U.S. DEPARTMENT OF ENERGY

Critical Materials Strategy




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Outline

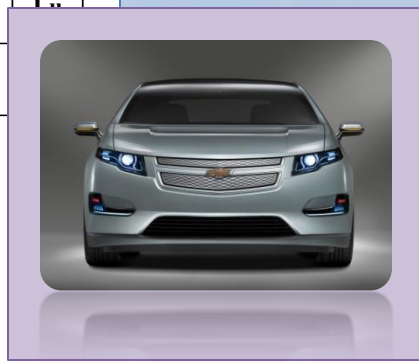
- Overview of DOE's Critical Materials Strategy
- Current DOE Work
  - Waste as a Resource R&D
  - Analysis of Market Dynamics
- Interagency Strategy

Overview of DOE's Critical Materials Strategy

Scope

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 Lu
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)	



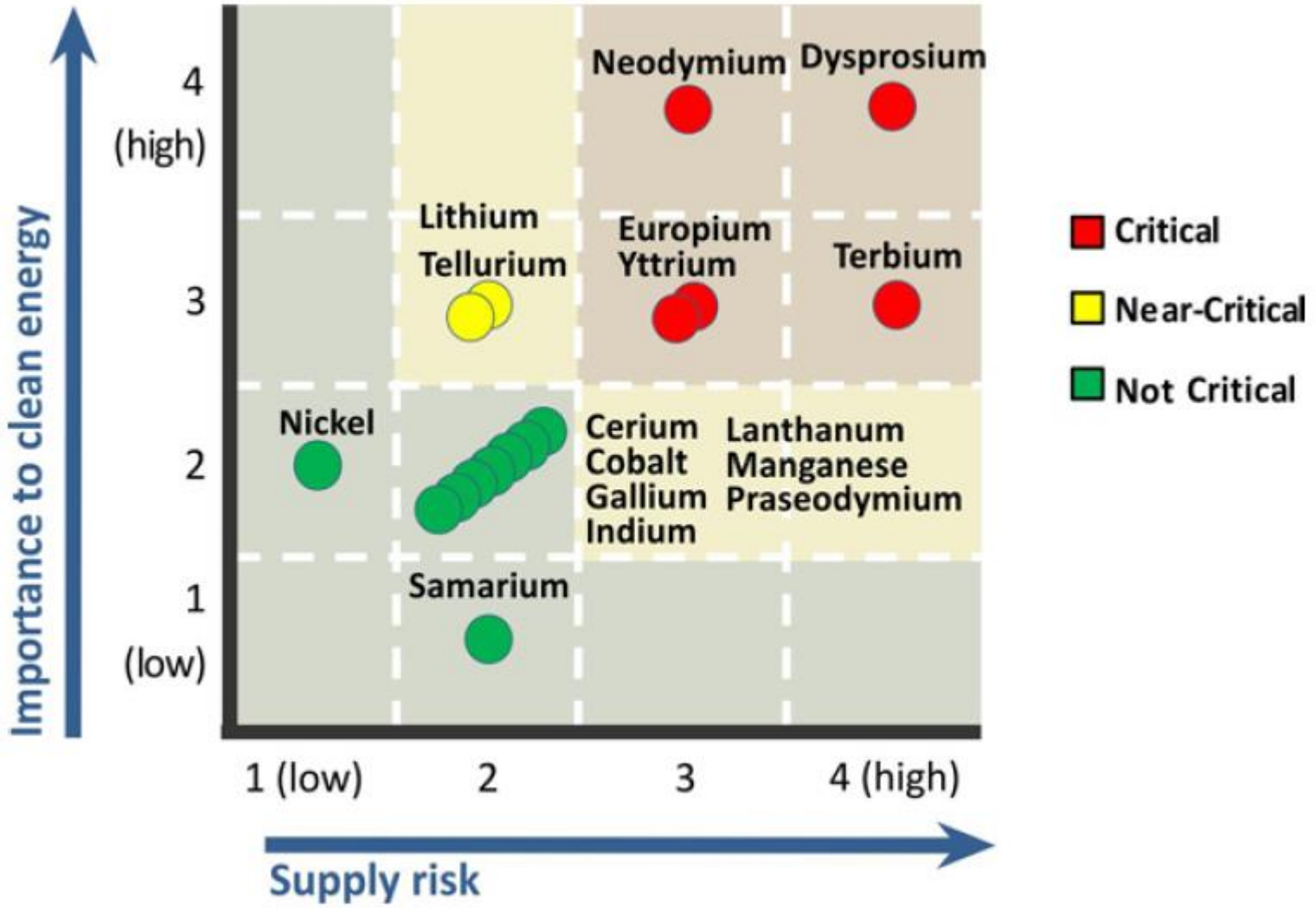
Vehicles

Lighting

Solar PV

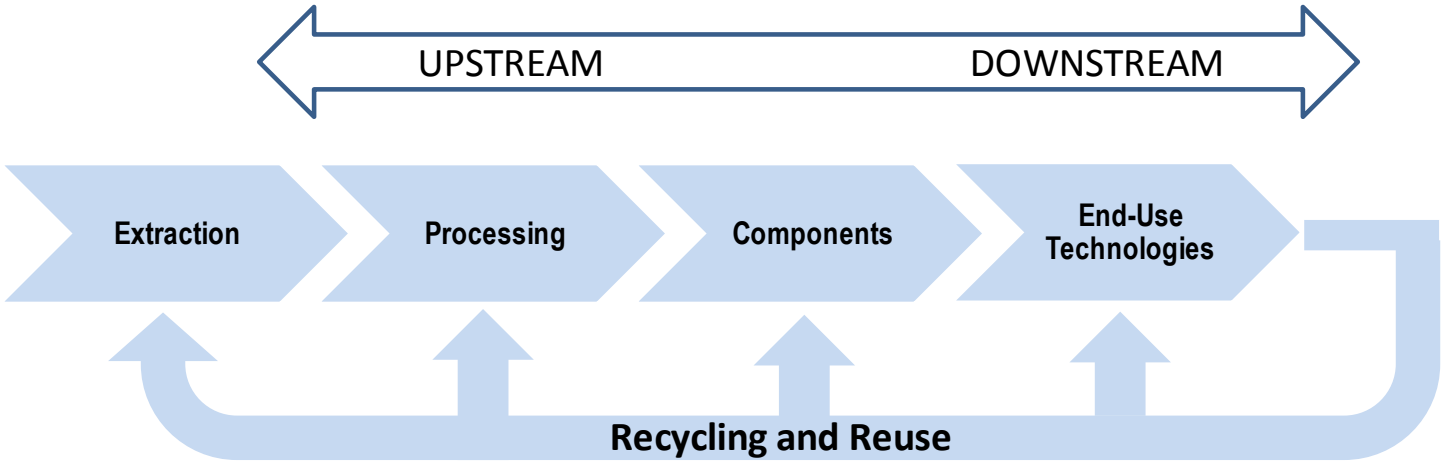
Wind

2011 CMS Medium-Term Criticality (2015-2025)



Strategic Pillars

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



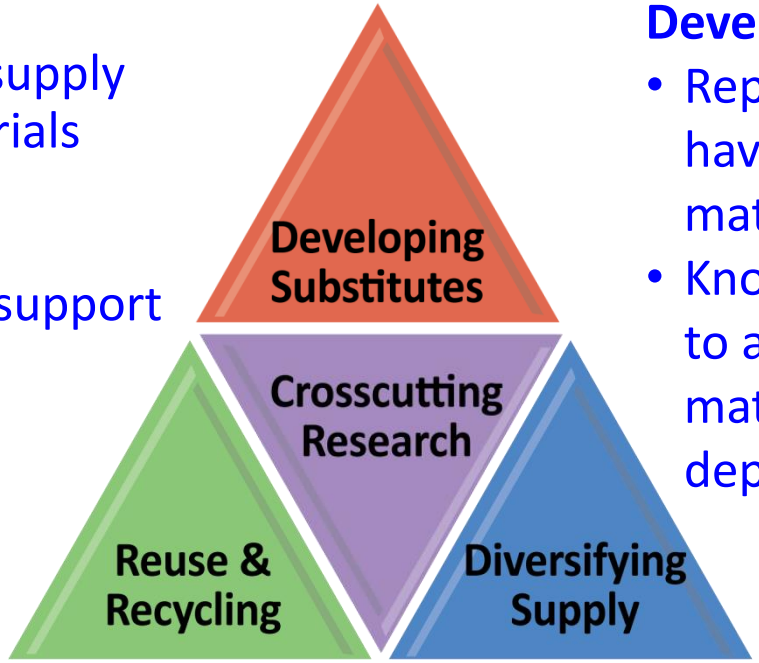
Material supply chain with environmentally-sound processes

Current DOE Work

Critical Materials Institute (Ames Lab lead)

Crosscutting Research

- Assess life cycles and supply chains of critical materials
- Develop theoretical, computational and experimental tools to support other focus areas



Developing Substitutes

- Replacement materials that have lower or zero critical materials content
- Knowledge-based approach to accelerate advanced material development and deployment

Reuse & Recycling

- Develop economically viable technologies for efficient material use in manufacturing, recycling and reuse

Diversifying Supply

- Enable new sources of critical materials not currently commercially viable
- Improve efficiency of processing

https://cmi.ameslab.gov/

Extracting Critical Materials from Phosphate Wastes and Processing

Sand tailings (~10% of REE)

Waste clay (~40% of REE)

Phosphate ore

Sulfuric acid

Dissolution

$$Ca_{10}F_2(PO_4)_6 + 10H_2SO_4 + 10nH_2O \rightarrow 10CaSO_4 \cdot nH_2O + 6H_3PO_4 + 2HF$$

Di-hydrate process, $n = 2$; Hemi-hydrate process, $n = 1/2$; Anhydrite, $n = 0$

Filtration

Phosphogypsum (~38% of REE)

Wet-Process Phosphoric Acid (~12% of REE)

Extraction

U / Th co-product

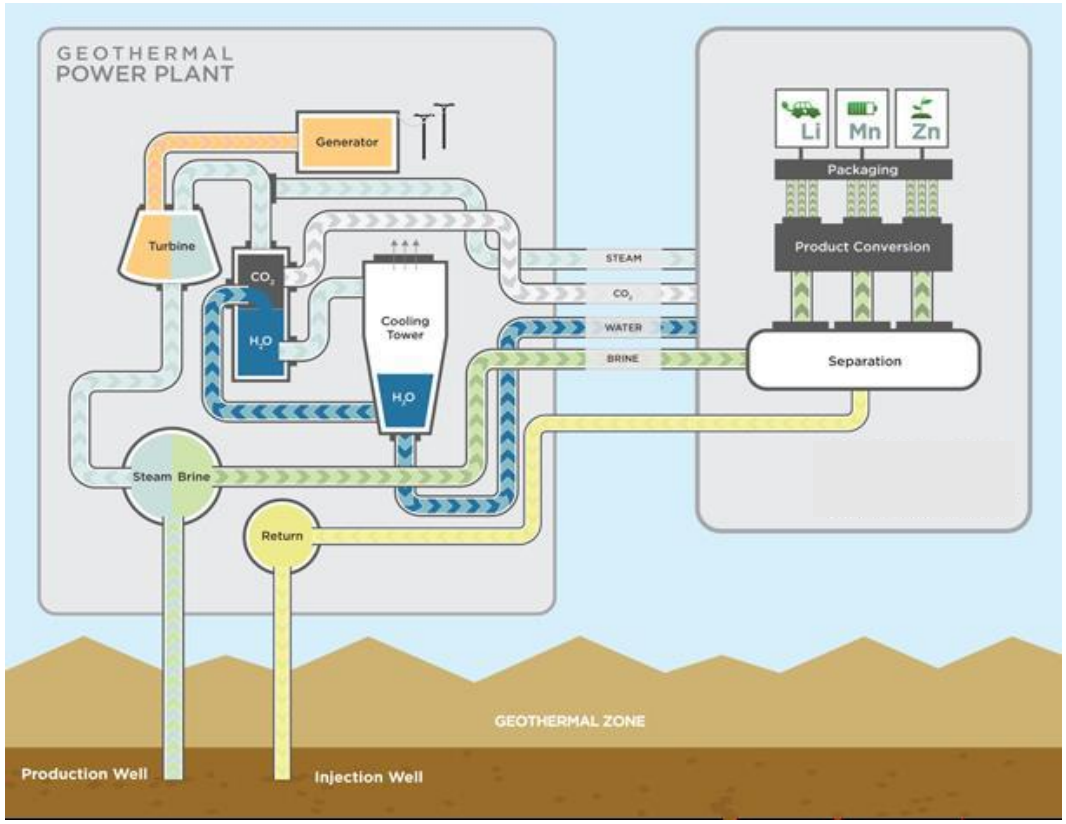
Evaporation

Fertilizer Production

CMI Critical Materials Institute
AN ENERGY INNOVATION HUB

FOA Objective:

Enable economically viable extraction of critical minerals as a path to optimize the value stream of low-to-moderate temperature resources



http://www.energy.gov/eere/geothermal/downloads/low-temperature-mineral-recovery-program-foa-selections

Low Temperature Geothermal Mineral Program – Last Week's Selectees

FOA Federal Funding Total: $4,064,628

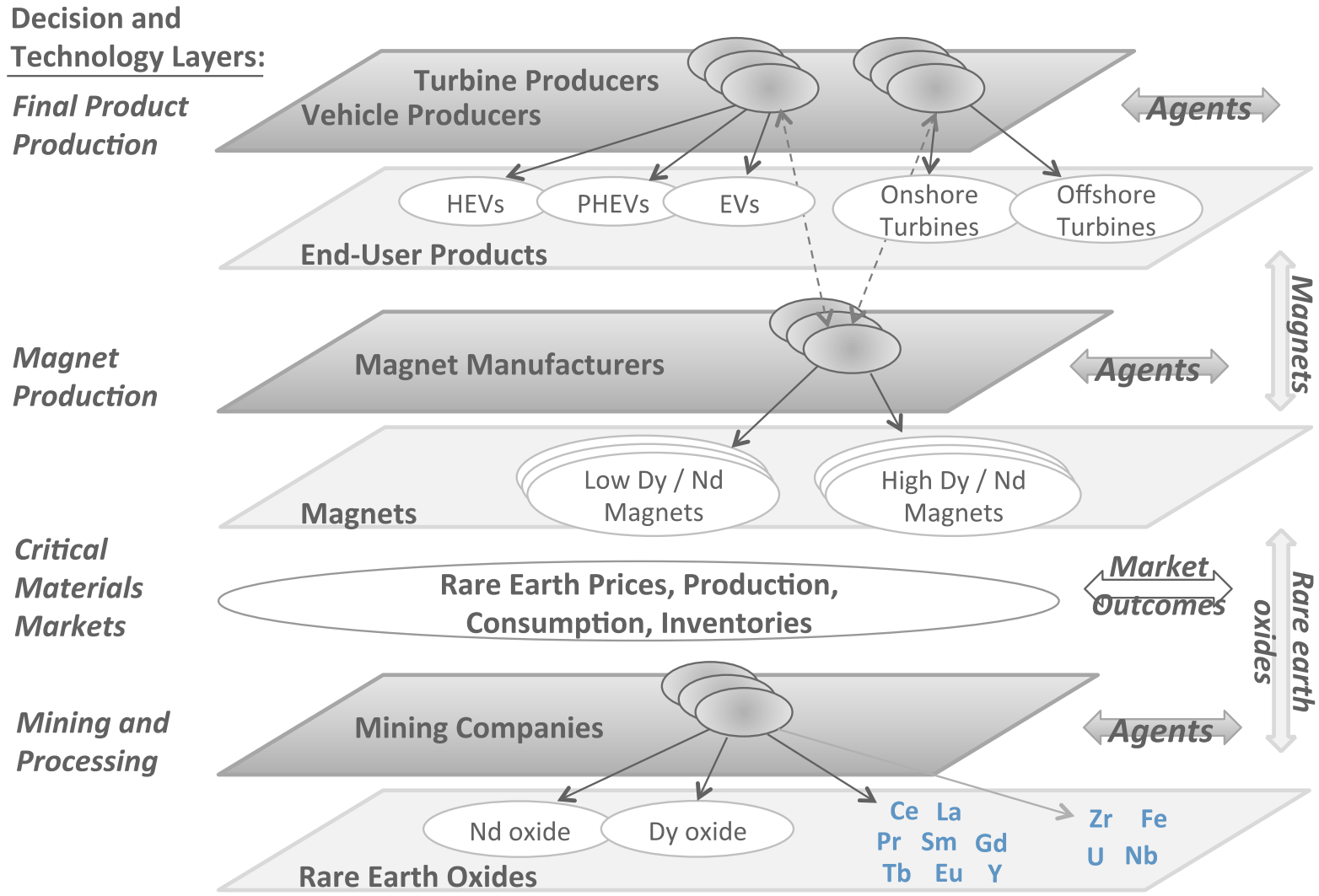
Selectee	Partner(s)	Title
SOUTHERN RESEARCH INSTITUTE	AMT, novus ENERGY INC, Alterra POWER CORP	Geothermal Thermoelectric Generation (G-TEG) with Integrated Temperature Driven Membrane Distillation and Novel Manganese Oxide for Lithium Extraction
SRI International	SIMBOL materials	Selective Recovery of Metals From Geothermal Brine
BERKELEY LAB		Engineering Thermophilic Microorganisms To Selectively Extract Strategic Metals From Low Temperature Geothermal Brines
	THERMOCHEM, UNIVERSITY OF OREGON	Maximizing REE Recovery in Geothermal Systems

Low Temperature Geothermal Mineral Program – Last Week's Selectees (cont.)

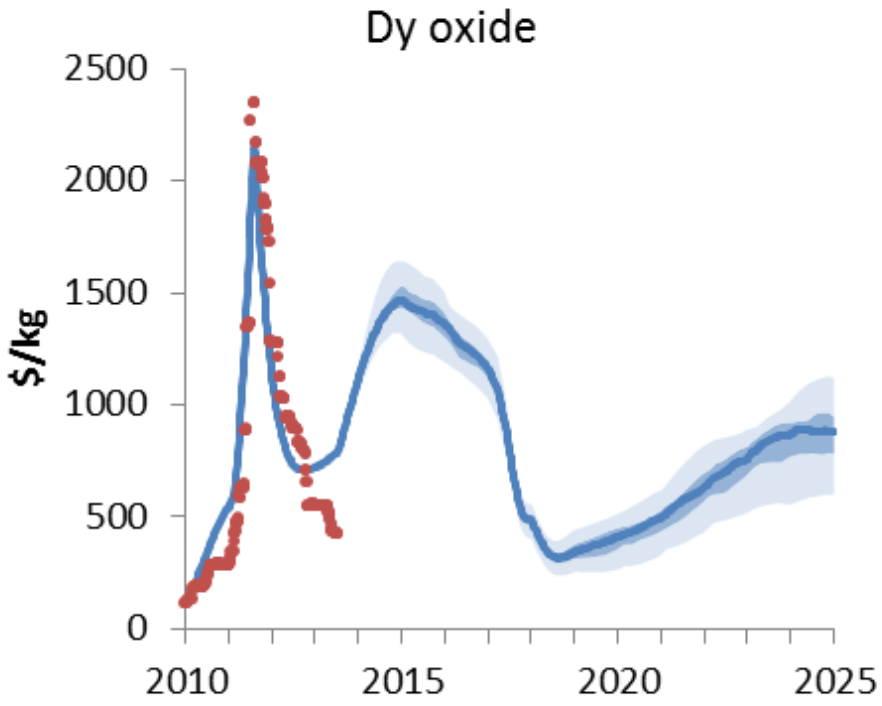
FOA Federal Funding Total: $4,064,628

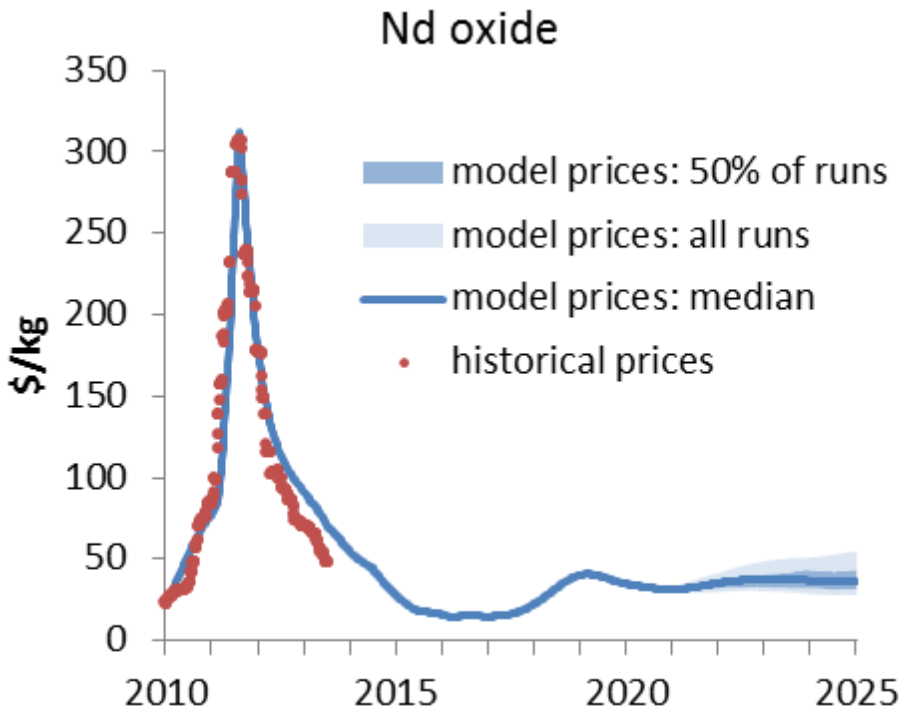
Selectee	Partner(s)	Title
Pacific Northwest National Laboratory	TBD	Magnetic Partitioning Nanofluid for Rare Earth Extraction from Geothermal Fluids
Pacific Northwest National Laboratory	BARR; University of Oregon	Recovery of Rare Earths, Precious Metals and other Critical Materials from Geothermal Waters with Advanced Sorbent Structures
Carnegie Mellon University		Chelating Resins for Selective Separation and Recovery of Rare Earth Elements from Low Temperature Geothermal Water
SIMBOL materials	Oak Ridge National Laboratory	Determination of Rare Earths in Geothermal Brines and Evaluation of Potential Extraction Techniques
Tusaar Corp	Veolia Environmental Services; Colorado School of Mines	Environmentally Friendly Economical Sequestration Of Rare Earth Metals From Geothermal Waters

Analysis of Market Dynamics: Rare Earth Magnet Supply Chains

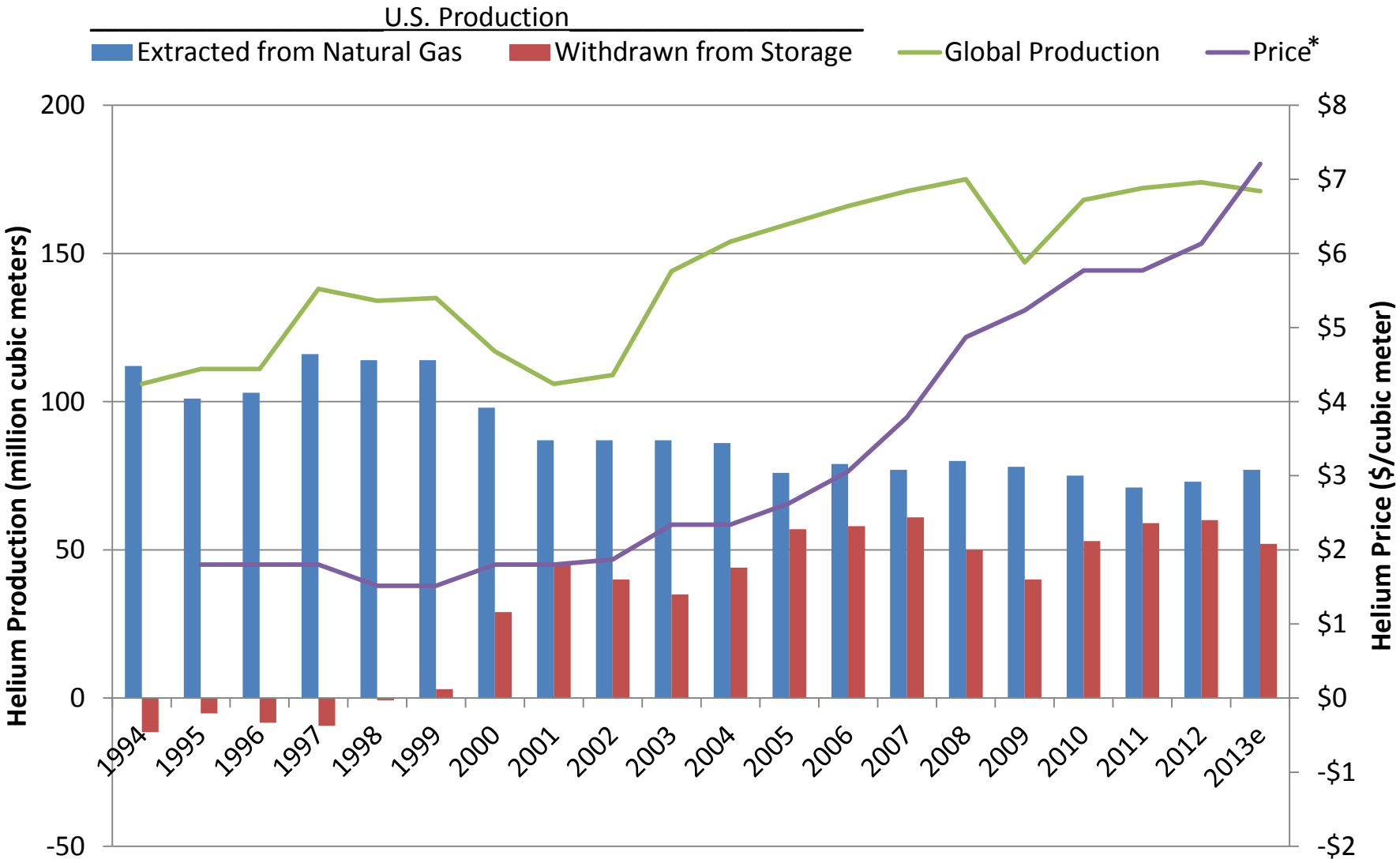


Model Results: Price Projections for Dysprosium Oxide





Market Dynamics: Helium



Data Source: USGS

* Grade A

Interagency Strategy

NSTC Subcommittee on Critical and Strategic Mineral Supply Chains (Est. 2010)

"The Subcommittee will facilitate strong, coordinated effort across federal agencies to identify and address important policy implications arising from strategic minerals supply issues"

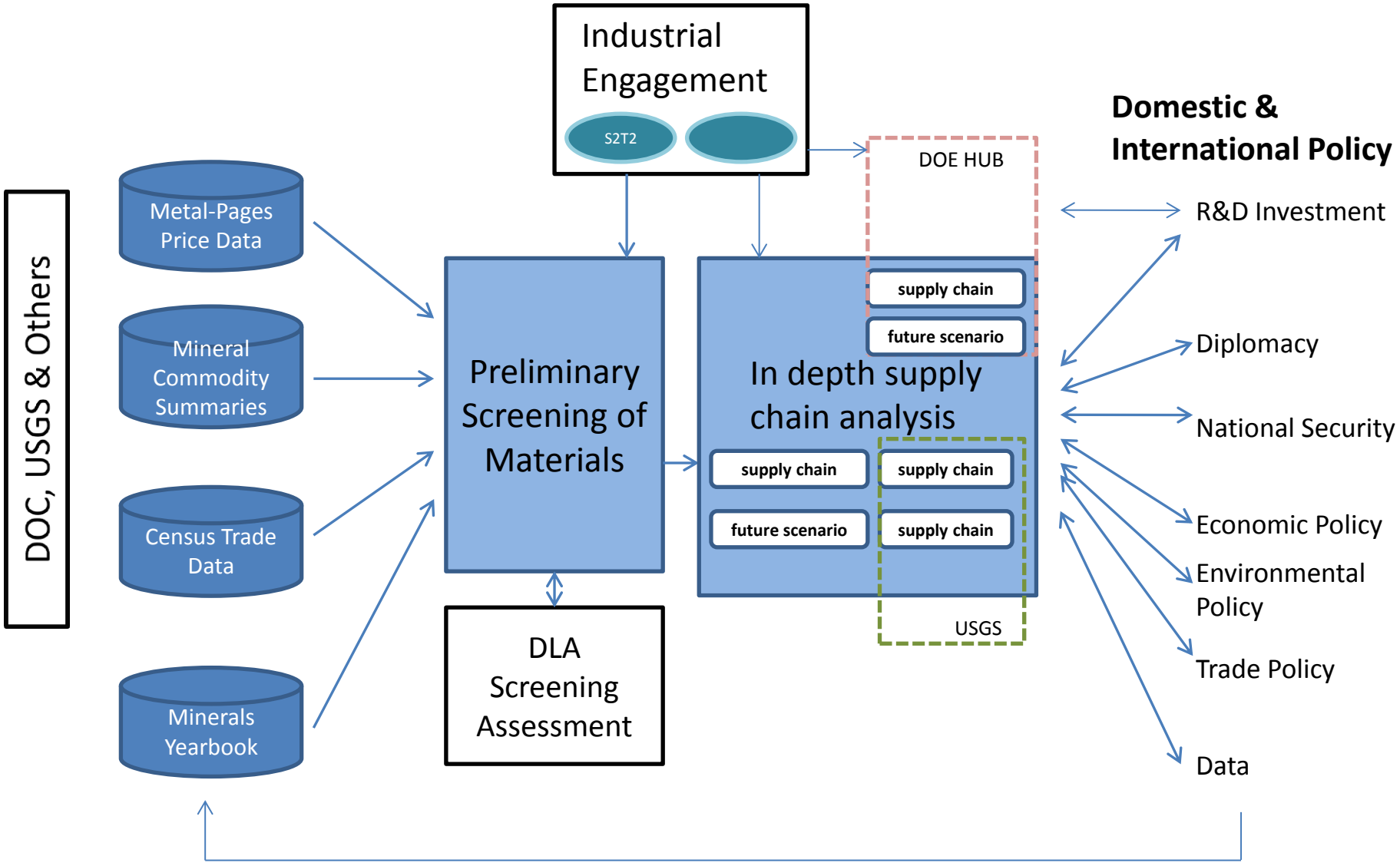
- Subcommittee Charter

Areas of Focus

- Criticality Assessment and Early Warning
- Long Term R&D Options
- Information Transparency

Co-Chairs: Cyrus Wadia (OSTP), Diana Bauer (DOE), and Larry Meinert (USGS)

NSTC Subcommittee on Critical and Strategic Mineral Supply Chains: Integrated View



RFI Categories

- Category 1: Demand
- Category 2: Exploration, Mining, and Smelting/Refining
- Category 3: Supply and Supply Chain
- Category 4: Market Dynamics
- Category 5: Mitigation
- Category 6: Other

For more info:

https://federalregister.gov/a/2014-17192

or

http://www.whitehouse.gov/administration/eop/ostp/blog

To submit responses, email criticalmaterials@ostp.gov

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Questions?