Solving Critical Materials Challenges –
An Industrial Update for GUIRR

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Imagination at work.

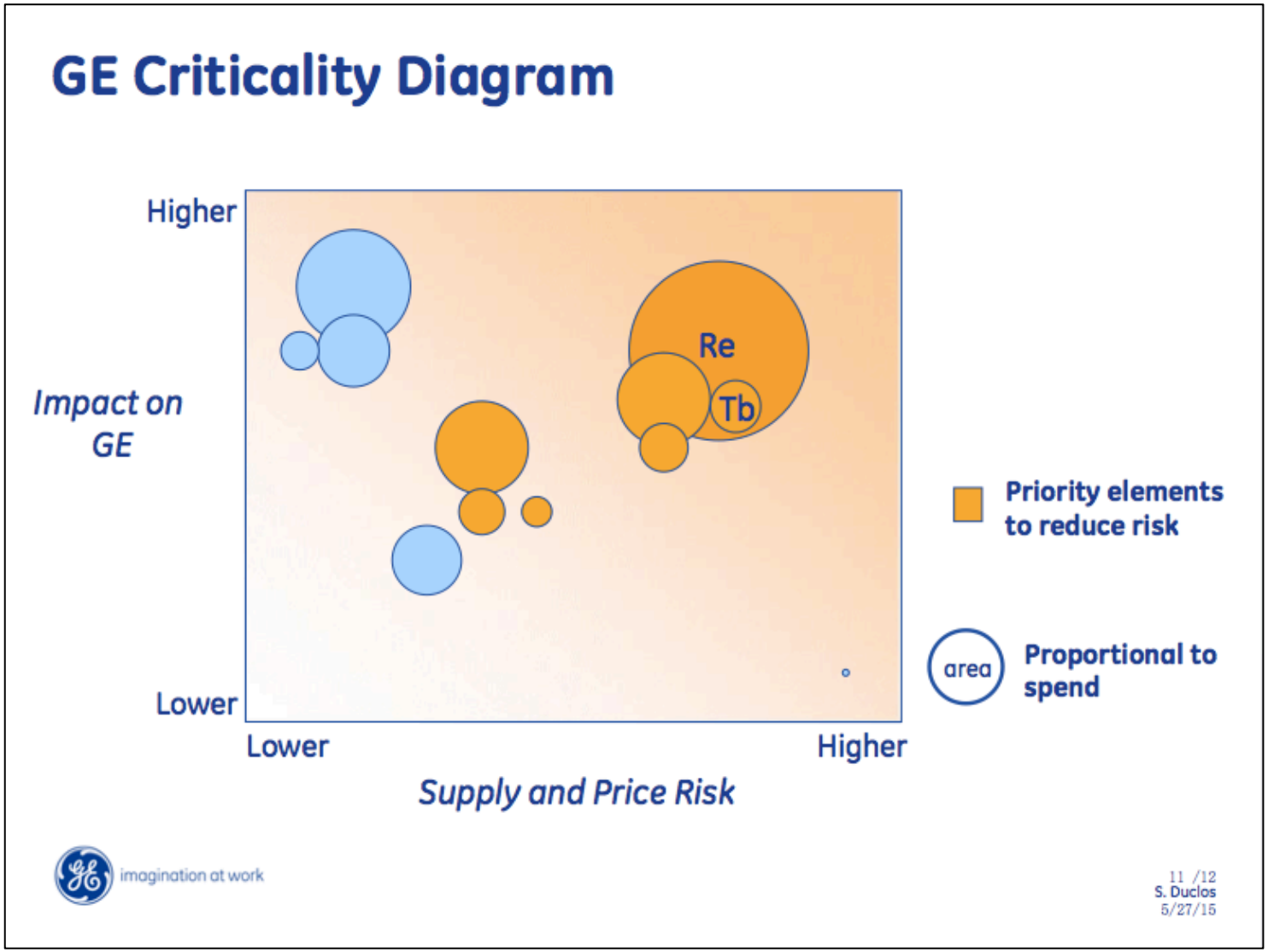
Acknowledgments: Anthony Ku and Jonathan Loudis

Outline

- Assessing Material Criticality – Industrial Criticality Diagrams
- Industrial Approaches to Criticality Solutions
- Some Examples
    - Sourcing critical materials
    - Reducing manufacturing scrap
    - Material substitutions
    - System substitutions

System Development and Material Engineering technologies are shown to be key approaches to solving critical materials challenges

GE Criticality Diagram - 2008



GE Criticality Diagram - 2012

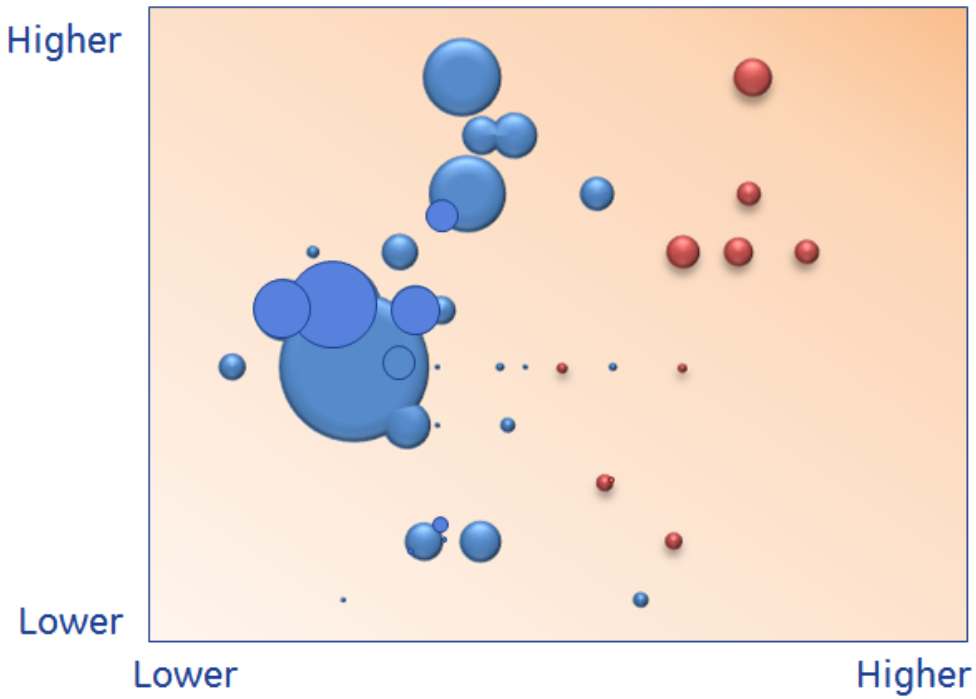
Impact on operations

Revenue impacted

% of world's use

Substitutability (specific applications)

Cost pass-through (specific applications)



Rare earth elements

area Proportional to spend

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Supply and Price Risk

World reserves	Political factors	Competing uses
Co-production	Human factors	Price volatility

Development of Defendable Criticality Diagrams

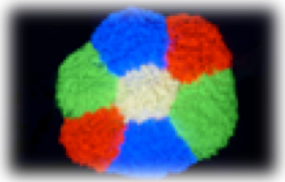
Supply Risk scoring	NRC	Yale	DOE	GE	BGS	EU
# of Materials	11	62	14 (2010)	33 (2008)	52 (2011)	41 (2010)
(Year of assessment)	(2007)	(2008)	16 (2011)	53 (2012)	41 (2012)	54 (2013)
Physical availability	**60%**	**33%**	**50%**	**22%**	**29%**	
Reserves/Depletion time	20%	1/6	2/5	1/9	1/7	
Companion production	20%	1/6	1/10	1/9		
Recycling rate	20%				1/7	Included
Production		**67%**	**40%**	**33%**	**56%**	
Producer concentration		1/6	1/5		2/7	Included
Producer stability		1/6				
Producer governance		1/6	1/5	1/6	2/7	
Producer policy		1/6		1/6		
Market factors	**40%**		**10%**	**45%**	**14%**	
Price volatility				1/9		
Substitutability	20%			1/6	1/7	Included
Competing demand	20%		1/10	1/6		
Impact scoring						
Importance	**33%**	**50%**	**75%**	**50%**		**100%**
Economic impact				1/4		
Usage % by population		1/2				
% of world's supply used				1/4		
Substitutability	**33%**	**50%**	**25%**	**25%**		
Performance		1/6		1/4		Included
Availability		1/6				in
Environmental impact		1/6				supply risk
Market factors	**33%**			**25%**		
Cost pass through				1/4		
Emerging uses	1/3					

Solutions to Criticality Challenges

Sourcing … ensure supply through diversification, fixed price contracts, forwards, options, etc.

Manufacturing efficiency … reduced waste, recycled waste, advanced manufacturing (i.e. additive)

Recycling … manufacturing shrinkage and end-of-life products, repair, re-manufacturing



Material re-design or substitution … reduce or eliminate at-risk element, use alternate material

System substitution … use an alternate technology to satisfy a customer's need

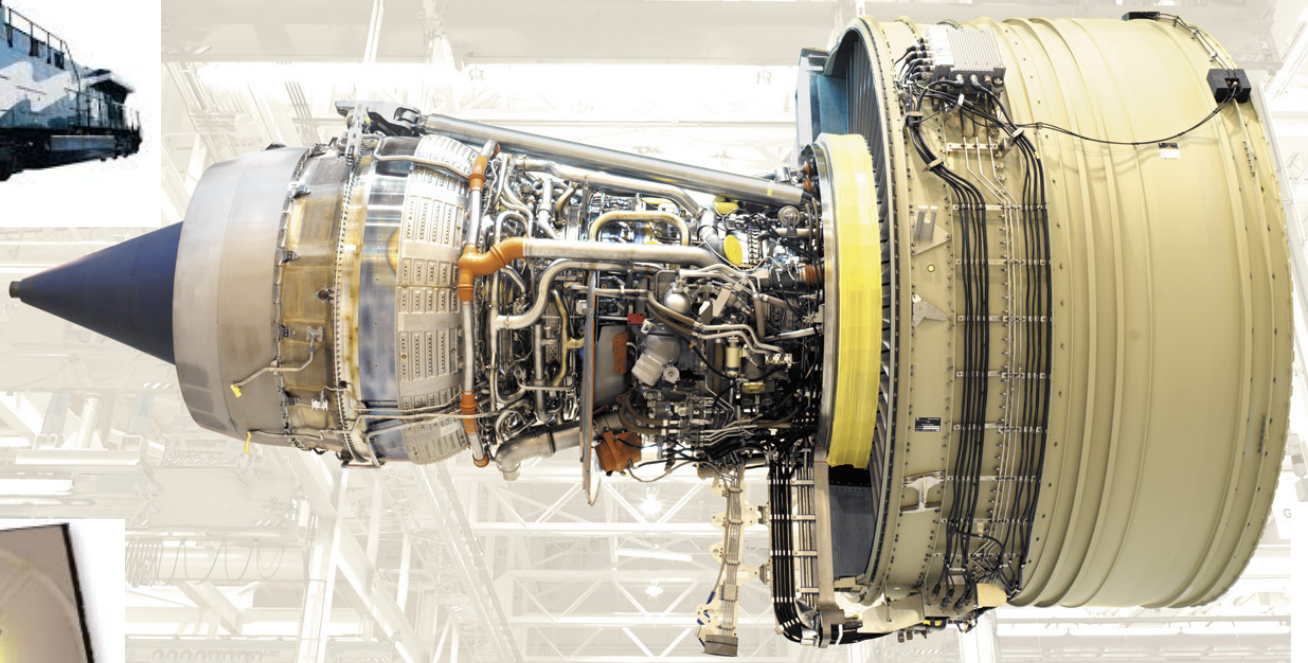
Broaden material sources

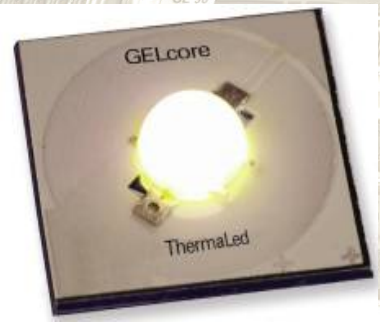
Optimize usage

Redesign materials & systems

GE

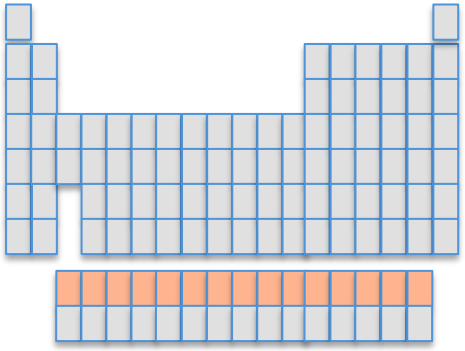
- GE uses ~3 Billion lbs of raw material in our products annually
- For manufacturing companies, typically one-half of their Cost of Goods & Services Sold is spent on materials. For GE, translates to ~$40 B/yr
- GE uses at least 75 of the first 83 elements on the periodic table





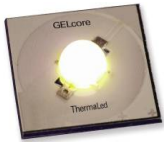
Example: Rare earth elements

- >90% produced in China
- Prices peaked at 10-20x in mid-2011



Y, Ce, Tb La, Eu

Fluorescent lamp phosphors



Y, Ce, Tb, Eu

White LED phosphors

Nd, Dy, Tb

Industrial motors

Y

Thermal barrier coatings for gas turbines and aircraft engines

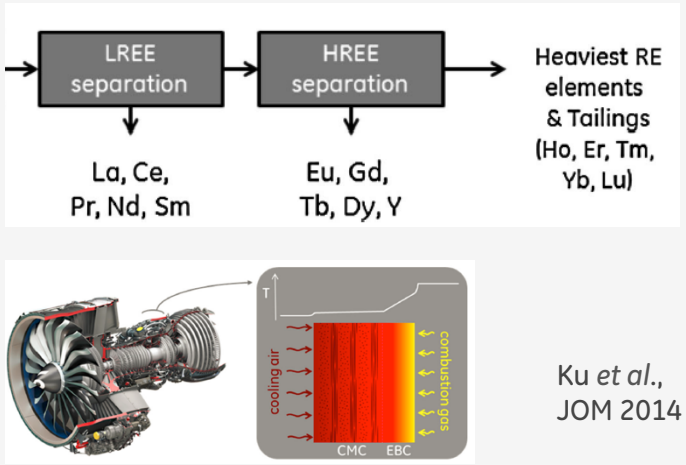
Y, Ce, Tb Gd, Eu, Lu

Scintillators for CT & PET imaging

Nd, Dy, Tb

Generators for 2.5MW+ wind turbines

Sourcing

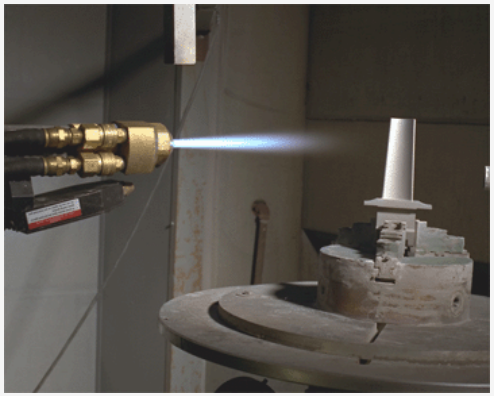


Diversifying the supply chain

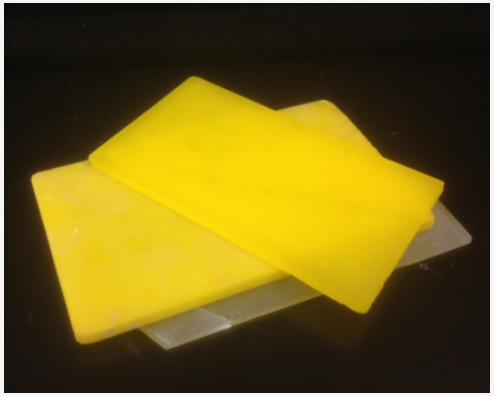
Revisiting raw material specs

Manufacturing efficiency

TBC overspray



Scintillator scrap



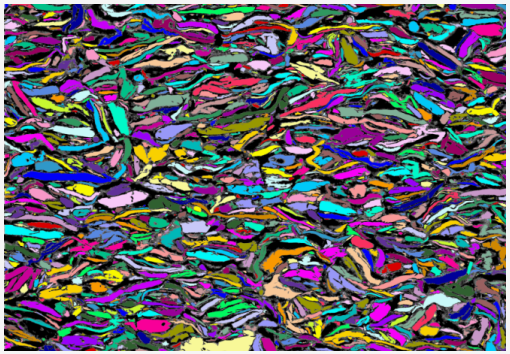
He recovery

Recovery and reuse of manufacturing scrap

Substitution

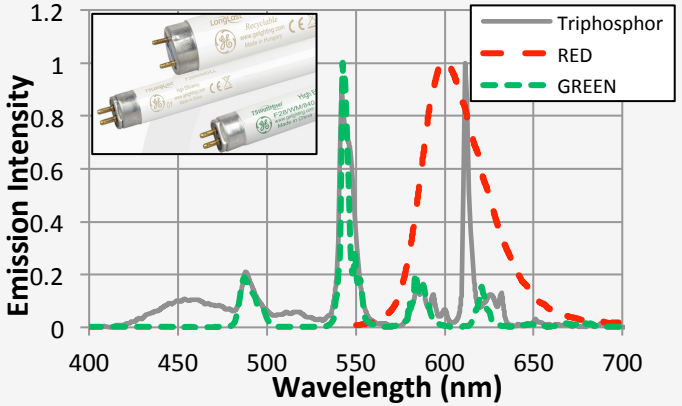
Materials R&D

New magnet materials



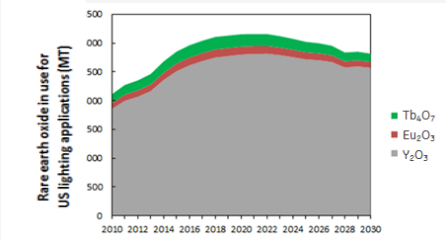
F. Johnson, GE Global Research

New phosphor materials



Alternate system designs

LEDs for lighting



DFIGs for wind

Summary

- Criticality diagrams have developed since 2008
- Critical elements change with time – rare earth criticality reduced
- Systems and materials engineering can reduce the criticality risks