U.S. DEPARTMENT OF ENERGY

Critical Materials Strategy

Sustainability and Energy Materials




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NAS Science and Technology for Sustainability Roundtable

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Outline of Briefing

I. Background

II. Analysis

   A. Supply

   B. Demand

   C. Criticality

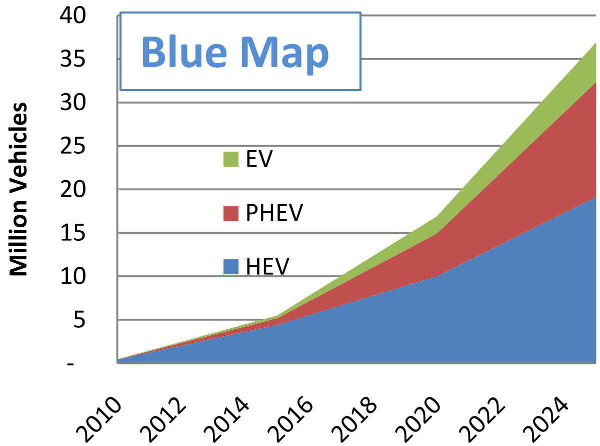
III. Program and Policy Directions

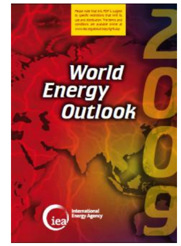
IV. Current Work

Sustainability: Level I
Addressing Climate Change Requires Energy Technology Transition

IEA Energy Technology Perspectives

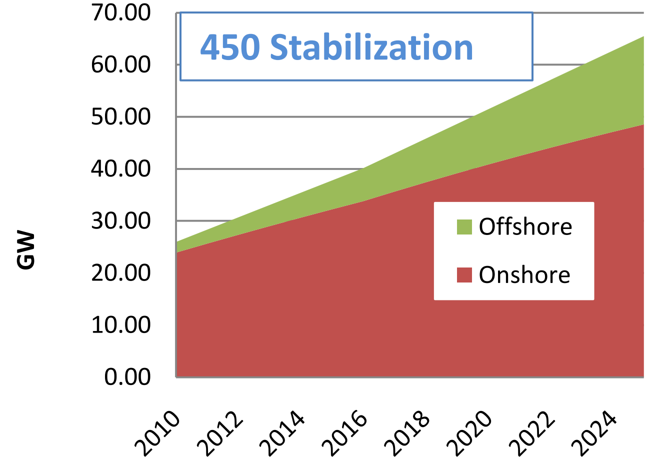
Electric Drive Vehicle Additions





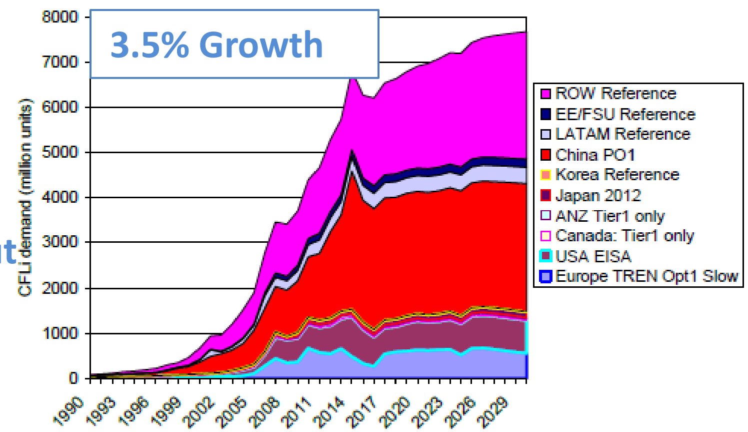
IEA World Energy Outlook

Wind Additions



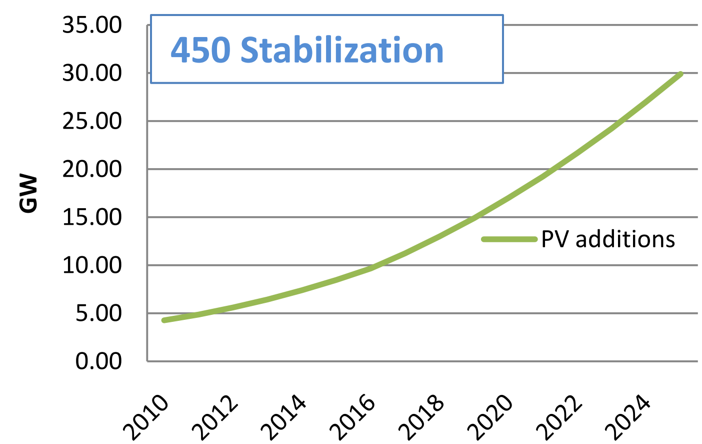
IEA: Phase Out of Incandescent Lights

Global CFL Demand

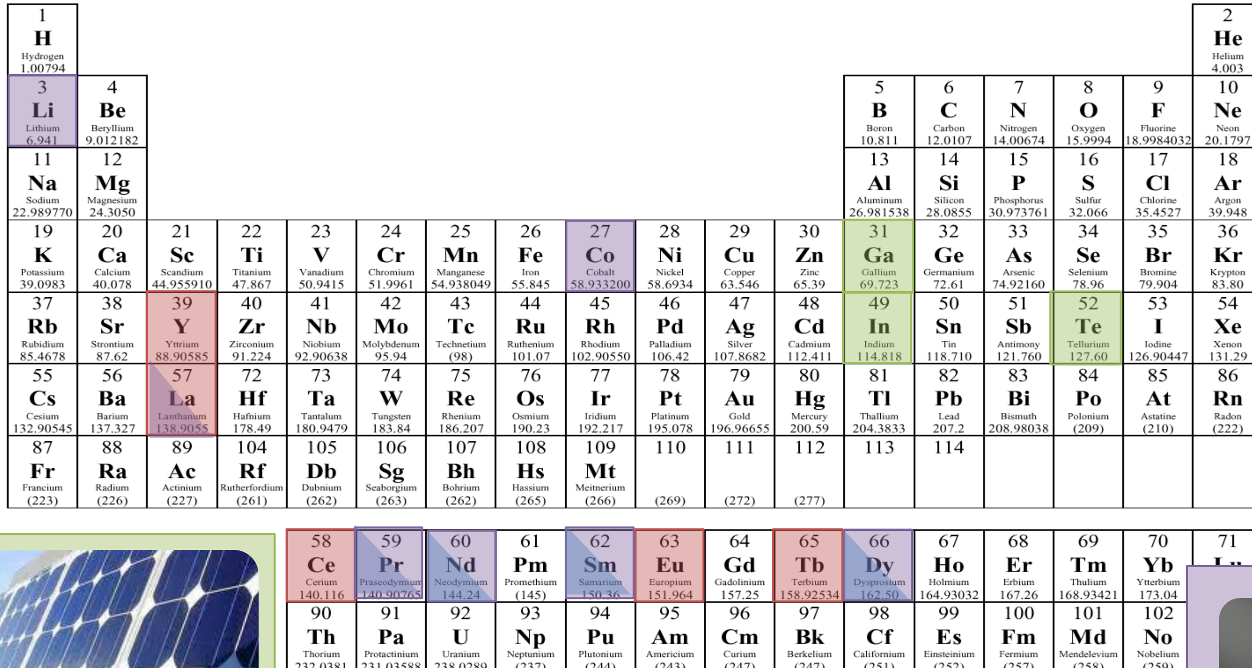


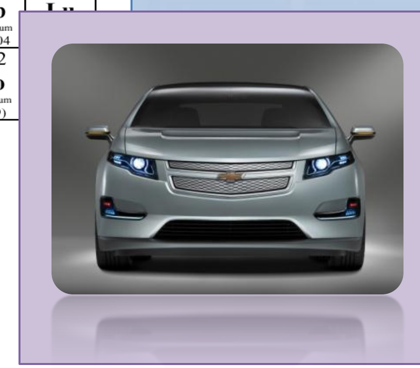
Source: IEA estimated.

Global PV Additions



Scope of DOE’s Critical Materials Strategy





Vehicles

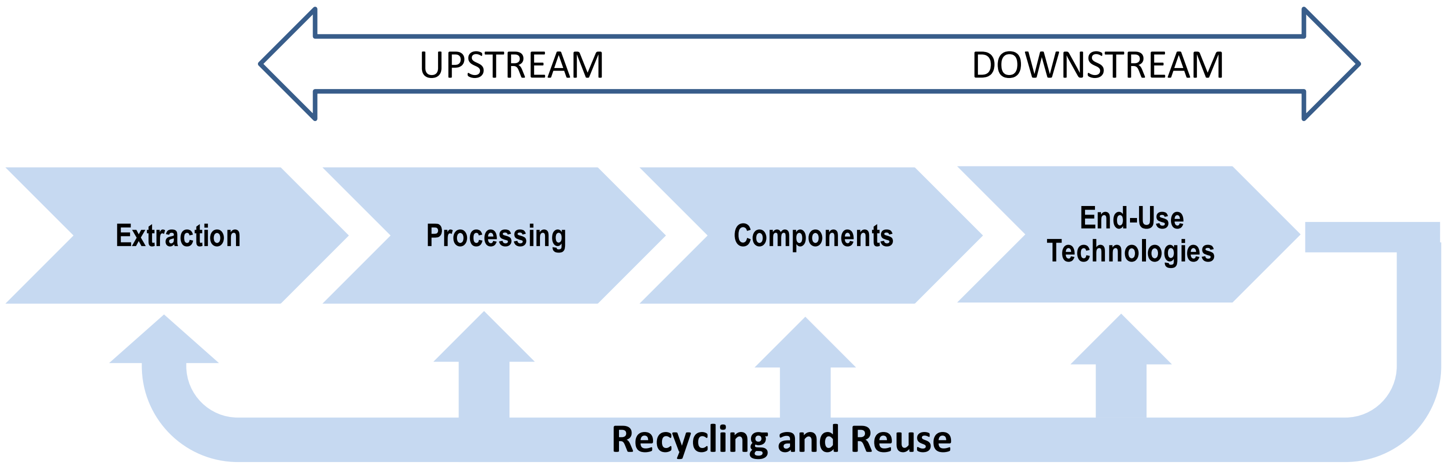
Lighting

Solar PV

Wind

Sustainability Level II: Strategic Pillars

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



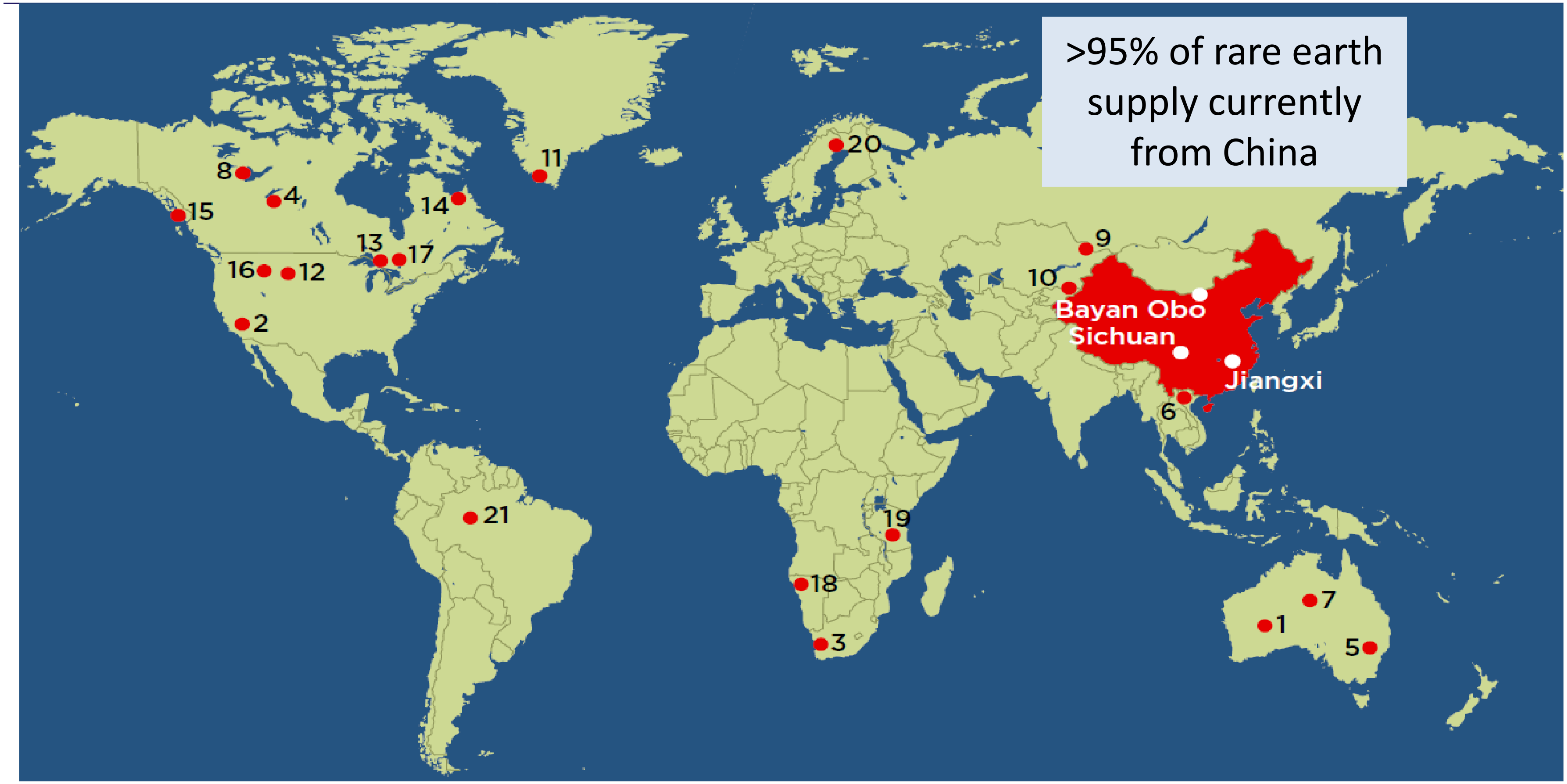
Sustainability Level III: Energy efficiency and pollution prevention throughout the supply chain as new processes and technologies are developed

Materials Policies in Other Nations

	Nation	Goal
Producers	Australia	Maintain mining **investment** while fairly taxing depletion of national resources
Producers	Canada	Promote **sustainable development** of mineral resources, protect environment, public health, and ensure attractive **investment** climate
	China	Maintain **stable domestic supply** through industry consolidation, mitigating overproduction and reducing illegal trade
Consumers	European Union	**Limit impact** of supply **shortages** on the European economy
Consumers	Japan	Secure a **stable supply** of raw materials for industries
Consumers	Korea	Ensure a **reliable supply** of materials for industries
Consumers	Netherlands	**Reduce material consumption** through "managed austerity"

II. Analysis

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

Current and Projected Rare Earth Supply by Element

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

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

Material Intensity

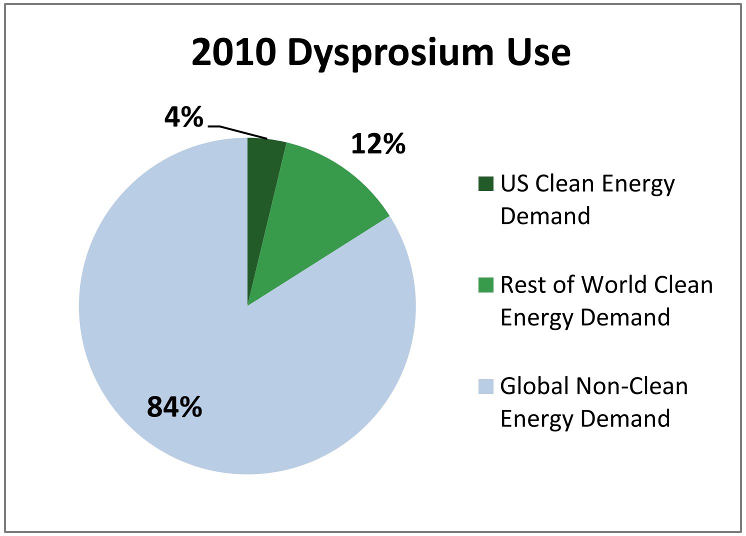
Technology	Component	Material	High Intensity	Low Intensity
Wind	**Generators**	Neodymium	186 kg/MW	124 kg/MW
		Dysprosium	33 kg/MW	22 kg/MW
Vehicles	**Motors**	Neodymium	0.62 kg/vehicle	0.31 kg/vehicle
		Dysprosium	0.11 kg/vehicle	0.055 kg/vehicle
	Li-ion Batteries (PHEVs and EVs)	Lithium	5.1-12.7 kg/vehicle	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

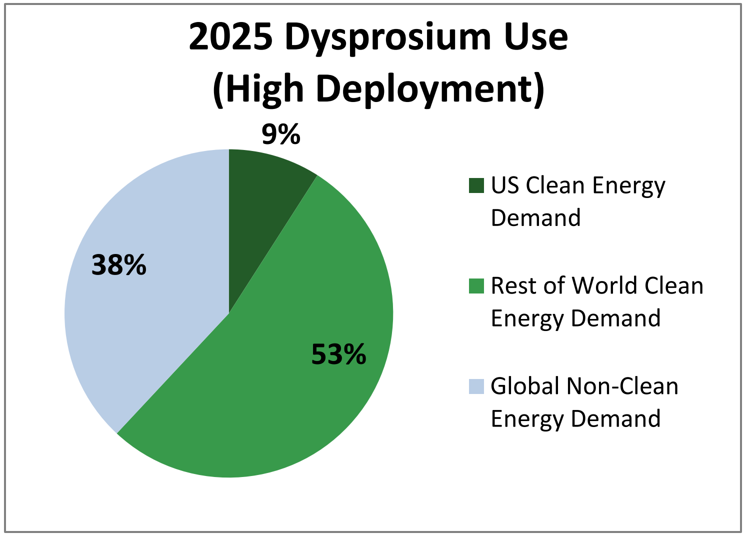
- ***Calculation methods differed by component based on available data***
- ***High Intensity = material intensity with current generation technology***
- ***Low Intensity = intensity with feasible improvements in material efficiency***

Clean energy's share of total material use currently small

…but could grow significantly with increased deployment.



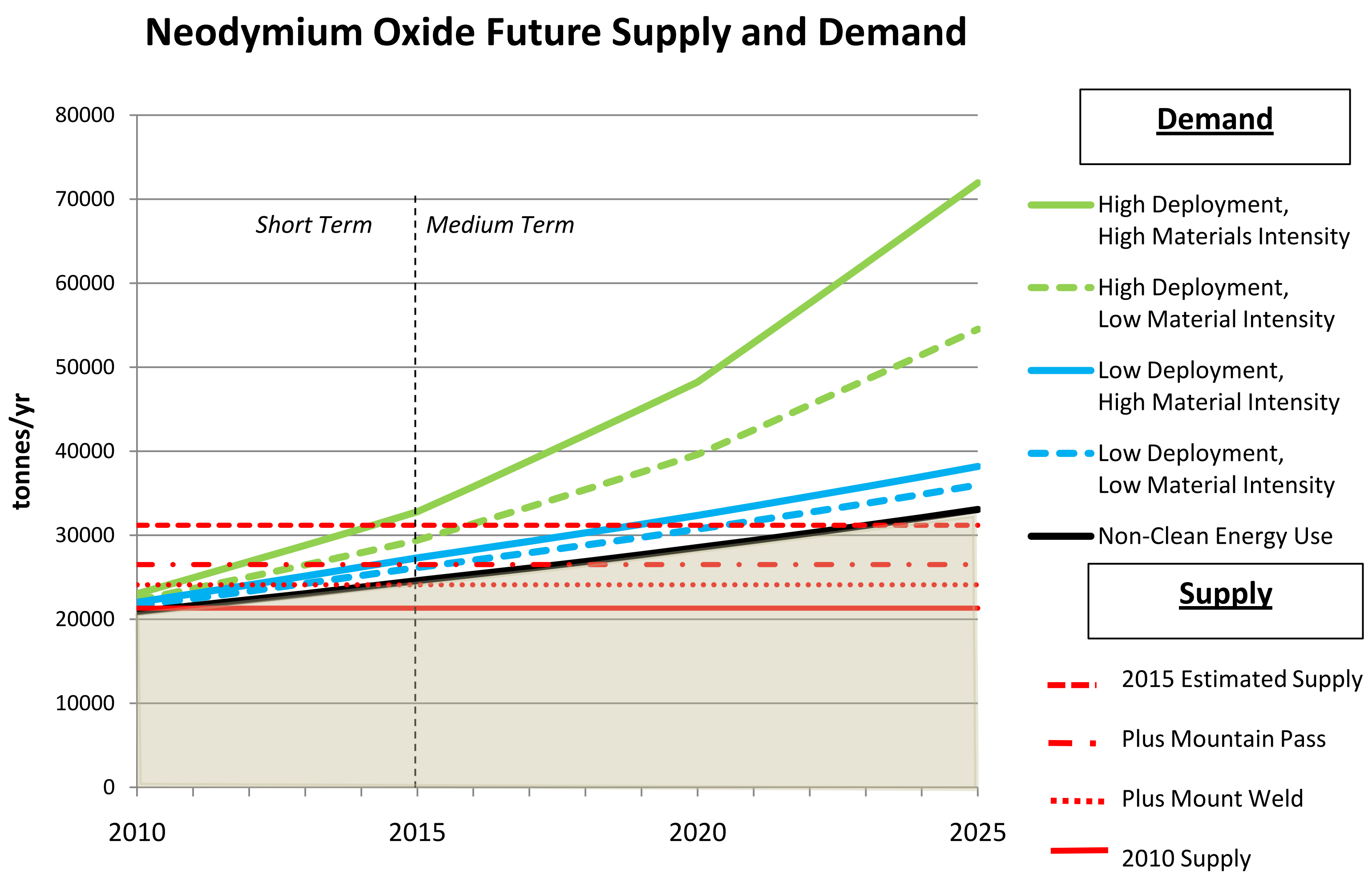
Dysprosium



16% is for Clean Energy

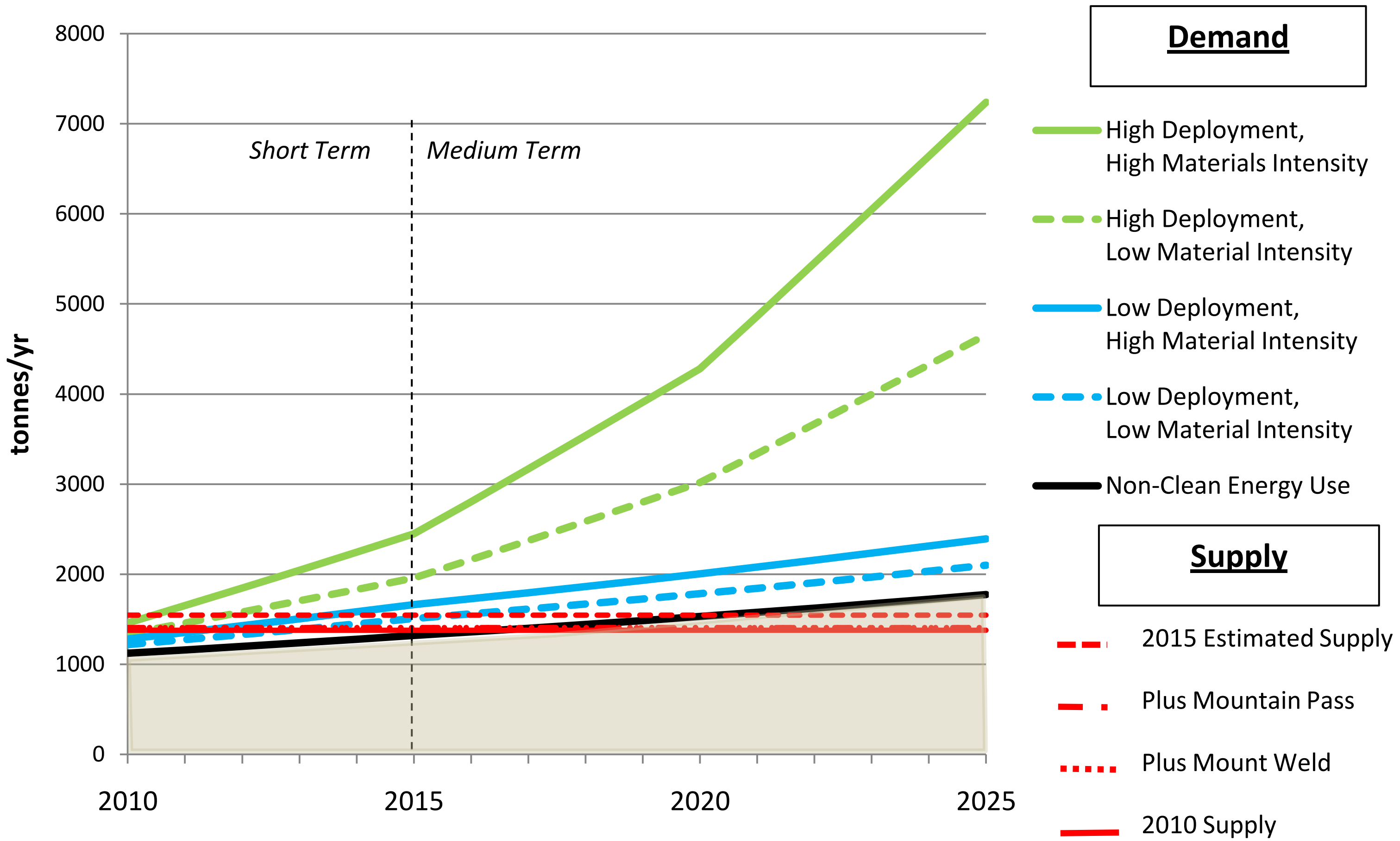
62% is for Clean Energy

Neodymium - Supply and Demand Projections



Dysprosium - Supply and Demand Projections

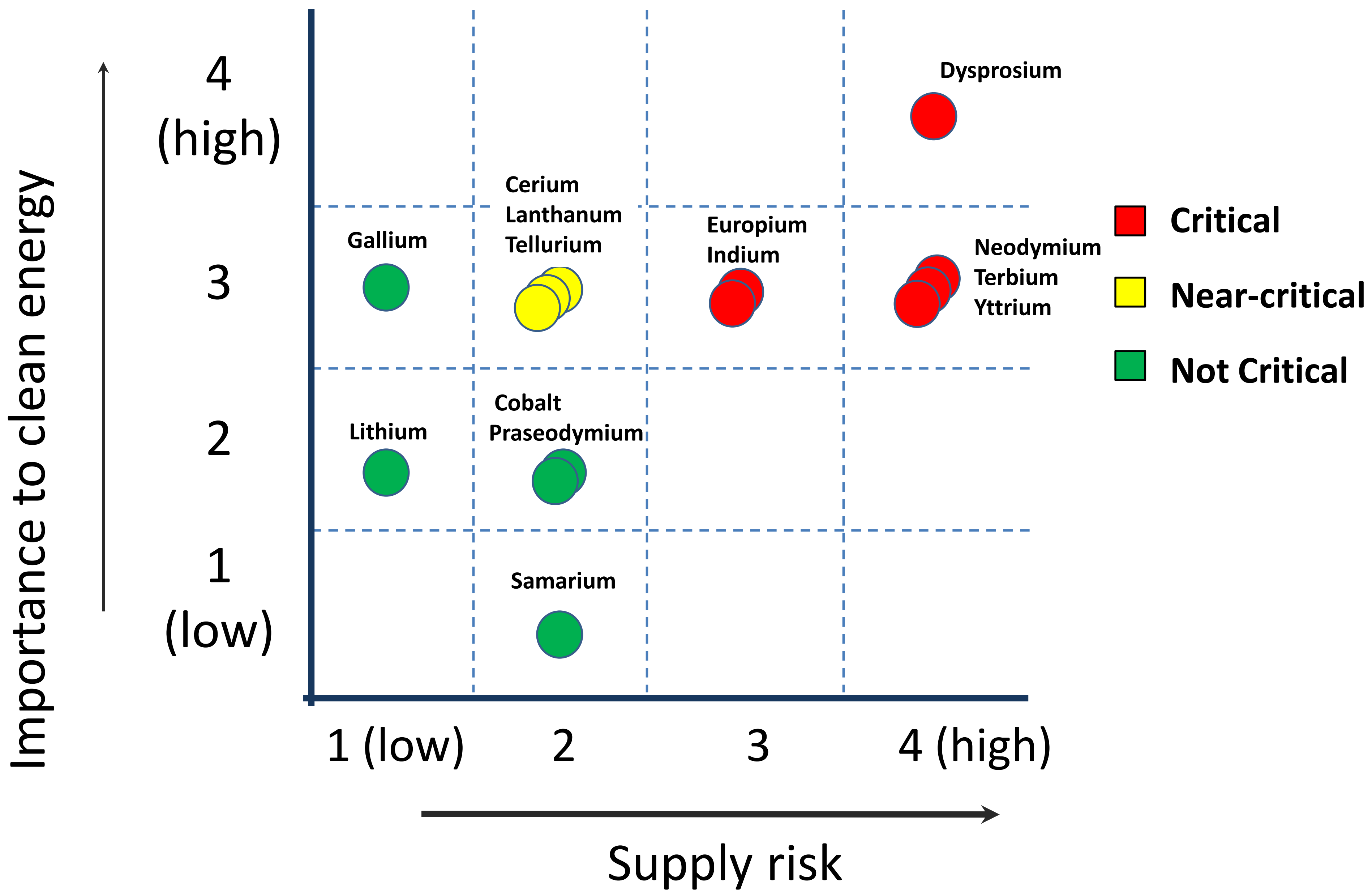
Dysprosium Oxide Future Supply and Demand



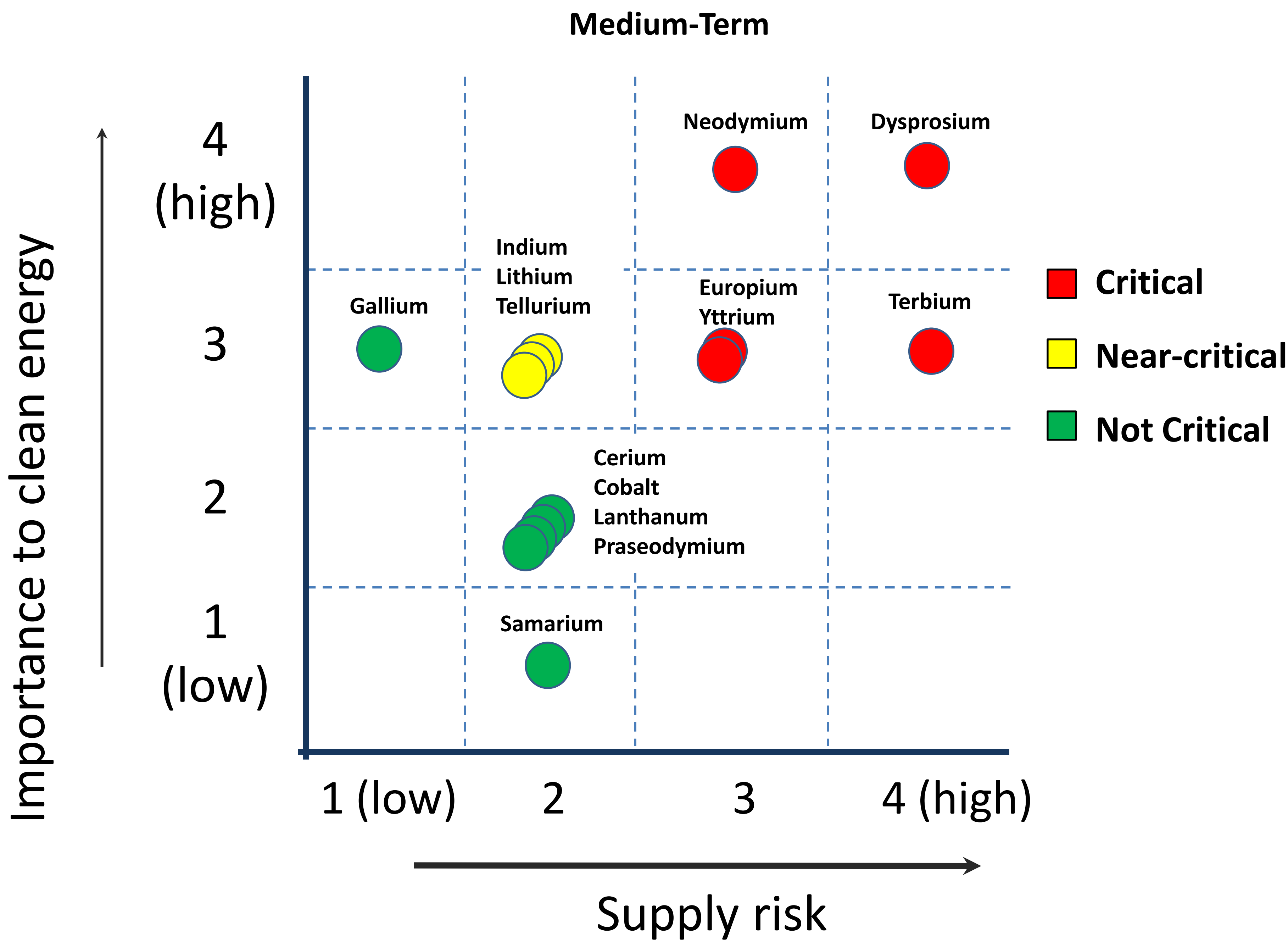
Criticality Assessments

- Based on methodology developed by National Academy of Sciences
- *Criticality* is a measure that combines
  - Importance to the clean energy economy
  - Risk of supply disruption
- Time frames:
  - Short-term (0-5 years)
  - Medium-term (5-15 years)

Short-Term

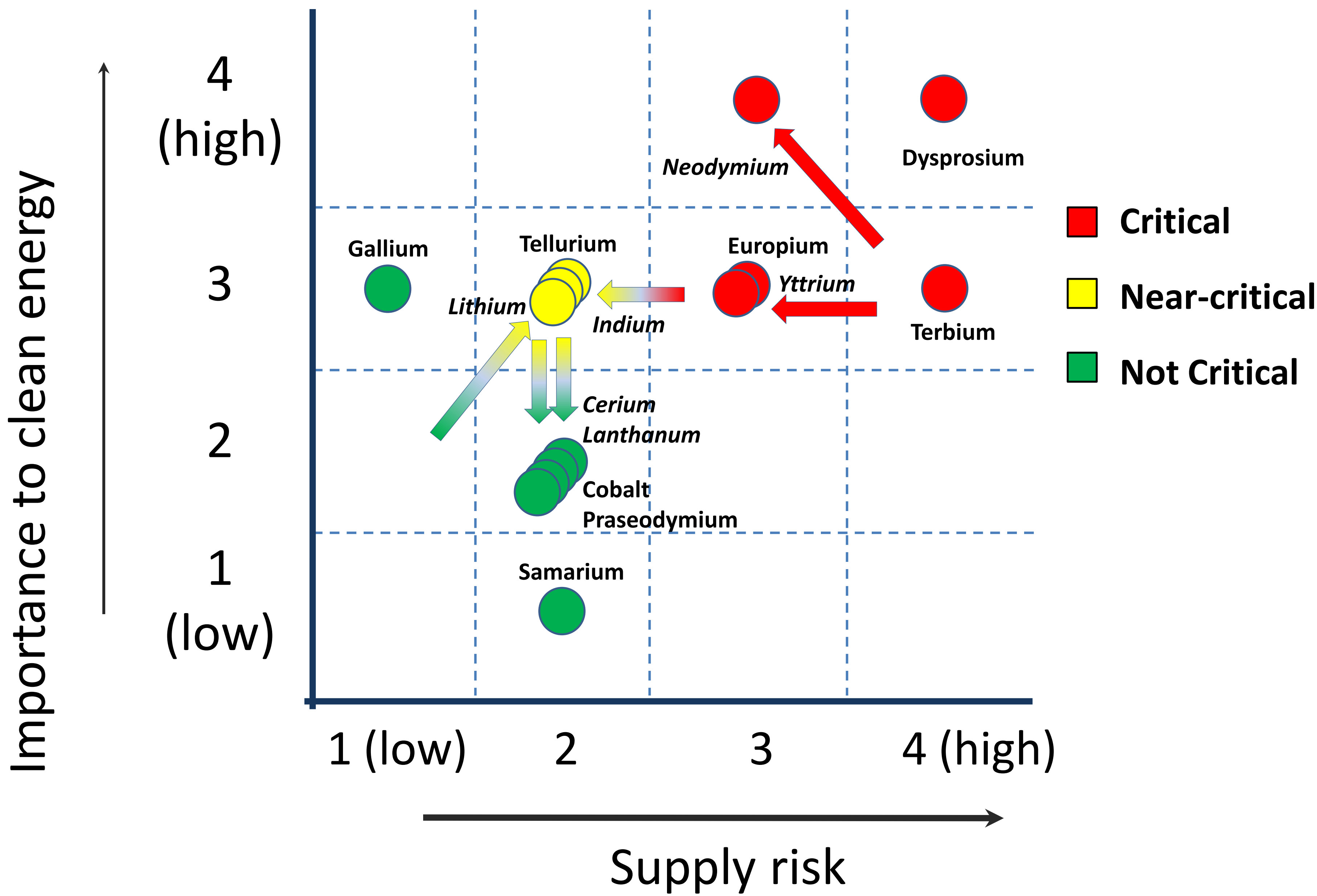


Importance to clean energy
4 (high)
3
2
1 (low)
Supply risk
1 (low)
2
3
4 (high)
Dysprosium
Gallium
Cerium
Lanthanum
Tellurium
Europium
Indium
Neodymium
Terbium
Yttrium
Lithium
Cobalt
Praseodymium
Samarium
Critical
Near-critical
Not Critical



Medium-Term
Importance to clean energy
4 (high)
3
2
1 (low)
Supply risk
1 (low)
2
3
4 (high)
Neodymium
Dysprosium
Gallium
Indium
Lithium
Tellurium
Europium
Yttrium
Terbium
Cerium
Cobalt
Lanthanum
Praseodymium
Samarium
Critical
Near-critical
Not Critical

Criticality Movement: Short to Medium Term



III. Program and Policy Directions

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's current programs – Office of Science

Basic research at Ames Laboratory

- ◆ **Extraordinarily Responsive Rare Earth Magnetic Materials**
- ◆ **Novel Materials Preparation and Processing Methodologies**
- ◆ **Correlations and Competition Between the Lattice, Electrons and Magnetism**
- ◆ **Nanoscale and Ultrafast Correlations and Excitations in Magnetic Materials**

Permanent Magnet Development for Automotive Traction Motors

Ames Lab

A New Class of Switched Reluctance Motors

Oak Ridge

Novel Flux Coupling Machine without Permanent Magnets

Oak Ridge

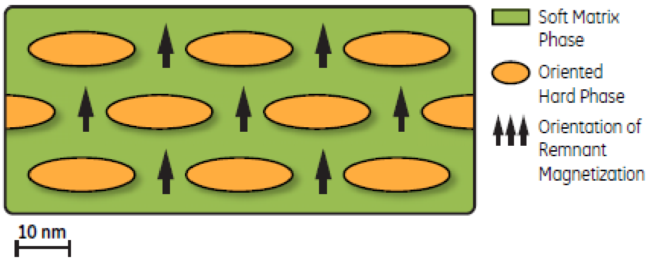
Development of Improved Powder for Bonded Permanent Magnets

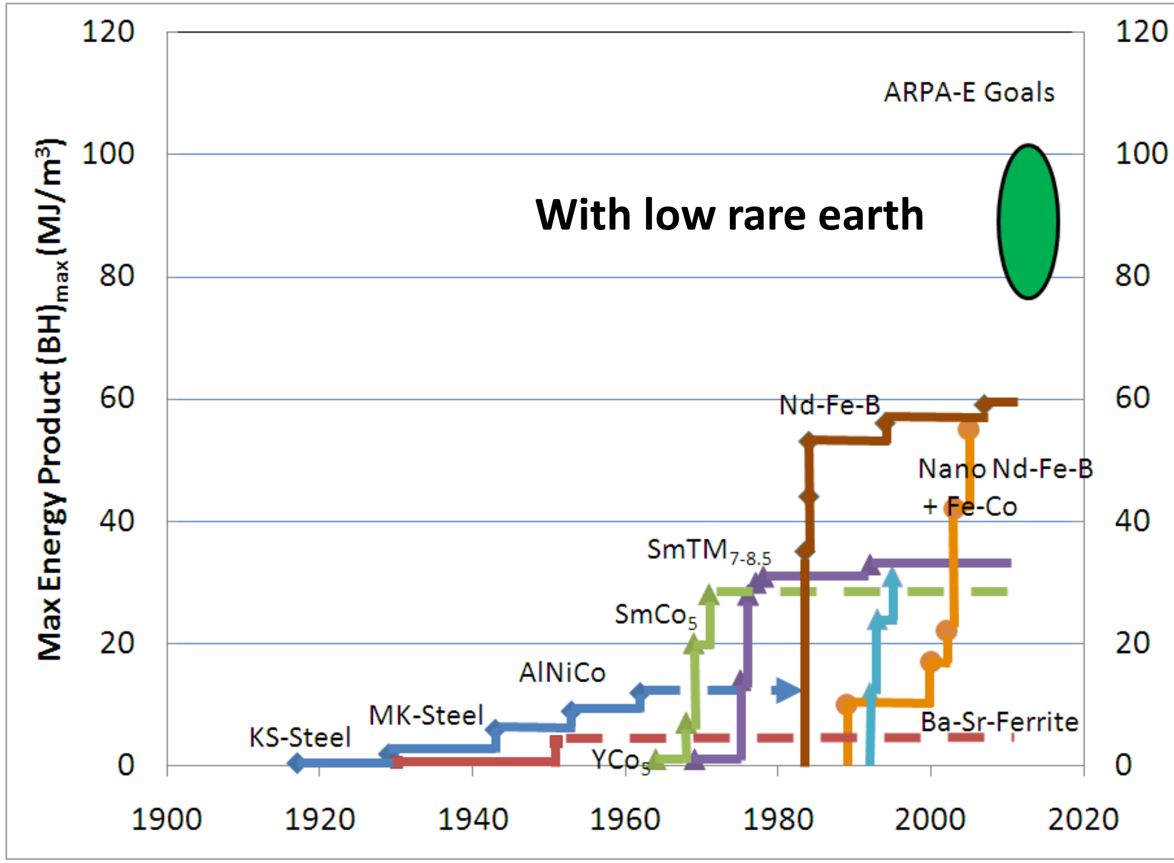
Ames Lab

Source: Universal (Ningbo) Magnetech Co., Ltd.

Source: Honda Civic Hybrid 2003

DOE's Current Programs:
ARPA-E Nanocomposite Permanent Magnets





Core@Shell Hard/Soft Exchange Spring Coupled Nanocomposite Magnets with:

- 80 MGOe (vs 59 MGOe NdFeB)
- 59 MGOe with 80% less rare earth

Nanocomposite exchange spring coupled permanent magnets with high energy product and less rare earths

Recent DOE Critical Materials Workshops & International Meetings

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

- Transatlantic Workshop (MIT - Dec 3)
- ARPA-E Workshop (Ballston, VA – Dec 6)
- US- Australia Joint Commission Meeting (DC – Feb 14)

Critical Materials Strategy Conclusions

- Some materials analyzed at risk of supply disruptions.

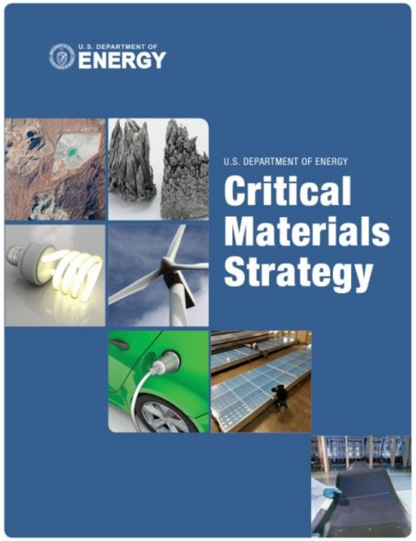
  Five rare earth metals (dysprosium, neodymium, terbium, europium and yttrium) and indium assessed as most critical.

- 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.



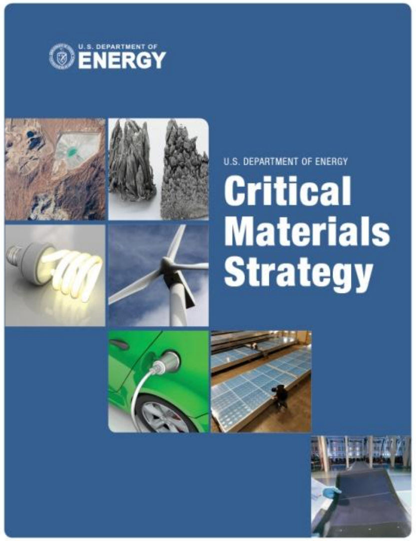
Critical Materials Strategy Conclusions (continued)

- Data are sparse.

  More information is required.

- Sound policies and strategic investments can reduce risk.

  …especially in the medium and long term.



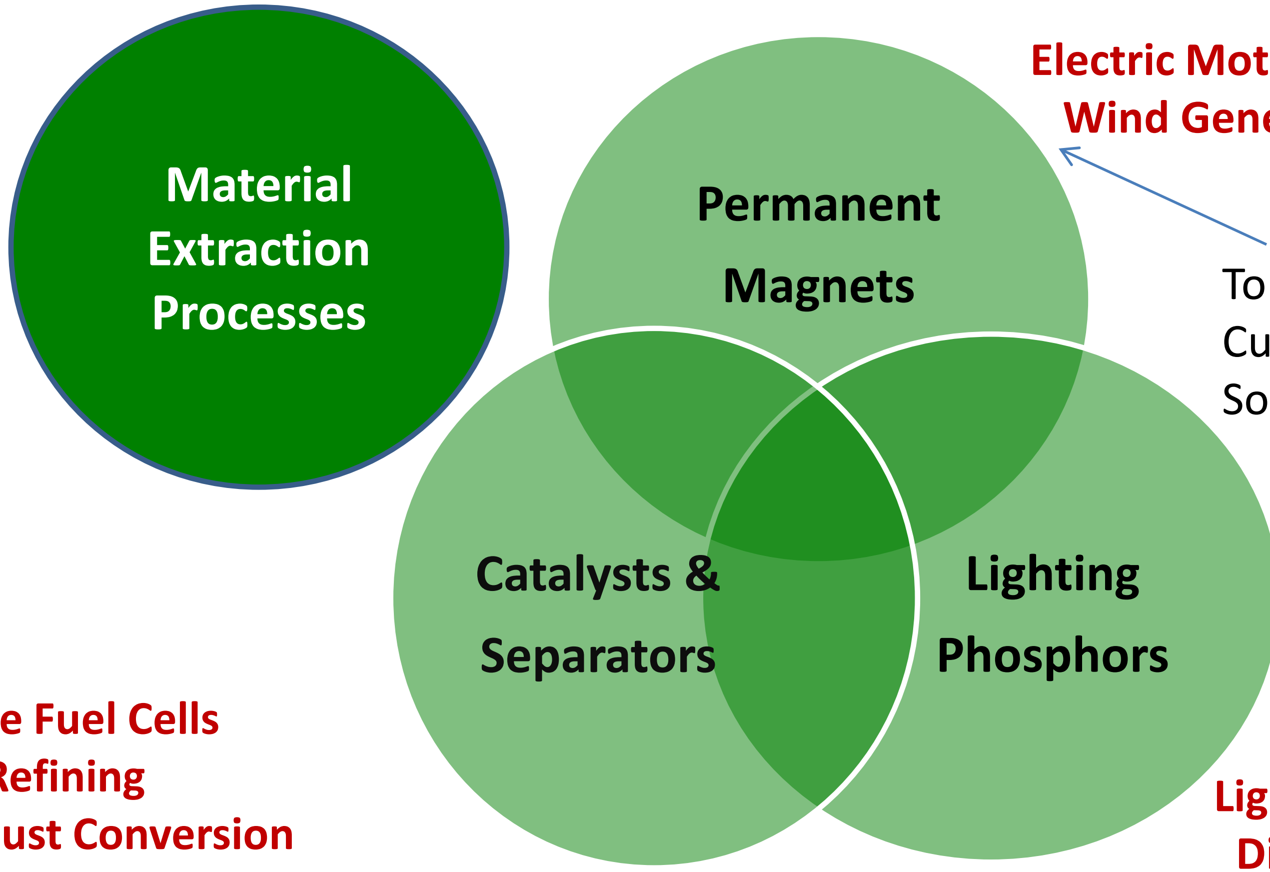
IV. Current Work

Next Steps for U.S. Department of Energy

- 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.

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

Geologic or Recycled Feedstocks



Electric Motors
Wind Generators

Topic for Current Solicitation

Solid Oxide Fuel Cells
Gasoline Refining
Auto Exhaust Conversion

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

Supply Technologies ⟷ **Application Technologies**

Request for Information on Critical Materials: Currently Open

- 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

- Led by the White House Office of Science and Technology Policy (OSTP), the group has included 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)

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Critical Materials Strategy

DOE welcomes comments




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