

Current State of the Art for Applications

ARPA-E Workshop on Rare Earth & Critical Materials

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GE Rare Earth Usage



Nd

Reveal
incandescent lamps



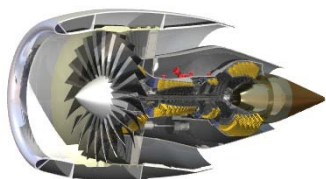
**Y, Ce, Tb
La, Eu**

Fluorescent lamp
phosphors



Nd, Dy, Tb

Generators for 1.5MW+
wind turbines



Y

Thermal barrier
coatings for aircraft
engines



Y

Thermal barrier
coatings for gas
turbines

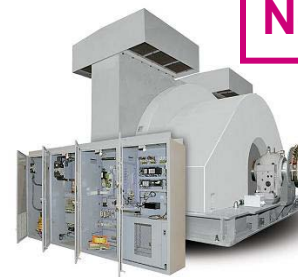


**Y, Ce, Tb
Gd, Eu, Lu**

Scintillators for CT &
PET imaging

Gd

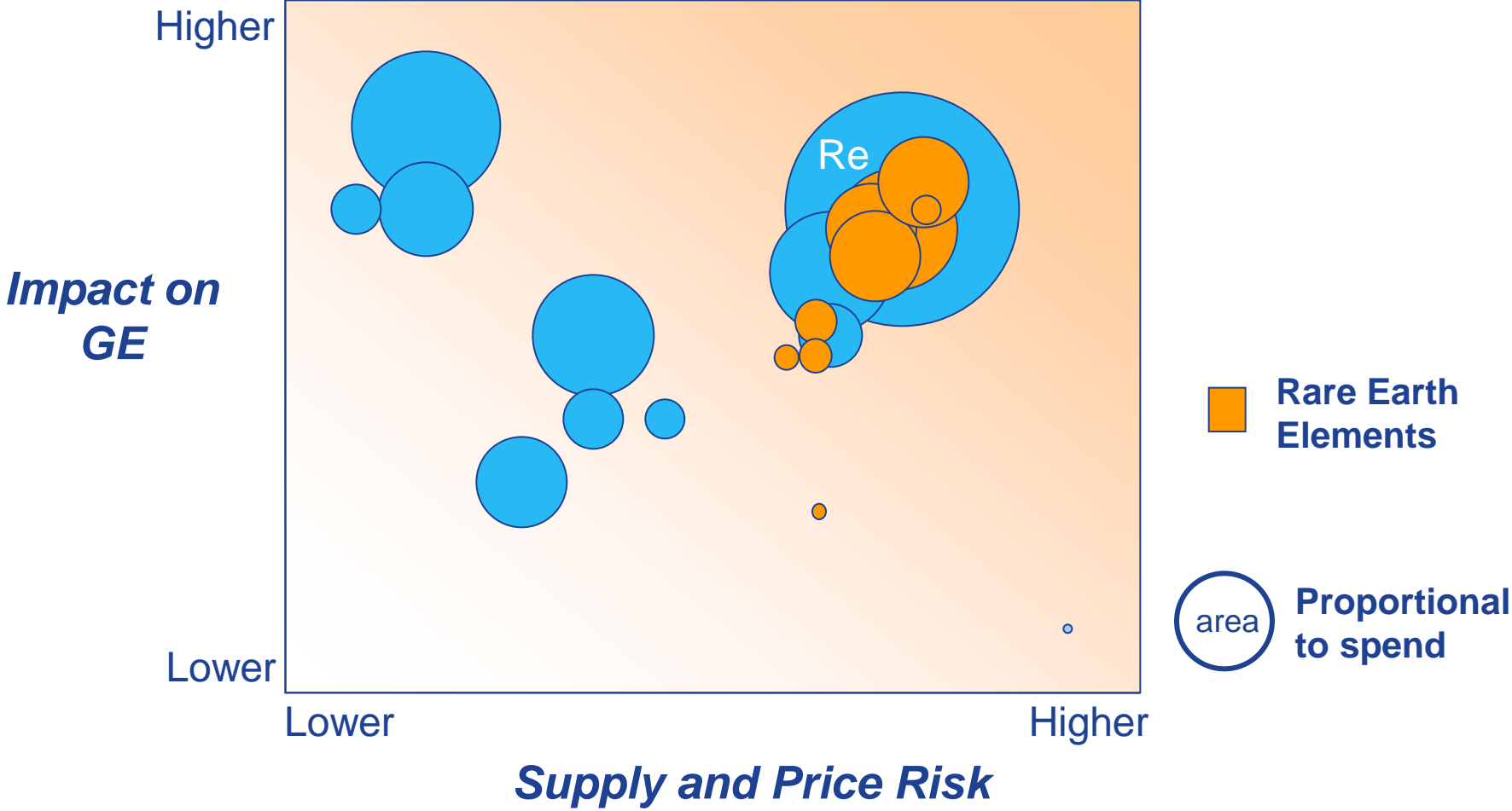
MR contrast
agents



Nd, Dy, Tb

Industrial motors

GE Criticality Diagram



OEM Technology Options in Addressing Metals Supply Challenges



Sourcing

- Broaden material sources
- Optimize usage
- Redesign materials
- Volume material buys
- Diversification
- Hedging
- Global sourcing
- Strategic inventory reserves

Manufacturing

- Sort & categorize manufacturing scrap to maximize recycle
- Use of recycled materials
- Minimize use of at-risk process materials
- Near-net shape manufacturing processes

Engineering/R&D

- Design for ease of recycling and re-use
- Material design to minimize at-risk elements
- Material substitutions
- System substitution

Each element and each application will use a unique mix of options

Material Substitution

Rare Earth Reduction	Strategy
0%	Only for highly optimized materials & systems
5-20%	Material composition optimization Recycling (manufacturing yield and end-of-life)
20-80%	Material Substitution
Up to 100%	System Substitution

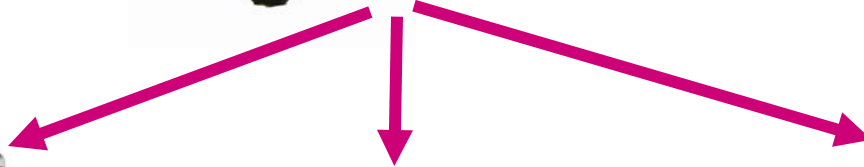
Multiple Solutions at the Material Level –
Goal Is To Undertake Technical Programs With A Mix
That Results In Significant Reduction

System Substitution

Incandescent Lamps



H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															
		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		



Fluorescent Lamps



White LEDs



White OLEDs

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															
		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															
		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		

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Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															
		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		



Multiple Solutions at the System Level

Research Approaches

Rare Earths

- Lighting
 - Recycling of fluorescent lamp phosphors
 - Development of phosphors with reduced RE content
 - LEDs/OLEDs
- Permanent Magnets / Wind
 - Development of PM recycling approaches
 - Development of PMs with reduced RE content
 - System design solutions

Tellurium

- CdTe solar
 - Develop technology to reduce the CdTe layer thickness