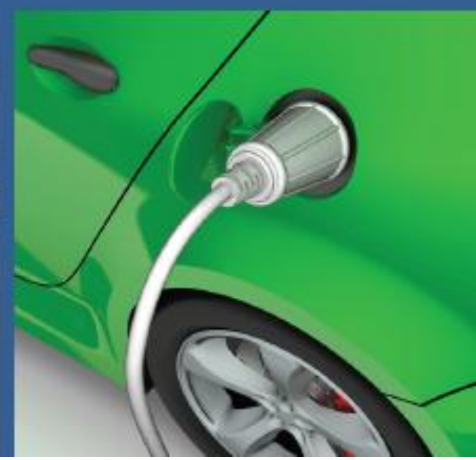
U.S. DEPARTMENT OF ENERGY

Critical Materials Strategy

Critical Materials for Energy Security

RARE EARTHS, CRITICAL METALS, ENERGY & NATIONAL SECURITY CONFERENCE






David Diamond, Ph.D.

Office of Policy and International Affairs

November 2, 2011

Outline of Briefing

I. Critical Materials and Energy Security

II. DOE Critical Materials Strategy

   A. Scope and Context

   B. Analysis

      1. Supply

      2. Demand

      3. Criticality

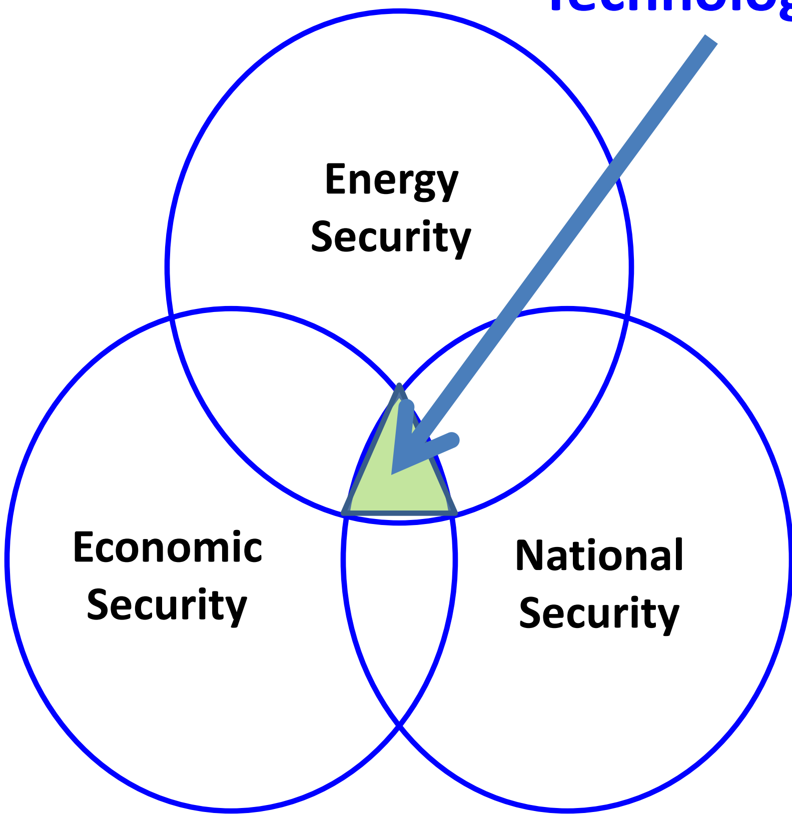
   C. Program and Policy Directions

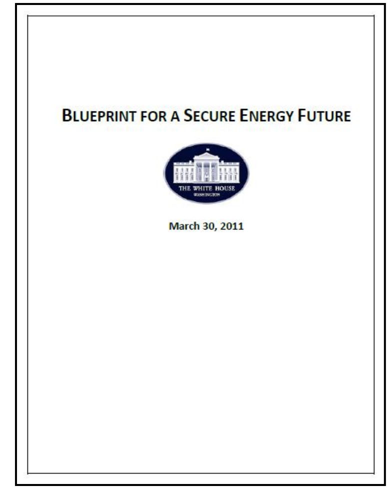
III. Continuing Steps

“Energy Security can be described as *‘the uninterrupted physical availability at a price which is affordable, while respecting environment concerns’*.”

- **International Energy Agency (IEA)**

Critical Materials for Clean Energy Technologies




BLUEPRINT FOR A SECURE ENERGY FUTURE

March 30, 2011

"[W]e must focus on … the cutting edge of clean energy technology so that we can build a 21st century clean energy economy and win the future."

- Blueprint for a Secure Energy Future
March 2011

DOE's Role

The mission of the Department of Energy is to ***ensure America's security and prosperity*** by addressing its energy, environmental, and nuclear challenges through transformative science and technology solutions.

Goal 1: Catalyze the ***timely, material, and efficient transformation of the nation's energy system*** and secure U.S. leadership in clean energy technologies.

Goal 2: Maintain a ***vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity*** with clear leadership in strategic areas.

- 2011 DOE Strategy

II. DOE Critical Materials Strategy

A. Scope and Context

B. Analysis

1. Supply
2. Demand
3. Criticality

C. Program and Policy Directions

Scope – 2010 Critical Materials Strategy

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.00794																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	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 32.066	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 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	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 208.98038	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 (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114				

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 173.04	71
90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.0289	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)	

Vehicles

Lighting

Solar PV

Wind

Project Timeline

- *March 2010 - Project launched*

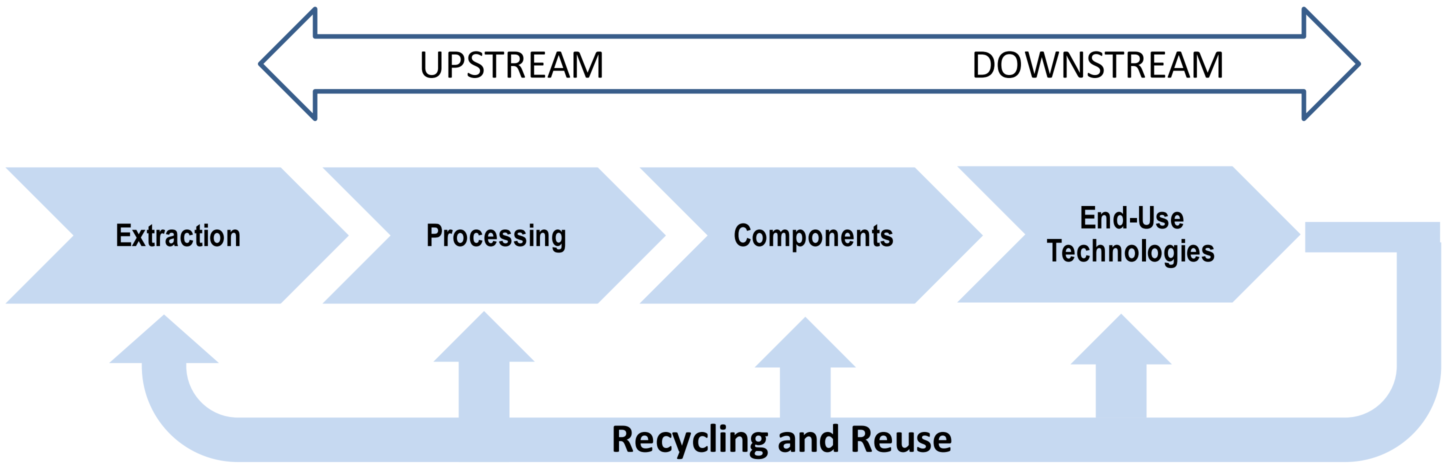
"I am today announcing that the Department of Energy will develop its first-ever strategic plan for addressing the role of rare earth and other strategic materials in clean energy technologies. "

"As a society, we have dealt with these types of issues before…We can and will do so again."

David Sandalow
Assistant Secretary for Policy and International Affairs
U.S. Department of Energy
March 17, 2010

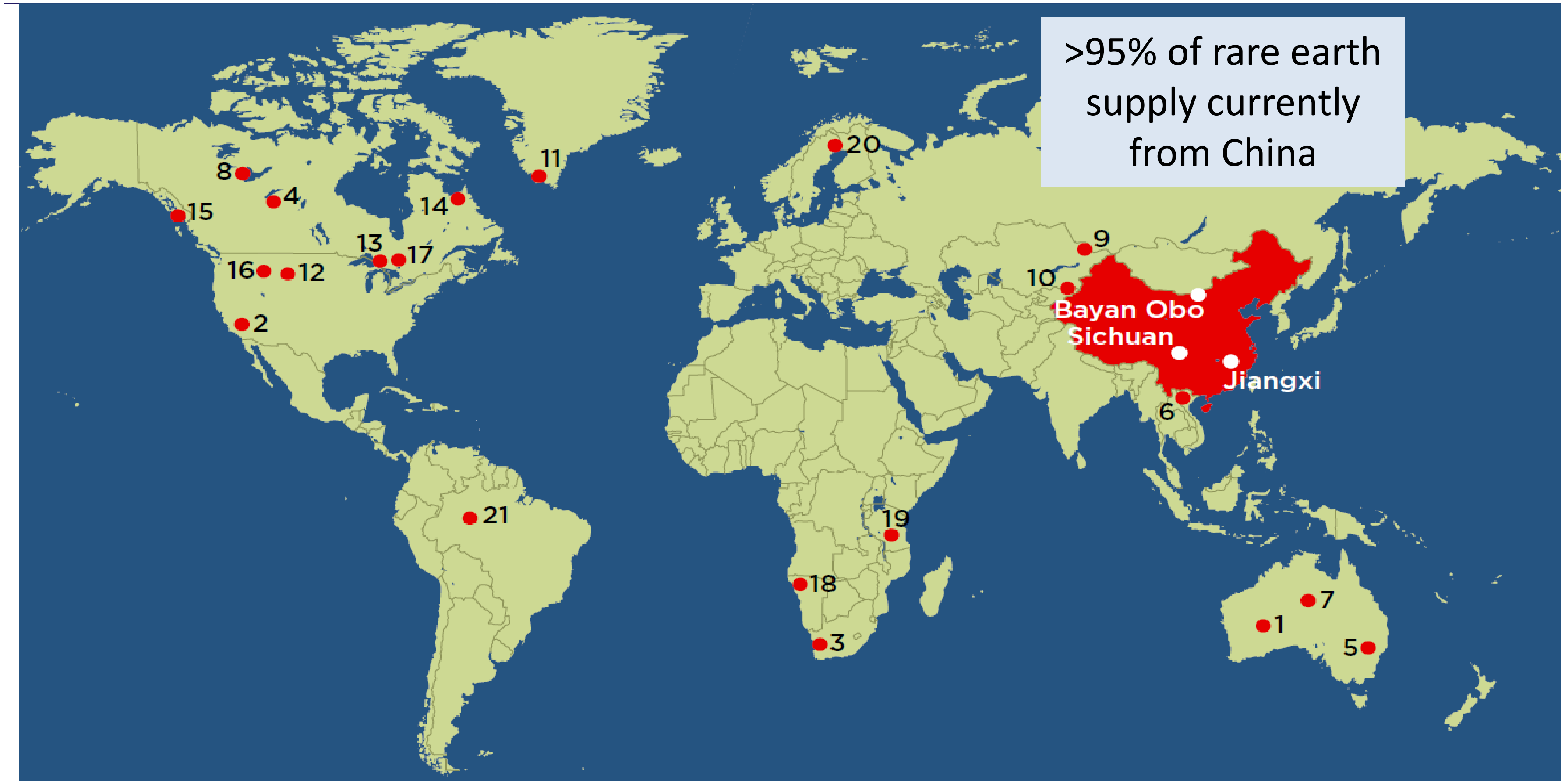
- *June 2010 – Responses to public Request for Information*
- *Summer 2010 – Performed analysis, internal and inter-agency consultations, and drafted strategy*
- *December 2010 – Public release of the Critical Materials Strategy*
- *Spring 2011 – 2^{nd} public Request for Information issued*
- *Fall 2011 – Release update of Critical Materials Strategy*

- *Diversify global supply chains*
- *Develop substitutes*
- *Reduce, reuse and recycle*



Material supply chain with environmentally-sound processes

Supply



(1) Lynas Corp., (2) Molycorp Minerals, (3) (4) Great Western Minerals, (5) Alkane Resources, (6) Vietnamese govt./Toyota Tsusho/Sojitz, (7) Arafura Resources, (8) Avalon Rare Metals, (9) Kazatomprom/Sumitomo, (10) Stans Energy, (11) Greenland Minerals and Energy, (12) Rare Element Resources, (13) Pele Mountain Resources, (14) Quest Rare Metals, (15) Ucore Uranium, (16) US Rare Earths, (17) Matamec Explorations, (18) Etruscan Resources, (19) Montero Mining, (20) Tasman Metals, (21) Neo Material Technologies/Mitsubishi

Source: Industrial Minerals

Rare earth metals are not rare – found in many countries including the United States

Coproduction Complications

Materials analyzed for clean energy are often lower revenue co-products or byproducts and may not drive production decisions

Material	Other Typical Extraction Products
Rare Earth Elements *(commonly found with thorium)*	Iron (Bautou mine)
Cobalt	Nickel and copper
Gallium	Aluminum and zinc
Indium	Zinc
Tellurium	Copper

Current and Projected Rare Earth Supply by Element
2010 Strategy

Rare Earth Supply by Element: Production Sources and Volume (tonnes/yr)										
		Assumed Additional Production by 2015								
	Estimated 2010 Production	Mt. Weld (Australia)	Mountain Pass (USA)	Dubbo Zirconia (Australia)	Nolans Bore (Australia)	Dong Pao (Vietnam)	Hoidas Lake (Canada)	Nechalacho (Canada)	Total Additional Production by 2015	Estimated 2015 Production
Lanthanum	33,887	3,900	6,640	585	2,000	1,620	594	845	16,184	50,071
Cerium	49,935	7,650	9,820	1,101	4,820	2,520	1,368	2,070	29,349	79,284
Praseodymium	6,292	600	868	120	590	200	174	240	2,792	9,084
Neodymium	21,307	2,250	2,400	423	2,150	535	657	935	9,350	30,657
Samarium	2,666	270	160	75	240	45	87	175	1,052	3,718
Europium	592	60	20	3	40	0	18	20	161	753
Gadolinium	2,257	150	40	63	100	0	39	145	537	2,794
Terbium	252	15	0	9	10	0	3	90	127	379
Dysprosium	1,377	30	0	60	30	0	12	35	167	1,544
Yttrium	8,750	0	20	474	0	4	39	370	907	9,657
TOTAL	**127,315**	14,925	19,968	2,913	9,980	4,924	2,991	4,925	60,626	**187,941**

Sources: Kingsnorth, Roskill, and USGS

Current and Projected Supply of Non-Rare Earth Elements 2010 Strategy

Supply of Other Elements Assessed: Production Sources and Volume (tonnes)

	Estimated 2010 Production	Potential Sources of Additional Production between 2010 and 2015		Estimated 2015 Supply
		Additional amount	*Sources*	
Indium	1,345	267	Recovery (co-produced) from additional zinc production mainly and recycling	1,612
Gallium	207	118[76]	Recovery (co-produced) from additional alumina and bauxite production and recycling[77]	325
Tellurium	500	720	Recovery (co-produced) from copper anode Slimes	1,220
Cobalt	75,900	197,830	Mines	273,730
Lithium (carbonate equivalent)	134,600	115,400	Mines[78]	250,000

Sources: USGS 2008a-e and Evans 2010.

[76] For indium, the additional amount is only the difference between the 2010 production and the maximum current production capacity for mining and refining the material. No new capacity is projected by 2015.
[77] Based on multiple correspondences with USGS, October 4-7, 2010.
[78] USGS, external review of Critical Materials Strategy draft, November 17, 2010.

Demand Projections: Four Trajectories

Material Demand Factors

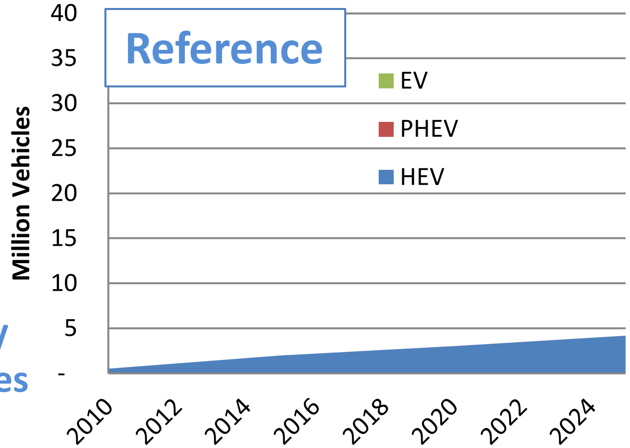
	Market Penetration	Material Intensity
Trajectory D	High	High
Trajectory C	High	Low
Trajectory B	Low	High
Trajectory A	Low	Low




- ***Market Penetration = Deployment*** (total annual units of a clean energy technology) ***X Market Share*** (% of units using materials analyzed)
- ***Material Intensity =*** Material demand per unit of the clean energy technology

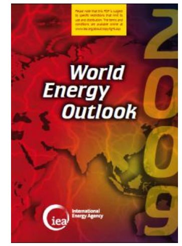
Low Technology Deployment Scenarios 2010 Strategy

Electric Drive Vehicle Additions

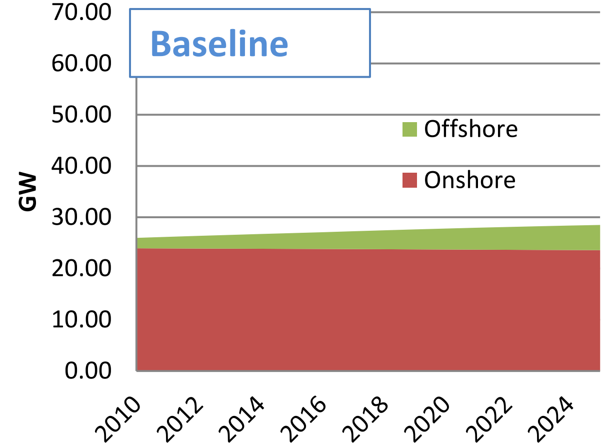


IEA Energy Technology Perspectives

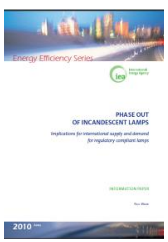
Wind Additions



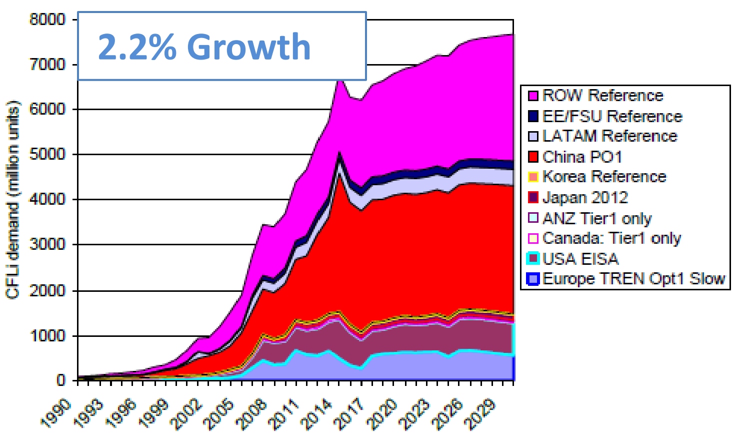
IEA World Energy Outlook



Global CFL Demand

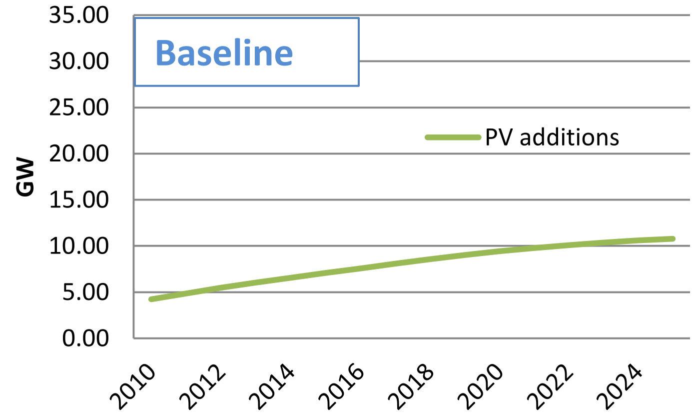


IEA: Phase Out of Incandescent Lights



Source: IEA estimated.

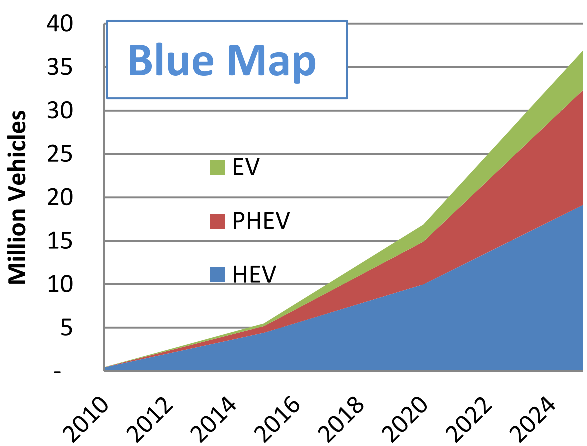
Global PV Additions

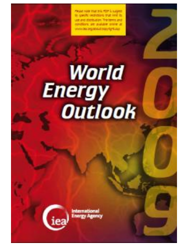


High Technology Deployment Scenarios
2010 Strategy

IEA Energy Technology Perspectives

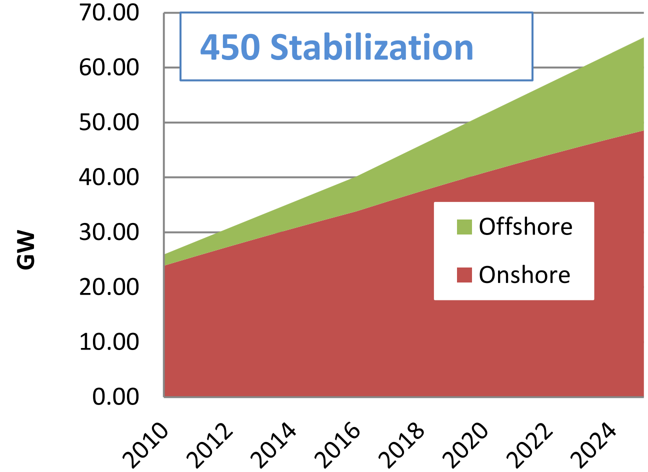
Electric Drive Vehicle Additions

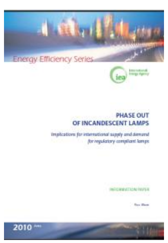




IEA World Energy Outlook

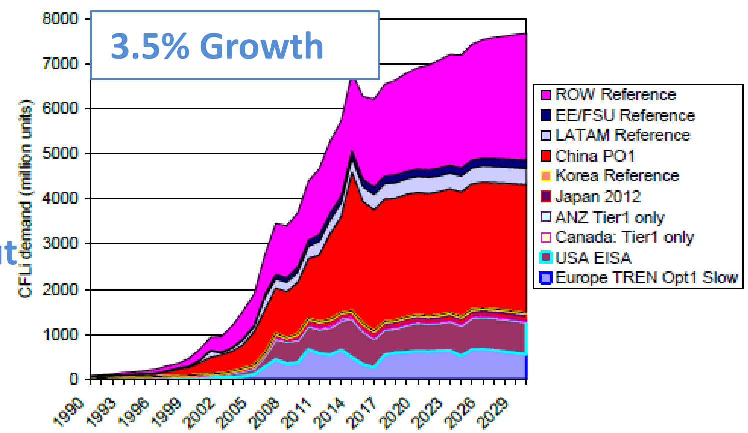
Wind Additions





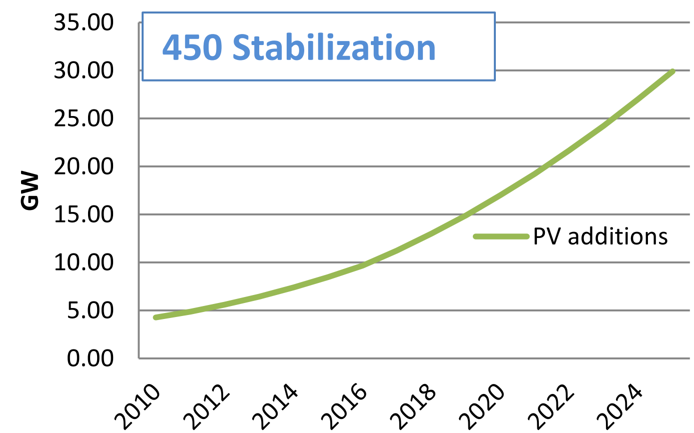
IEA: Phase Out of Incandescent Lights

Global CFL Demand



Source: IEA estimated.

Global PV Additions



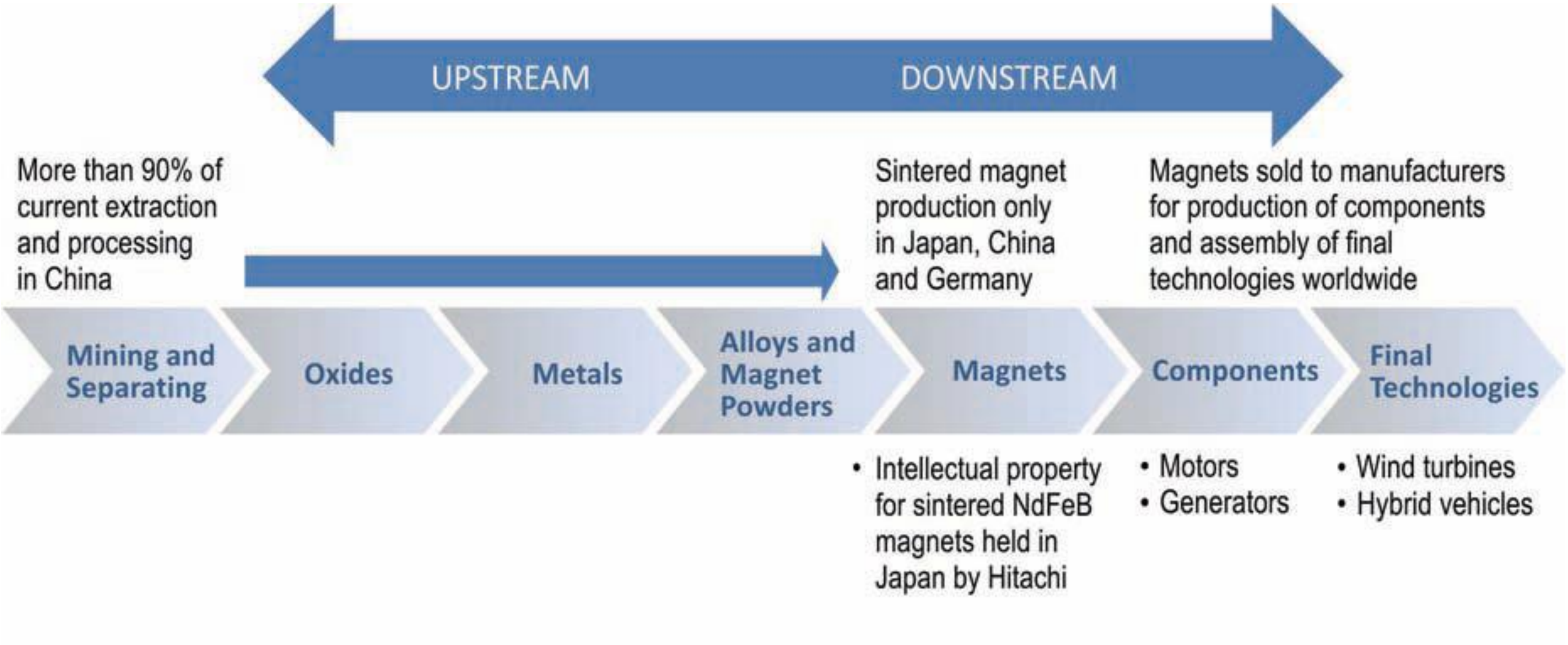
Material Intensity
2010 Strategy

Technology	Component	Material	High Intensity	Low Intensity
Wind	**Generators**	Neodymium	186 kg/MW	124 kg/MW
		Dysprosium	33 kg/MW	22 kg/MW
Vehicles	**Motors**	Neodymium	0.62 kg/vehicle	0.31 kg/vehicle
		Dysprosium	0.11 kg/vehicle	0.055 kg/vehicle
	Li-ion Batteries (PHEVs and EVs)	Lithium	5.1-12.7 kg/vehicle	1.4-3.4 kg/vehicle
		Cobalt	9.4 kg/vehicle	0 kg/vehicle
	NiMH Batteries (HEVs)	Rare Earths (Ce, La, Nd, Pr)	2.2 kg/vehicle	1.5 kg/vehicle
		Cobalt	0.66 kg/vehicle	0.44 kg/vehicle
PV Cells	**CIGS Thin Films**	Indium	110 kg/MW	16.5 kg/MW
		Gallium	20 kg/MW	4 kg/MW
	CdTe Thin Films	Tellurium	145 kg/MW	43 kg/MW
Lighting	**Phosphors**	Rare Earths (Y, Ce, La, Eu, Tb)	6715 metric tons* total demand in 2010, 2.2% (low) or 3.5% (high) annually	

*rare earth oxide equivalent

- ***Calculation methods differed by component based on available data***
- ***High Intensity = material intensity with current generation technology***
- ***Low Intensity = intensity with feasible improvements in material efficiency***

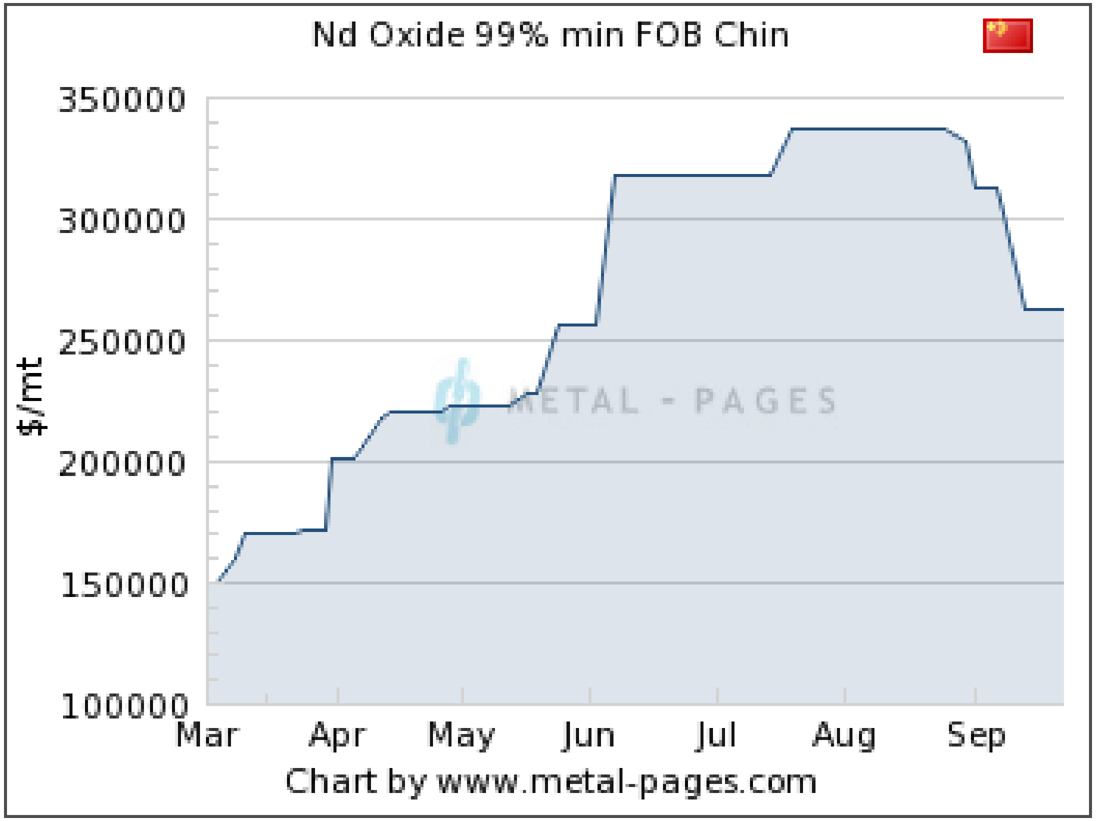
Supply Chain for Rare Earth Element Permanent Magnet Technologies



- Illustrates the supply chain for vehicle and wind turbine applications using Neodymium-Iron-Boron (NdFeB) permanent magnets

This Year's Rare Earth Price Volatility

Neodymium Oxides (Purity 99% min)



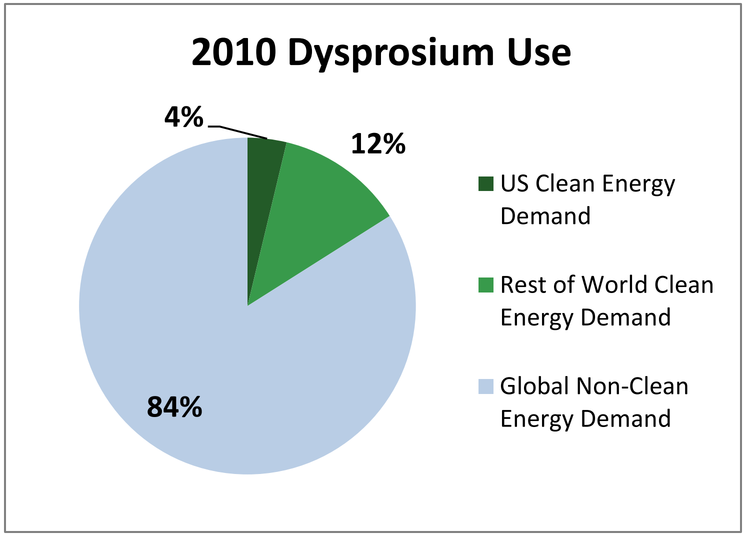
Source: Metal Pages

- Prices have been generally increasing over the past 10 years
- Prices have leveled off after rising dramatically over the past 18 months.

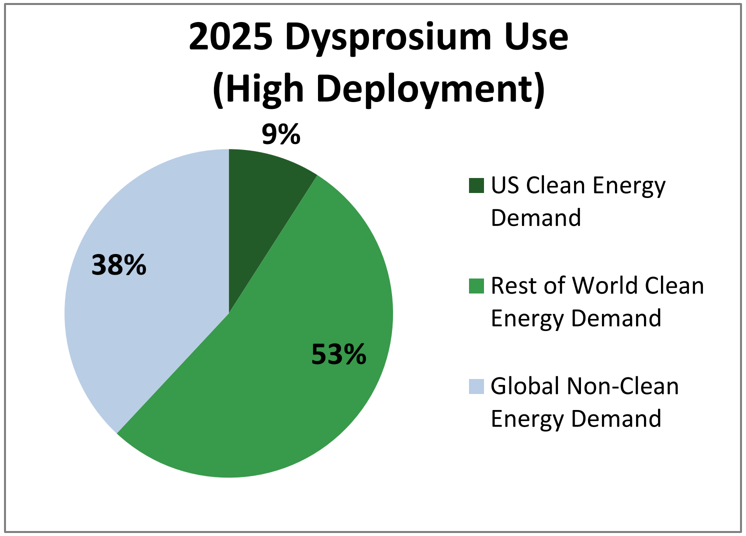
Clean Energy's Share of Critical Material Use
2010 Strategy

Clean energy's share of total material use currently small

…but could grow significantly with increased deployment.



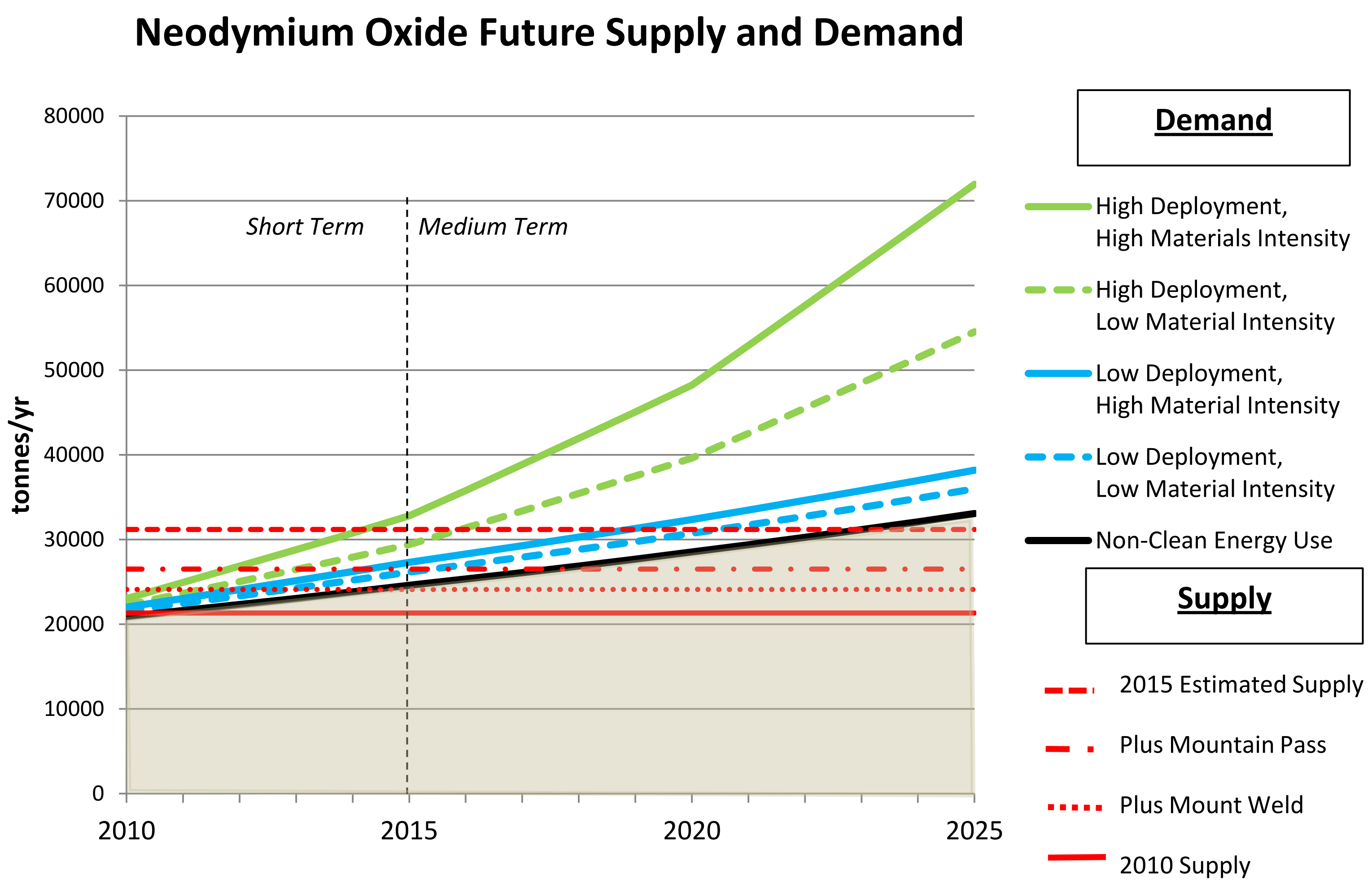
Dysprosium



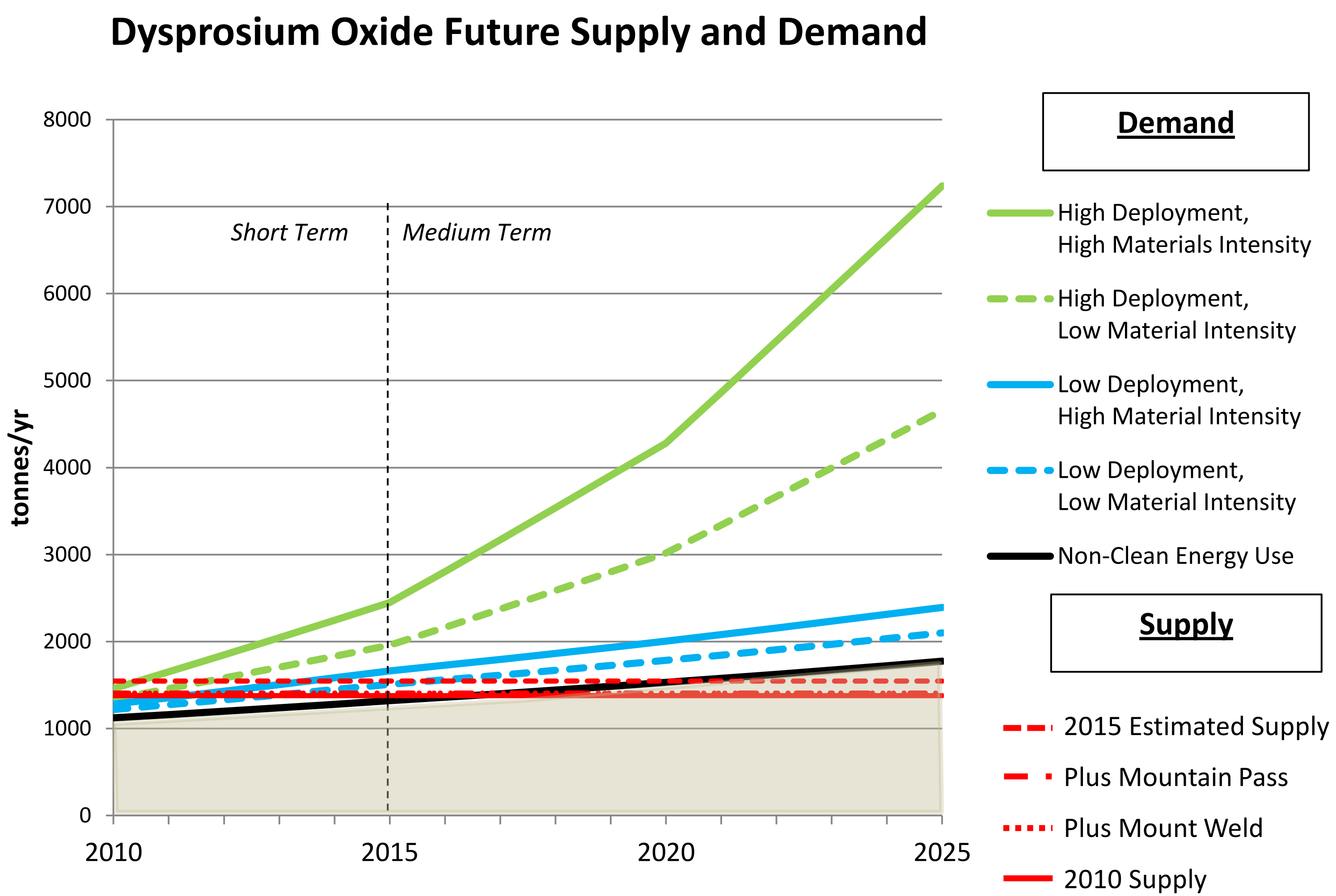
16% is for Clean Energy

62% is for Clean Energy

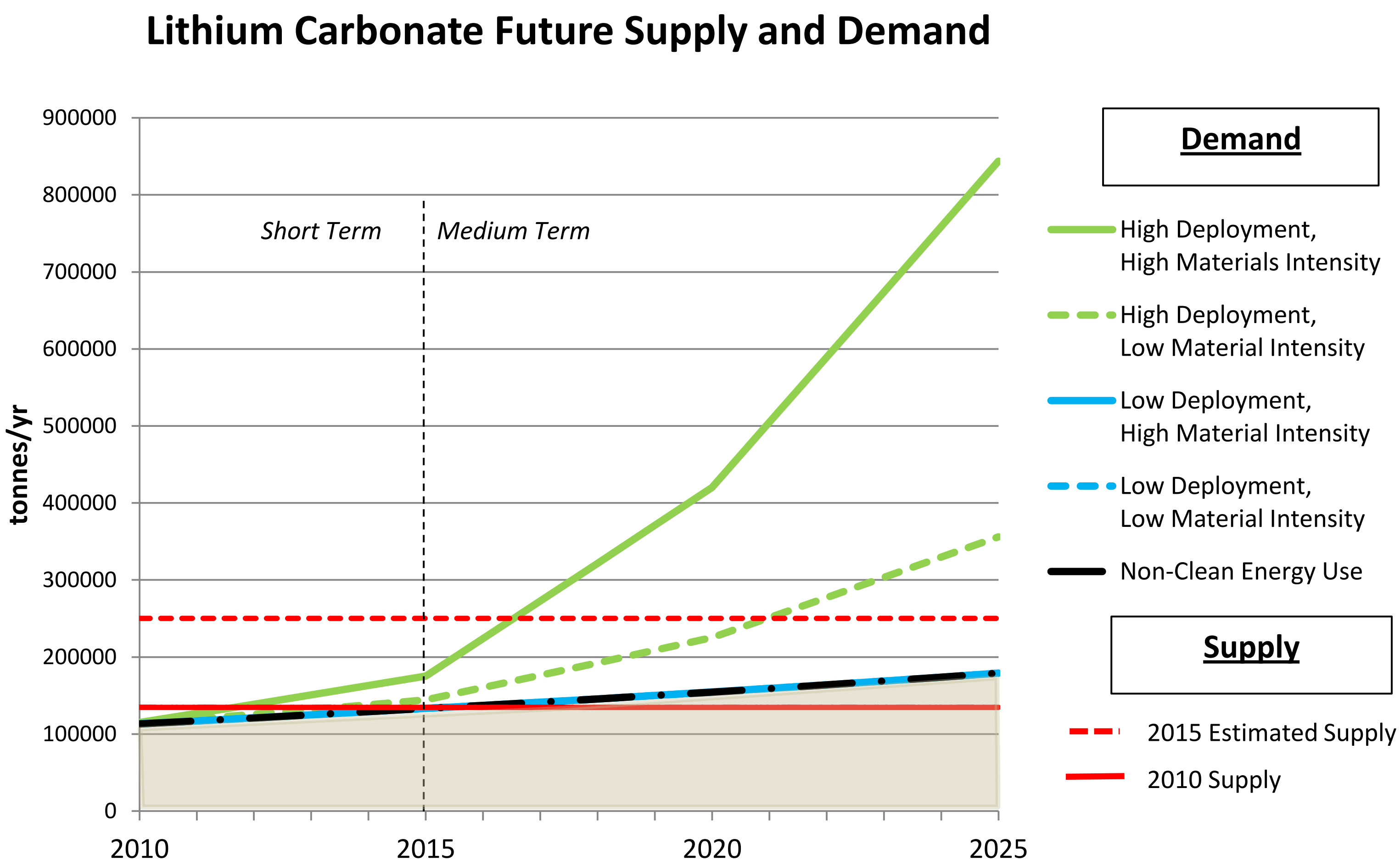
Neodymium - Supply and Demand Projections
2010 Strategy



Dysprosium - Supply and Demand Projections
2010 Strategy



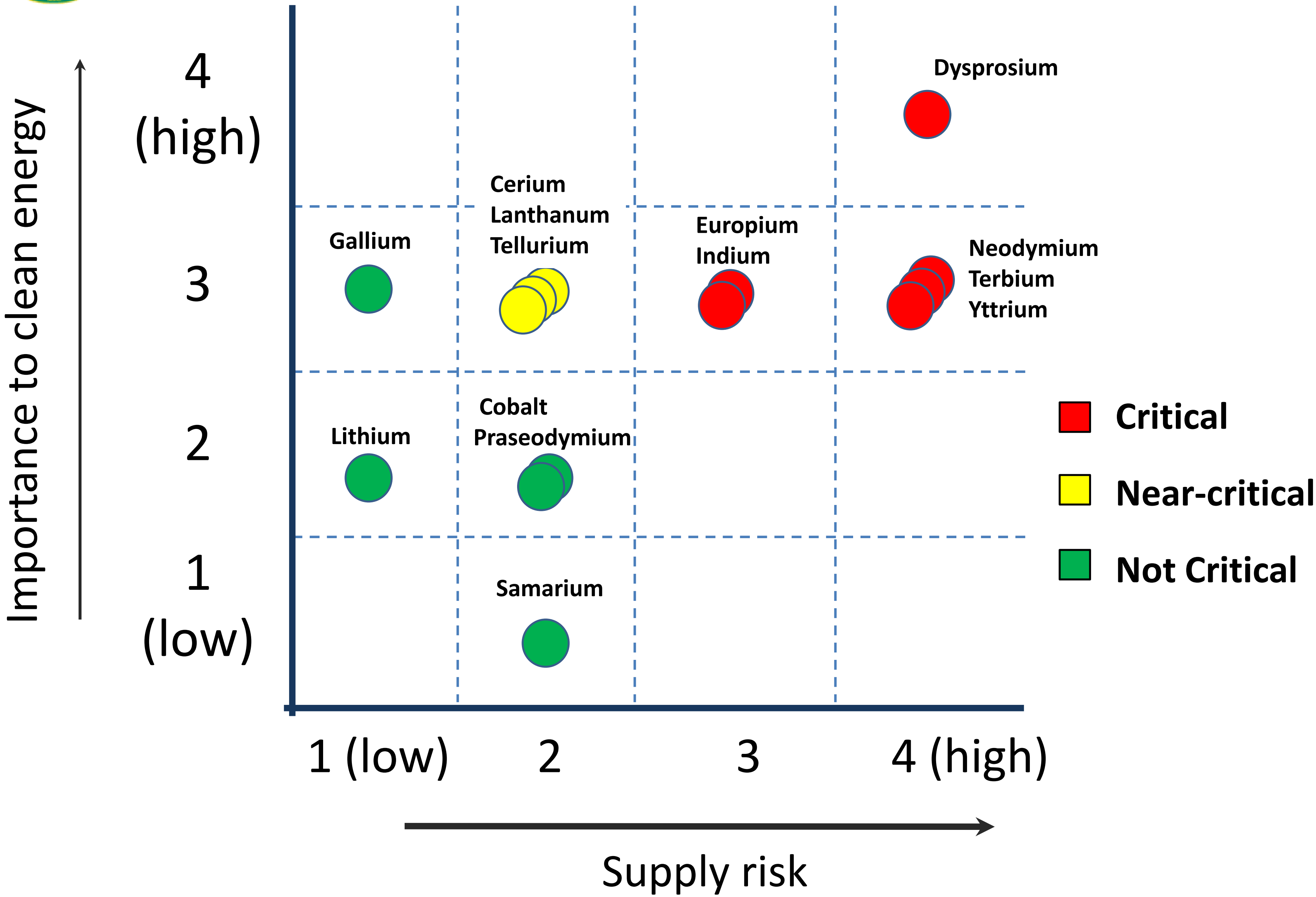
Lithium – Supply and Demand Projections
2010 Strategy



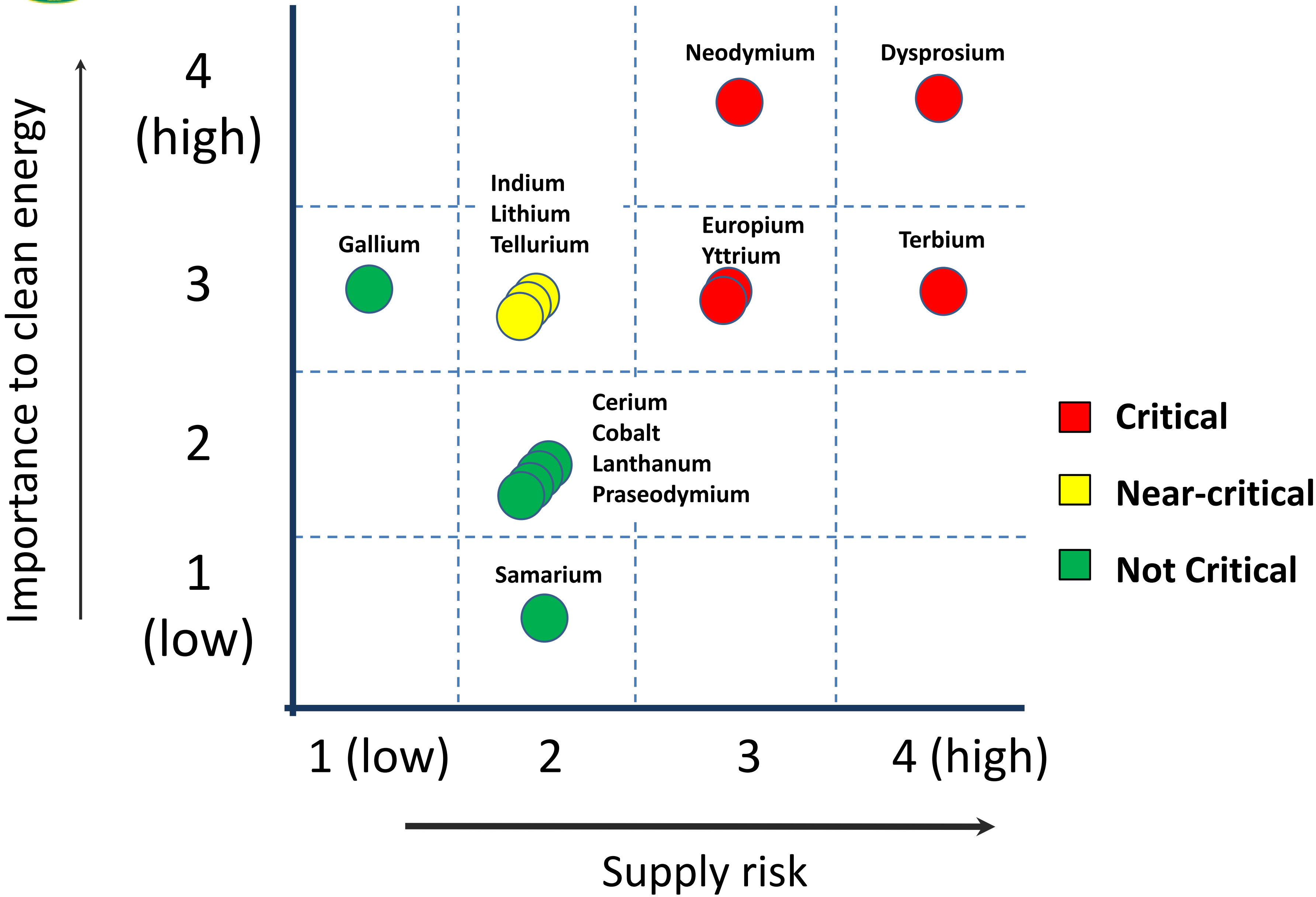
Criticality Assessments

- Adapted from National Academy of Sciences methodology
- *Criticality* is a measure that combines
  - Importance to the clean energy economy
    - Clean Energy Demand; Substitutability Limitations
  - Risk of supply disruption
    - Basic Availability; Competing Technology Demand; Political, Regulatory and Social Factors; Co-Dependence on Other Markets; Producer Diversity
- Time frames:
  - Short-term (0-5 years)
  - Medium-term (5-15 years)

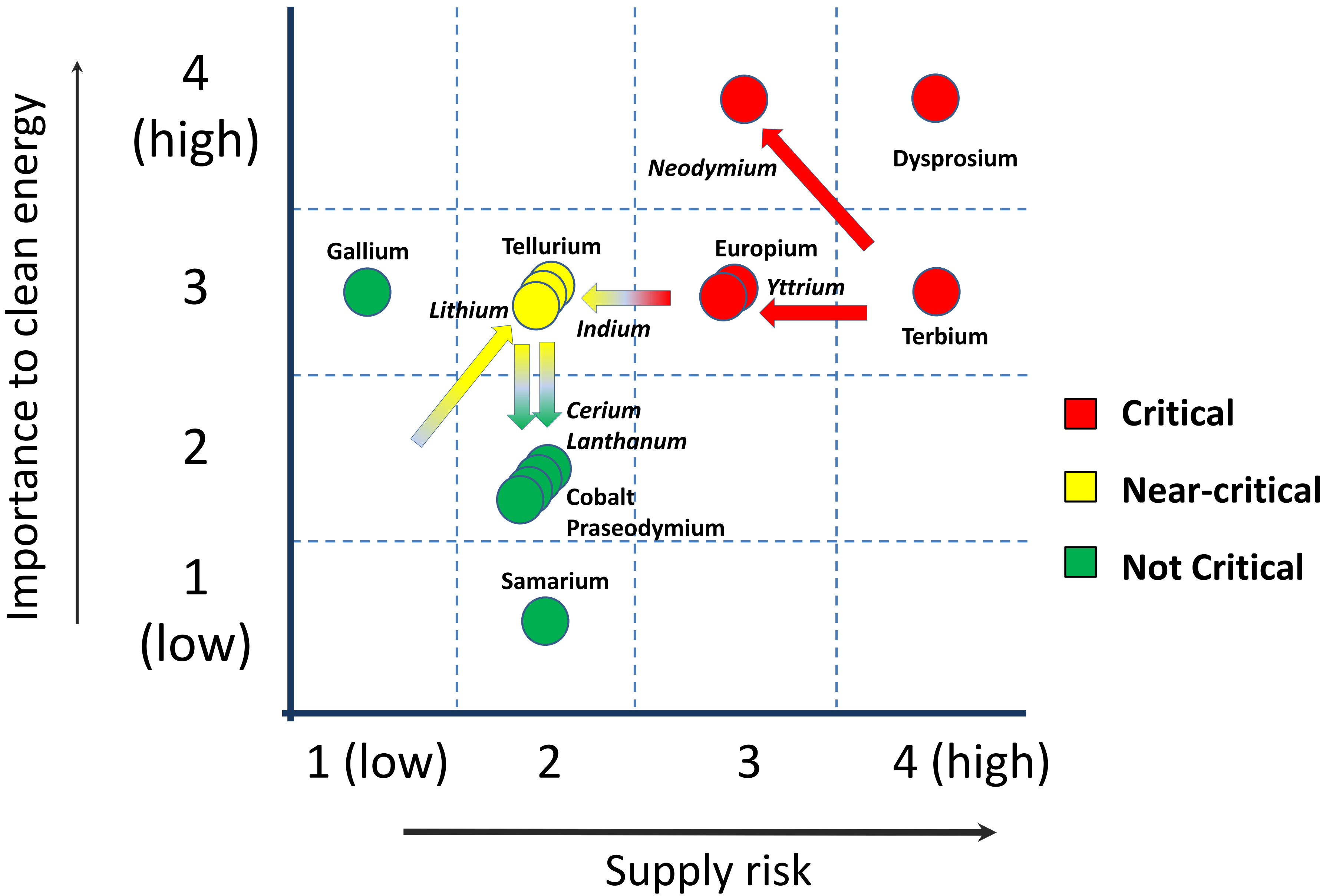
Short-Term Criticality
2010 Strategy



Medium-Term Criticality
2010 Strategy



Criticality Movement: Short to Medium Term
2010 Strategy

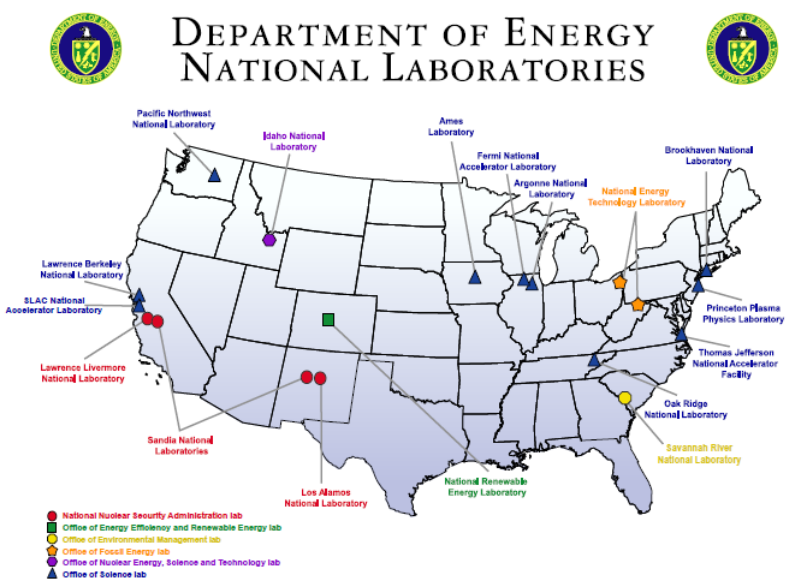


Program and Policy Directions

- Research and development
- Information-gathering
- Permitting for domestic production
- Financial assistance for domestic production and processing
- Stockpiles
- Recycling
- Education
- Diplomacy

Some are within DOE’s core competence, others aren’t

- DOE is the *nation's leading funder* of research on the physical sciences.
- Long history of materials work – Ames Lab, EERE, Office of Science, ARPA-E



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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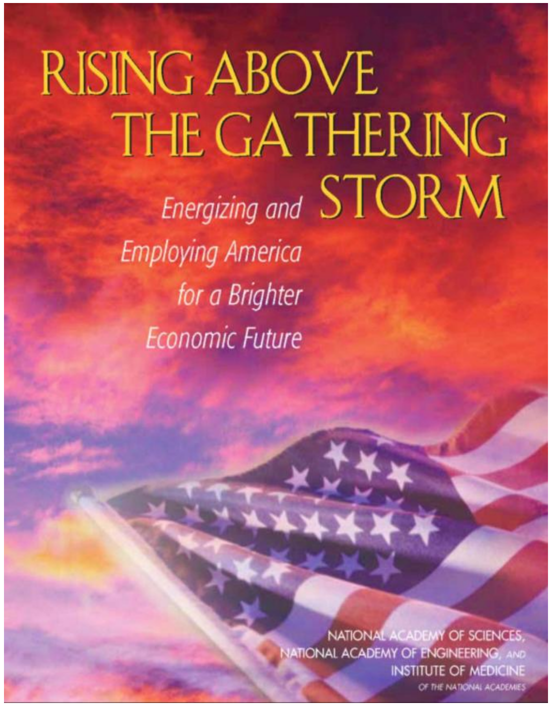


- *Develop the next generation of rare earth and critical materials experts through education and training*
- *Promote science, technology, engineering and math (STEM) training at all education levels*

"Improving education in math and science is about producing engineers and researchers and scientists and innovators who are going to help transform our economy and our lives for the better."

President Barack Obama
November 23, 2009

R&D Workshops & International Meetings

- Japan-US Workshop (Lawrence Livermore National Lab - Nov 18-19, 2010)

- Transatlantic Workshop (MIT - Dec 3, 2010)

US-EU ENERGY COUNCIL

- ARPA-E Workshop (Ballston, VA – Dec 6, 2010)

arpa·e

- US- Australia Joint Commission Meeting (DC – Feb 14, 2011)

- Trilateral R&D Workshop with Japan and EU (DC – Oct 4-5, 2011)

EU-JAPAN-US TRILATERAL CRITICAL MATERIALS INITIATIVE

2010 Strategy Conclusions

- Some materials analyzed at risk of supply disruptions.

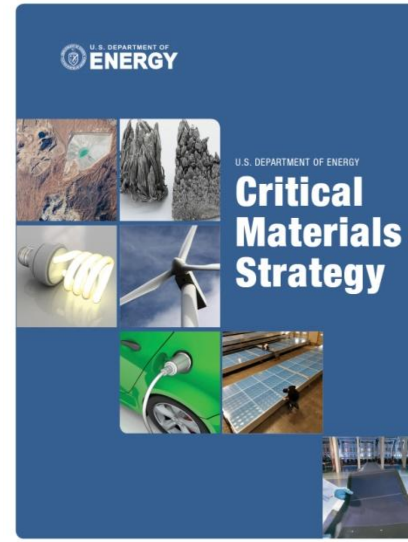
  Five rare earth metals (dysprosium, neodymium, terbium, europium and yttrium) and indium assessed as most critical.

- Clean energy's share of material use currently small

  …but could grow significantly with increased deployment.

- Critical materials are often a small fraction of the total cost of clean energy technologies.

  Demand does not respond quickly when prices increase.



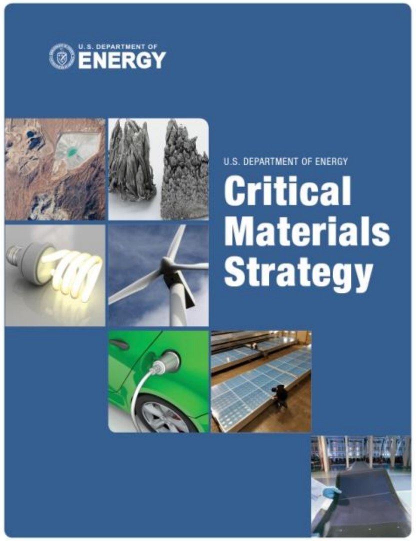
2010 Strategy Conclusions (continued)

- Data are sparse.

  More information is required.

- Sound policies and strategic investments can reduce risk.

  …especially in the medium and long term.



IV. Continuing Steps

DOE Next Steps

- Develop an *integrated research plan*, building on three recent workshops.
- Strengthen *information-gathering capacity.*
- *Analyze additional technologies .*
- Continue to work closely with:
  - *International partners*
  - *Interagency colleagues*
  - *Congress*
  - *Public stakeholders*
- *Update the strategy* by the end of 2011.

2011 RFI Topics

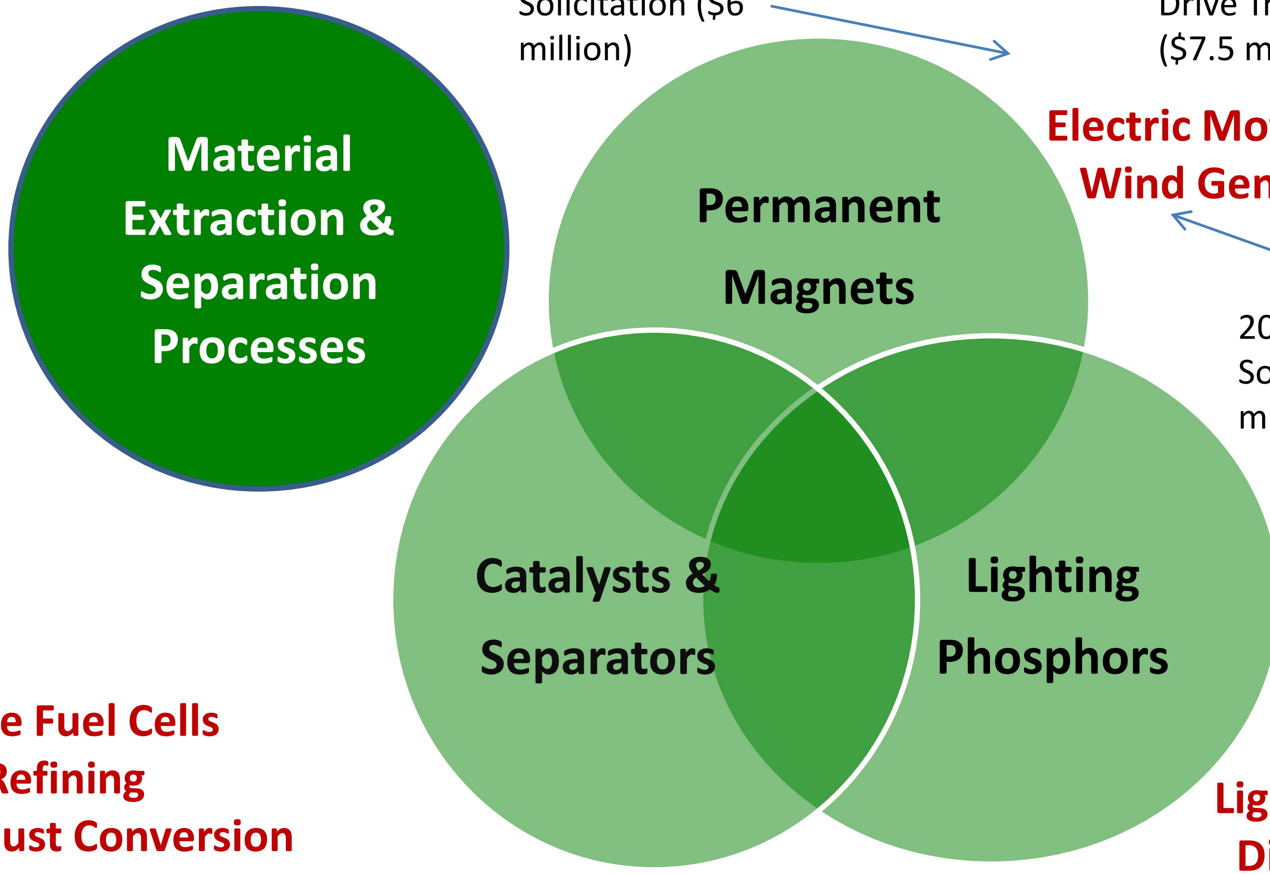
- Technology Critical Material Content
- Supply Chain and Market Projections
- Financing and Purchase Transactions
- Research, Education and Training
- Energy Technology Transitions and Emerging Technologies
- Recycling Opportunities
- Mine and Processing Plant Permitting
- Additional Information

Beginnings of an R&D Plan: Technology R&D Topics from ARPA-E Workshop

2011 EERE VTP Solicitation ($6 million)

2011 EERE Wind Power Drive Train Solicitation ($7.5 million)

Geologic or Recycled Feedstocks



Electric Motors
Wind Generators

2011 ARPA-E Solicitation ($30 million)

Solid Oxide Fuel Cells
Gasoline Refining
Auto Exhaust Conversion

Light Emitting Diodes (LED)
Compact Fluorescent Lights (CFL)

Supply Technologies ⟷ **Application Technologies**

2012 Critical Materials Innovation Hub - $20 million/year

- Seminar: Strategic Implications of Global Shortages of Critical Materials
- R&D Workshop Topics
  - *Reducing Neodymium and Dysprosium Requirements for Permanent Magnets*
  - *Component and System-Level Substitutions for Rare Earth Materials*
  - *Materials and Processes for Environmentally Sound, Economical Separation of Rare Earths in Diverse Ore Bodies and Recycling Streams*
  - *Rare Earth Recycling Technologies and Optimization*

- Led by the White House Office of Science and Technology Policy (OSTP), the group includes multiple departments and agencies
  - DOE, DOD, USGS, DOC, EPA, DOJ, DOS and USTR
- Initial focus
  - Critical mineral prioritization and early warning mechanism
  - R&D prioritization
  - Responsible development of global supply chains
  - Transparency of information (both geologic and market)

U.S. DEPARTMENT OF ENERGY

Critical Materials Strategy

DOE welcomes comments

Comments and additional information can be sent to *materialstrategy@hq.doe.gov*