Lawrence Berkeley National Laboratory.

Scaling Up Production

- Annual market demands that affect electrochromic windows
 - Current U.S. commercial window demand at 40 million m²
 - Current global window demand at 300 million m²
 - Dynamic window demand currently insignificant, but projected to reach 3 million m² by 2020
 - Current dynamic window plant capacity at ~0.5 million m²
- Market demand estimates help characterize
 - Impacts from resource use
 - Potential energy savings
 - Projected plant capacity
 - Manufacturing methods
 - Bulk material pricing

Smart Glass Demand (Square Meters), World Market:



Slide from: Arman Shehabi, et al (Lawrence Berkeley National Lab) 2014;

Pike Research, 2012

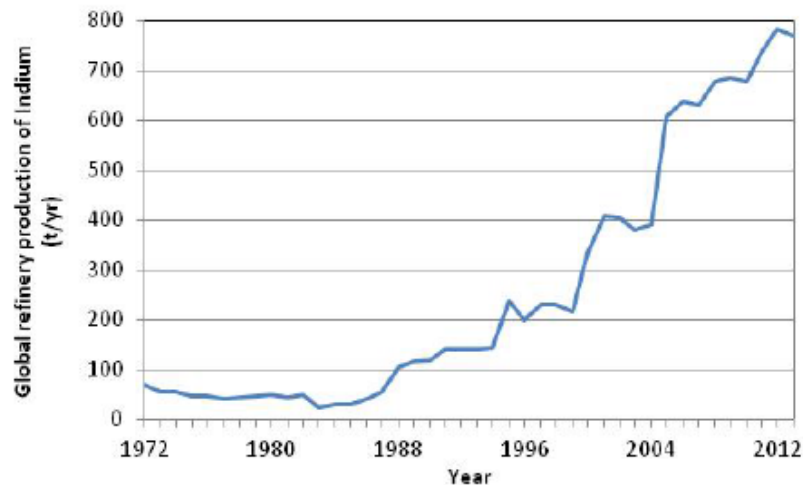
LCA XIV Conference (with permission)

Supply Chain Impacts

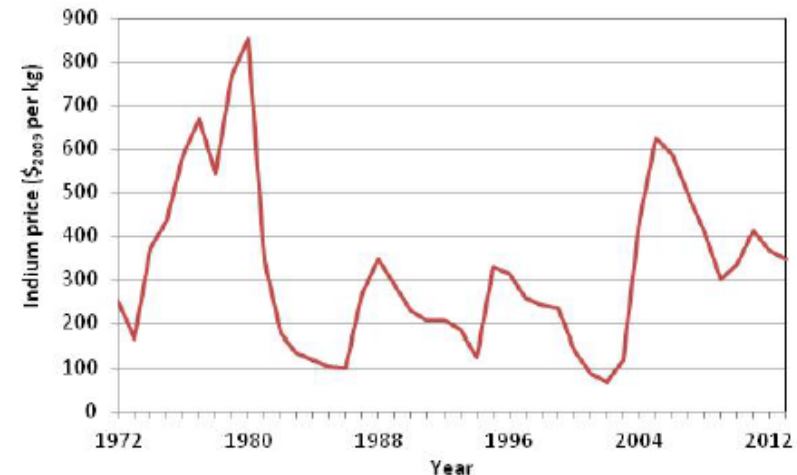
Raw Materials

- Example: Critical material concerns of Indium

Current primary production of Indium \approx 800 t/yr



Historical price fluctuation: <\$100 to >\$800 per kg



Scenario projections:

- Medium:
 - 30 million ft² annual output (1% of total market)
 - Indium demand \approx 8.3 t/yr (or 1.1% of 2013 production)
- High:
 - 1 billion ft² per year (\approx global demand in 2020 for architectural glass)
 - Indium demand \approx 276 t/yr (or 36% of 2013 production)

Slide from: Arman Shehabi, et al (Lawrence Berkeley National Lab) 2014;

LCA XIV Conference (with permission)

Indium production and cost data from USGS (2014)

Acknowledgements / Refs

- Karl Dunkle Werner, He aficionado
- Jason Vincenz, MechE extraordinaire
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Good Reads for You

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