U.S. DEPARTMENT OF ENERGY

Critical Materials Strategy

2011

Summary Briefing




Mike McKittrick

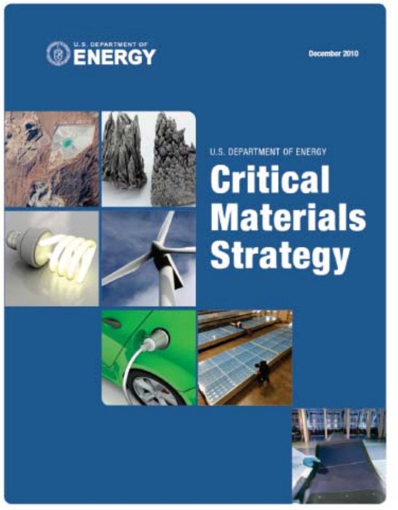
U.S. EPA Office of Research and Development

Rare Earth Elements Workshop

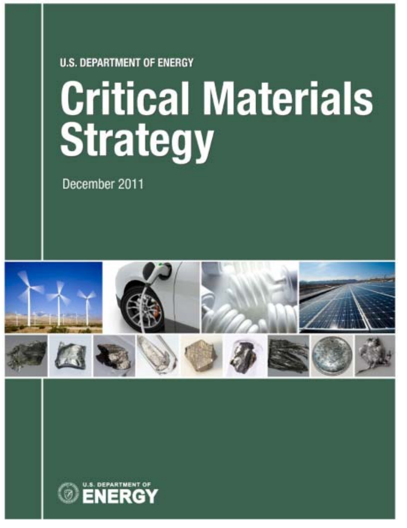
May 10, 2012

Timeline

- March 2010 – DOE begins work on first strategy
- December 2010 – 2010 Critical Materials Strategy released



- Spring 2011 – Public Request for Information
- December 2011 – 2011 Critical Materials Strategy released



Project Scope

New for 2011

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

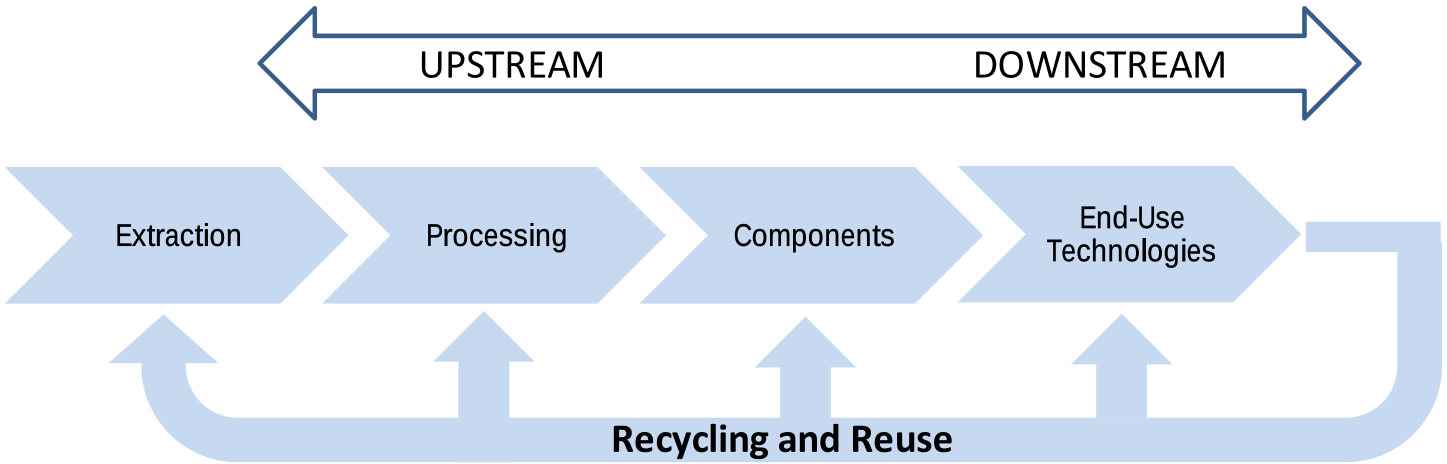
Lighting

Solar PV

Wind

Strategic Pillars

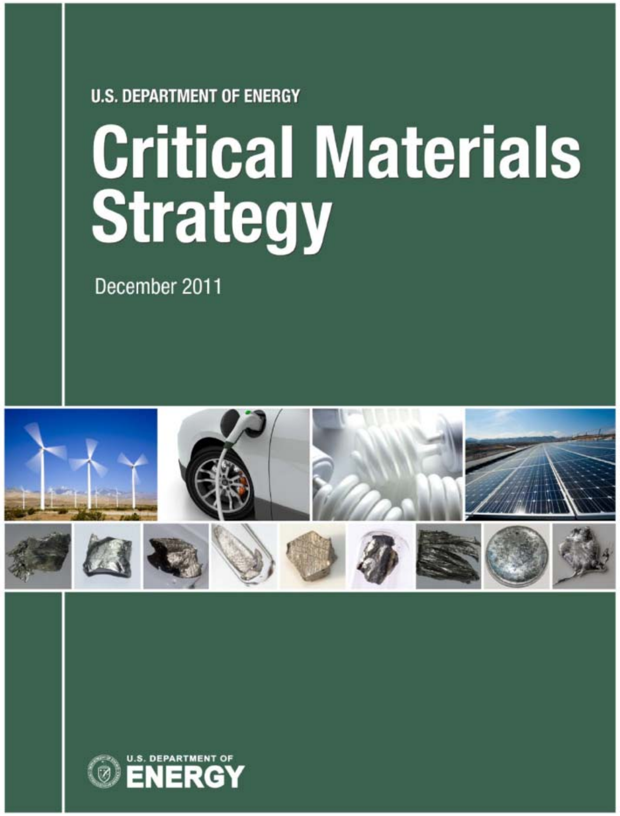
- *Diversify global supply chains*
- *Develop substitutes*
- *Reduce, reuse and recycle*



Material supply chain with environmentally-sound processes

2011 Critical Materials Strategy:

- Provides an updated criticality analysis
- Sets forth several case studies, including oil refining catalysts
- Discusses critical materials market dynamics
- Presents DOE's Critical Materials R&D Plan



DOE’s 2011 Critical Materials Strategy - Main Messages

1. Critical supply challenges for five rare earths (dysprosium, neodymium, terbium, europium, yttrium) may affect energy technologies in years ahead
2. In past year, DOE and other stakeholders have scaled up work to address these challenges
3. Building workforce capabilities through education and training will help realize opportunities
4. Much more work required in years ahead

Current and Projected Rare Earth Oxide Supply by Element – 2011 Critical Materials Strategy

	2010 Production	Potential Sources of Additional Production between 2010 and 2015									Total 2015 Production Capacity
		United States		Australia			Vietnam	South Africa			
		Mt. Pass Phase I	Mt. Pass Phase II	Mt. Weld	Nolans Bore	Dubbo Zirconia	Dong Pao	Steenkamps-kraal	Russia & Kazakhs-tan	India	
La	**31,000**	5,800	6,800	5,600	2,000	510	970	1,100	140	560	54,000
Ce	**42,000**	8,300	9,800	10,300	4,800	960	1,500	2,300	290	1200	81,000
Pr	**5,900**	710	840	1,200	590	110	120	250	20	140	9,900
Nd	**20,000**	2,000	2,300	4,100	2,200	370	320	830	44	460	33,000
Sm	**2,800**	130	160	510	240	56	27	125	5	68	4,000
Eu	**370**	22	26	88	40	2		4	1		550
Gd	**2,400**	36	42	176	100	56		83	1	30	3,000
Tb	**320**	5	6	22	10	8		4	0.4		370
Dy	**1,600**	9	10	22	30	53		34	1		1,700
Y	**10,500**			66		410	21	250			11,300
Others	**2,000**	73	86			75	25	12	3	25	2,300
Total	**120,000**	17,000	20,000	22,000	10,000	2,600	3,000	5,000	500	2,500	200,000

Sources: Kingsnorth, Lynas, Molycorp, Roskill(2011)

Current and Projected Rare Earth Projects

(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

Source: Watts 2011

Rare earth metals are not rare –

found in many countries including the United States

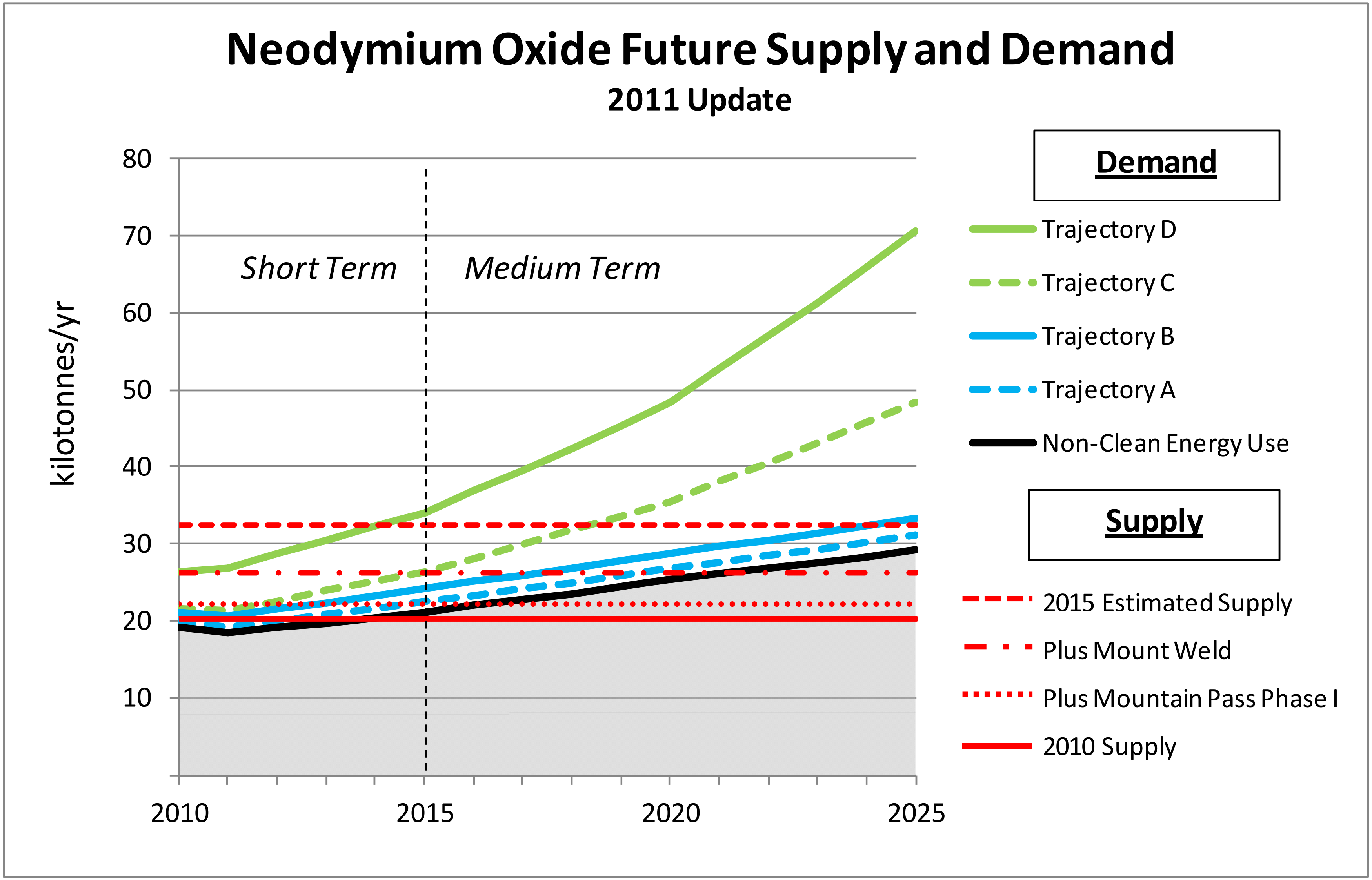
Demand Projections: Four Trajectories

Material Demand Factors

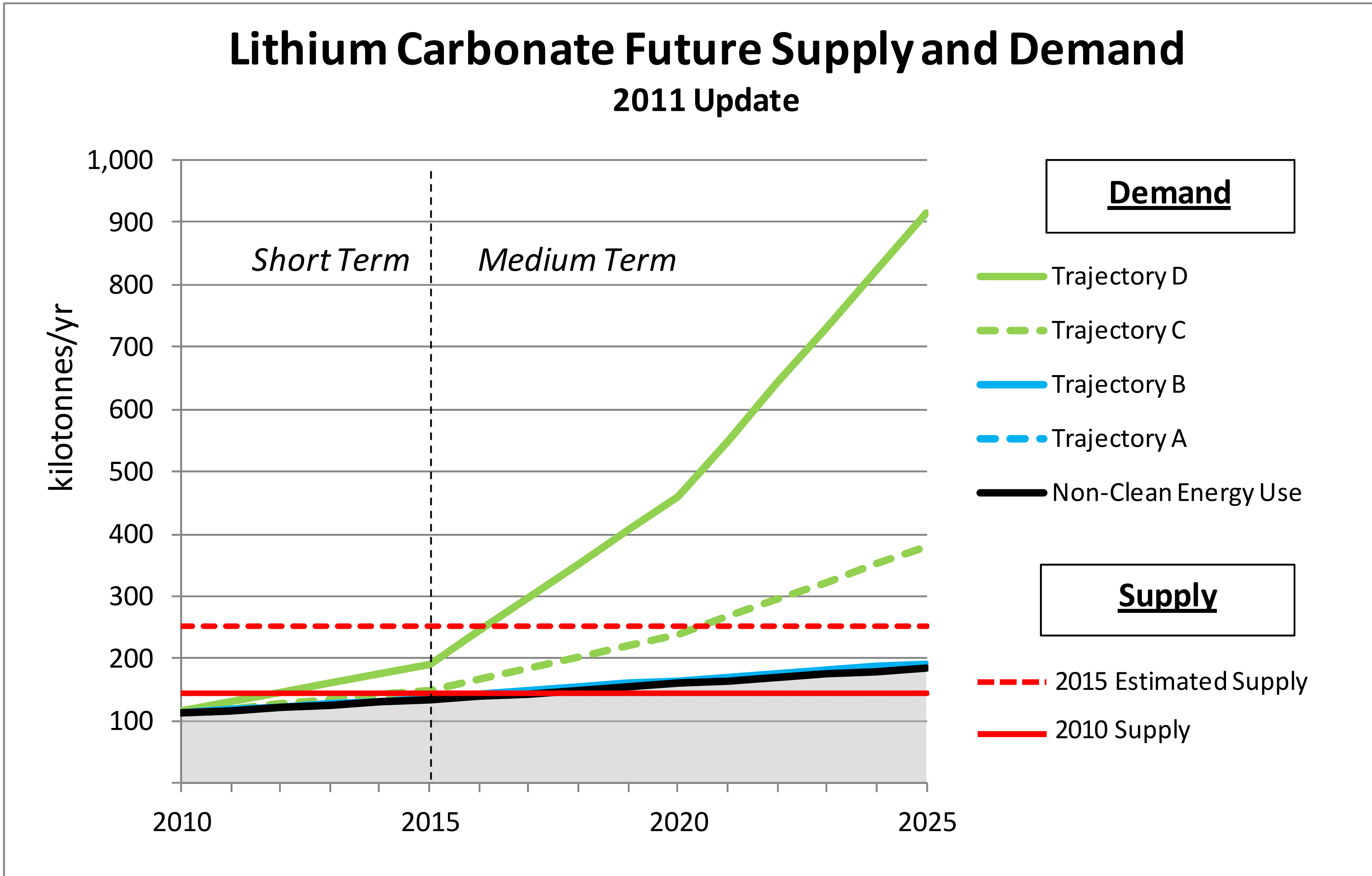
	Market Penetration	Material Intensity
Trajectory D	High	High
Trajectory C	High	Low
Trajectory B	Low	High
Trajectory A	Low	Low

- ***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

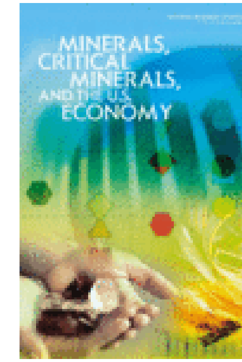
Neodymium - Supply and Demand Projections
Critical Materials Strategy 2011



Lithium – Supply and Demand Projections
Critical Materials Strategy 2011

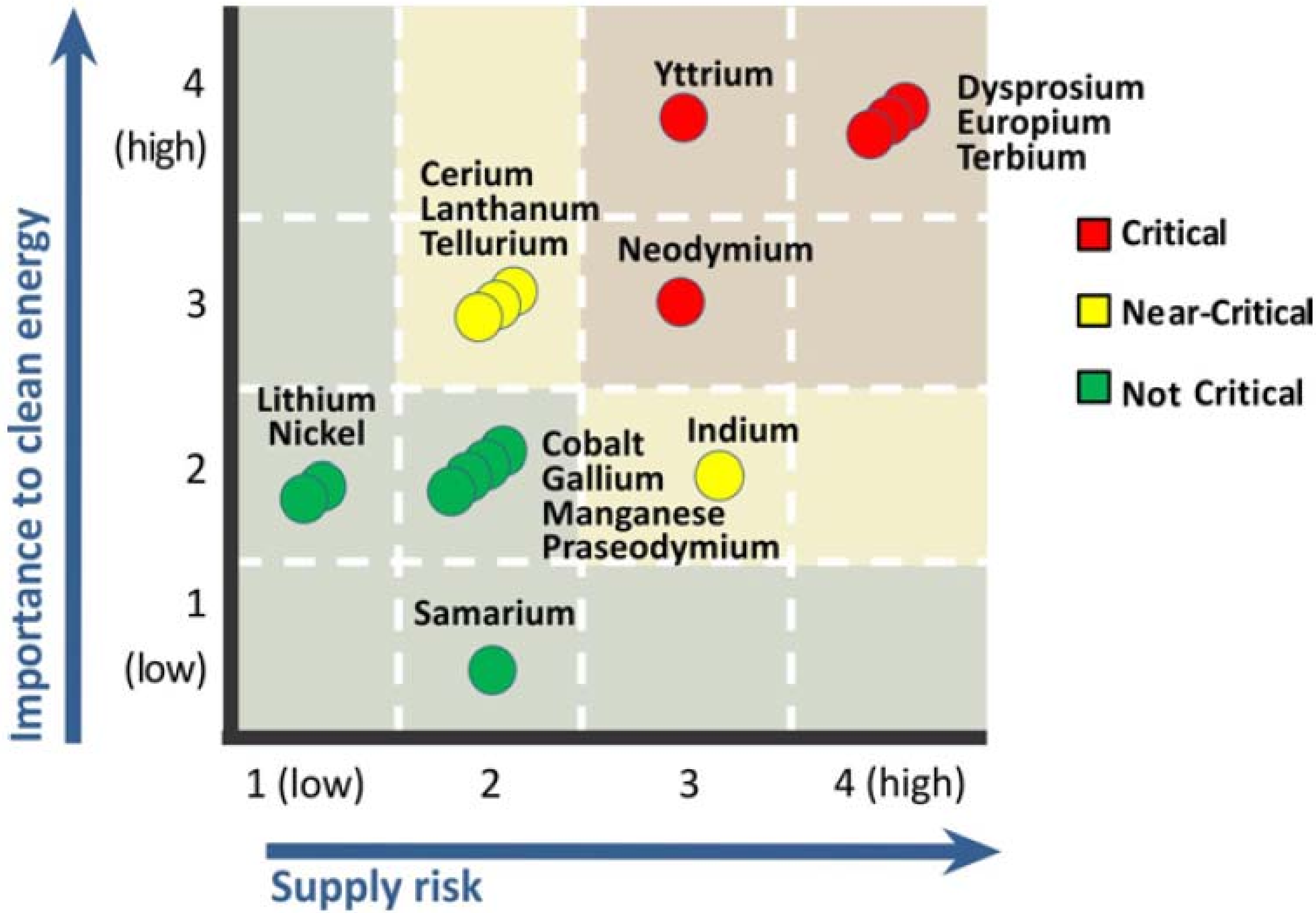


Criticality Assessments

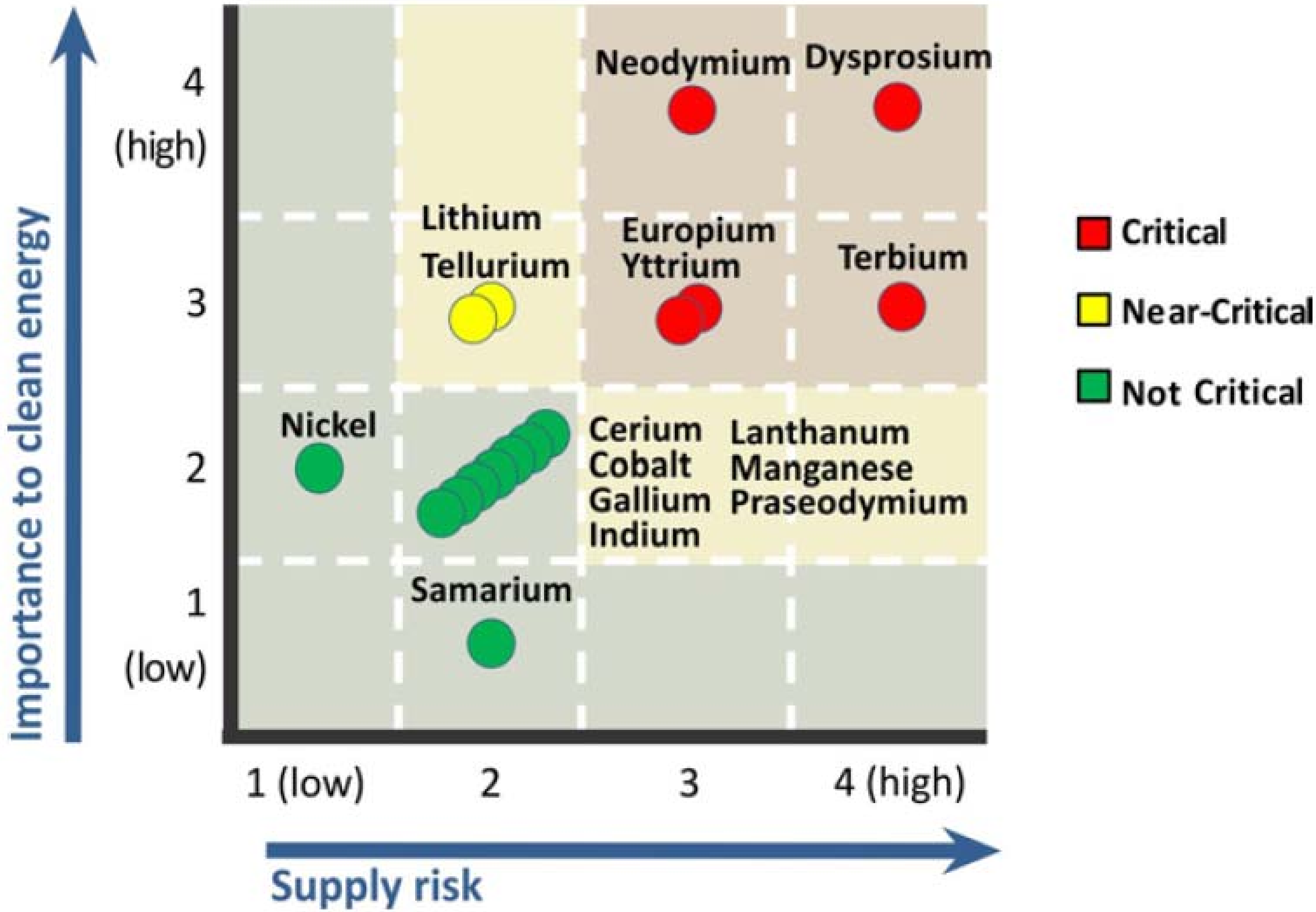


- Methodology adapted from National Academy of Sciences
- *Criticality* is a measure that combines
  - Importance to clean energy technologies
    - Clean Energy Demand; Substitutability Limitations
  - Risk of supply disruption
    - Basic Availability; Competing Technology Demand; Political, Regulatory and Social Factors; Co-Dependence on Other Markets; Producer Diversity
- Time frames:
  - Short-term (Present - 2015)
  - Medium-term (2015 - 2025)

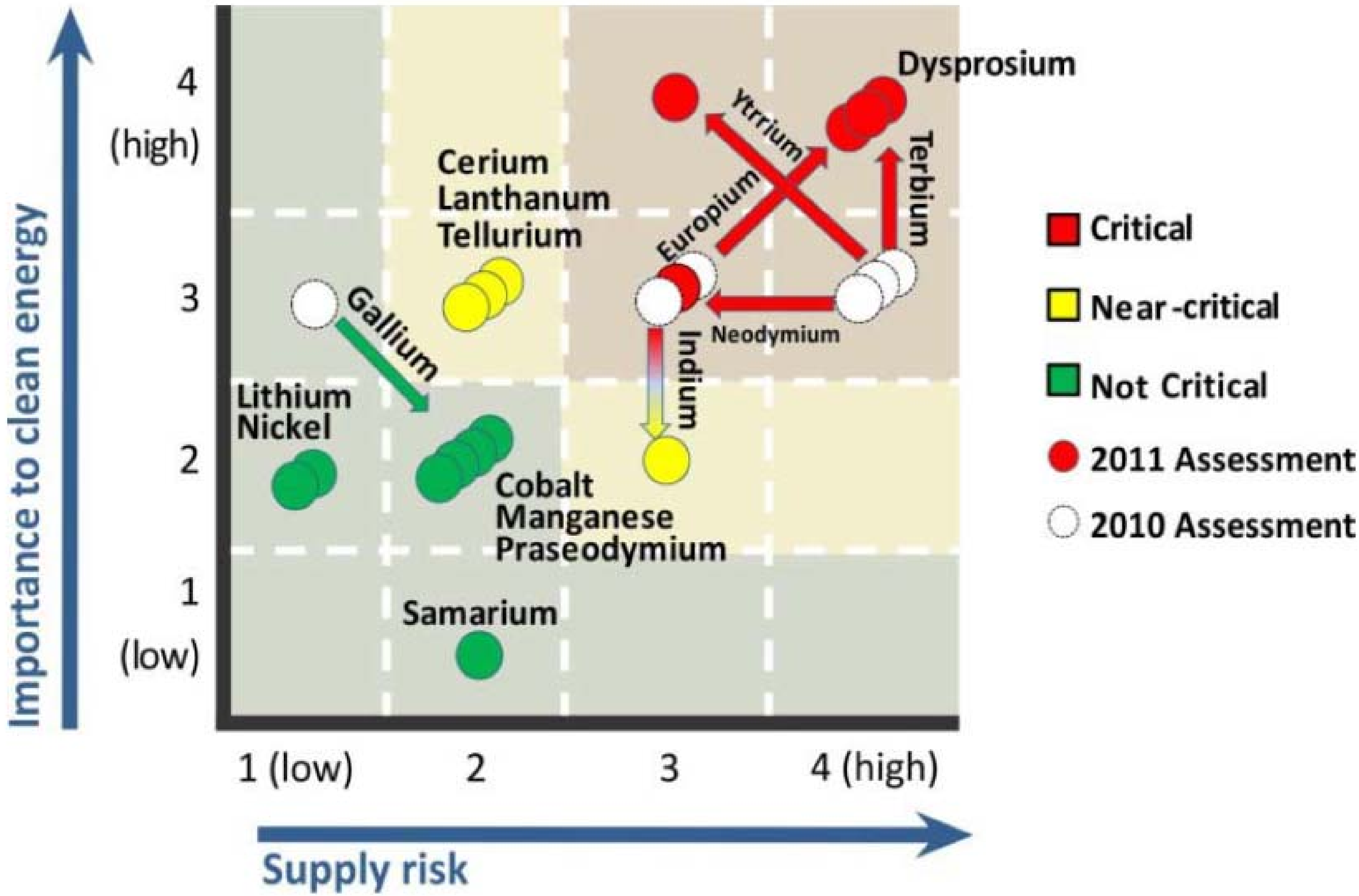
2011 CMS Short-Term Criticality (Present - 2015)



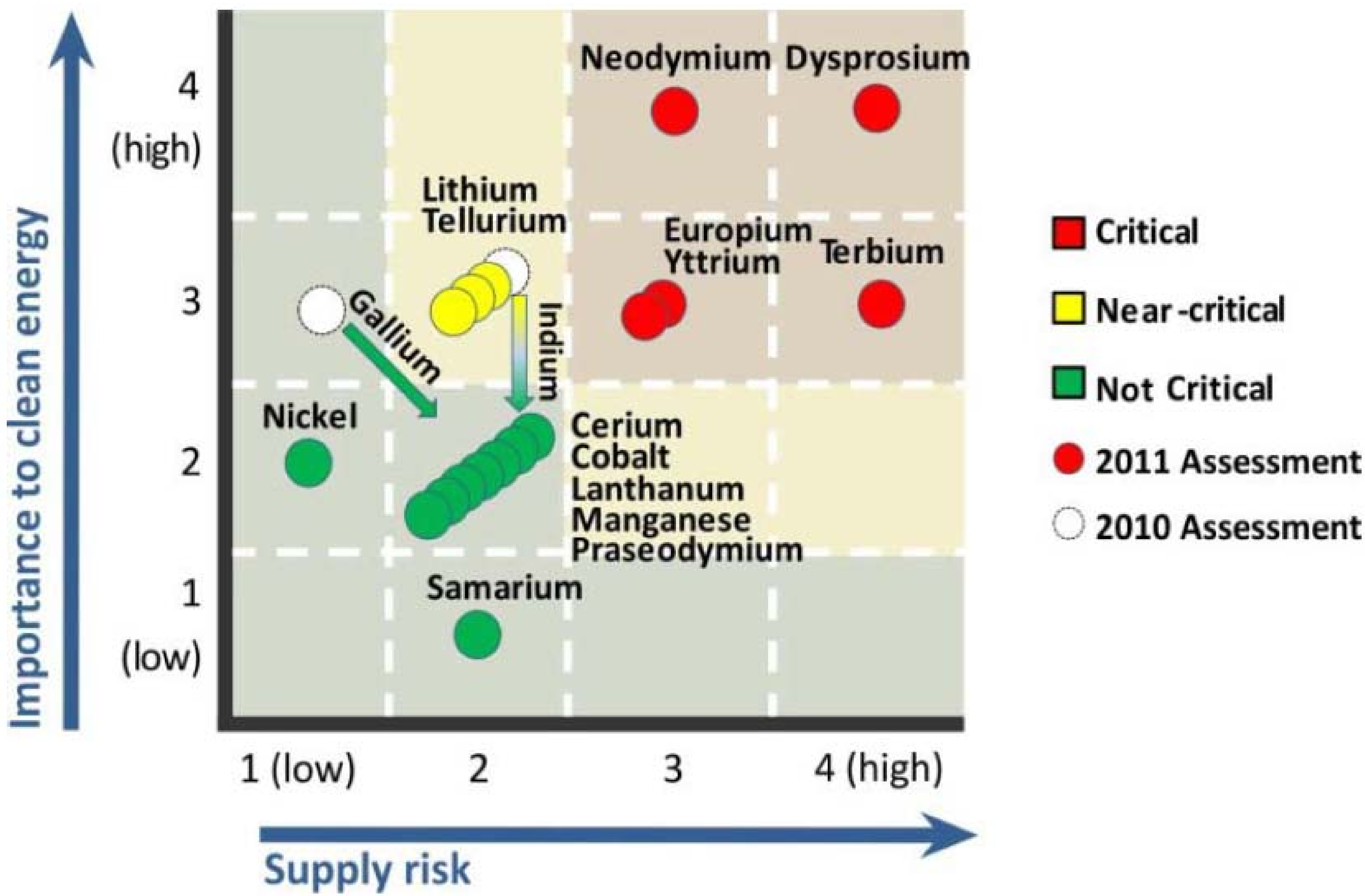
2011 CMS Medium-Term Criticality (2015-2025)



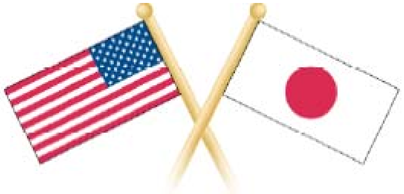
Short-Term Comparison between 2010 CMS and 2011 CMS



Medium-Term Comparison Between 2010 CMS and 2011 CMS



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



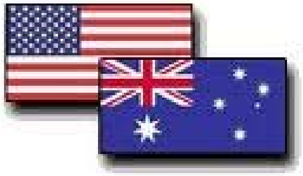
- **Transatlantic Workshop (MIT – Dec 3, 2010)**

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 Workshops with Japan and EU (DC – Oct 4-5, 2011, Tokyo – March 28-29, 2012)**

EU-JAPAN-US TRILATERAL CRITICAL MATERIALS INITIATIVE

R&D Plan

- DOE R&D aligns with the 3 strategic pillars
  - Diversification of Supply: Separation and processing
  - Substitutes
    - Magnets, motors, generators
    - PV
    - Batteries
    - Phosphors
  - Recycling

PV and Batteries

DOE invests in a broad technology portfolio with diverse materials:

FY 2011 R&D Investments - PV	
EERE Solar Energy Technologies Program	$22 million

- Cadmium-Telluride
- CIGS
- Silicon

→

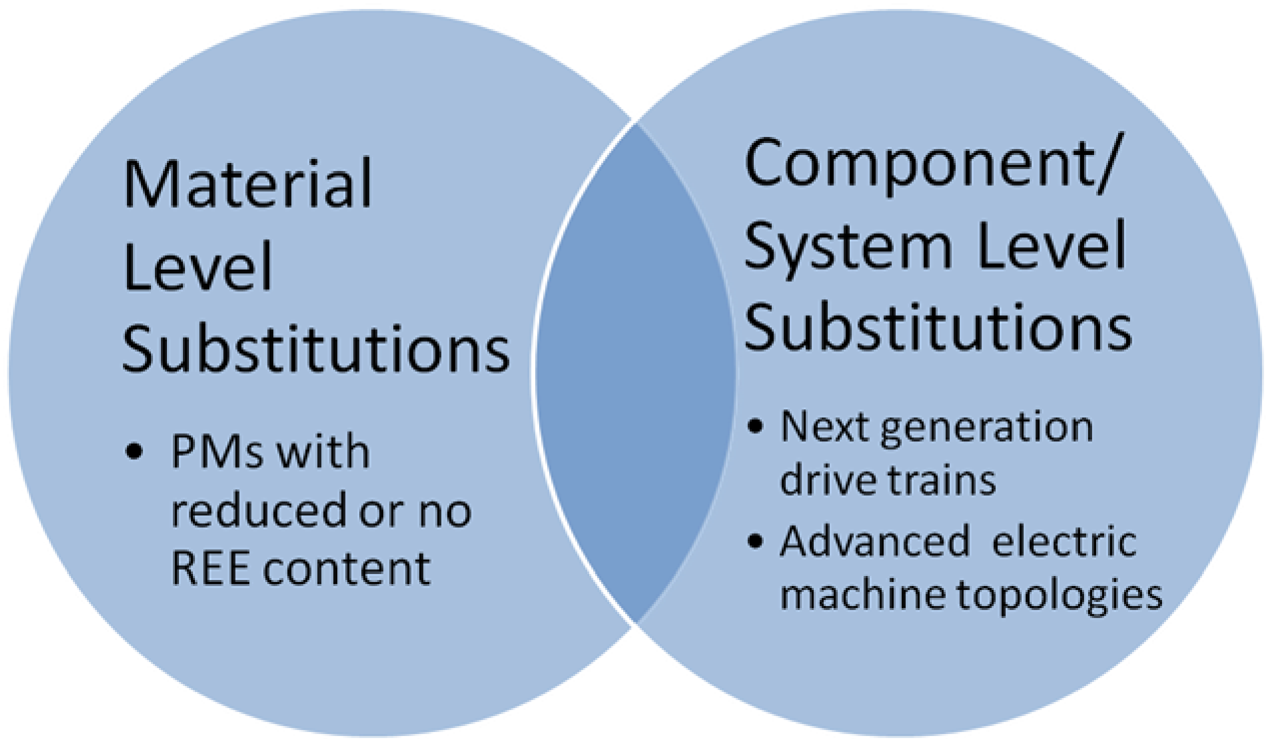
- Iron Pyrite
- Copper-Nitride
- Copper-Zinc-Tin-Sulfide

R&D Investments - Batteries		
EERE Vehicle Technologies Program	FY11	$24 million
ARPA-E Batteries for Electrical Energy Storage in Transportation	FY10	$35 million

NiMH → Li-ion → Next-generation: Li-sulfur, Mg-ion, Zn-air

Substitutes for Rare Earth Permanent Magnets for Motors and Wind Generators

FY 2011 R&D Investments		
ARPA-E REACT	EERE Vehicle Technologies Program	EERE Wind Program
$30 million	$6 million	$7.5 million



Novel High-Energy Permanent Magnets without Critical Elements

PI: R. William McCallum, Ames Laboratory, Ames, IA

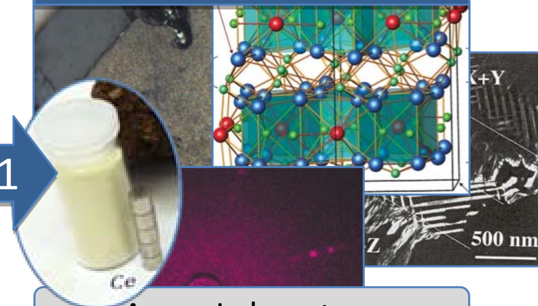
50% of oxide in ore is Ce

Molycorp Minerals

Stan Trout

1

Designer Ce-TM Magnet

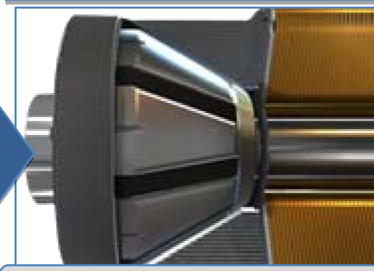


Ames Laboratory

R. W. McCallum, D. Johnson, V. Antropov, K. Gschneidner, M. Kramer, V. Pecharsky

2

Larger-Field Motor via Magnet Shape Design

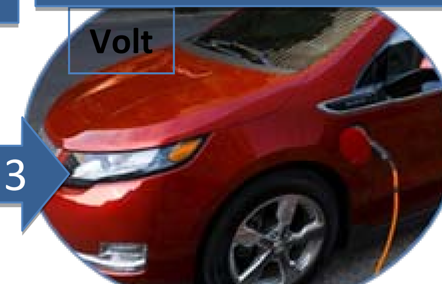


NovaTorque

John Petro

3

Usable Drive Motors



General Motors

Fred Pinkerton

Molycorp Bastnasite
4x (12x) more Ce than Nd (Pr)
=> 4x more Ce-based magnets than Nd-Pr-based magnets

Key Milestones & Deliverables
• Jointly characterize Ce-TM *baseline* alloys • Develop/assess Ce-(Fe,TM)-X alloys (X=H,N).
• Evaluate and down-select interstitially and/or substitutionally modified Ce-TM magnets

Suitable Ce-based magnets are undeveloped. *Via integrated computational engineering and advanced synthesis and processing, **Ames Laboratory will***:

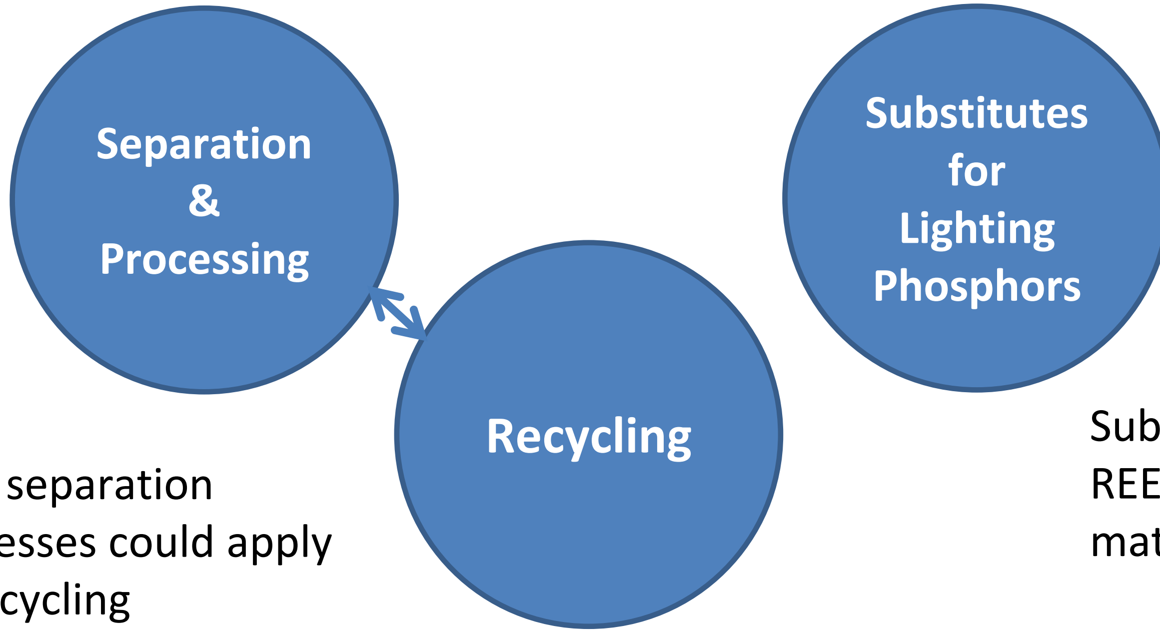
Control and manipulate the intrinsic and extrinsic magnetic properties of **Ce-Transition-Metal permanent magnets <u>for automotive traction motors</u>**.

Develop a Ce-TM based magnet for motors having Tc > 300 C, a remnant magnetization >1 Tesla, and a coercivity >10 KOe, needed for technology.

Courtesy of arpa·e

Next R&D Challenges and Opportunities

Efficient & environmentally friendly processes

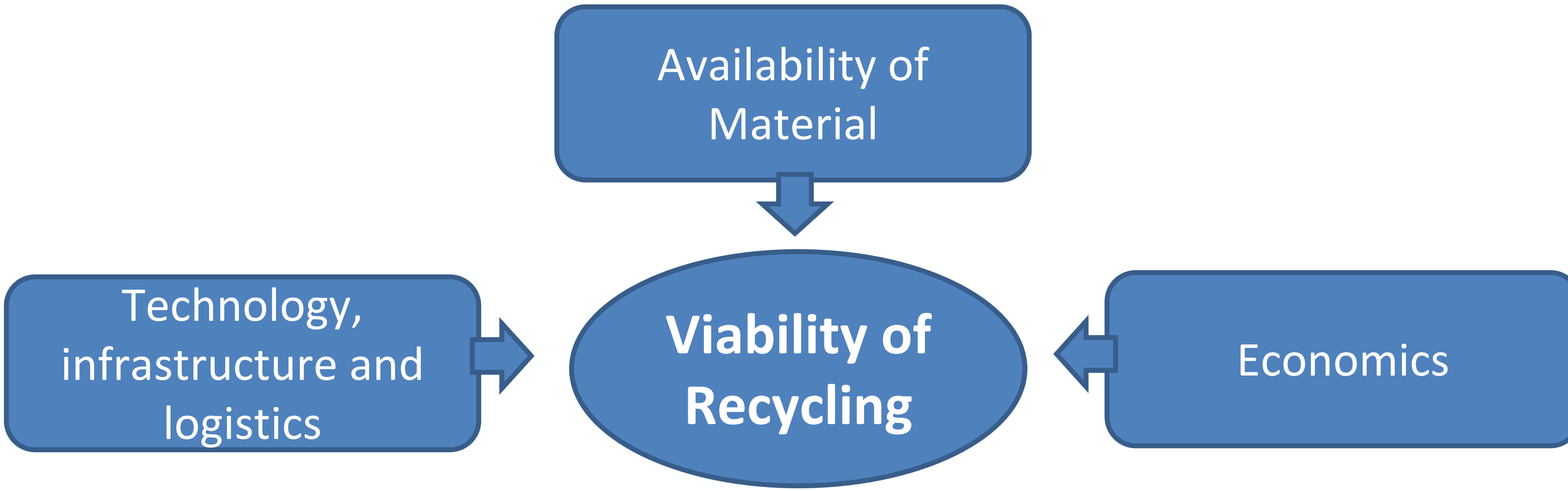


New separation processes could apply to recycling

Substitute critical REEs with abundant materials

Related DOE R&D Initiatives

- Critical Materials Energy Innovation Hub – identifying more efficient use of critical materials in energy technologies and improving the efficiency, and reducing the production costs, for supplies of critical materials
- Innovative Manufacturing Initiative – transformational manufacturing process and materials technologies
- Small Business Innovation Research (FY12 FOA)– lanthanide separation & processing topics



Recycling Opportunities

End of Product Life Recycling		30% of fluorescent bulbs are already recycled for mercury removal, but phosphors end up in landfills
Reducing/Reusing Manufacturing Loss		30% loss of magnetic material during machining, but could be reduced

Education and Training: Skills Required Across the Rare Earth Supply Chain

Disciplines

Bioengineering
Chemical Engineering
Chemistry
Civil Engineering
Electrical Engineering
Economics
Environmental Engineering
Environmental Science
Geosciences
Hydrology
Industrial Ecology
Materials Science
Mechanical Engineering
Physics

Concentrations

Process Operations
Separations
Lanthanide chemistry
Solid-state chemistry
Ecology
Economic Geology
Geology
Mineralogy
Mining sciences
Ceramics
Magnetic materials
Metallurgy
Optical sciences
Solid-state physics

Trans-disciplinary Skills

Characterization/Instrumentation
Green Chemistry/Engineering
Manufacturing Engineering
Materials recycling technology
Modeling
Product design
Rational design

Next Steps

- Implement DOE's integrated research plan.
- Strengthen information-gathering capacity.
- Continue to work closely with:
  - Interagency colleagues
  - International partners
  - Congress
  - Public
- Update the Strategy periodically.

Interagency Coordination

Office of Science and Technology Policy (OSTP) convened four work groups:

- Critical Material Criteria and Prioritization
- Federal R&D Prioritization
- Globalization of Supply Chains
- Depth and Transparency of Information

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DOE Welcomes Comments

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