Creating a circular economy: The challenges and opportunities presented by Technology Metals for future business

Sustainable Resource Management Conference

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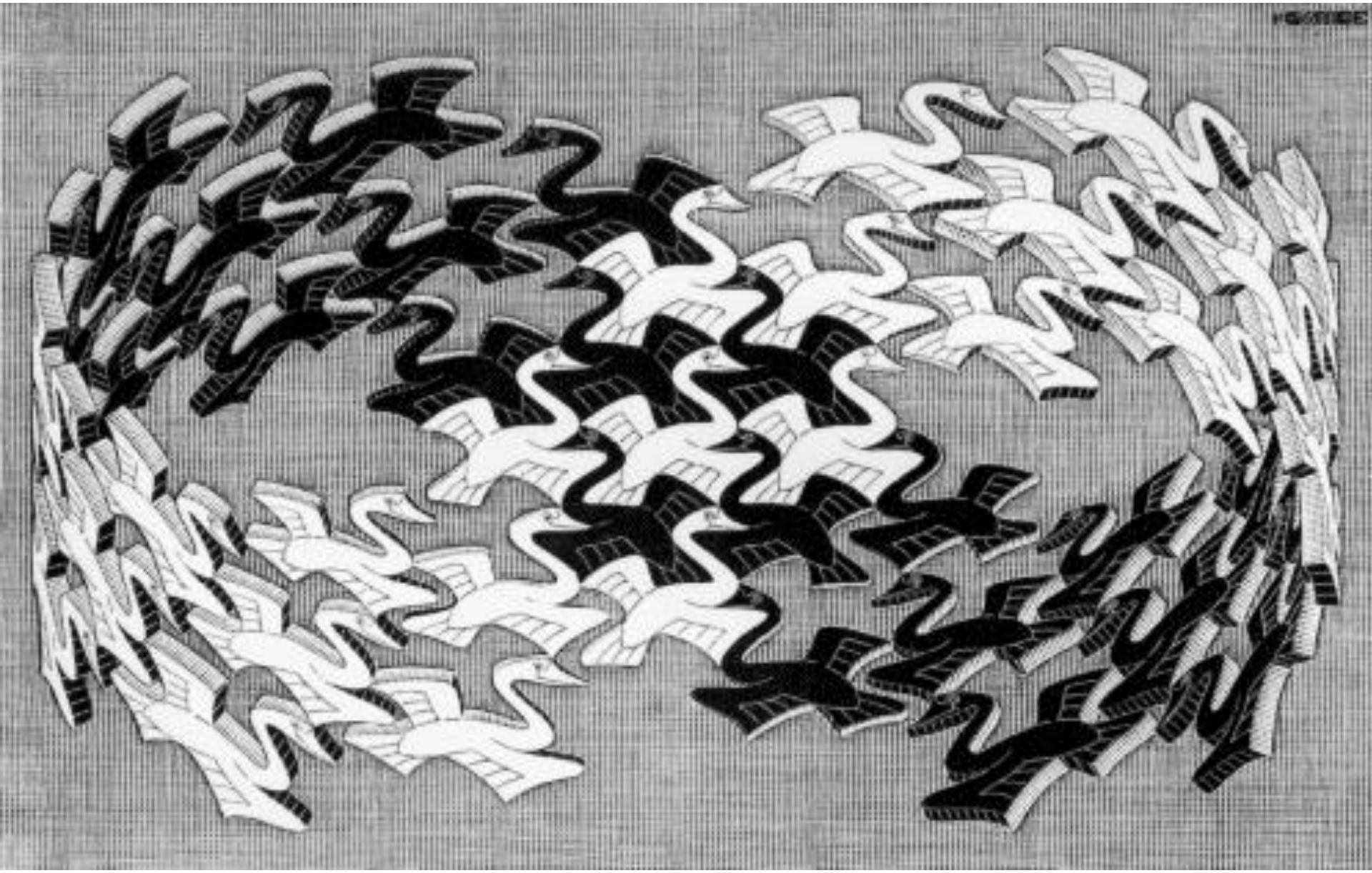
New York, NY USA

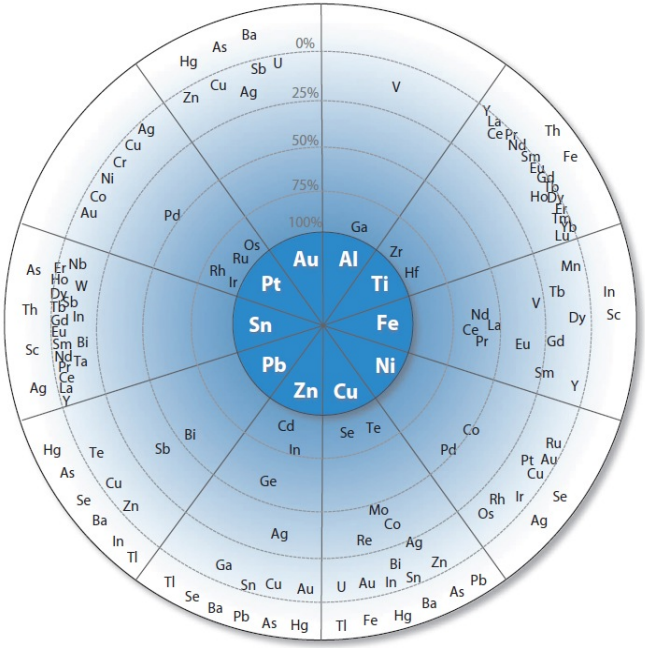
Industrial Ecology – Circular Economy



M. C. Escher- "Swans (White Swans, Black Swans)"- February 1956

Outline

- Trends in Commodity Use
  - 3 Groups
- Technology Metals
  - Old models do not apply
- Materials Flows of Technology Metals
  - Closing the cycle



Trends in Commodity Use

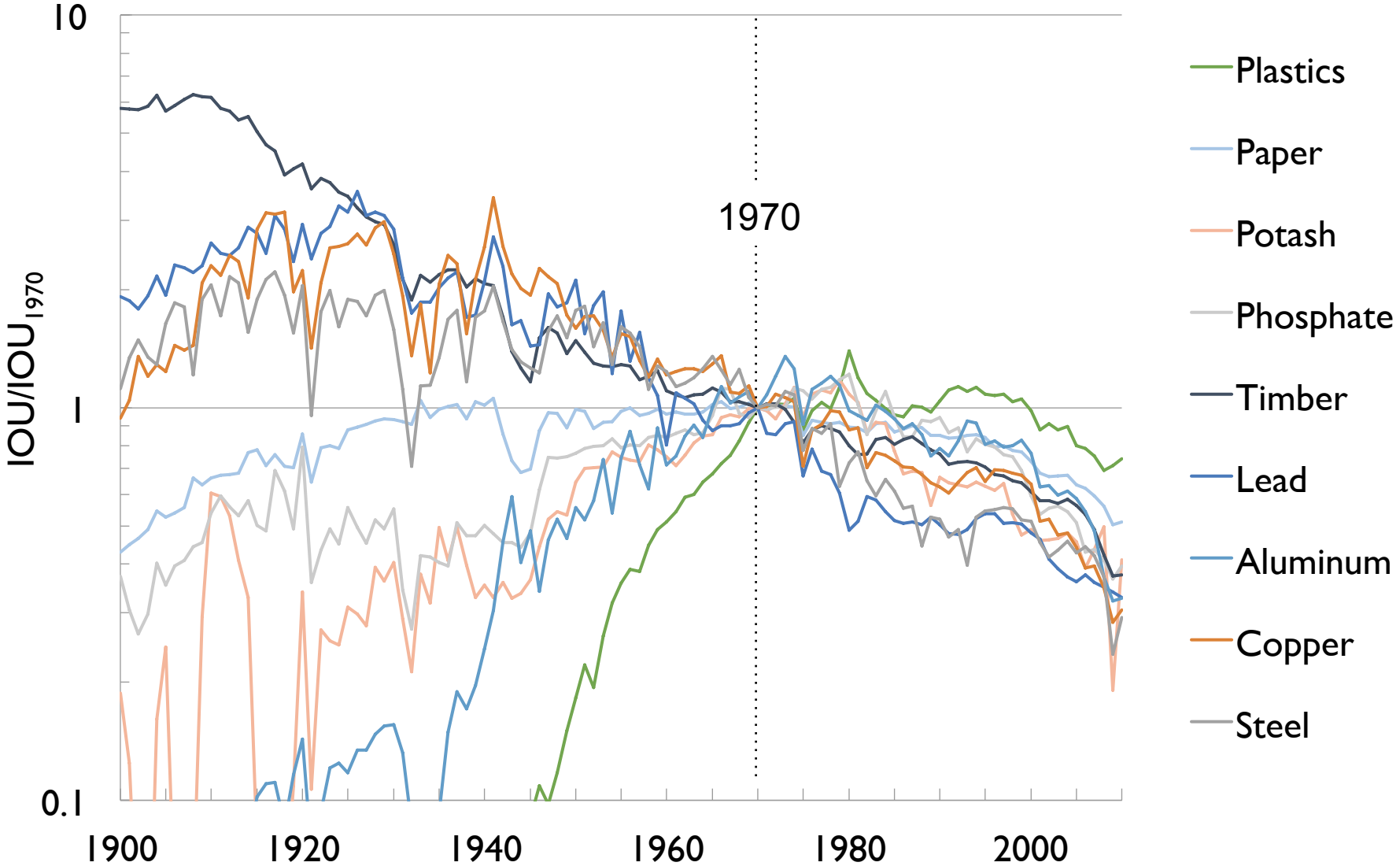
Measures of Commodity Use

- Relative
  - *Intensity of Use* (**IOU**) measured as kg/$GDP
  - Falling IOU ==> “Dematerialization“
- Absolute
  - *Absolute use* (**ABS**) measured as kg, kWh, Ha, liters…
  - Falling ABS ==> “Peak”

Wernick & Ausubel 2014

Trends in Commodity Use

IOU of 9 basic commodities: US 1900-2010

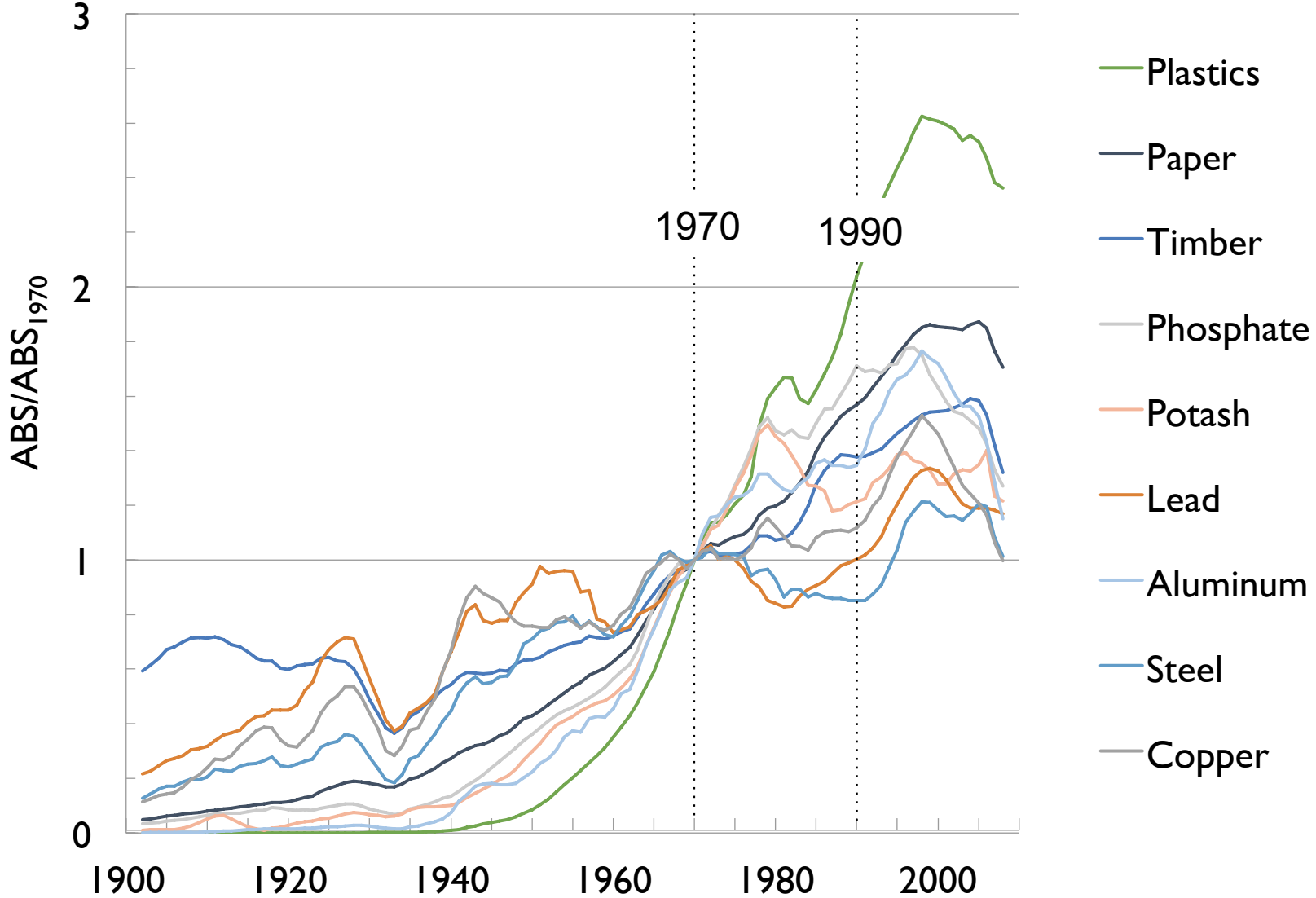


Data sources: USGS National Minerals Information Center, 2013; Johnston and Williamson, 2013.
[Notes: Uses 5 yr. moving average; GDP in 2005 dollars; Legend is ordered top down by value in 2010]

Wernick & Ausubel 2014

Trends in Commodity Use

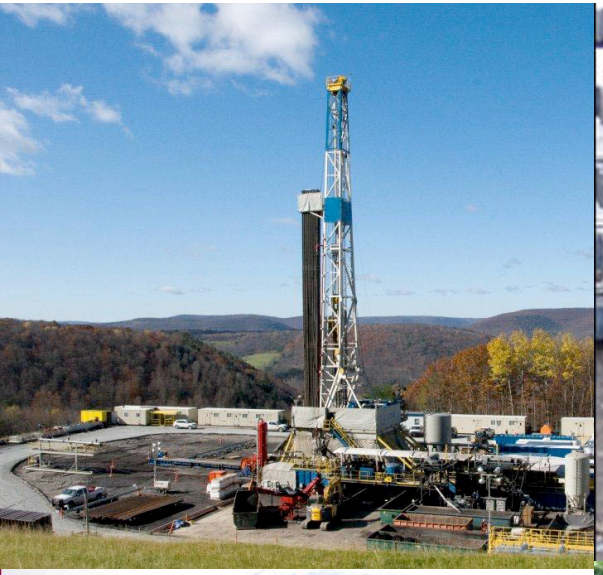
ABS of 9 basic commodities: US 1900-2010



Data sources: USGS National Minerals Information Center 2013.
[Notes: Uses 5 yr. moving average; Legend is ordered top down by value in 2010]

Wernick & Ausubel 2014

Study on the use of 100 commodities in USA 1900 - 2010






Wernick & Ausubel 2014

100 Commodities Studied

1	Abrasives (Natural)	34	Gold	68	Pumice & Pumicite
2	Aluminum	35	Graphite (Natural)	69	Quartz Crystal (Industrial)
3	Antimony	36	Gypsum	70	Rare Earths
4	Arsenic	37	Hafnium	71	Rhenium
5	Asbestos	38	Helium	72	Salt
6	Barite	39	Indium	73	Sand & Gravel (Construction)
7	Bauxite & Alumina	40	Iodine	74	Sand & Gravel (Industrial)
8	Beef	41	Iron & Steel Scrap	75	Selenium
9	Beryllium	42	Iron & Steel Slag	76	Silicon
10	Bismuth	43	Iron Ore	77	Silver
11	Boron	44	Lead	78	Soda Ash
12	Bromine	45	Lime	79	Sodium Sulfate
13	Cadmium	46	Lithium	80	Steel
14	Cement	47	Magnesium Compounds	81	Stone (Crushed)
15	Chicken	48	Magnesium Metal	82	Stone (Dimension)
16	Chromium	49	Manganese	83	Strontium
17	Clays	50	Mercury	84	Sulfur
18	Coal	51	Mica	85	Talc & Pyrophyllite
19	Cobalt	52	Molybdenum	86	Tantalum
20	Copper	53	Natural Gas	87	Thallium
21	Corn	54	Nickel	88	Thorium
22	Cotton	55	Niobium	89	Timber
23	Cropland	56	Nitrogen (Ammonia)	90	Tin
24	Diamond (Industrial)	57	Non-Renewable Organics	91	Titanium Dioxide
25	Diatomite	58	Non-Renewable Organics (Oil & Gas)	92	Titanium Metal
26	Electricity	59	Paper & Board	93	Tungsten
27	Feldspar	60	Perlite	94	Uranium
28	Fish	61	Petroleum	95	Vanadium
29	Fluorspar	62	Phosphate Rock	96	Vermiculite
30	Gallium	63	Pig Iron	97	Water
31	Garnet (Industrial)	64	Platinum-Group Metals	98	Wheat
32	Gemstones	65	Pork	99	Zinc
33	Germanium	66	Potash	100	Zirconium Mineral Concentrates
		67	Potatoes		

Wernick & Ausubel 2014

Trends in Commodity Use

Behavior from 1970-2010 yields 3 groups

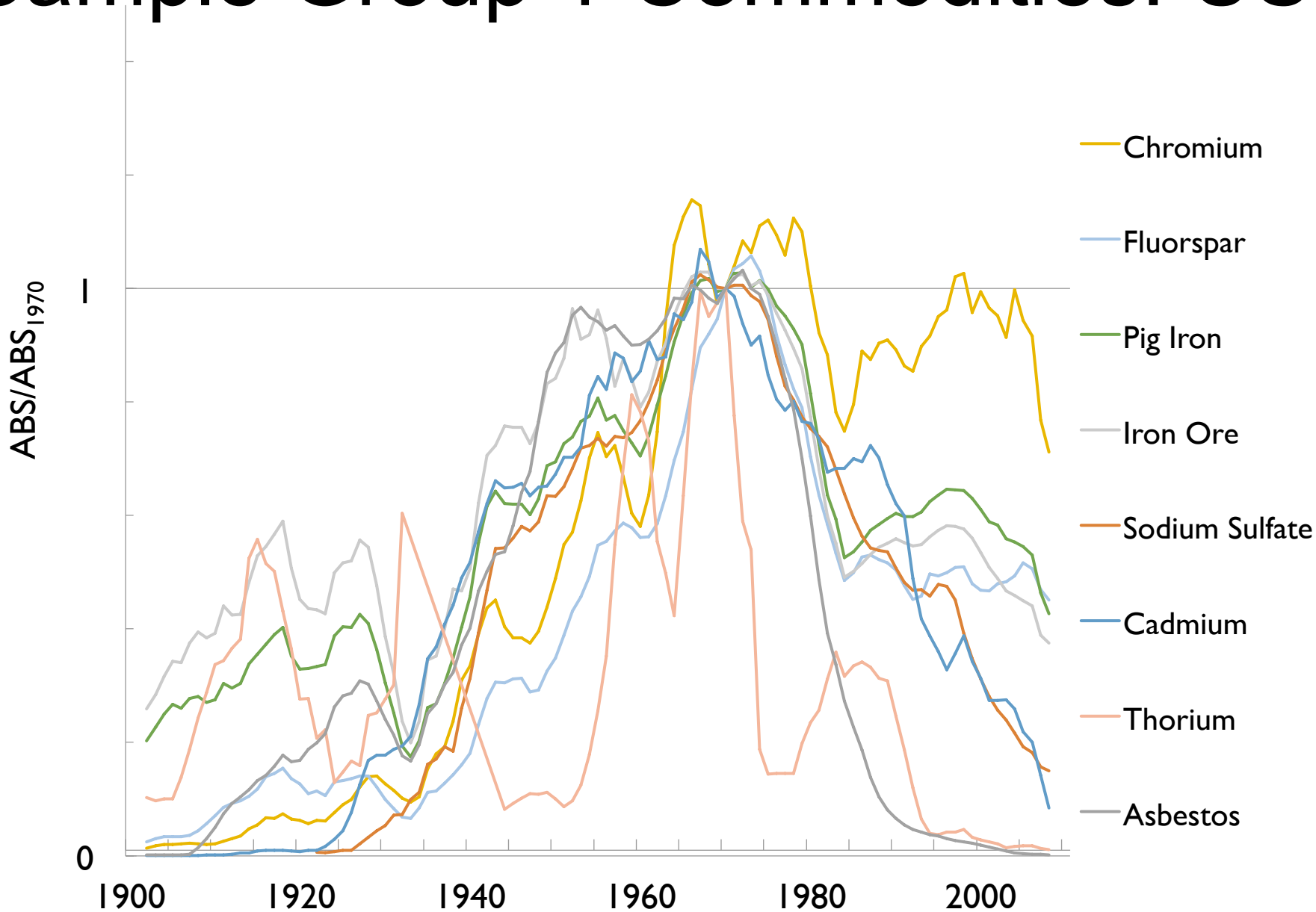
Group 1	IOU	↓	ABS	↓
Group 2	IOU	↓	ABS	↑
Group 3	IOU	↑	ABS	↑

Wernick & Ausubel 2014

Group 1 (36/100)	Group 2 (53/100)		Group 3 (11/100)
ΔIOU < 0 and ΔABS < 0	ΔIOU < 0 and ΔABS > 0		ΔIOU > 0 and ΔABS > 0
Antimony	Abrasives (Natural)	Nitrogen (Ammonia)	Chicken
Arsenic	Aluminum	Non-Renewable Organics (NRO)	Diamond (Industrial)
Asbestos	Barite	NRO (Oil & Gas)	Gallium
Bauxite & Alumina	Beef	Paper & Board	Garnet (Industrial)
Bismuth	Beryllium	Perlite	Gemstones
Cadmium	Boron	Petroleum	Helium
Chromium	Bromine	Phosphate Rock	Indium
Clays	Cement	Platinum-Group Metals*	Niobium
Copper	Coal	Pork	Quartz Crystal (Industrial)
Cotton	Cobalt	Potash	Rhenium
Fluorspar	Corn	Potatoes	Stone (Dimension)
Iodine	Cropland	Salt	
Iron & Steel Scrap	Diatomite	Sand & Gravel (Industrial)	
Iron & Steel Slag	Electricity	Silver	
Iron Ore	Feldspar	Stone (Crushed)	
Lithium	Fish	Sulfur	
Magnesium Compounds	Germanium	Tantalum	
Manganese	Gold	Timber	
Mercury	Graphite (Natural)	Titanium Dioxide	
Mica	Gypsum	Titanium Metal	
Pig Iron	Hafnium	Tungsten	
Pumice & Pumicite	Lead	Uranium	
Rare Earths	Lime	Vanadium	
Sand & Gravel (Cons.)	Magnesium Metal	Water	
Selenium	Molybdenum	Wheat	
Silicon	Natural Gas	Zirconium Mineral Conc.	
Soda Ash	Nickel		
Sodium Sulfate			
Steel			
Strontium			
Talc & Pyrophyllite			
Thallium			
Thorium			
Tin			
Vermiculite			
Zinc			

Δ = change per year 1970 – 2010

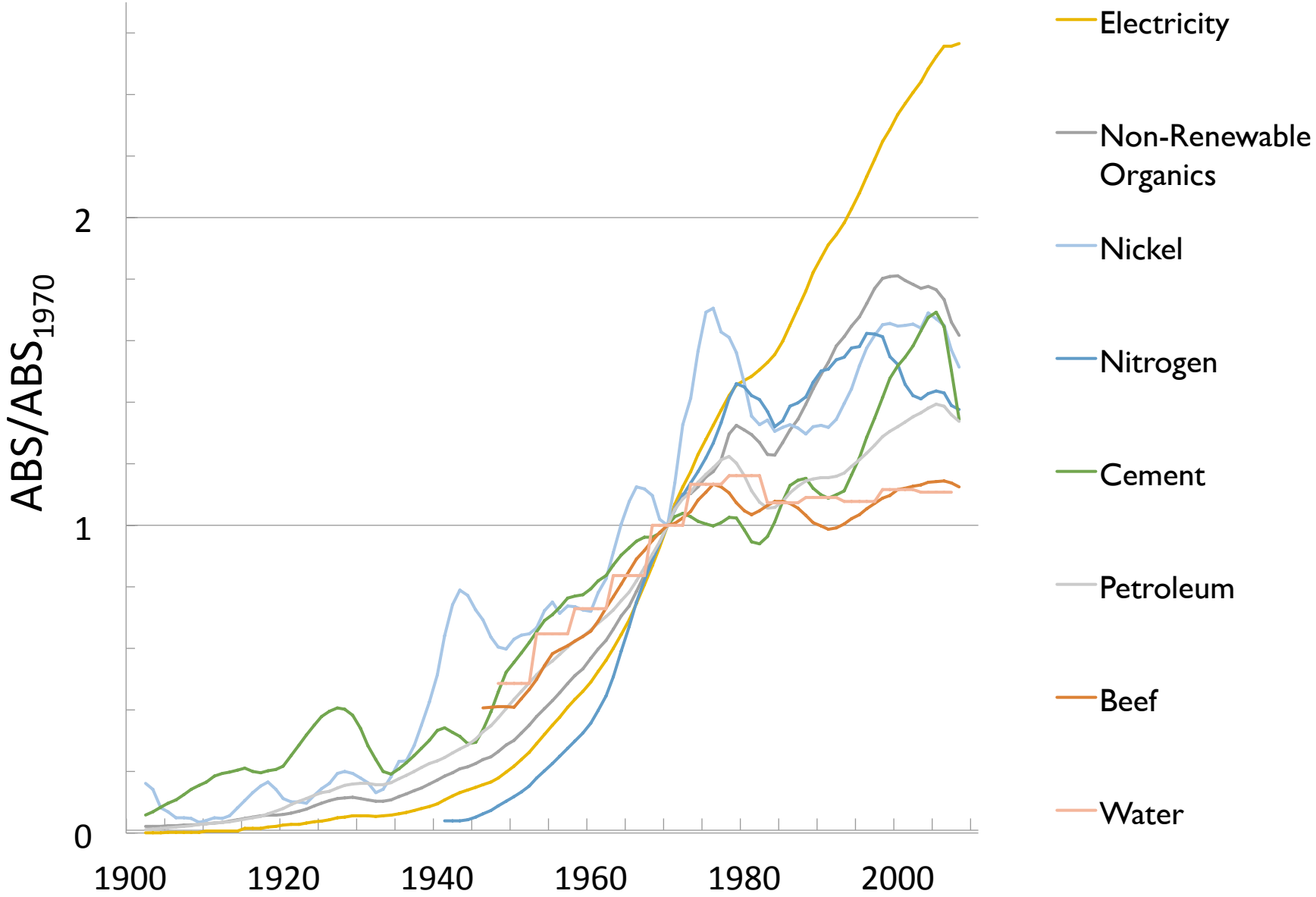
Sample Group 1 Commodities: US



Data sources: USGS National Minerals Information Center 2013.
[Notes: Uses 5 yr. moving average; Legend is ordered top down by value in 2010]

Wernick & Ausubel 2014

Sample Group 2 Commodities: US



Data sources: USGS National Minerals Information Center 2013.
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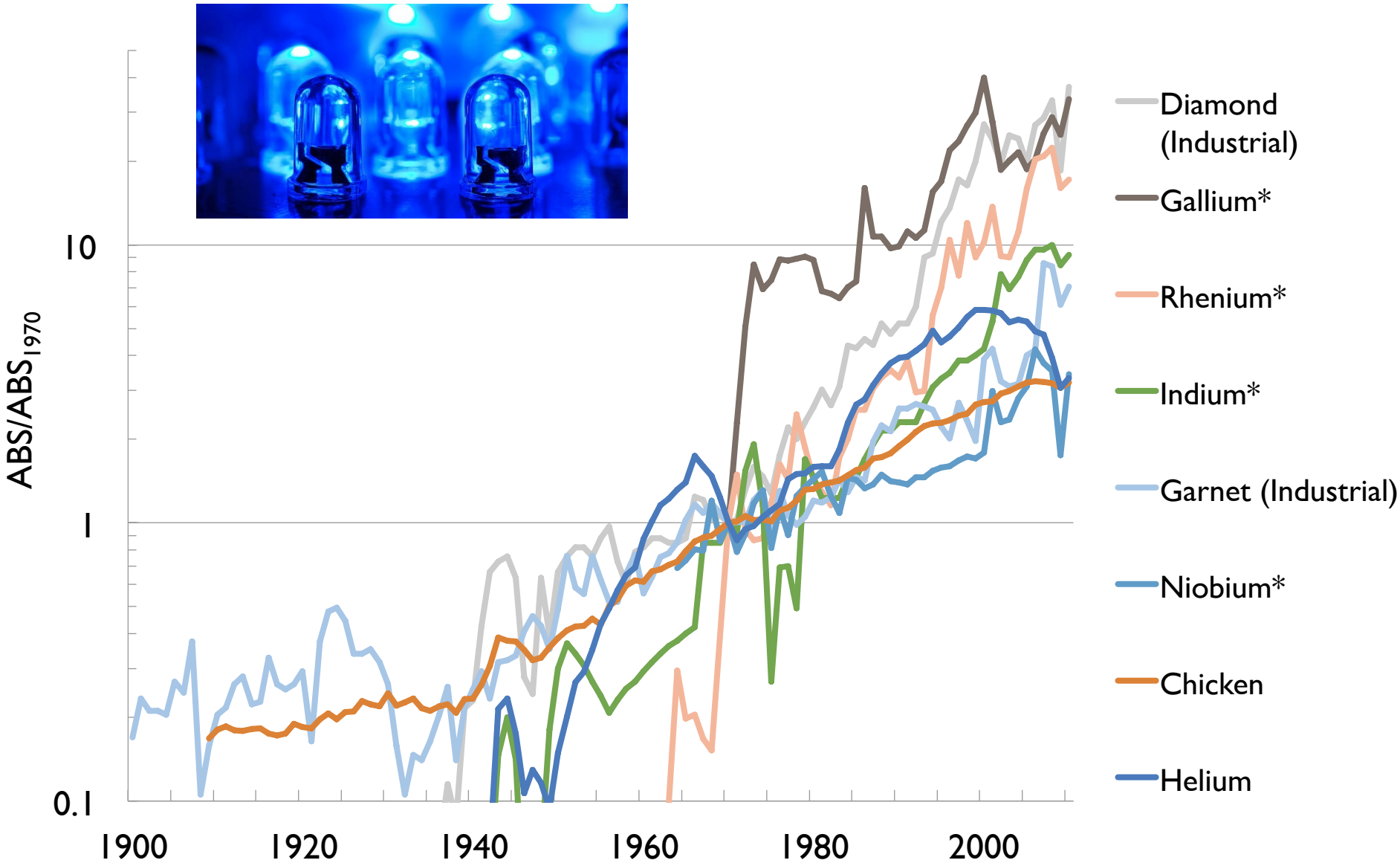
Sample Group 3 Commodities: US



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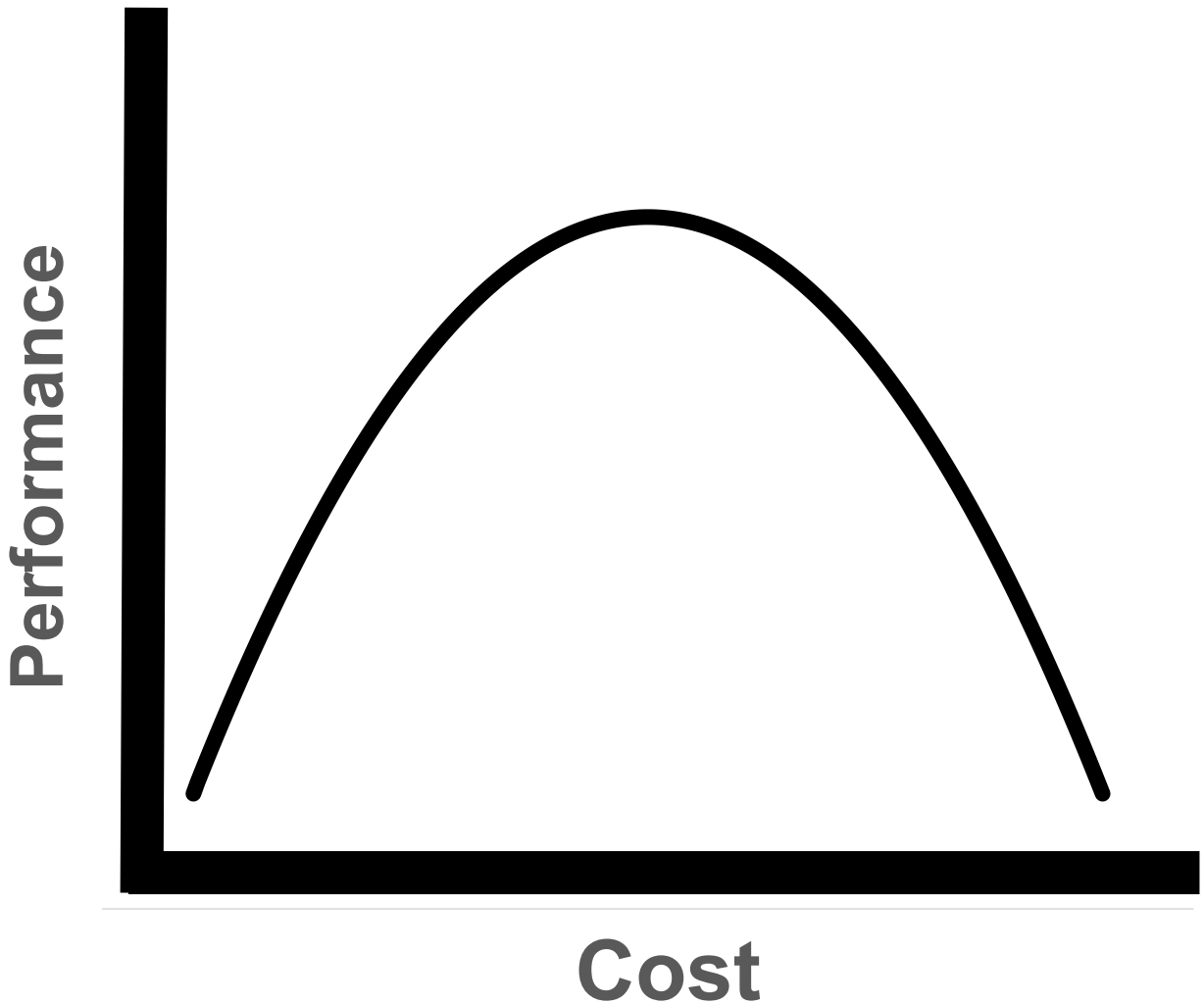
Wernick & Ausubel 2014

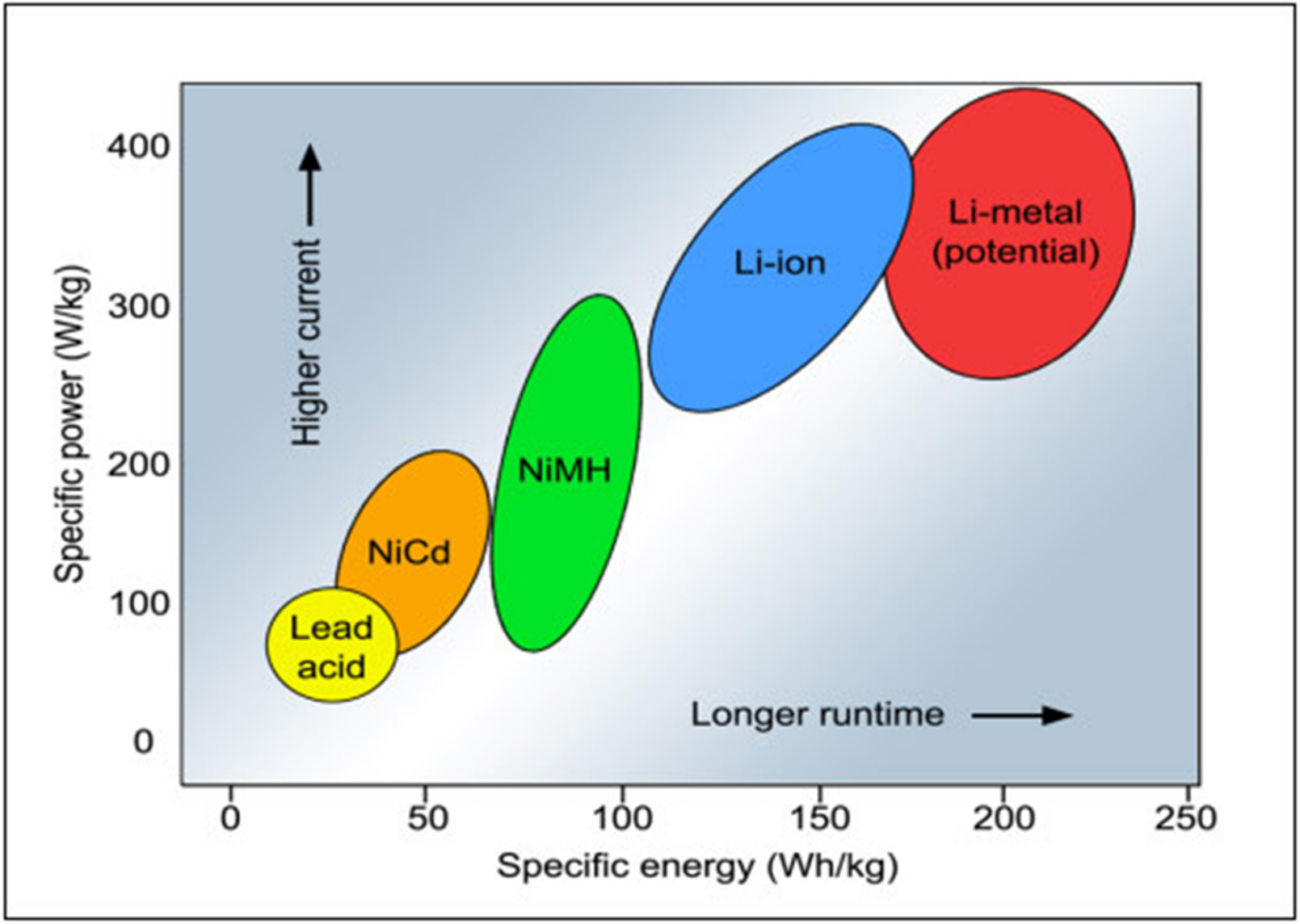
Technology Metals

'…uses are specialized; substituting an alternative can lead to reduced performance and increased cost….' Nassar et al. 2015



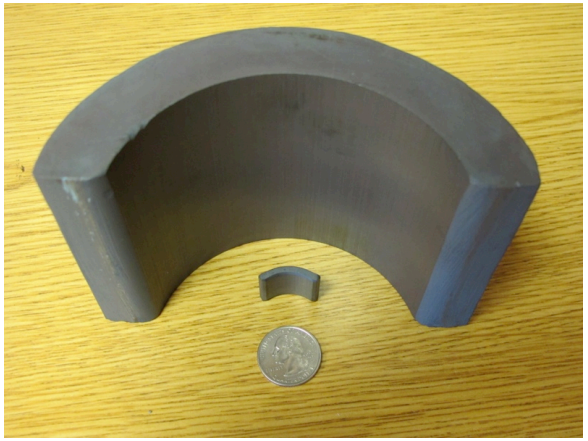
Technology Metals

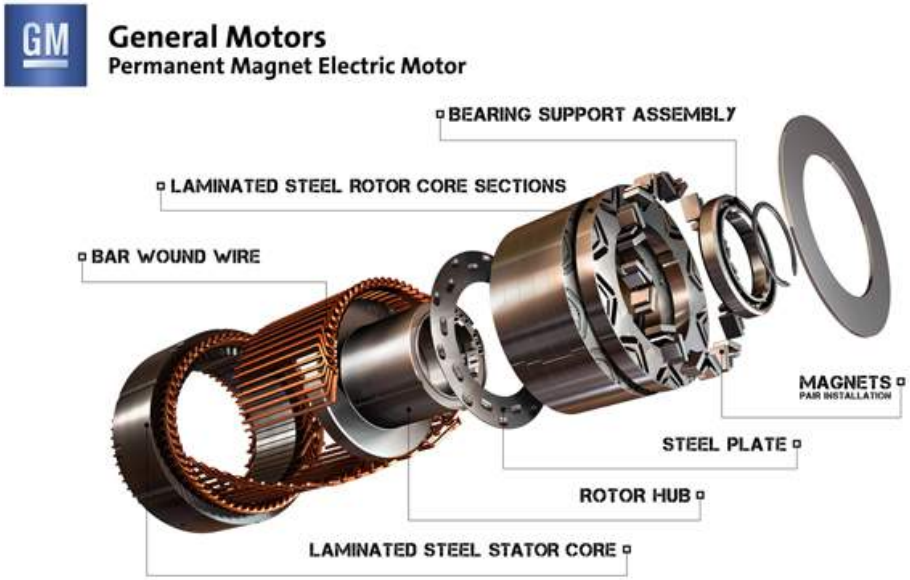
Example of Batteries



Technology Metals

Example of Electric Motors/Generators





Technology Metals

Baotou Xijun Rare Earth (Nd) refinery in Baotou, China

http://www.dailymail.co.uk/home/moslive/article-1350811/In-China-true-cost-Britains-clean-green-wind-power-experiment-Pollution-disastrous-scale.html#ixzz4RzJZJR3X

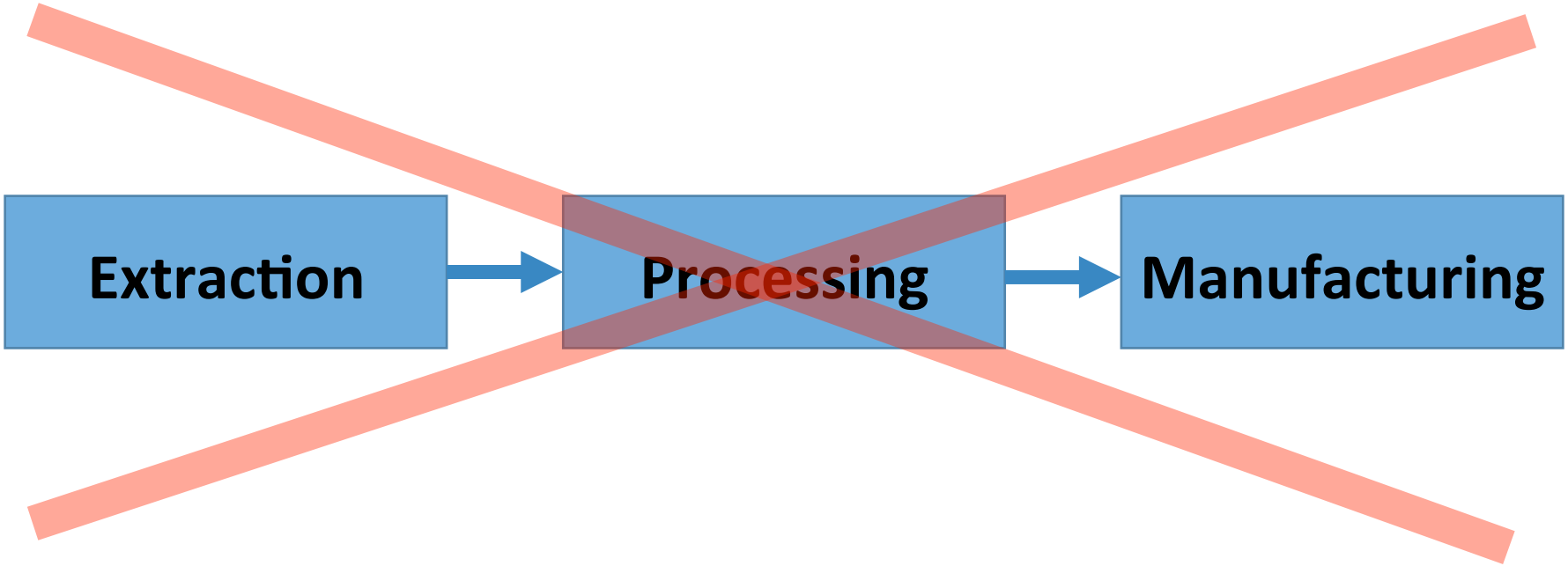
Technology Metals

Niobium - 80% to HSLA Steel

Millau Viaduct in Southern France.
Nb content of steel ~.025%

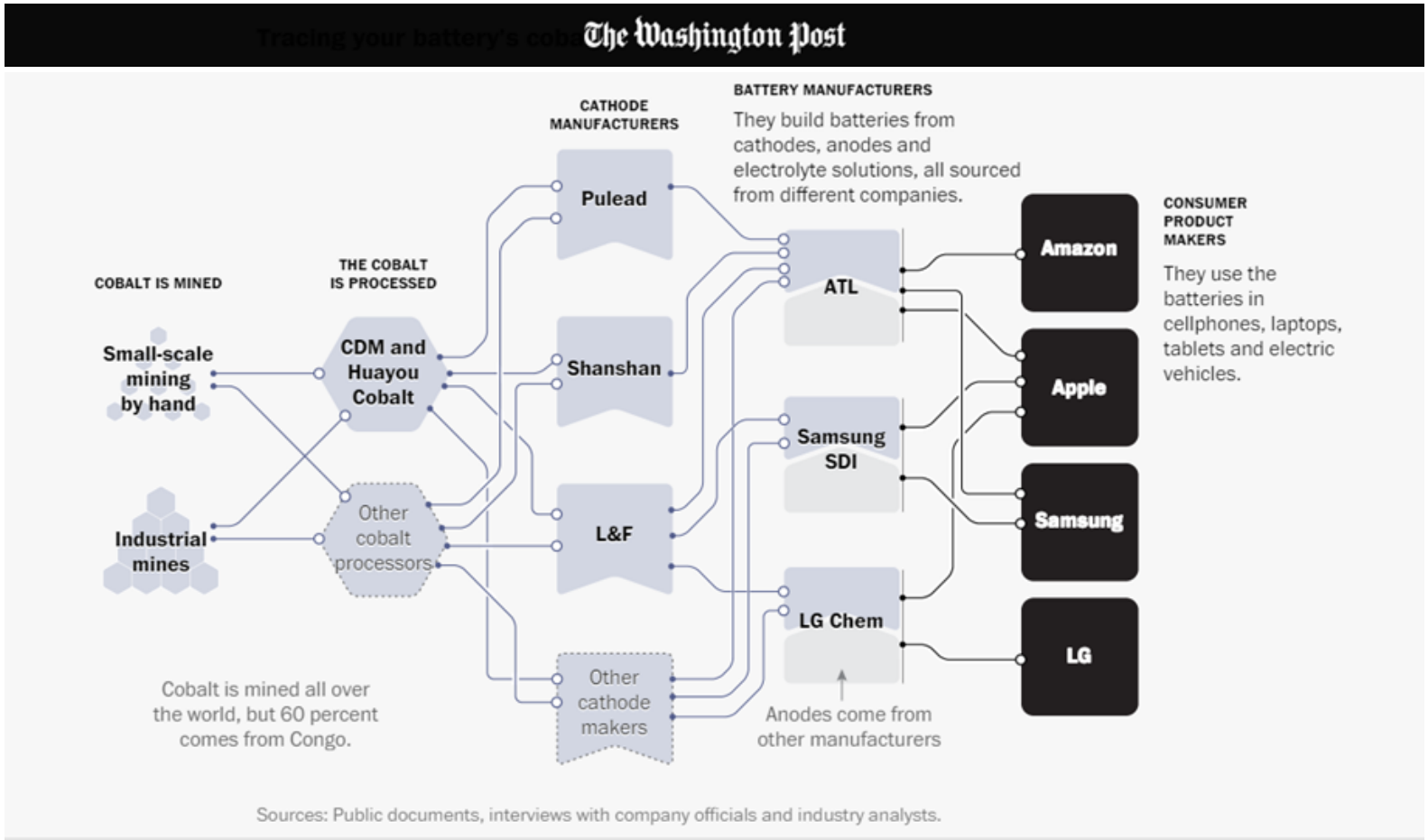
Technology Metals

Old models do not apply



Technology Metals

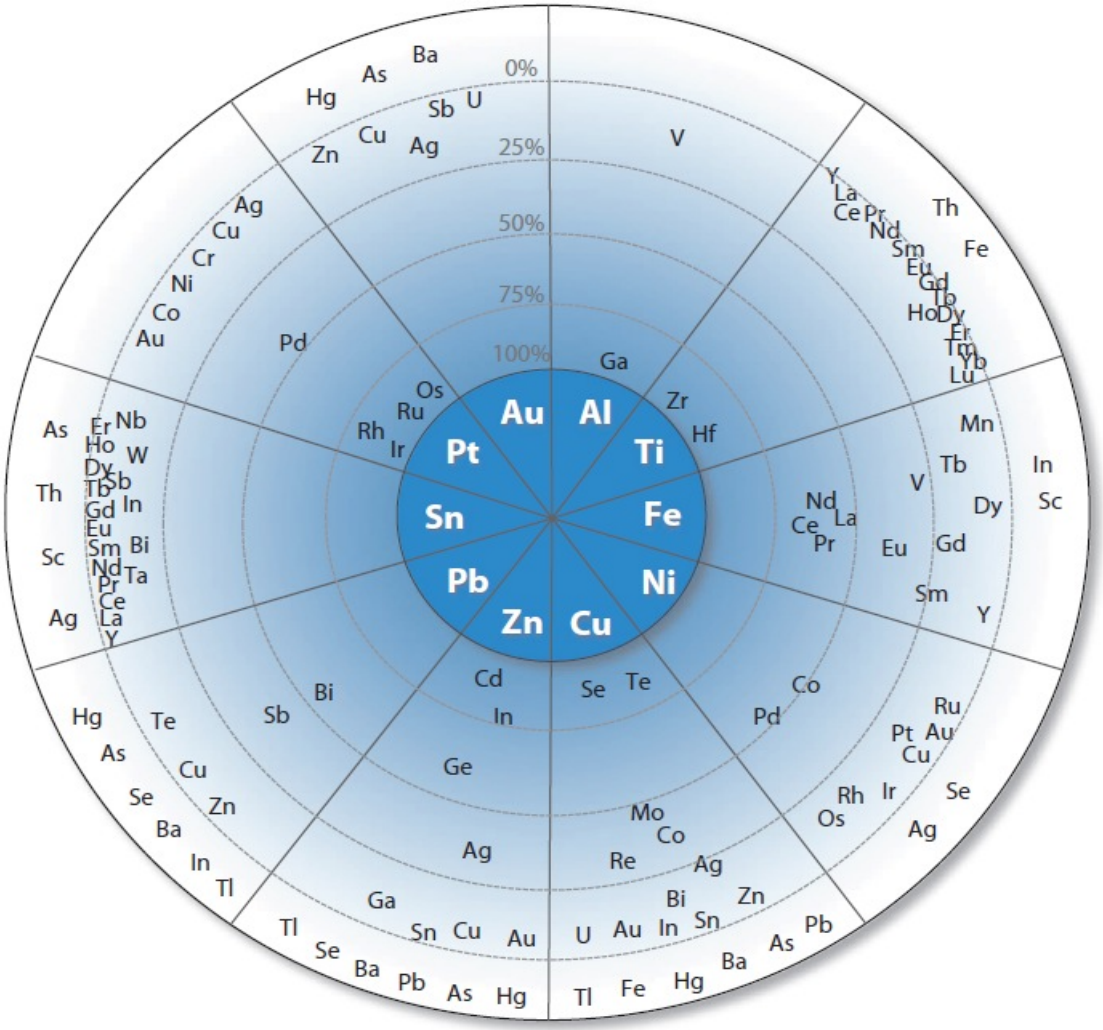
Old models do not apply – complex supply chains



https://www.washingtonpost.com/graphics/business/batteries/congo-cobalt-mining-for-lithium-ion-battery/

Technology Metals

Old models do not apply – Many byproduct streams

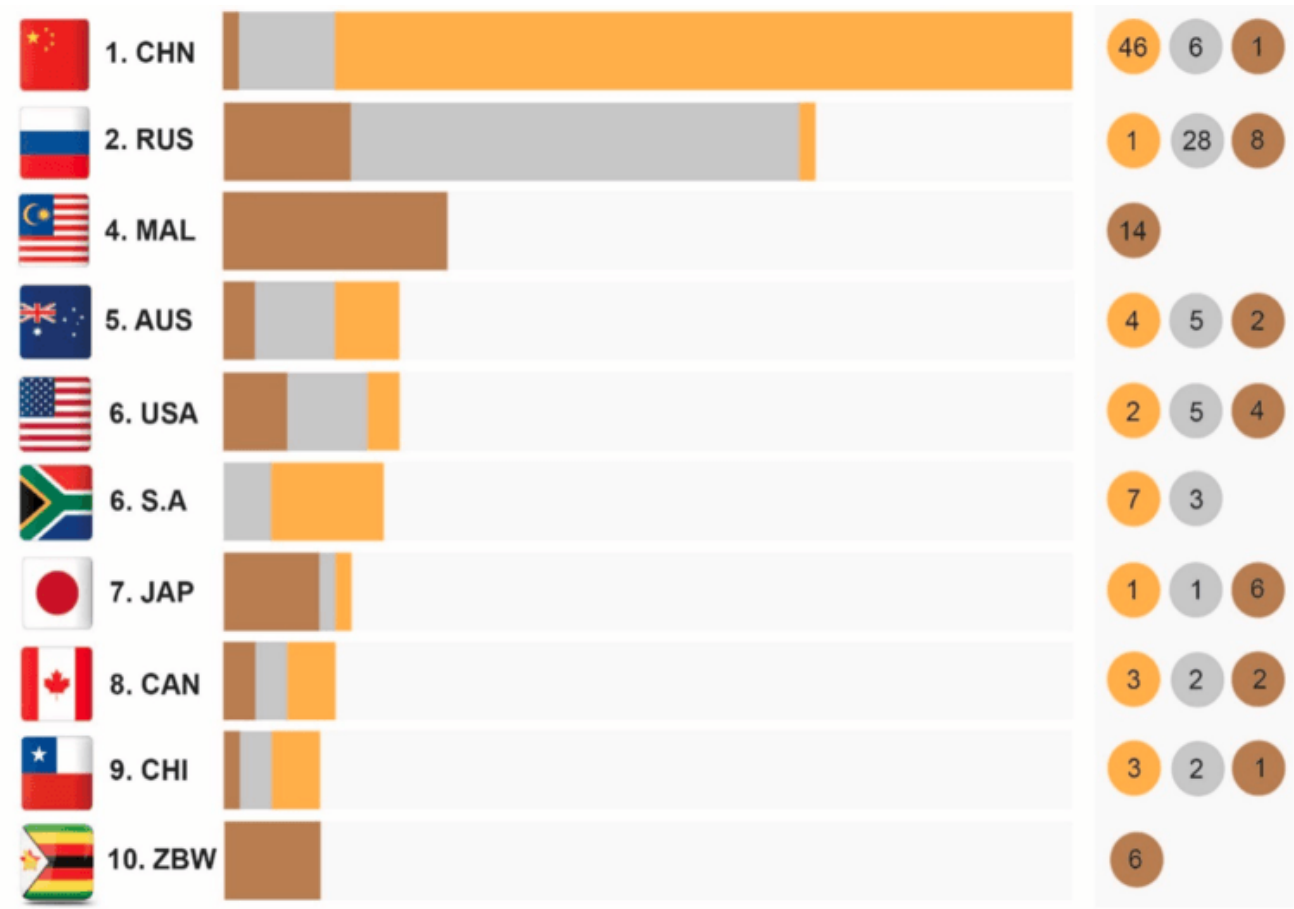


Source: Nassar et al. 2015

Technology Metals

Old models do not apply – Refineries geographically concentrated

Major and Minor Technology Metals 2015 by Country
#1 Global Producer Gold; #2 Silver; #3 Bronze



Data source: USGS Analysis by Dylan McFarlane, Robert Pell, University of Exeter

Technology Metals

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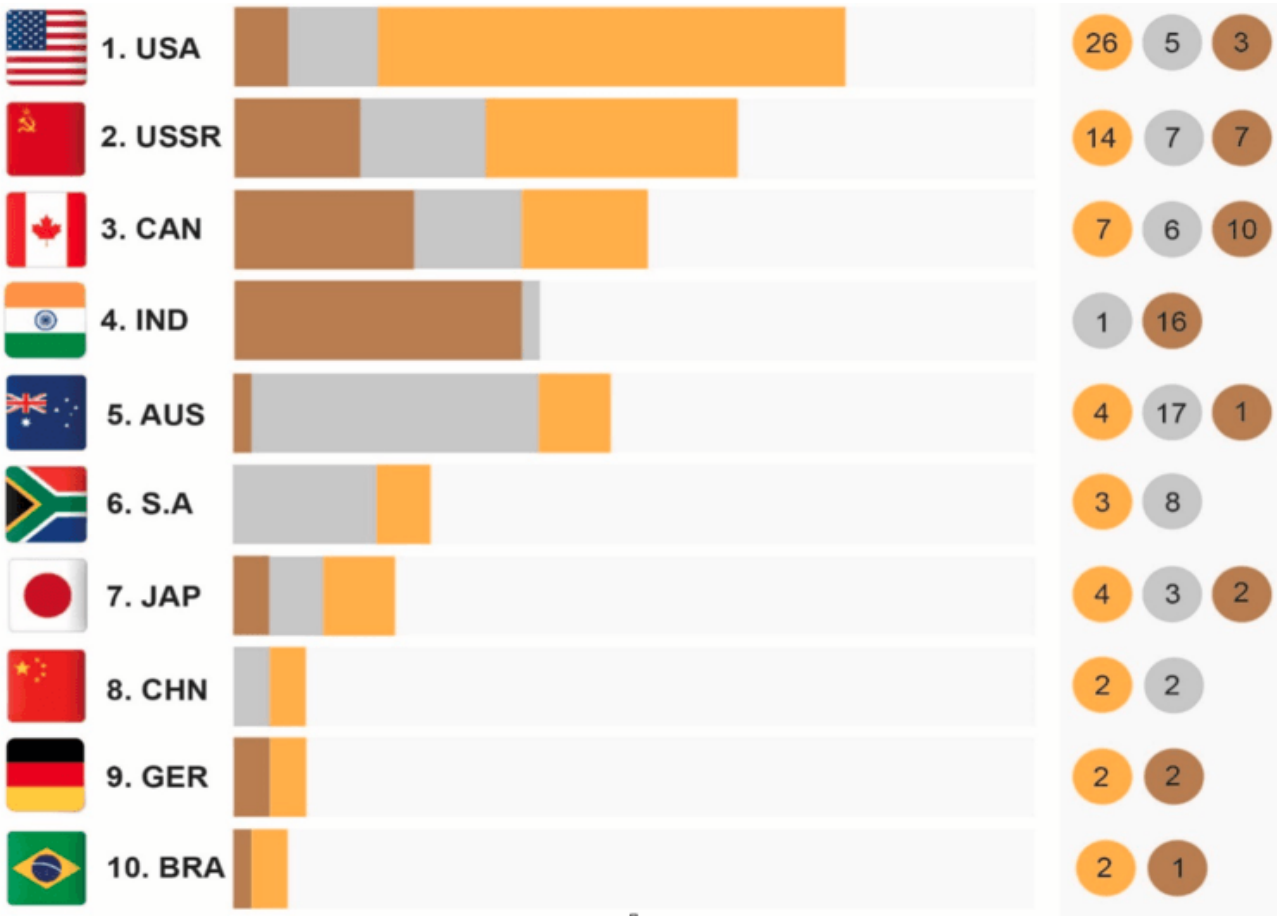

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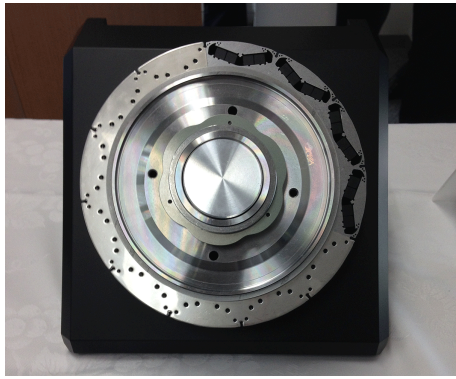
Materials Flows of Technology Metals



Option 1: Developing Substitutes

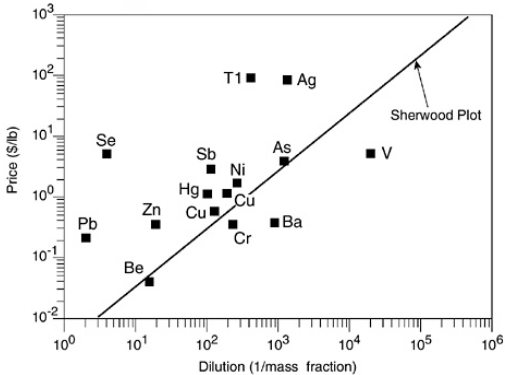
Honda hybrid motor without rare-earth metals

Option 2: Improve Efficiency

Overwhelming demand – ‘Jevons paradox’

Option 3: Recover technology metals

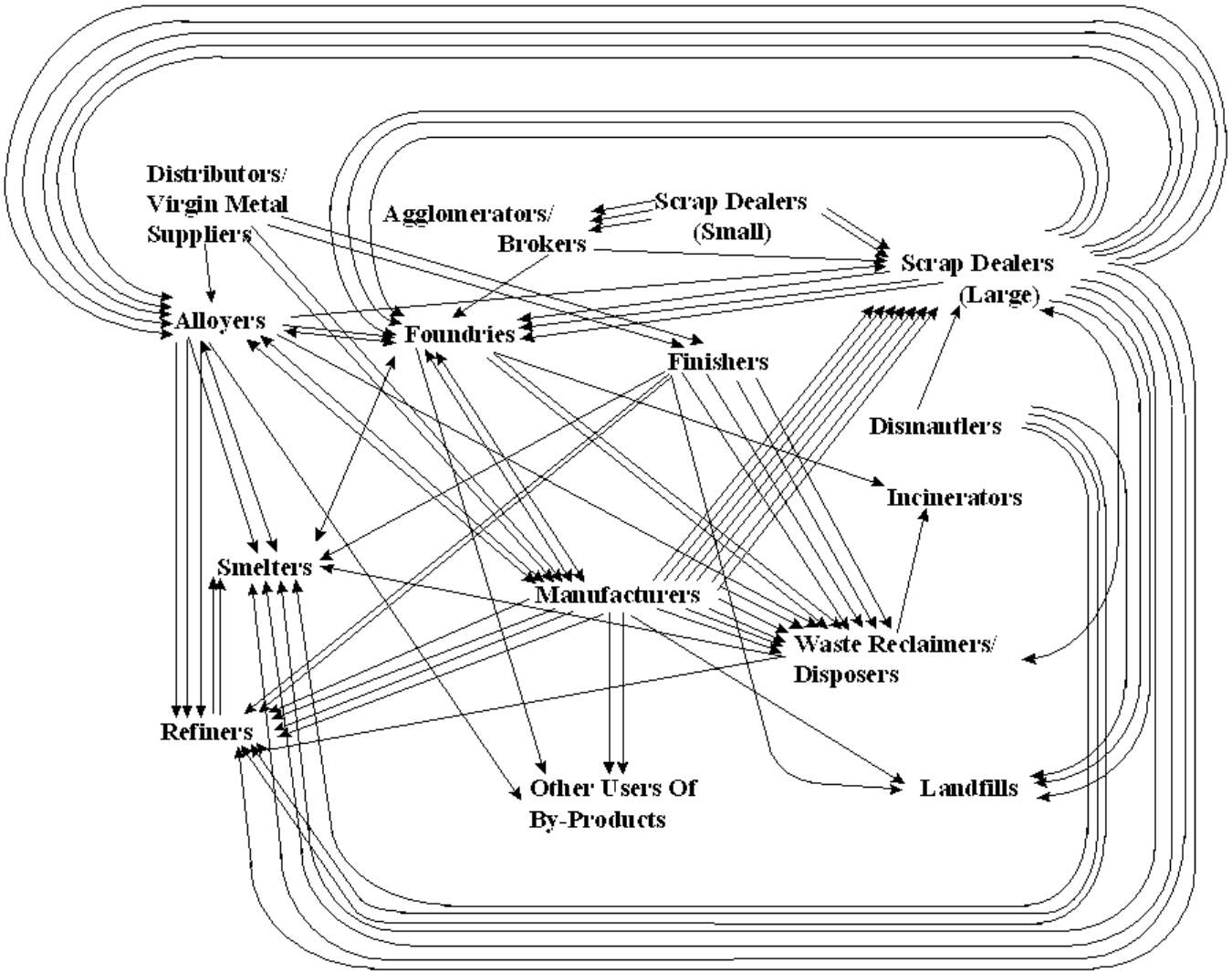
Commodity price vs. dilution. The diagonal line correlates concentration of metal
in commercial ores to market price of metals
(Allen & Behamenesh 1994).



Materials Flows of Technology Metals

Closing the cycle – Recycling Infrastructure

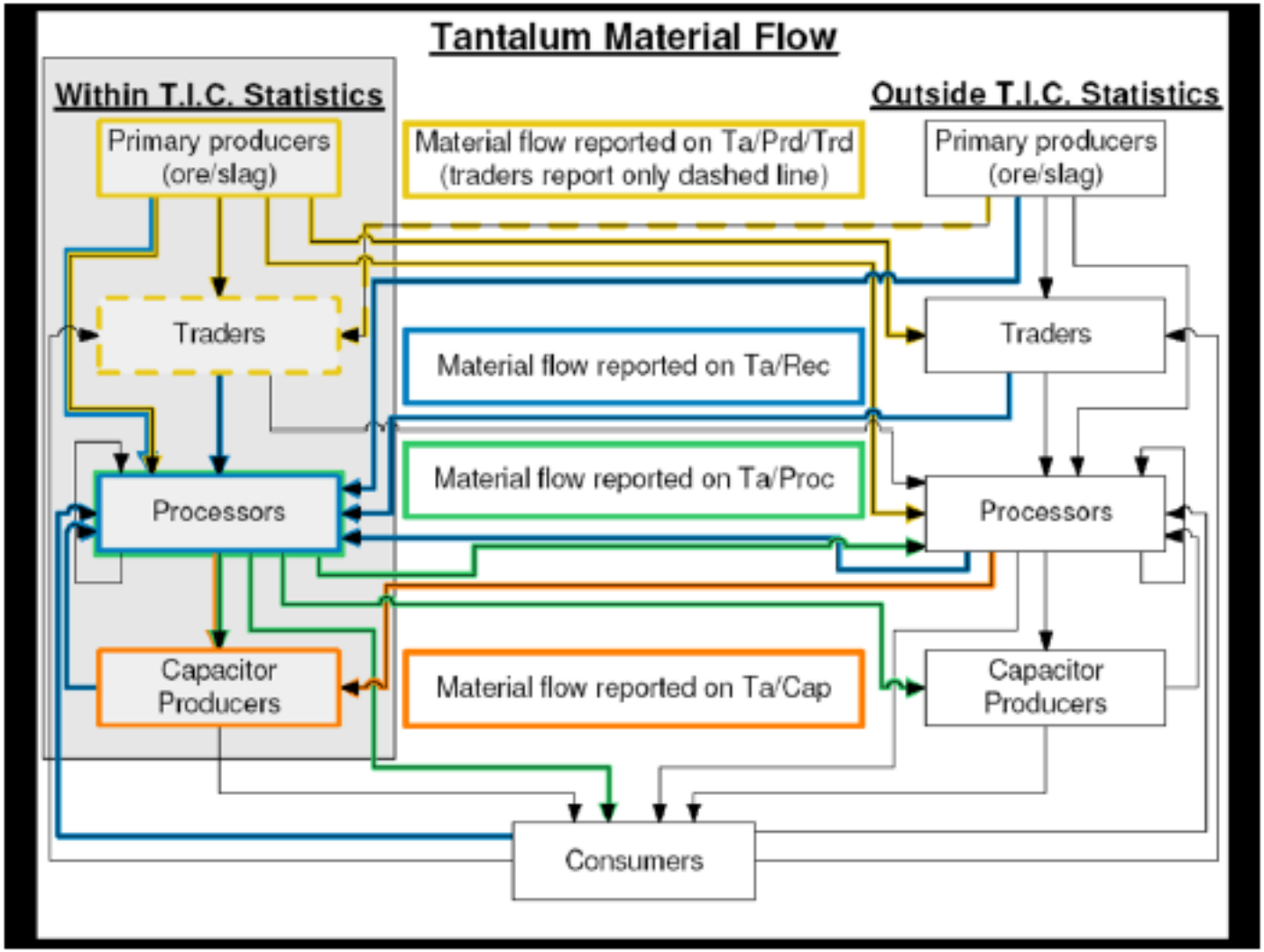
Material Flows copper scrap New England USA c. 1995



Wernick & Themelis, 1998

Materials Flows of Technology Metals

Closing the cycle – Recycling Infrastructure



Tantalum-Niobium International Study Center 2016

Materials Flows of Technology Metals

Closing the cycle - Mechanochemistry

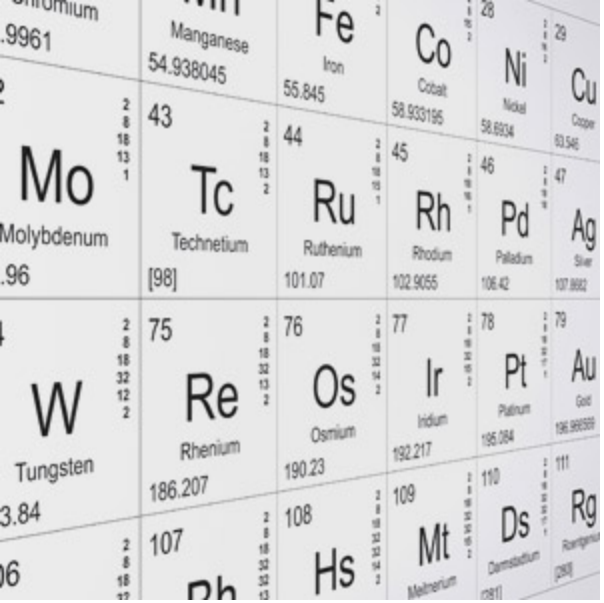
Mechanochemistry - geochemically-analogous process of metal recovery from second-hand resources via mechanochemistry - Use methods of *extractive metallurgy* to recover from waste streams

- Milling
- Leaching

Materials Flows of Technology Metals

Closing the cycle - Mechanochemistry

- CRT Glass → Lead
- Batteries → Lithium, Cobalt
- Fluorescent Lamps → Rare Earths
- LCD Screens → Indium
- Used tooling → Tungsten



A
Circular Economy/Industrial Ecology for Technology Metals

Will require:

- New manufacturing technology
- New material recovery technology
- New business models

Will allow manufacturers:

- Greater flexibility
- Greater independence

Thank you for your attention

Thanks to my colleagues Jesse Ausubel and Alan Curry

Program for the Human Environment
The Rockefeller University

phe.rockefeller.edu

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