Resources and Resourcing for Future Generations

Paul Nex,
Wits

Are **YOU** concerned about:

Climate Change?

Pollution?

Environmental Issues?

The Earth Running Out of (Mineral) Resources?

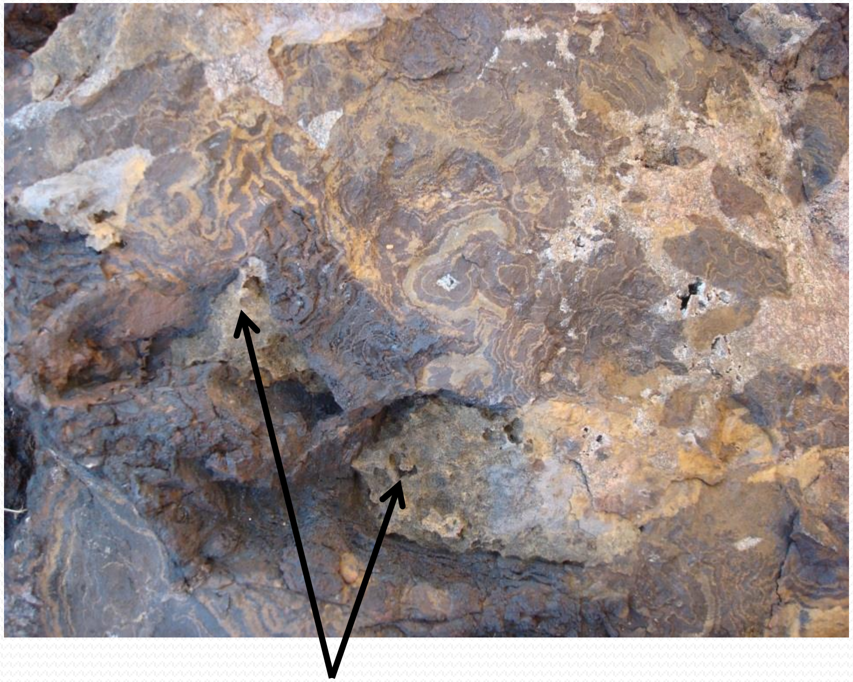
EGRI

WITS UNIVERSITY

cimera

CIMERA – DST-NRF Centre of Excellence for Integrated Mineral and Energy Resource Analysis

My Favourite Rock:



The 3rd from the sun

Pale green monazite in ferroan carbonatite with textures indicating modified magmatic origin, probably hydrothermal

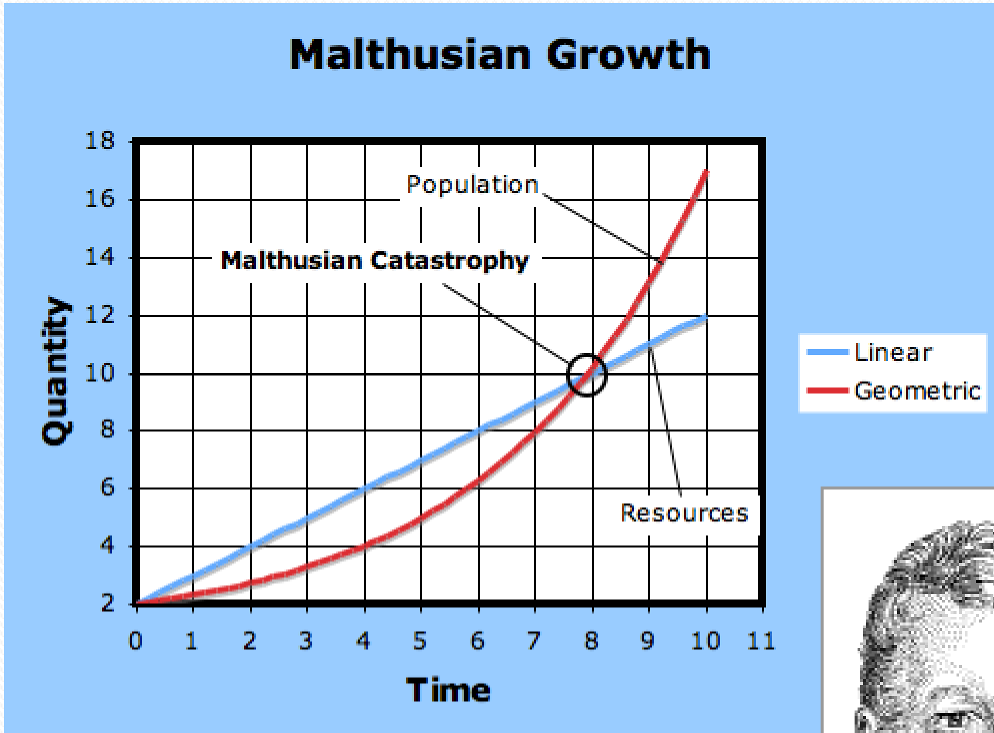
Resourcing Future Generations (RFG)

- Initiated & Developed by IUGS:
  - International Union of Geological Sciences
- "Securing the mineral, energy and water resources required by future generations"
- A bridge between industry, academia and geological surveys

Resourcing Future Generations (RFG)

- Currently a bit of a "buzz-phrase"; its catchy, its sexy it helps get attention (and possibly funding).
- However, the consequences of getting it wrong are probably severe on future generations.
- Proposed by Lambert *et al.*, (2013) to the IUGS as a proposed international collaborative programme to satisfy the demands of society for natural resources in the long term (10-20 years!!!!!!!).
- Essentially based on Malthusian economics (exponential growth of population vs arithmetic growth of resources) and Sustainable Development via the Brundtland Report (1987) etc.

Malthus & the Club of Rome



Urbano, 2011

Malthus, 1798 “An Essay on the Principle of Population”

Thomas Malthus

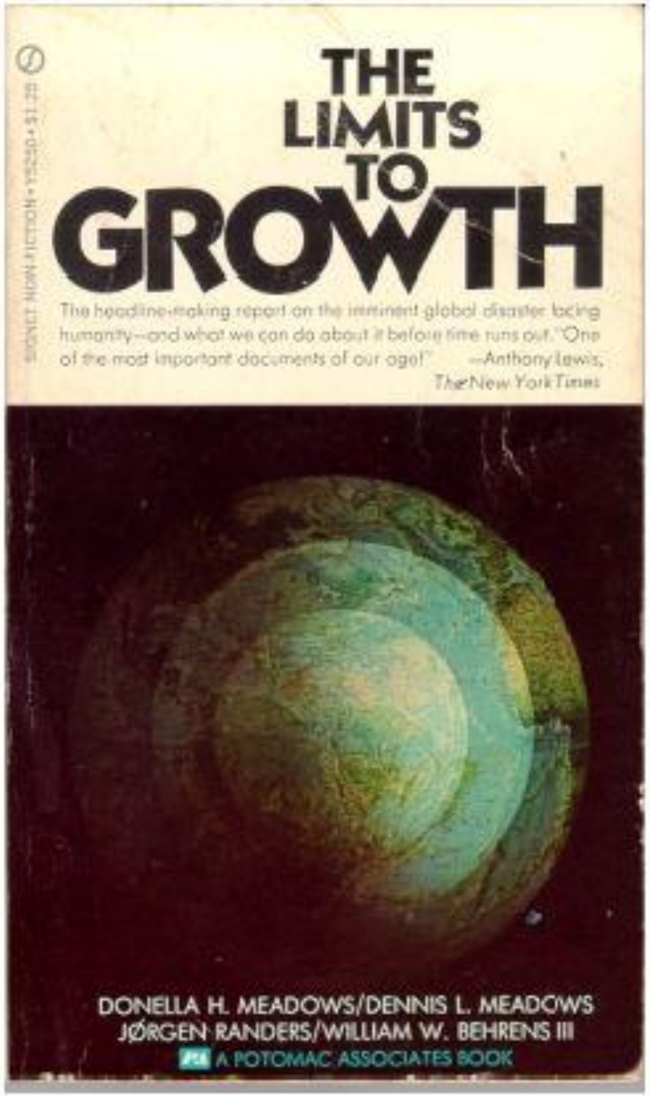
“The power of population is so superior to the power of the Earth to produce subsistence for man, that premature death must in some shape or other visit the human race.” —*Thomas Malthus, 1798*

“If the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next 100 years.” —*The Club of Rome think tank, 1972*

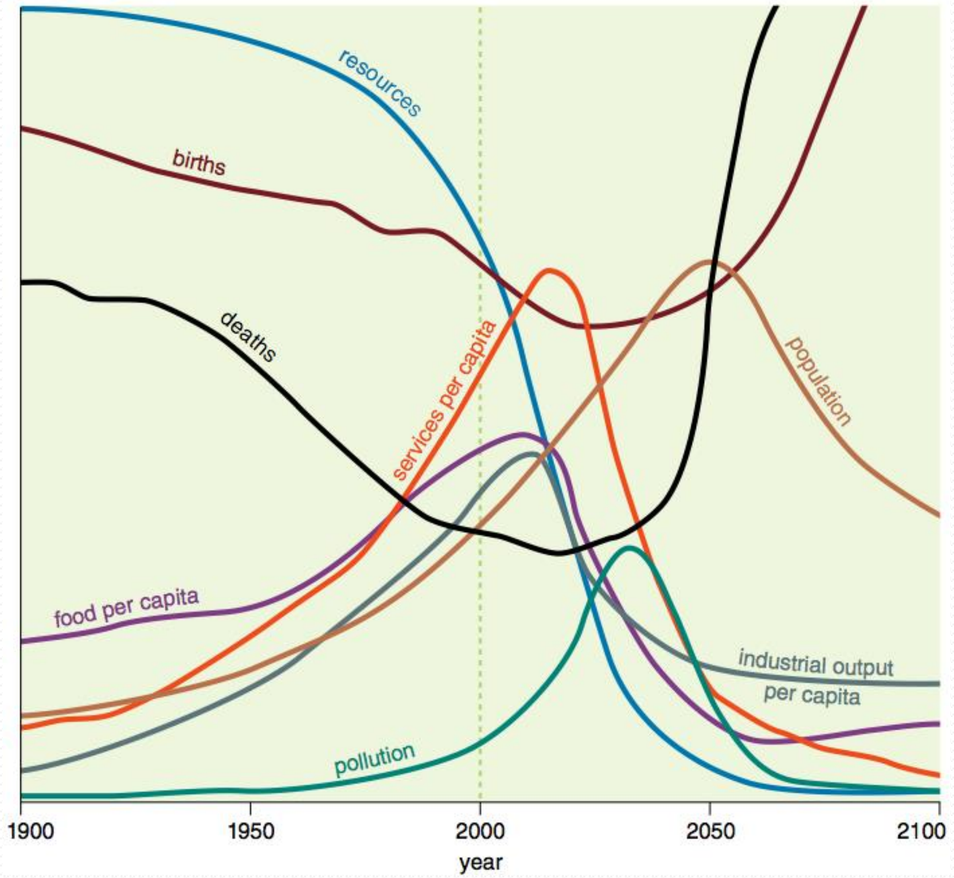
Lahart et al., 2008

Club of Rome

- 1968 A meeting of 30 individuals in Rome gathered to discuss "the present and future predicament of man" and ultimately formed the club of Rome
- 1972 "The Limits of Growth"
  - One of the most controversial and influential books of the century.
  - (Available as a free PDF download on the web)



- The team at MIT undertook computer simulations of exponential economic and population growth with finite resource supplies. To investigate “behavioural tendencies” in the system not to make predictions.
- 5 variables:
  - World population
  - Industrialisation
  - Pollution
  - Food production
  - Resource depletion



World Model – standard run – no changes

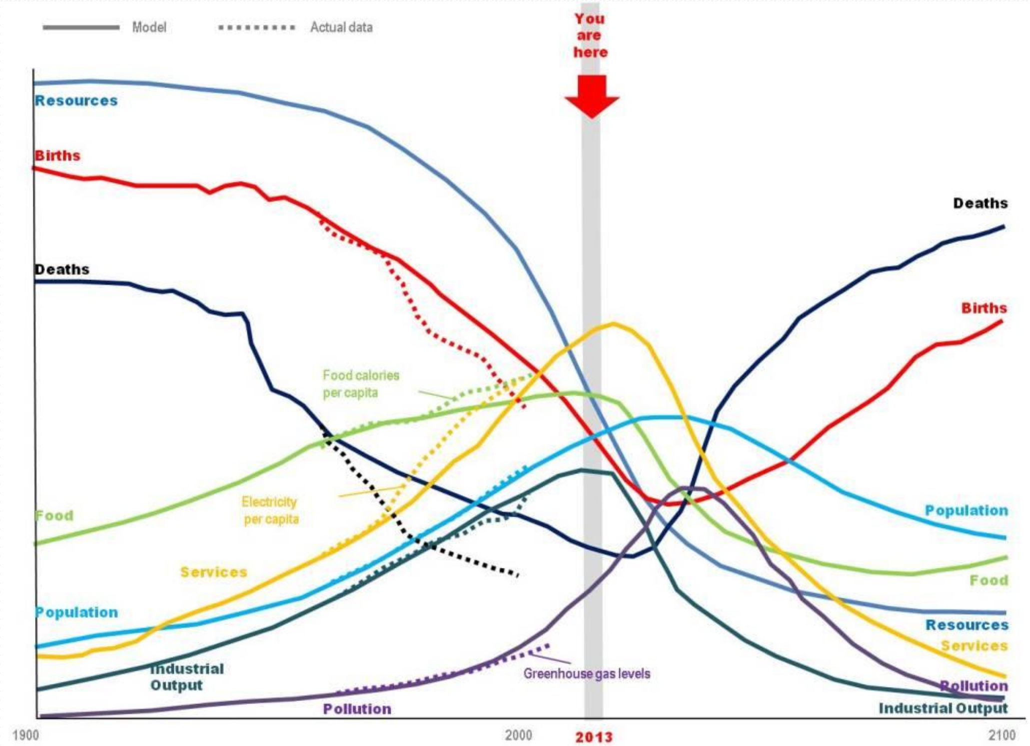
Conclusions from LtG

- The pessimistic:
  - "If the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years"

- The optimistic:
  - "It is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future"

Limits to Growth

- 2004 "The Limits to Growth: The 30-year update".
- The arguments still rage and whether it is an appropriate method of systems analysis.
- There are a couple of consensus points:
  - We can never accurately quantify our finite resources.
  - The predictions are only indicative.
  - Resources are finite.



NB. Limits to Growth considers the next 100-300 years. RFG is really only focused on the next 10-20.

Sustainable Development

- This term was coined in the "Brundtland Report" (Gro Harlem Brundtland, former PM of Norway (UN, 1987)) and the document "Our Common Future" also known as the "Report of the World Commission on Environment and Development: Our Common Future" (downloadable free as a pdf on the web)

- "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

Sustainable Development

To achieve this we need natural resources

The Resources We Need

- Food
- Water
- Shelter

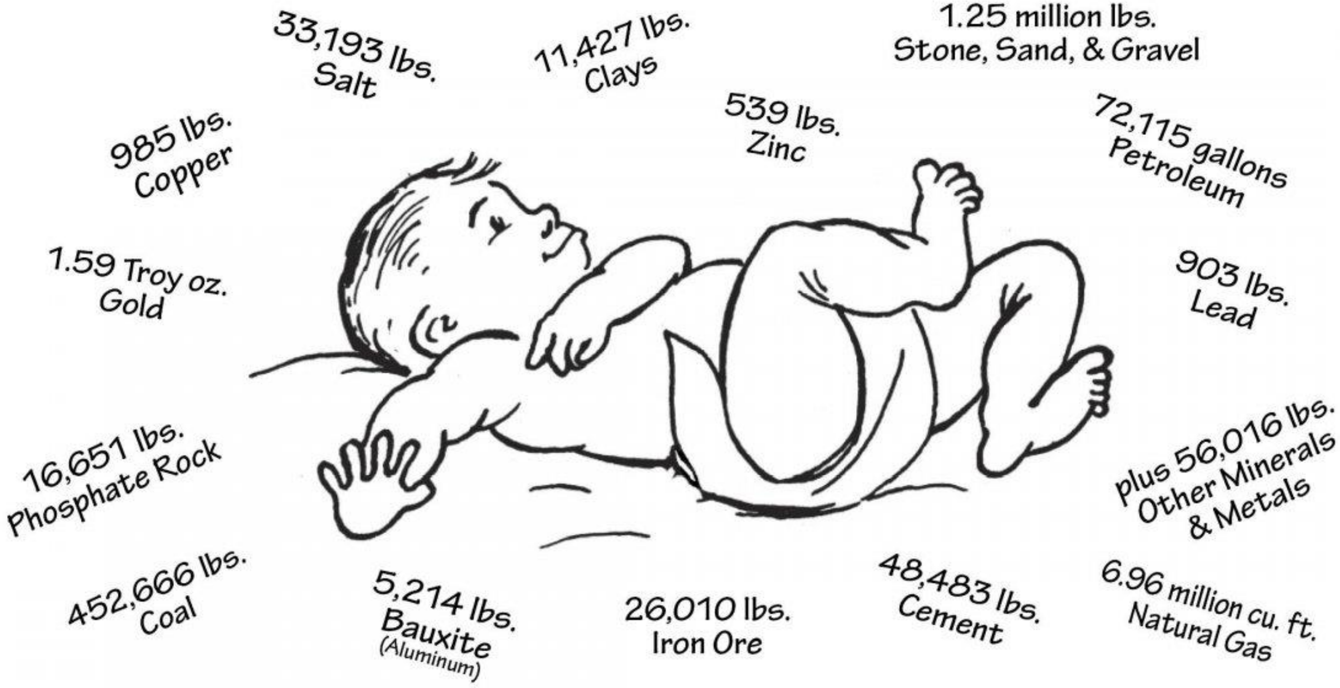
- **Energy**
- **Metals and Materials**
- If it is not used directly then typically it is used in manufacturing and/or intermediate products to make things we use directly or consume.
- Disconnect between the mine / metal and the end user.
- How do we know what future generations will need?

Houses, cars, watches, make-up, talcum powder, toothpaste, plumbing, electrical wiring, aeroplanes, cell phones, computers, road construction, bridges, jewellery, ferries, glass, concrete for buildings, aluminium foil.

Individually

(1 lb = 0.453592 kg)

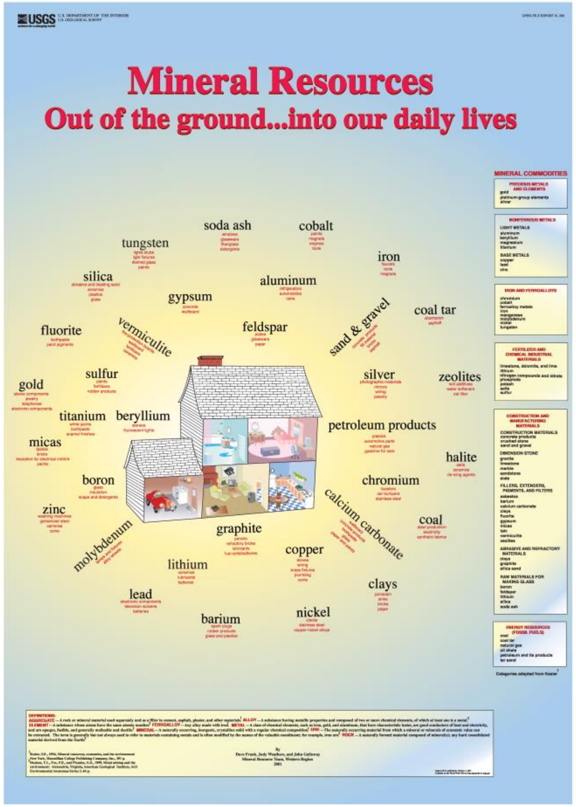
Every American Born Will Need...

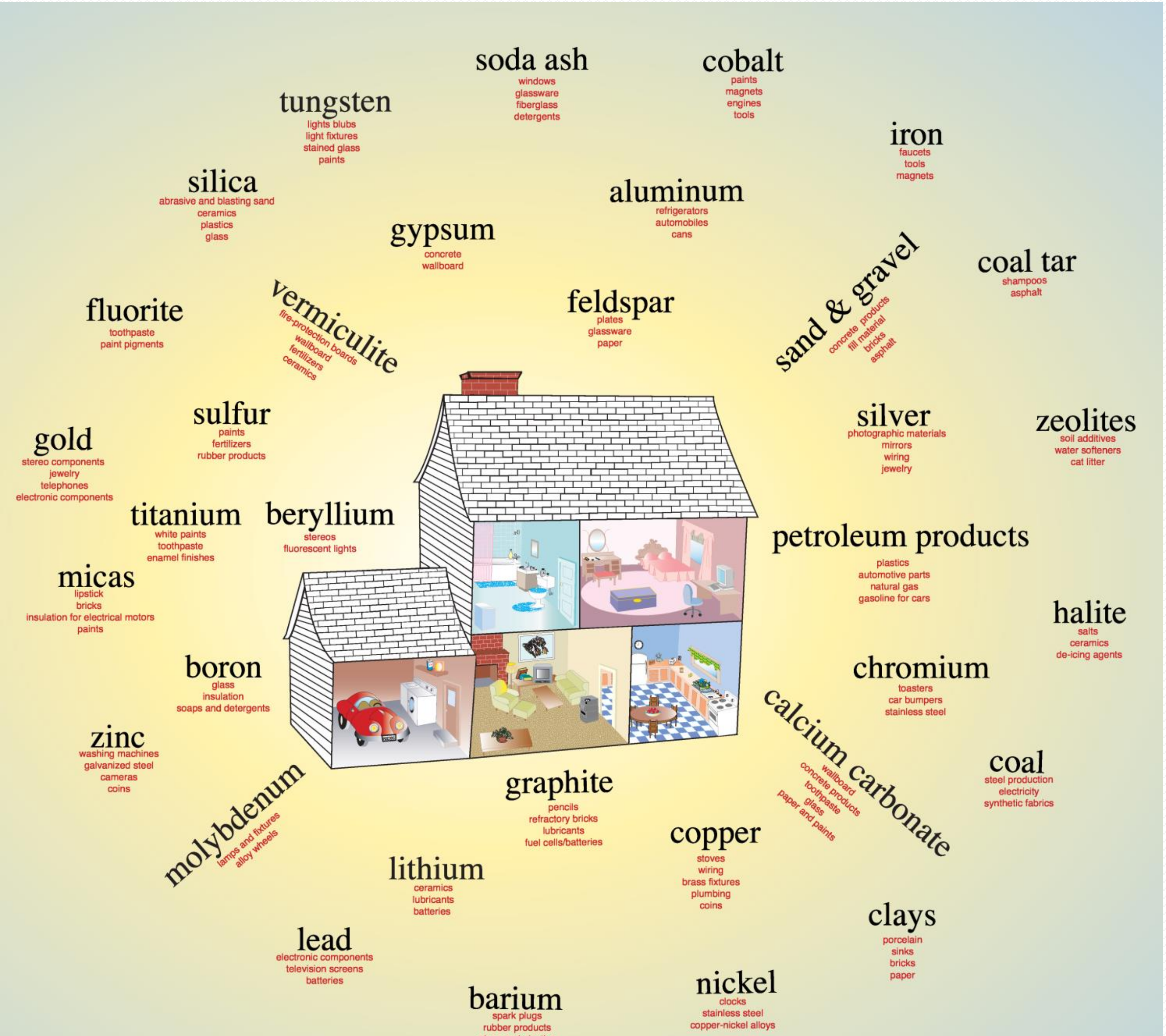


3.11 million pounds of minerals, metals, and fuels in their lifetime

Learn more at www.MineralsEducationCoalition.org

Our daily lives – (or aspirations)





Frank et al (2001) USGS

Minerals in our Environment (Bathroom)

1. DEODORANT: Includes aluminum and the container is made of petroleum products.
2. TOOTH PASTE: Includes fluorite, barite and calcite. The container is made of petroleum products or aluminum.
3. DRINKING GLASSES: Includes feldspar, silica and soda ash.
4. ABRASIVE CLEANSER: Includes silica or calcite.
5. LIPSTICK AND MAKEUP: Includes clay, mica, talc, limestone and petroleum products.
6. PLUMBING: Made of copper, clay and petroleum products.
7. RUGS: Includes limestone, petroleum products and selenium.
8. PLASTIC SHOWER CURTAINS: Contains petroleum products.
9. FLOWER POT: Made of clays and metallic minerals for pigments in glaze.
10. TALCUM POWDER: Contains talc and mica.
11. DANDRUFF SHAMPOO: Includes coal tar, lithium clays and selenium. The container is made of petroleum products.
12. MIRROR: Includes feldspar, silica and silver.
13. FAUCETS: Includes iron, nickel and chromium.
14. TILES: Made of clay, feldspar, wollastonite or talc, mineral pigments.
15. TOILET: Includes clays, silica, copper, zinc, petroleum products and borates.

Weathers et al (2000) USGS

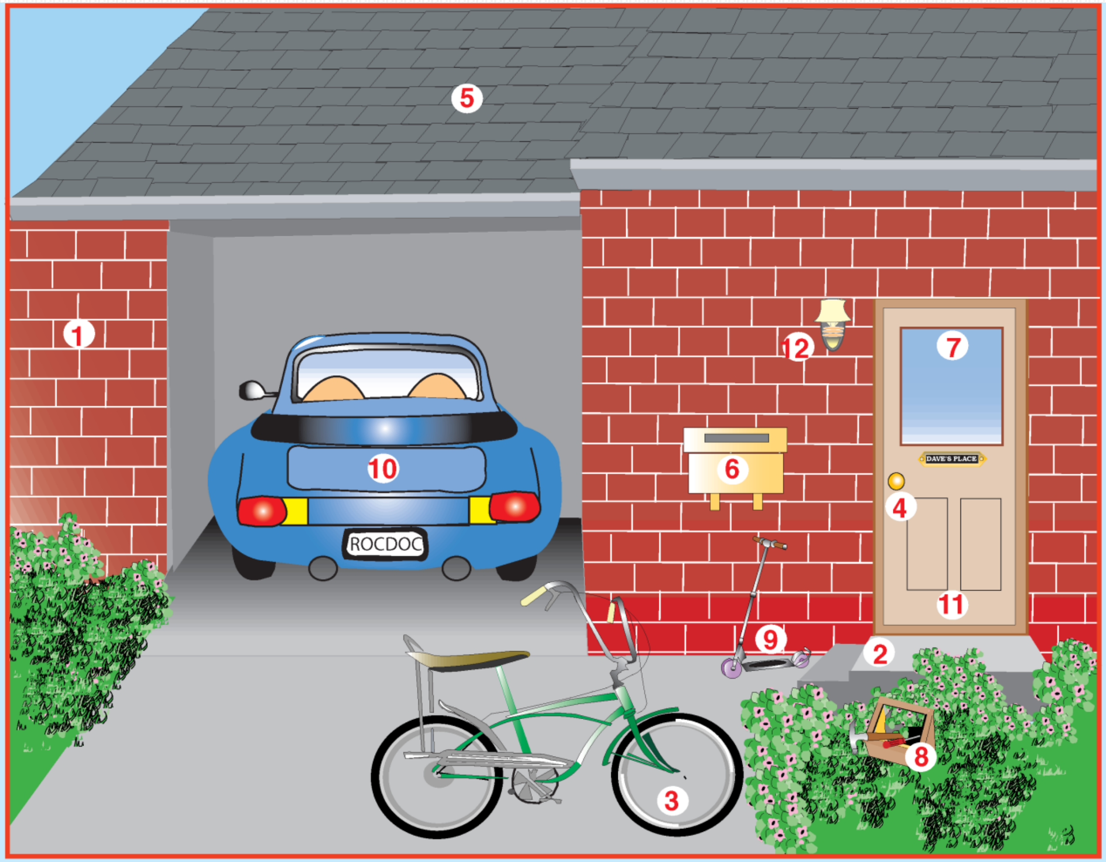
Minerals in our Environment (Kitchen)

Weathers et al (2000) USGS

1. RADIO: Includes aluminum, copper, gold, iron and petroleum products.
2. TOASTER: Includes copper, iron, nickel, mica, chromium and petroleum products.
3. ELECTRICAL WIRING: Includes copper, aluminum and petroleum products.
4. MICROWAVE: Includes copper, gold, iron, nickel and silica.
5. STOVE: Includes aluminum, copper, iron, nickel and silica.
6. REFRIGERATOR: Includes aluminum, copper, iron, nickel, petroleum products and zinc.
7. TABLE SALT: Includes halite; light salt can be made from sylvite. Most salt has added iodine.
8. PLATES: Includes clays, silica and feldspar.
9. CUTLERY: Includes iron, nickel, silver and chromium.
10. CLOCK: Includes iron, nickel, petroleum products and silica.
11. STAINLESS STEEL SINK: Includes iron and nickel.
12. BLACKBOARD: Includes clays. Chalk includes limestone or petroleum products.
13. MAGNET: Includes cobalt.
14. DISH RACK: Made of petroleum products.

Minerals in our Environment (Garage)

Weathers et al (2000) USGS



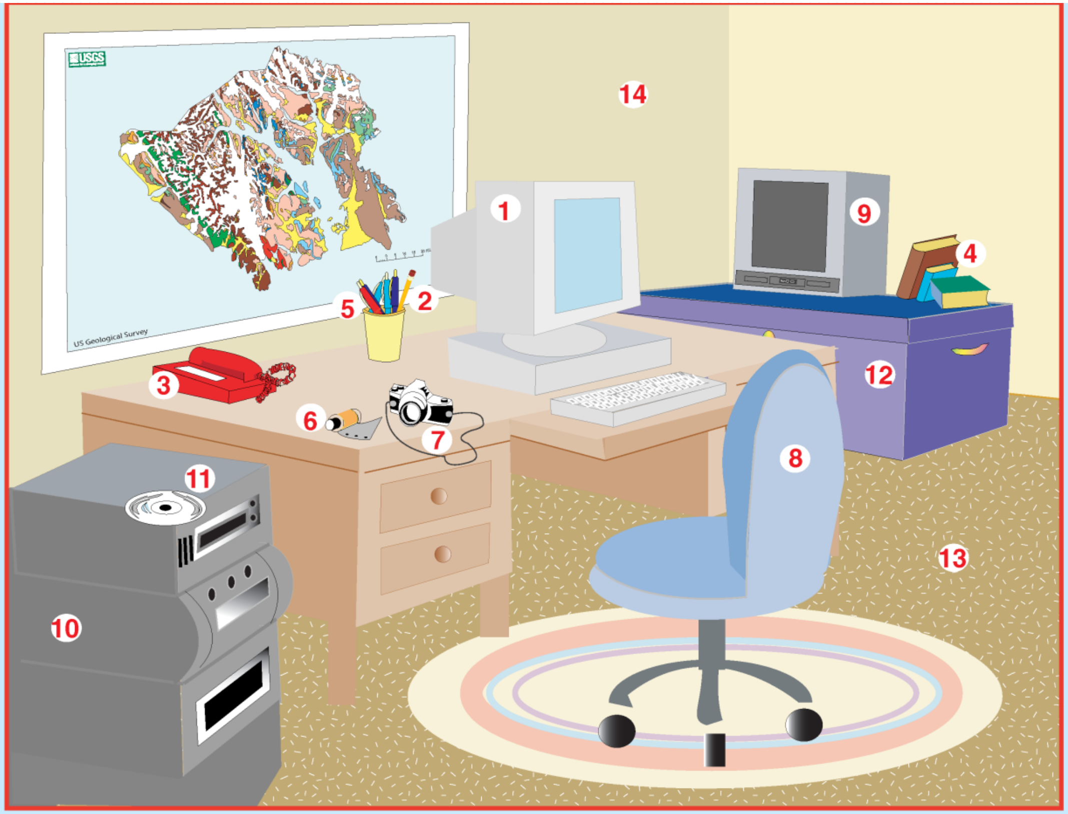
1. BRICKS: Includes graphite, clays and silica.
2. CONCRETE STEP: Includes gypsum, iron, limestone, clays and silica.
3. BIKE: Includes barite, iron, nickel and petroleum products.
4. DOOR KNOB: Includes copper and zinc, which make brass.
5. SHINGLES: Includes petroleum products and clays.
6. MAIL BOX: Includes copper and zinc, which make brass.
7. WINDOWS: Includes silica, feldspar, soda ash, coal and salt.
8. TOOLS: Includes iron and nickel.
9. SCOOTER: Includes aluminum, calcite, mica, nickel, petroleum products, clays, silica and talc.
10. AUTOMOBILE: Includes aluminum, barite, calcite, iron, lead, mica, nickel, petroleum products, clays, silica and zinc.
11. PAINT: Includes titanium, gypsum, barite and sulfur.
12. LIGHT AND FIXTURE: Includes tungsten, molybdenum, aluminum, silica, copper and zinc.

Approved for publication March 2001

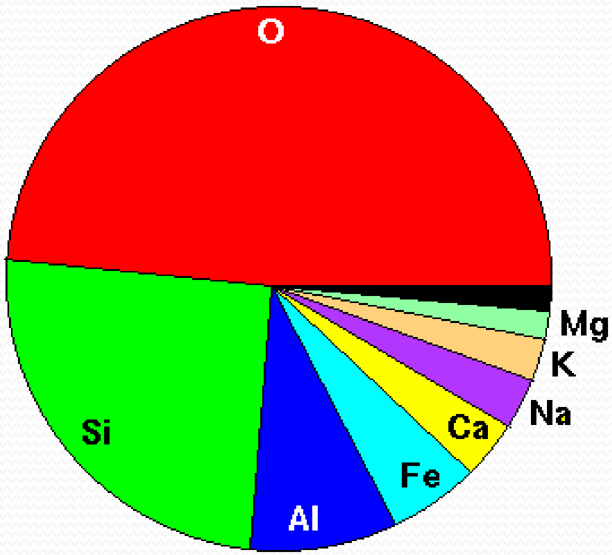
Minerals in our Environment (Office)

Weathers et al (2000) USGS

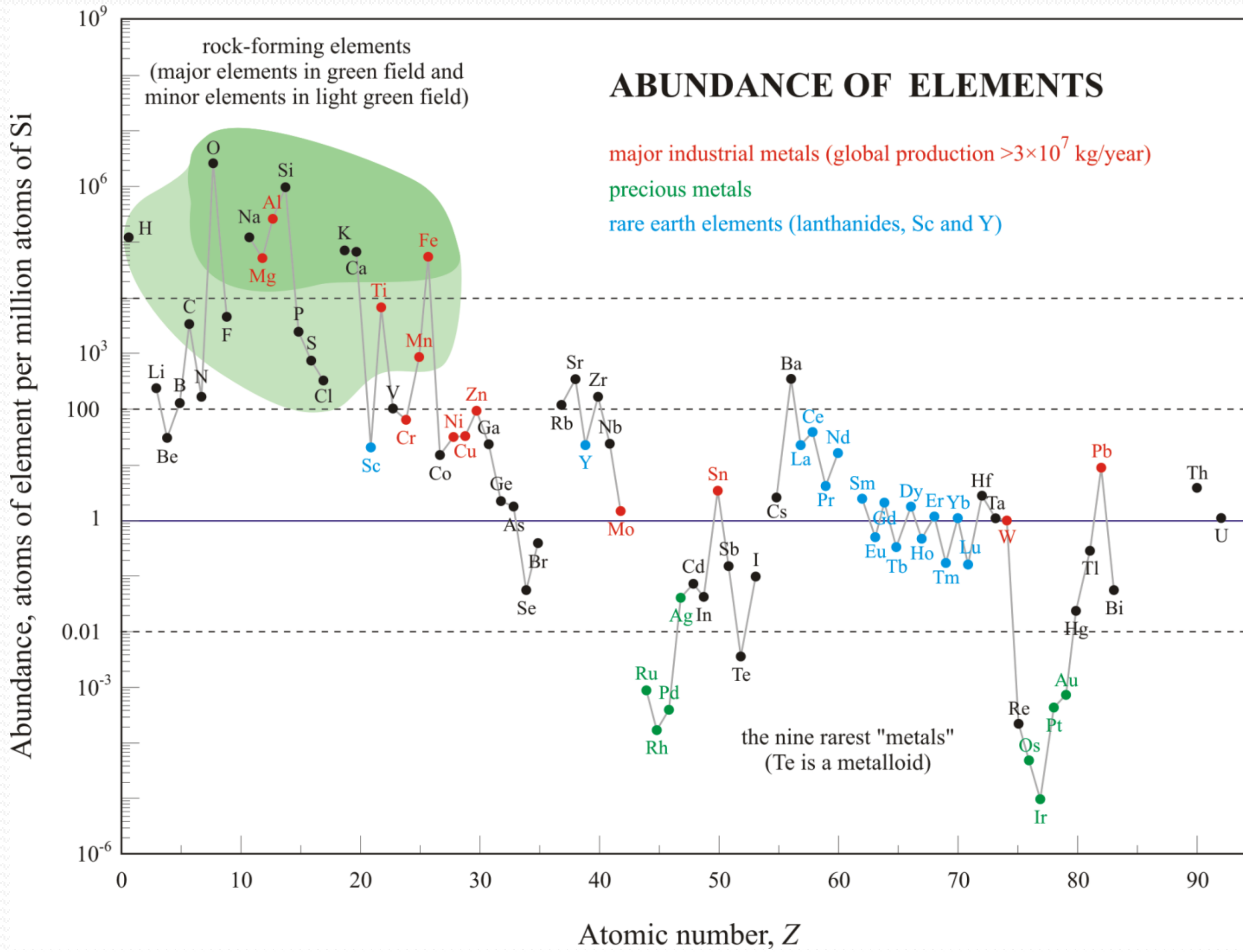
1. COMPUTER: Includes gold, silica, nickel, aluminum, zinc, iron, petroleum products, and about thirty other minerals.
2. PENCIL: Includes graphite and clays.
3. TELEPHONE: Includes copper, gold and petroleum products.
4. BOOKS: Includes limestone and clays.
5. PENS: Includes limestone, mica, petroleum products, clays, silica and talc.
6. FILM: Includes petroleum products and silver.
7. CAMERA: Includes silica, zinc, copper, aluminum and petroleum products.
8. CHAIR: Includes aluminum and petroleum products.
9. TELEVISION: Includes aluminum, copper, iron, nickel, silica, rare earths, and strontium.
10. STEREO: Includes gold, iron, nickel, beryllium and petroleum products.
11. COMPACT DISC: Includes aluminum and petroleum products.
12. METAL CHEST: Includes iron and nickel. The brass trim is made of copper and zinc.
13. CARPET: Includes limestone, petroleum products and selenium.
14. DRYWALL: Includes gypsum, clay, vermiculite, calcium carbonate and micas.



What does our planet (crust)contain?



Elemental Crustal Abundances

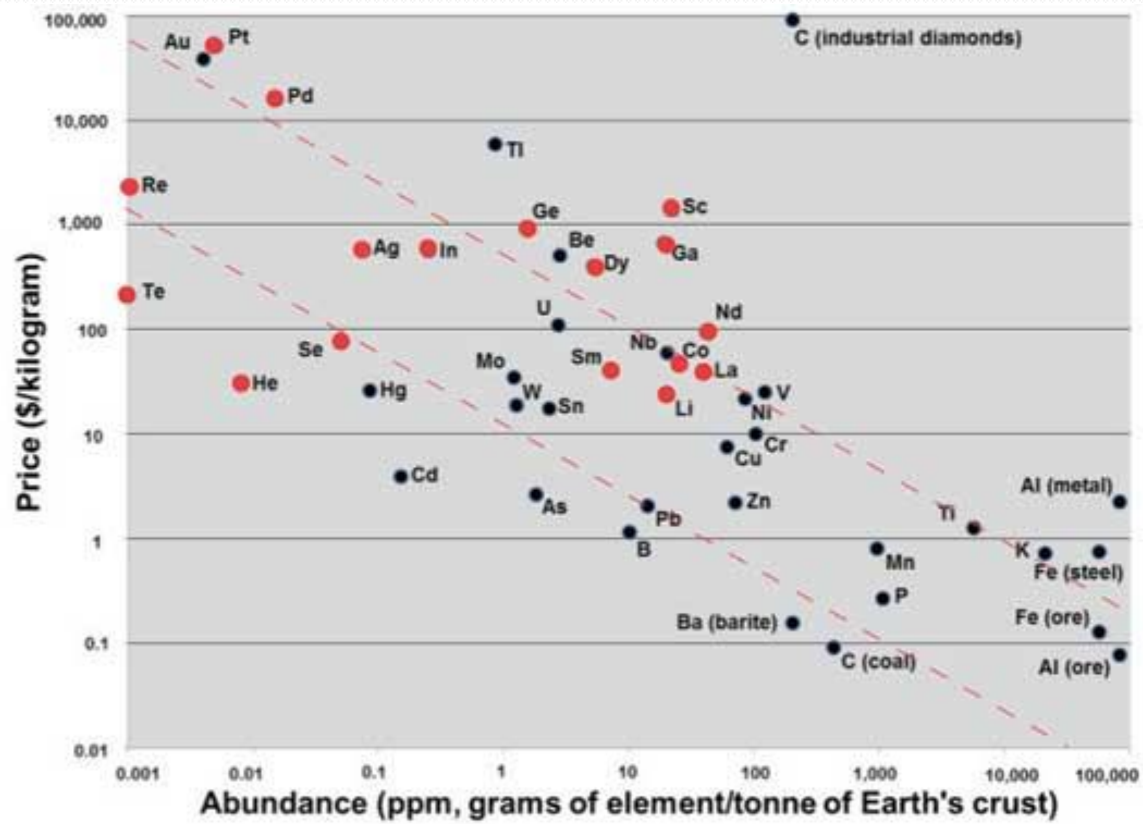


Metals are not abundant!!!

Unsurprisingly, the price of a commodity is related to its abundance.

In addition, our planet does not have a uniform distribution of minerals or mineral deposits.

A mineral deposit is a geochemical anomaly – it has formed by normal geological processes although some special factors must have been at work.



Concentration factors

- To make a deposit economic the commodity of interest must be concentrated to a level that is economically viable to mine.

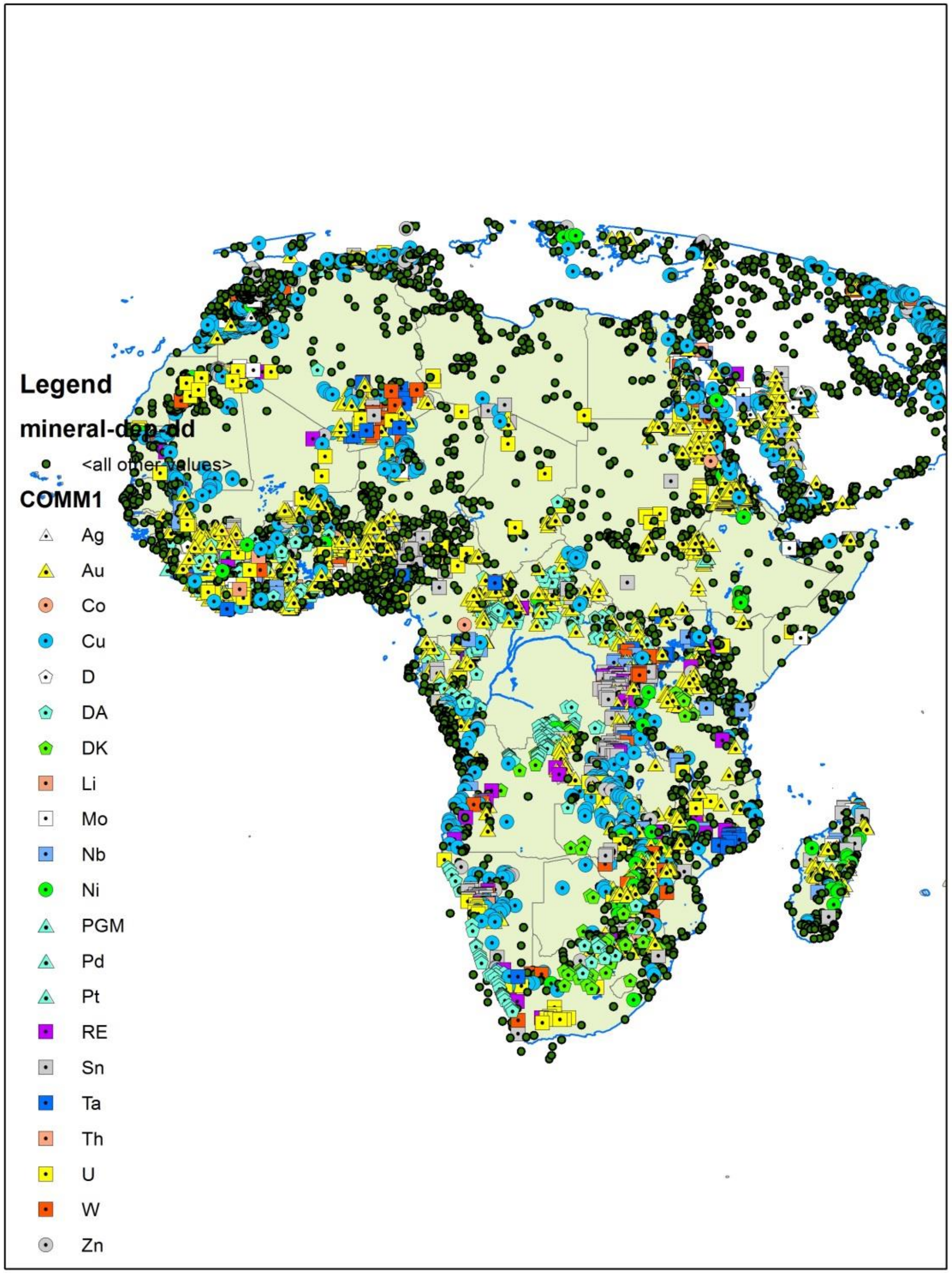
Commodity	In crust (g/t)	In "typical" deposit	Upgrade
Iron	50,000	600, 000	(x) 12
Uranium	3	500	(x) 166
Copper	55	10,000	(x) 181
Gold	0.004	5	(x) 1250
Platinum	0.002	5	(x) 2500
Tin	2	8000	(x) 4000
Lead	12	100,000	(x) 8333

Africa's Minerals

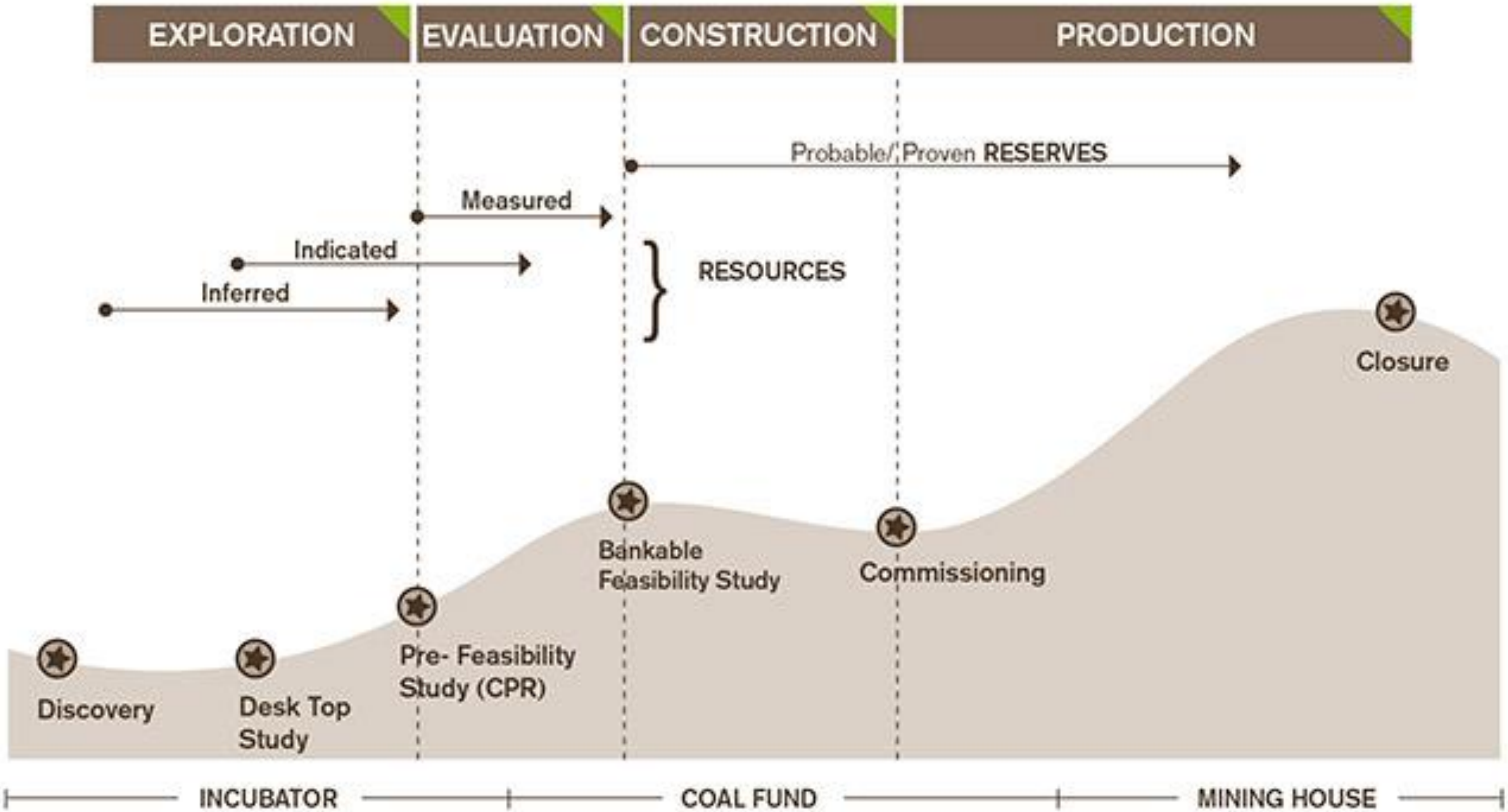
Selected and simplified map showing Africa's mineral occurrences (not deposits or mines)

Note the uneven distribution of the occurrences. This reflects:

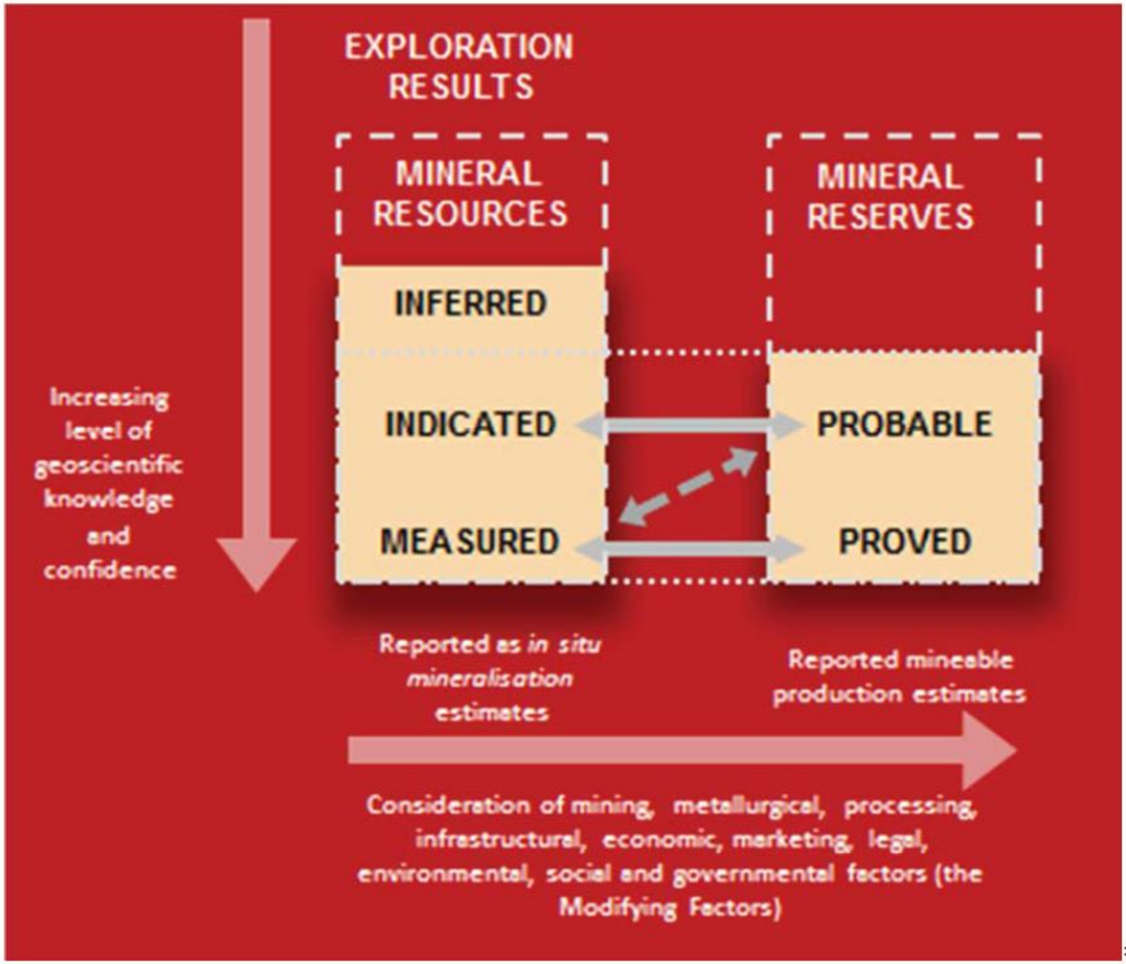
Known distribution
Known clustering



The Value Curve



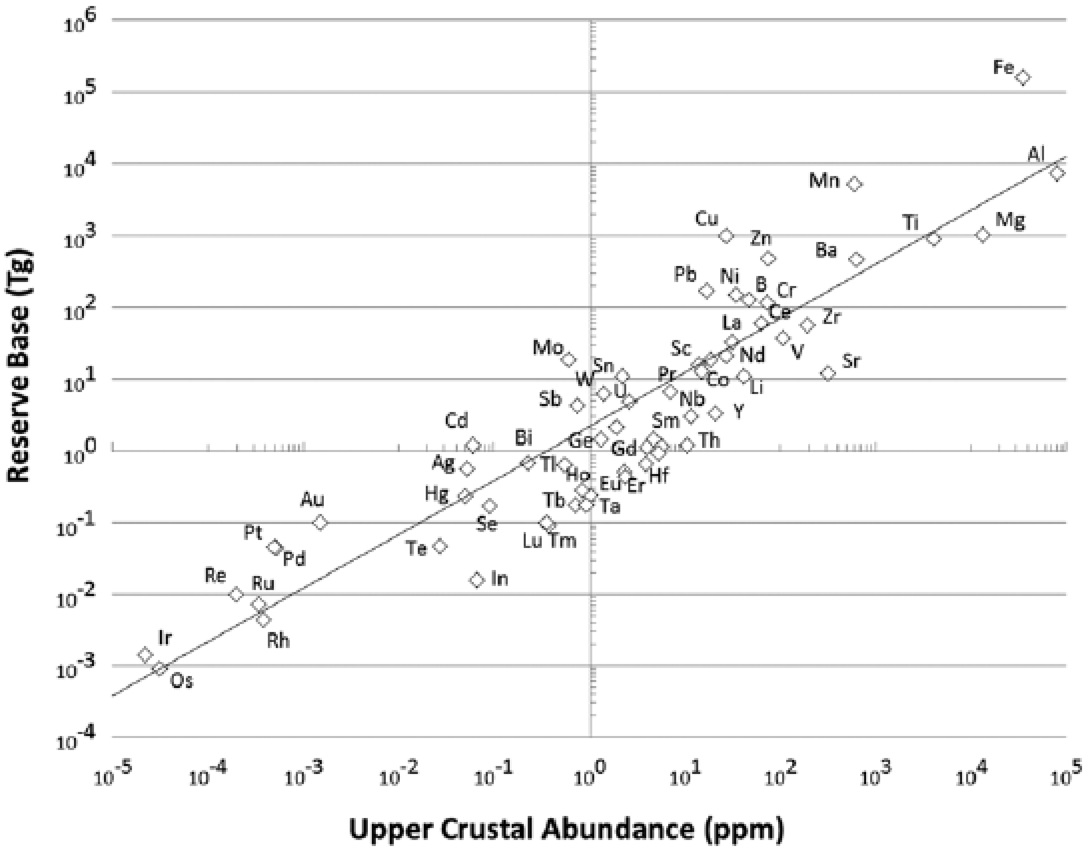
Resources and Reserves



Resources and Reserves are dynamic and will fluctuate with time depending on knowledge of the deposit, exchange rates, commodity prices, processing efficiencies. In fact, all the Geological and the Modifying Facors.

“McKelvey diagram” from SAMREC code (2016)

Reserve Base (RB)



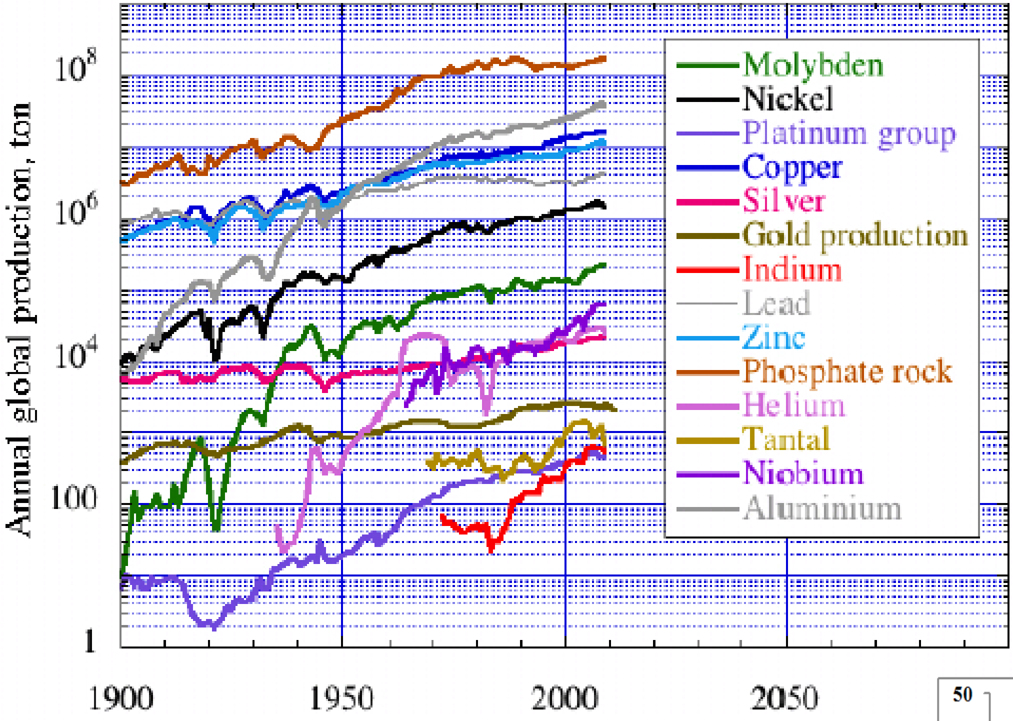
RB in Tg (10^{12} g)

Not Stock-exchange compliant and referring to “That part of an identified resource that meets specified minimum physical and chemical criteria related to current mining practices” USGS, (2009) in Graedel & Nassar, (2015)

Figure from Graedel & Nassar (2015)

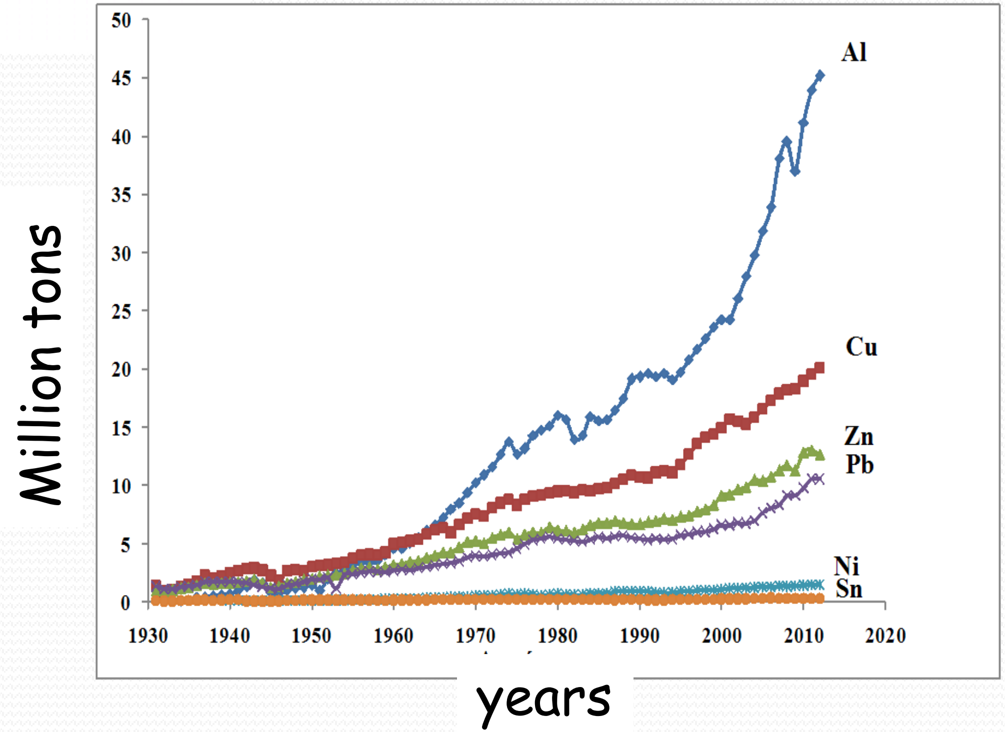
How well do we know global resources: An example

- Sverdrup & Ragnasdottir (2016) in an investigation of platinum extraction, supply, demand, and recycling concluded that their model indicates maximum extraction 2020-2050 and that market supply will peak 2070-2080.
- They were not aware of two recent major discoveries (PTM Waterberg project and Ivanplats, Platreef Project) and so of necessity their model is flawed at best or totally incorrect. Projects on the Platreef are likely to have > 100 years LOM.

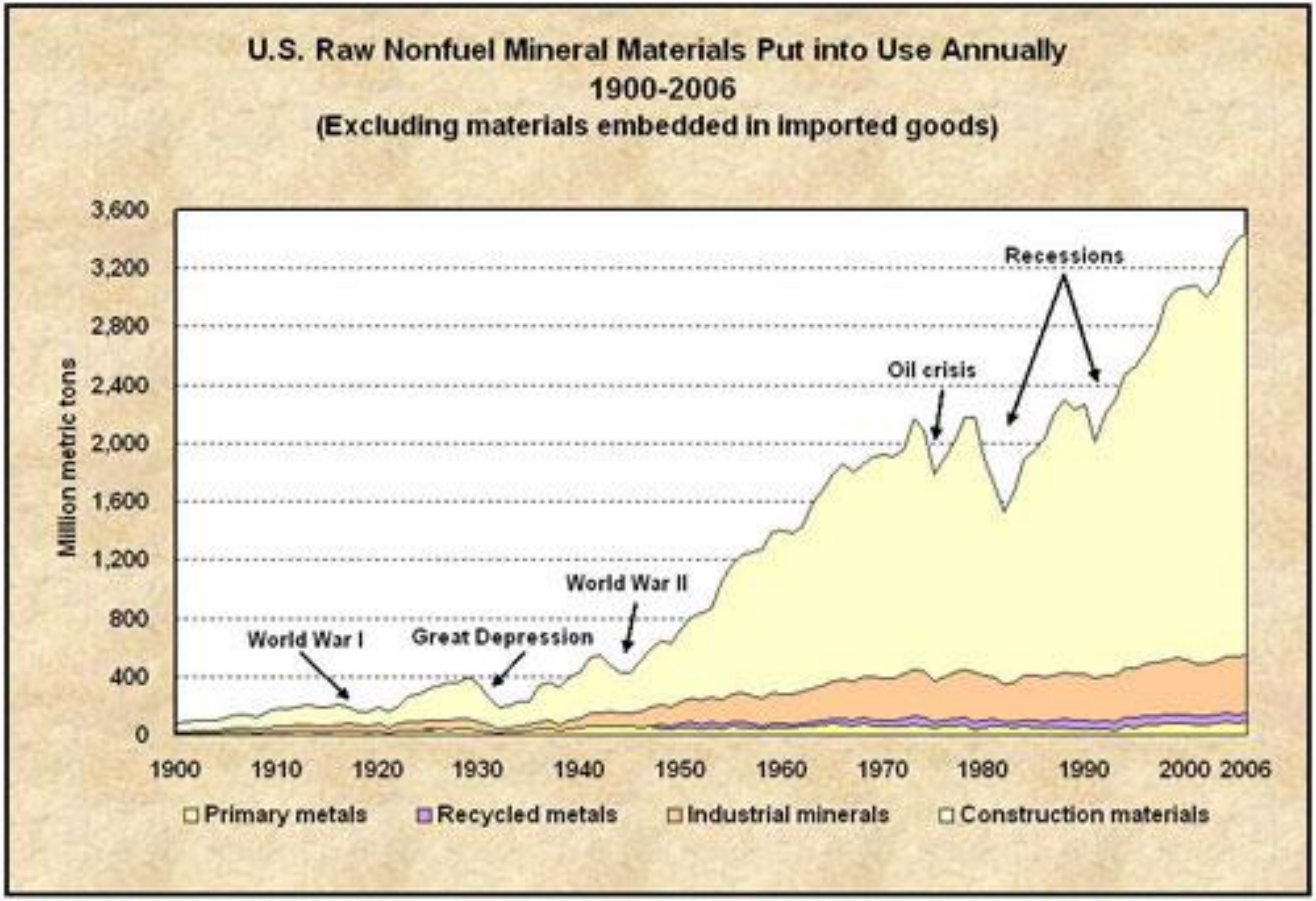


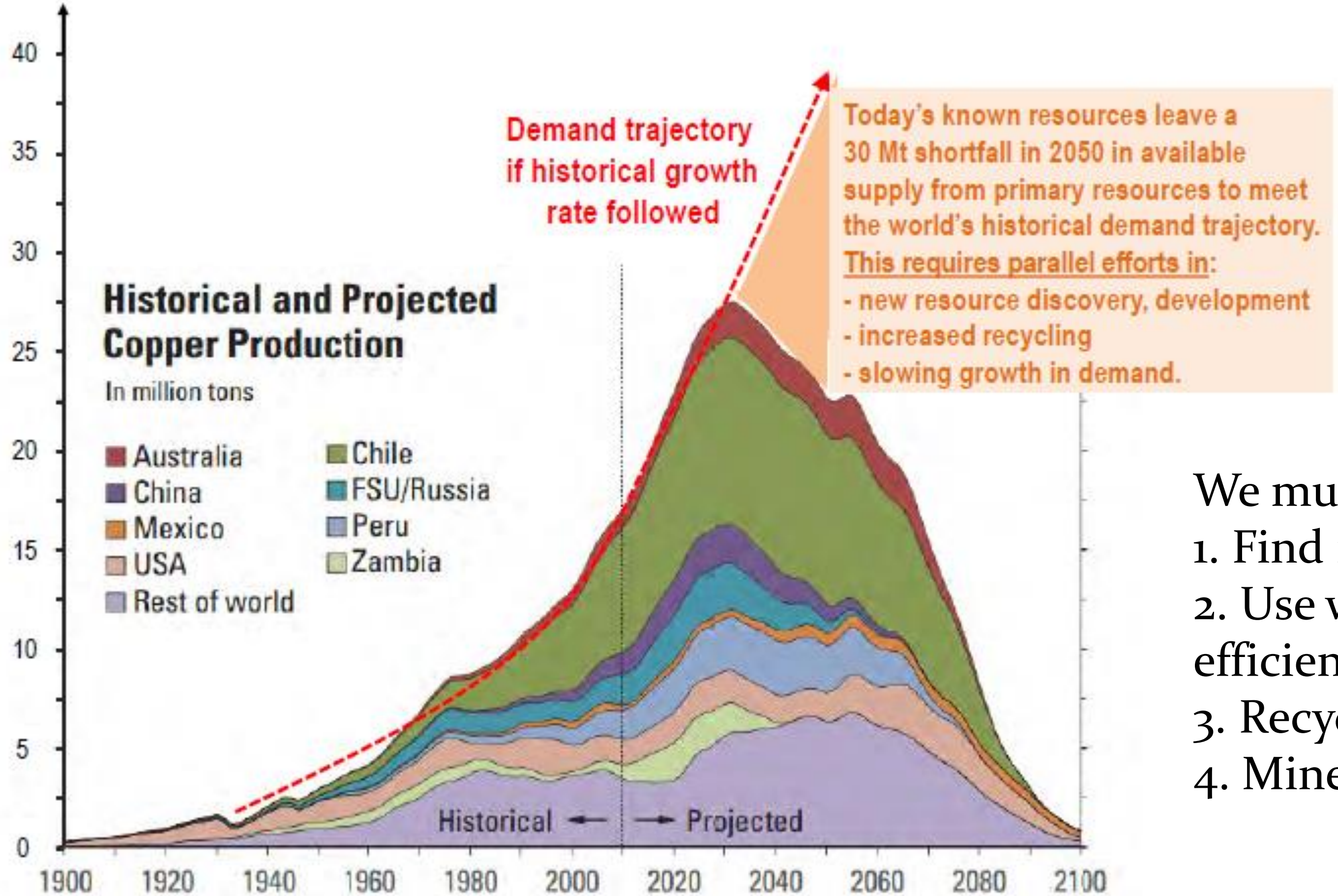
Sverdrup *et al.*, (2013)

Increasing Demand



Increasing demand





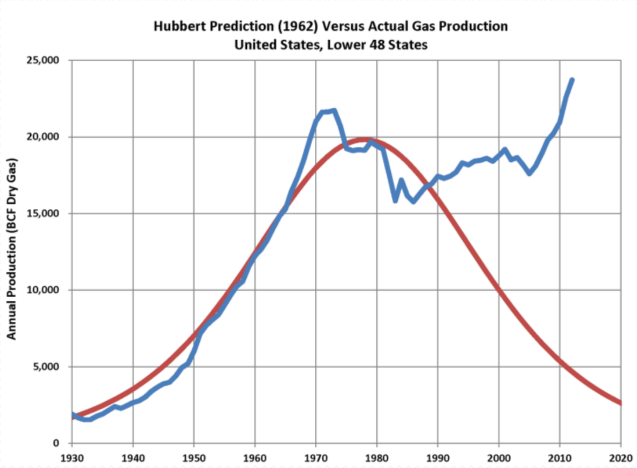
We must:
1. Find new deposits
2. Use what we have more efficiently
3. Recycle
4. Mine more efficiently

Nickless *et al.*, (2015)

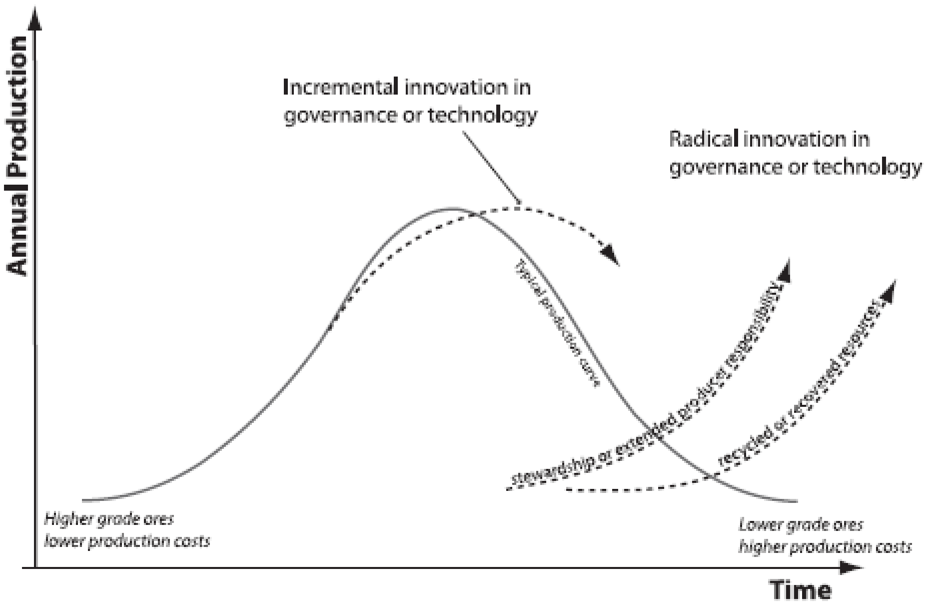
Reduce, Reuse, Recycle

Have we got enough

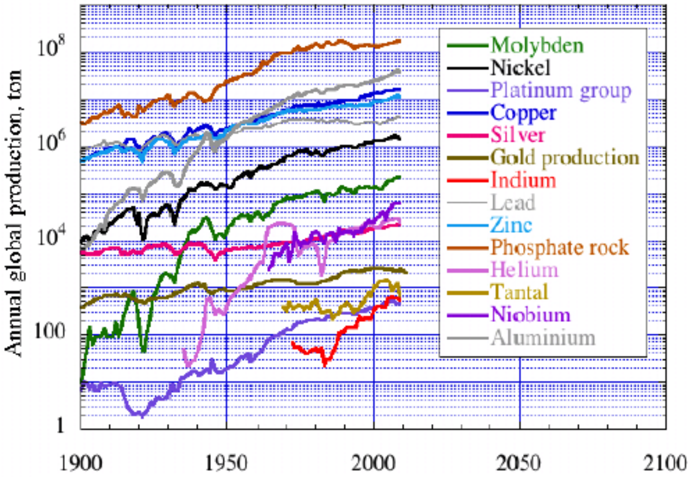
- Hubbert Peak Oil /Minerals
- (1956)



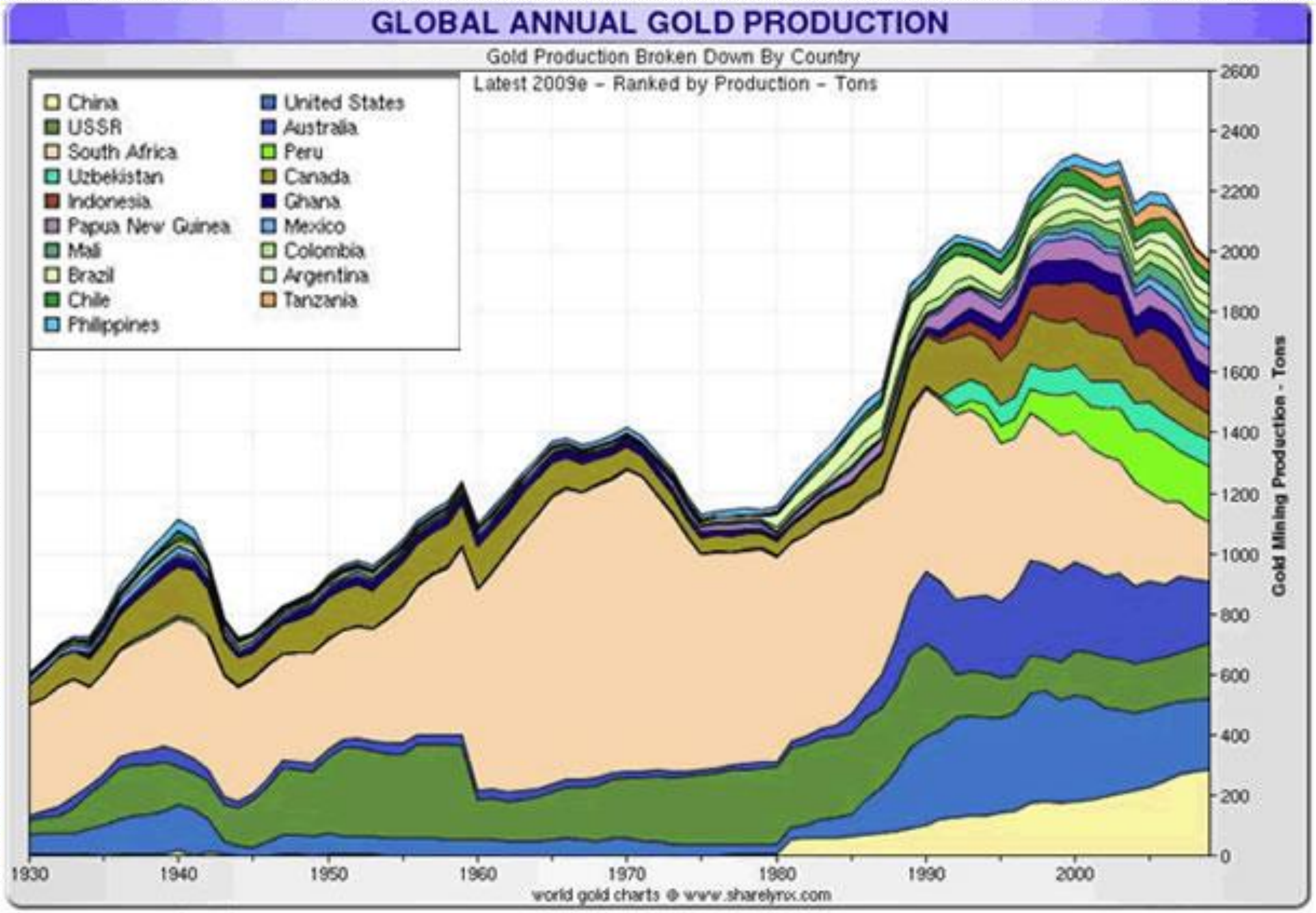
By Plazak - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=25859126



Prior et al., 2012



5 Peaks of gold production from 1930-2010 – 5 Hubbert Peaks – 5 different estimates



Source: www.sharelynx.com

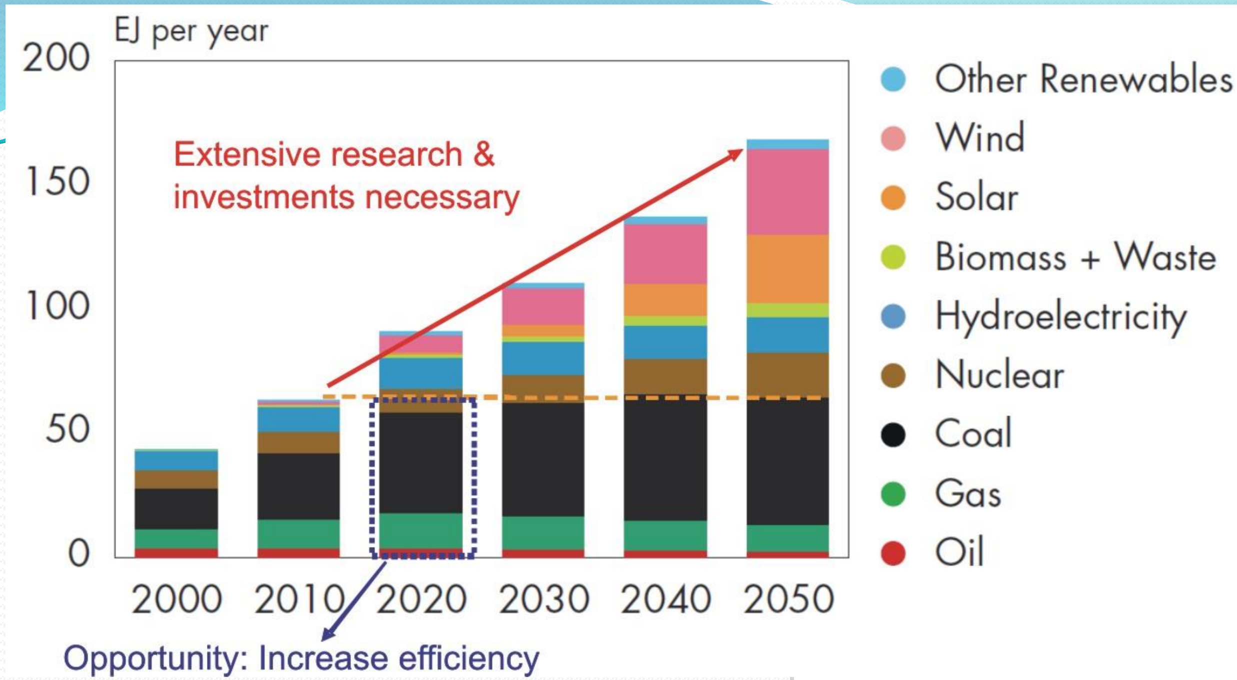
Energy – The Green Economies

- High Commodity Prices 2004-2010
- REE "crisis" of 2010
- Peak Oil? Oil prices increasing
- Climate Change

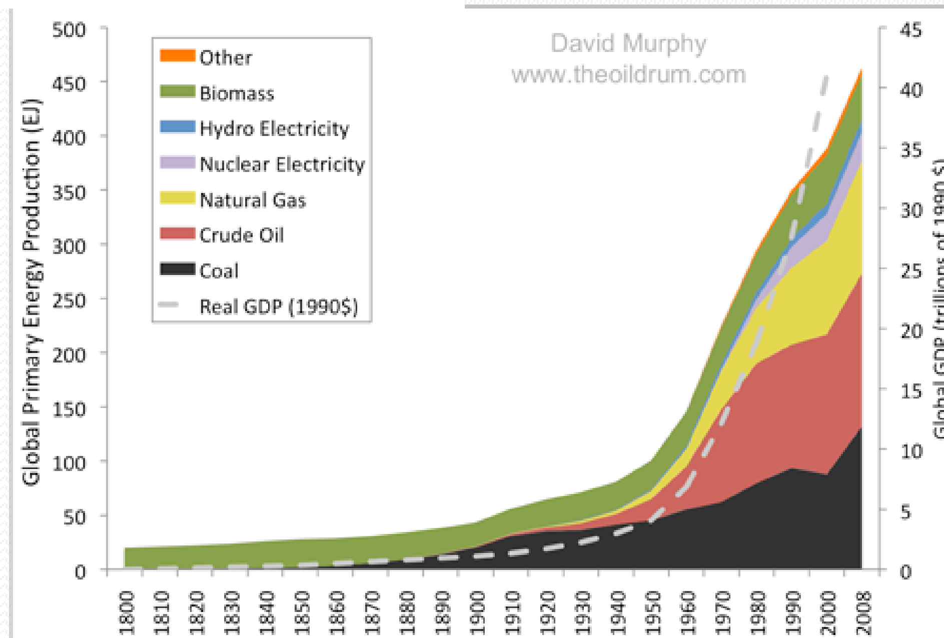
- Wind turbines? Nuclear Power? Solar Power, Wave Power,
- Electric cars, Fuel Cell cars.

- These may be alternatives to fossil fuels but they still need metals & materials for infrastructure and manufacture.

- Many of these require so-called "Critical" metals / materials.



The Energy Mix:



Essentially we need every source of energy that we know about.

Forecasts may vary but many suggest that in the next 100 years energy requirements will more than double.

Critical Metals & Materials

- Required in high-tech industries.
- Required in the "green economy"

- Highlighted by
  - Boom & Bust economics of the mining industry
  - 2003-2007 Commodity prices increasing
  - Western Governments worried – where were the raw materials going to come from for industry / manufacturing
  - Many people had became aware of Rare Earth Elements (REE)

US Reliance on Raw Material from other countries

2007 U.S. NET IMPORT RELIANCE FOR SELECTED NONFUEL MINERAL MATERIALS

Commodity	Percent	Major Import Sources (2003-06)[1]
ARSENIC (trioxide)	100	China, Morocco, Hong Kong, Chile
ASBESTOS	100	Canada
BAUXITE and ALUMINA	100	Guinea, Jamaica, Australia, Brazil
CESIUM	100	Canada
FLUORSPAR	100	China, Mexico, South Africa, Mongolia
GRAPHITE (natural)	100	China, Mexico, Canada, Brazil
INDIUM	100	China, Japan, Canada, Belgium
MANGANESE	100	South Africa, Gabon, Australia, China
MICA, sheet (natural)	100	India, Belgium, China, Brazil
NIOBIUM (columbium)	100	Brazil, Canada, Estonia, Germany
QUARTZ CRYSTAL (industrial)	100	Brazil, Germany, Madagascar, Canada
RARE EARTHS	100	China, France, Japan, Russia
RUBIDIUM	100	Canada
STRONTIUM	100	Mexico, Germany
TANTALUM	100	Australia, Brazil, China, Germany
THALLIUM	100	Russia, Netherlands, Belgium
THORIUM	100	United Kingdom, France
VANADIUM	100	Czech Republic, Swaziland, Canada, Austria
YTTRIUM	100	China, Japan, France, Austria
GALLIUM	99	China, Ukraine, Japan, Hungary
GEMSTONES	99	Israel, India, Belgium, South Africa
BISMUTH	95	Belgium, Mexico, China, United Kingdom
PLATINUM	94	South Africa, United Kingdom, Germany, Canada
STONE (dimension)	90	Italy, Turkey, China, Mexico
DIAMOND (natural industrial stone)	88	Botswana, Ireland, Namibia, South Africa
ANTIMONY	86	China, Mexico, Belgium
RHENIUM	86	Chile, Germany
BARITE	83	China, India
TITANIUM MINERAL CONCENTRATES	82	South Africa, Australia, Canada, Ukraine
POTASH	81	Canada, Belarus, Russia, Germany

USGS, 2007

Metals and Minerals in a car

- 960kg iron &steel
- 109kg Aluminum
- 22.7kg Carbon
- 19 kg Copper, 34kg for a hybrid
- 19kg Silicon
- 11 kg Lead
- 10kg Zinc
- 7.7kg manganese
- 6.8kg Chromium
- 4.1kg Nickel
- 0.3 kg Platinum

•+ Antimony, barium, beryllium, cobalt, gallium, gold, magnesium, molybdenum, neodymium, indium, palladium,
• Sulphur, rhodium, silver, strontium, tin, titanium, tungsten, vanadium, zirconium.

mineral resources
Department:
Mineral Resources
REPUBLIC OF SOUTH AFRICA

DMR, 2014

Metals and minerals in a Smart Phone

- Copper (16 grams) [1]
- Silver (0.35 grams) [1]
- Gold (0.034 grams) [1]
- Palladium (0.015 grams) [1]
- Platinum (0.00034 grams) [1]
- Ceramic magnetic switches containing rare earths [2]
- Indium[2]
- Titanium dioxide [2]
- Indium tin oxide [2]

- [1] source – USGS http://pubs.usgs.gov/fs/2006/3097/
- [2] source – NRC critical minerals report

mineral resources

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Mineral Resources
REPUBLIC OF SOUTH AFRICA

DMR, 2014

What are these elements and what are they used for?

Green Economies, low fossil fuels

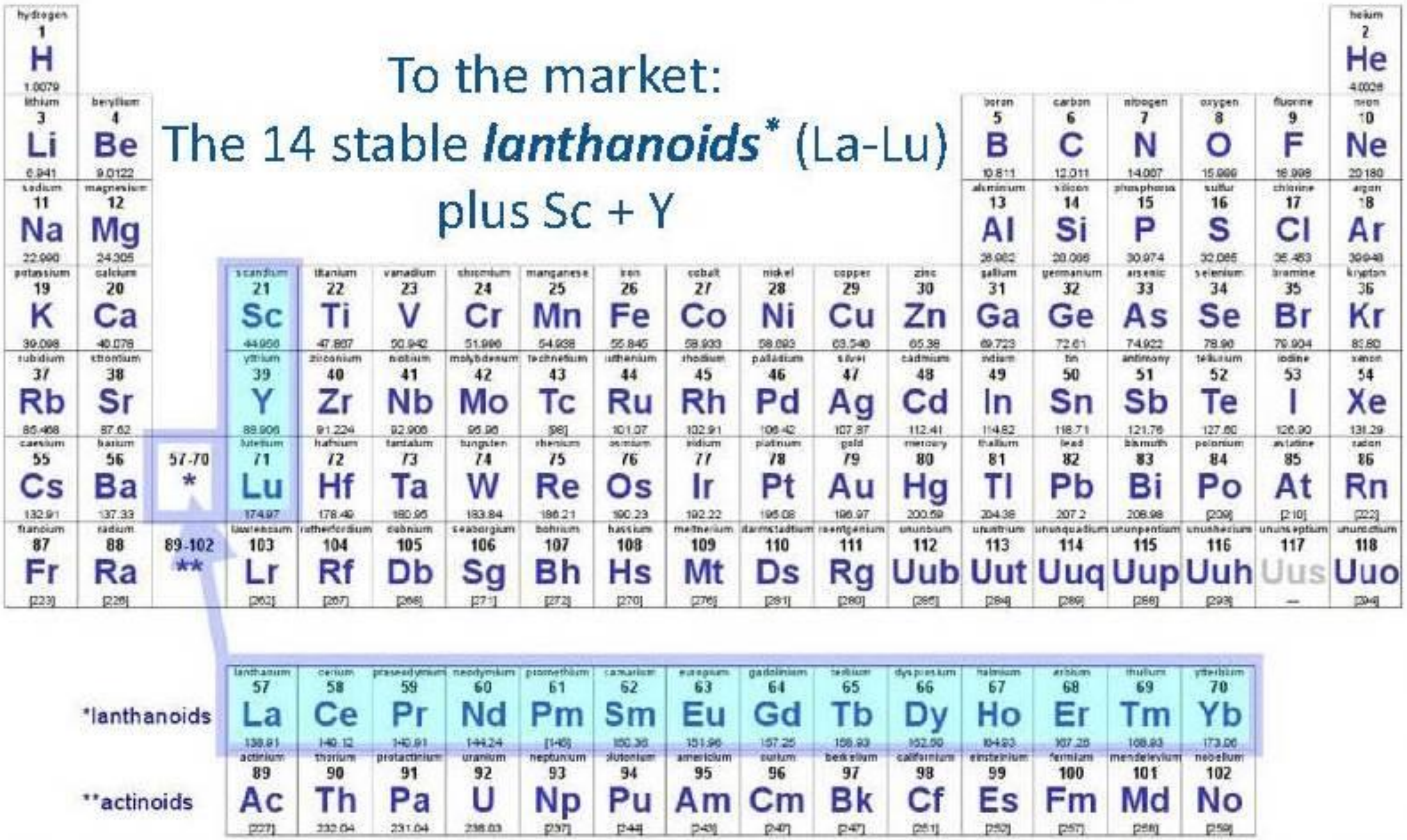
Significant Metals by Technology

Metal	Solar	Wind	Nuclear	CCS	Total
Tellurium	50.4%	*	*	*	50.4%
Indium	18.0%	*	1.4%	*	19.4%
Tin	9.6%	*	0.02%	*	9.6%
Hafnium	*	*	7.0%	*	7.0%
Silver	4.8%	*	0.4%	*	5.2%
Dysprosium	*	4.0%	*	*	4.0%
Gallium	3.9%	*	*	*	3.9%
Neodymium	*	3.8%	*	*	3.8%
Cadmium	1.5%	*	0.03%	*	1.5%
Nickel	*	0.7%	0.2%	0.5%	1.5%
Molybdenum	*	1.0%	0.4%	0.02%	1.4%
Vanadium	*	*	0.01%	1.3%	1.3%
Niobium	*	*	0.04%	1.2%	1.2%
Selenium	0.8%	*	*	*	0.8%

Chapman, 2012

OAKDENE HOLLINS

REE: What are they?



IUPAC defines them as the 15 Lanthanides plus Sc and Y

IUPAC Light REE: La, Ce, Pr, Nd, Sm
IUPAC Heavy REE: Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu and Y

Lithium

Tellurium

Germanium

Gallium

Indium

Rhenium

Antimony

Images from USGS Fact Sheets (2011-2015)
(free pdf download)

PGE

Rare Earth Elements

USGS, 2014

Wind Turbines

- Permanent Magnets

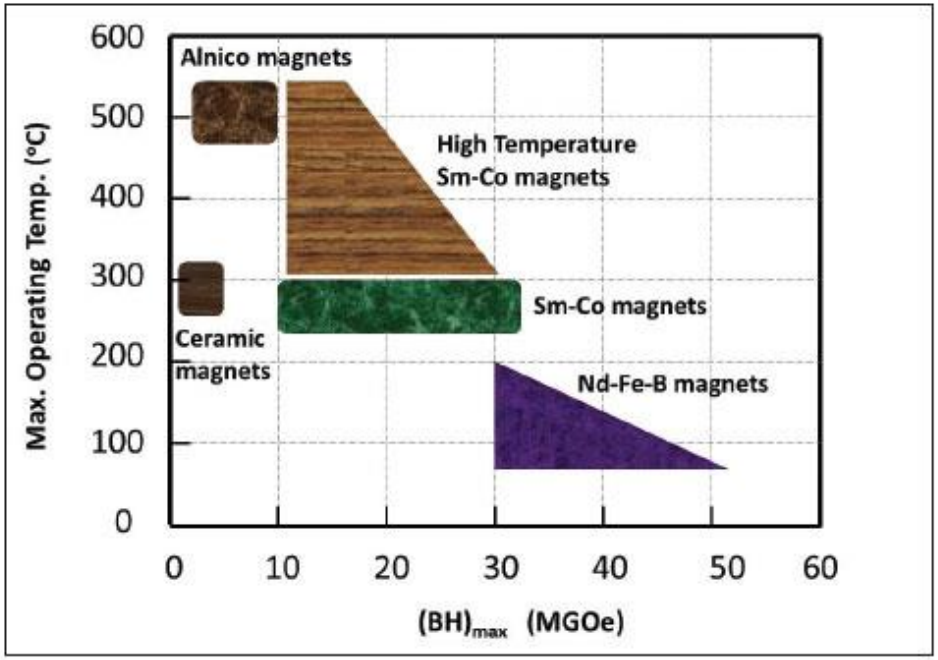


Figure 2. Maximum Operating Temperature Versus Maximum Energy Product, $(BH)_{max}$

SmCo and Nd-Fe-B are both considered Rare Earth magnets

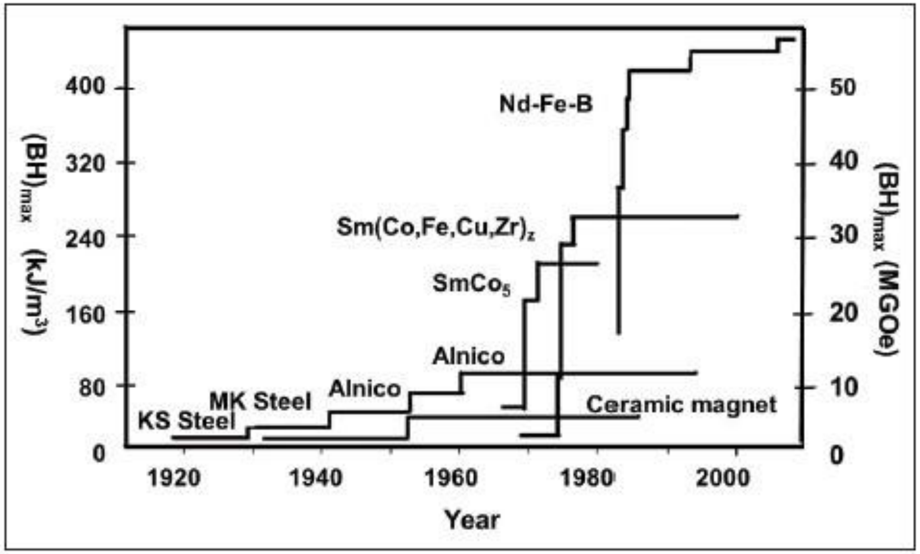
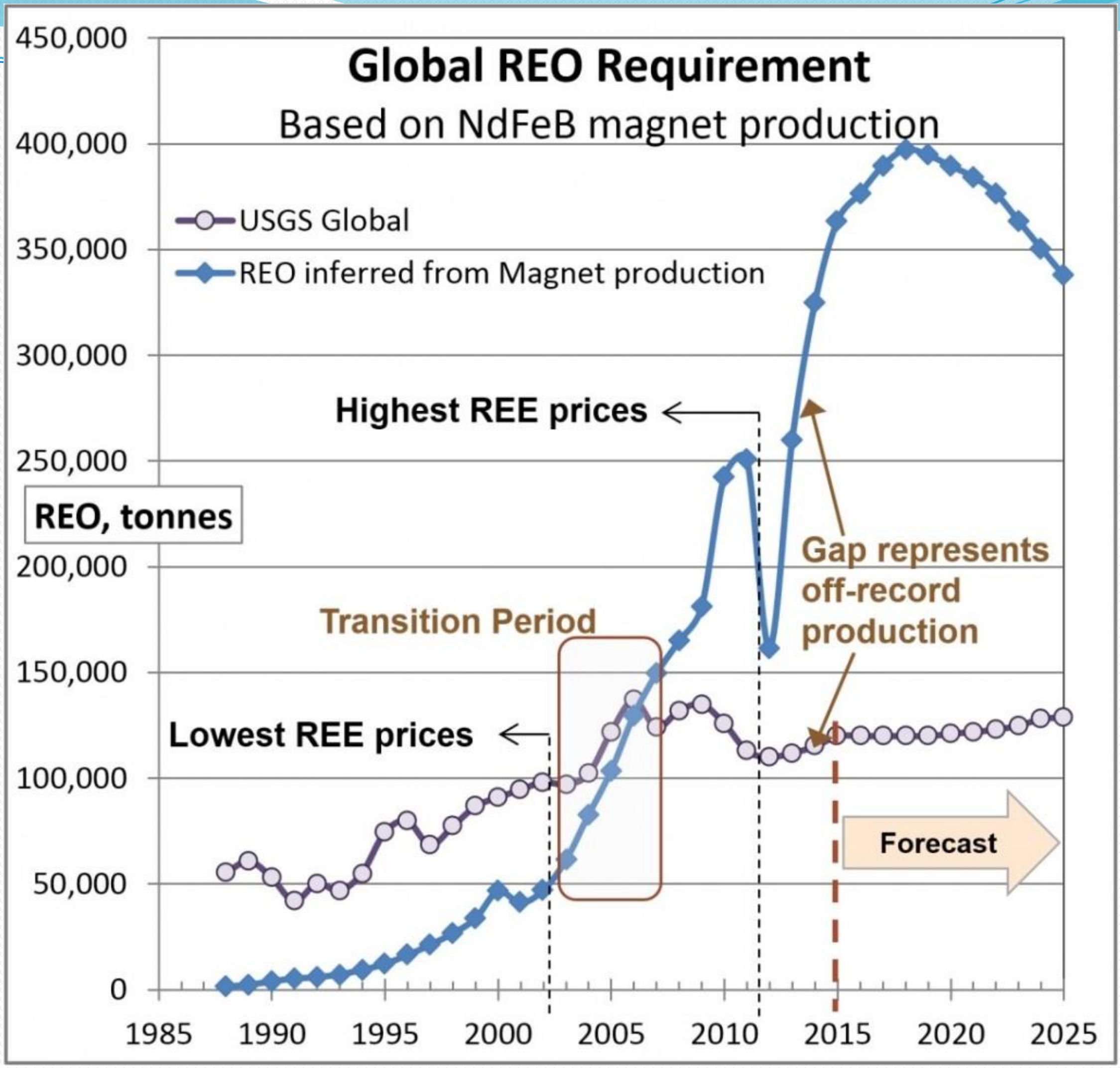


Figure 1. Development of Permanent Magnets in the Last 100 Years

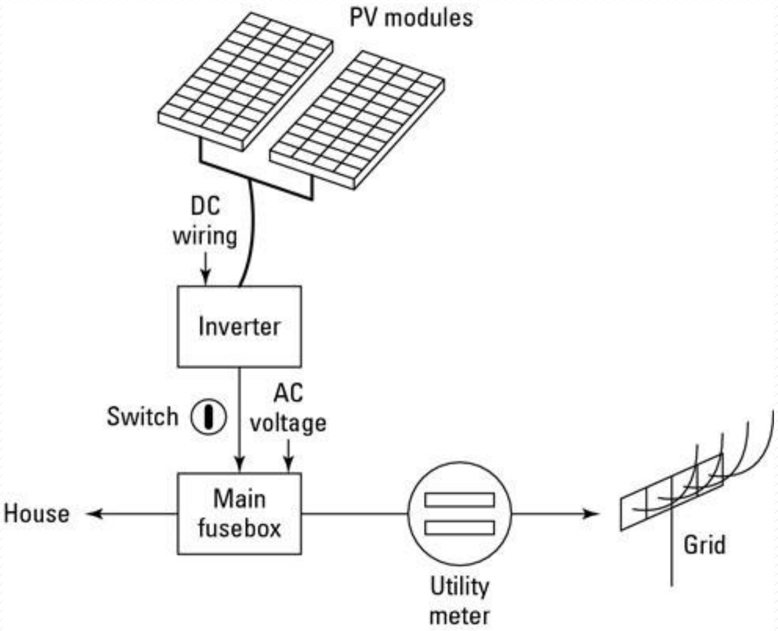
Liu, 2016



Constantinides, 2016

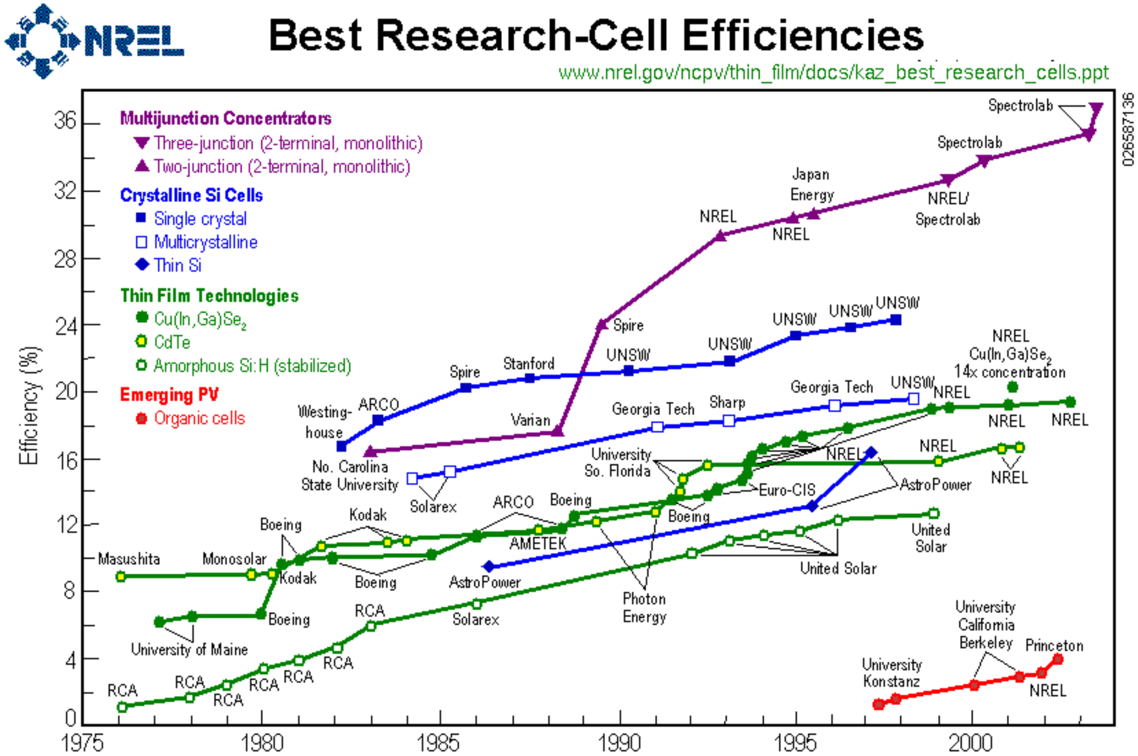
Solar Cells
Photovoltaic (PV)Panels

- Tellurium
- Indium
- Gallium

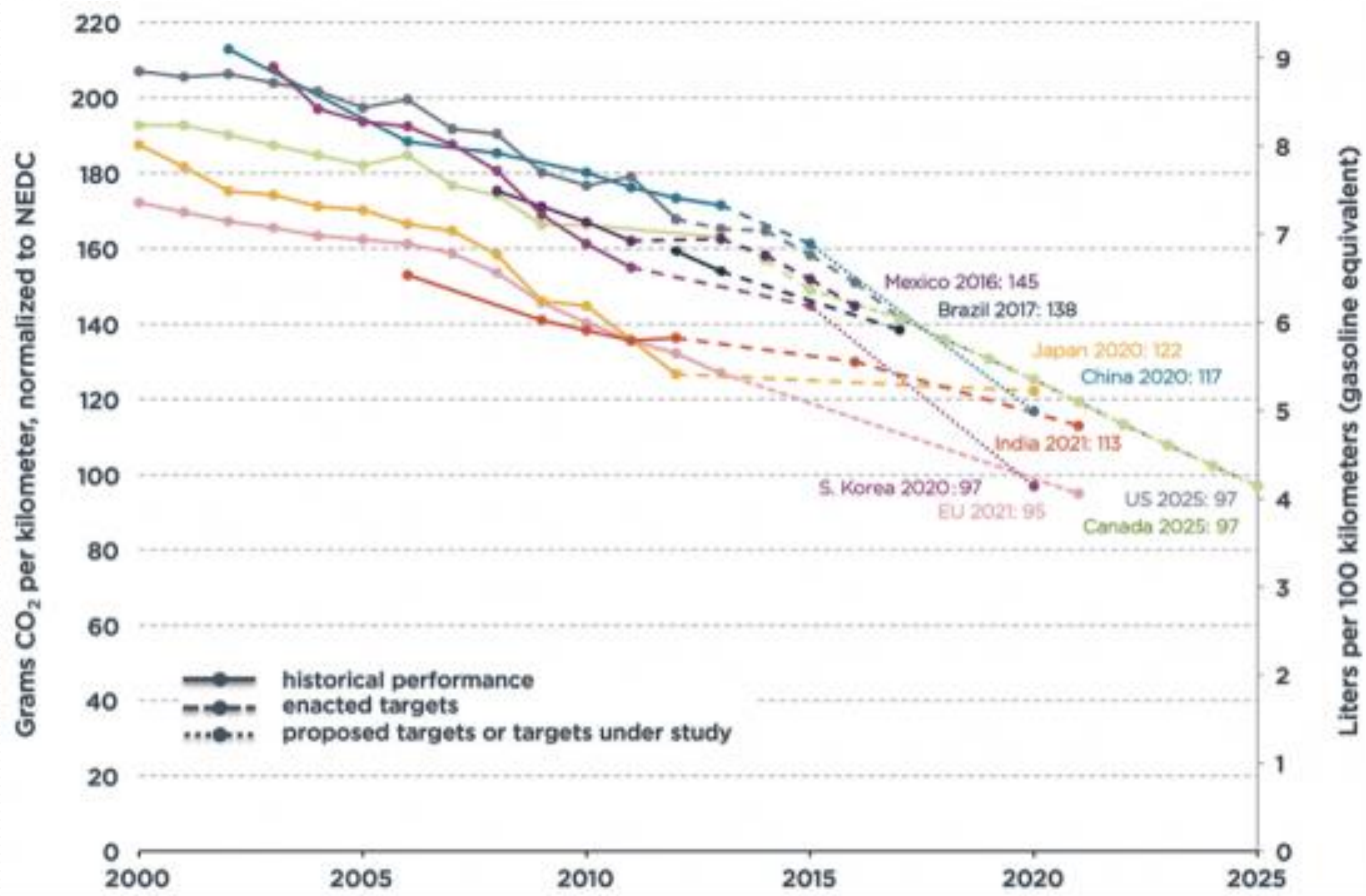


- Photovoltaic cells convert sunlight to electricity.
- Various types:
  - Monocrystalline silicon
  - Polycrystalline silicon
  - Thin films
  - Multijunction Cells

- Cu-In-Ga-Se
  Cd-Te
  Ga-As
  Ga-In-P



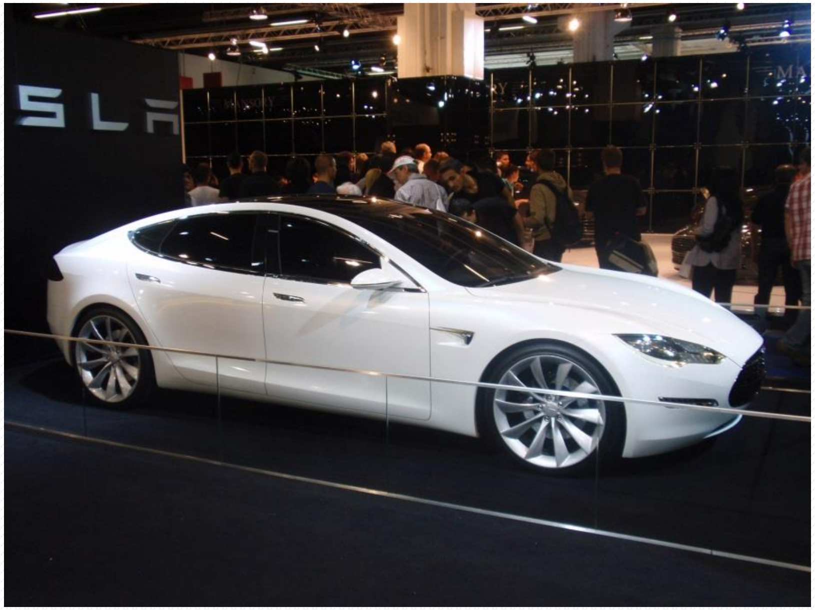
Lower pollution, better fuel economy



ICCT

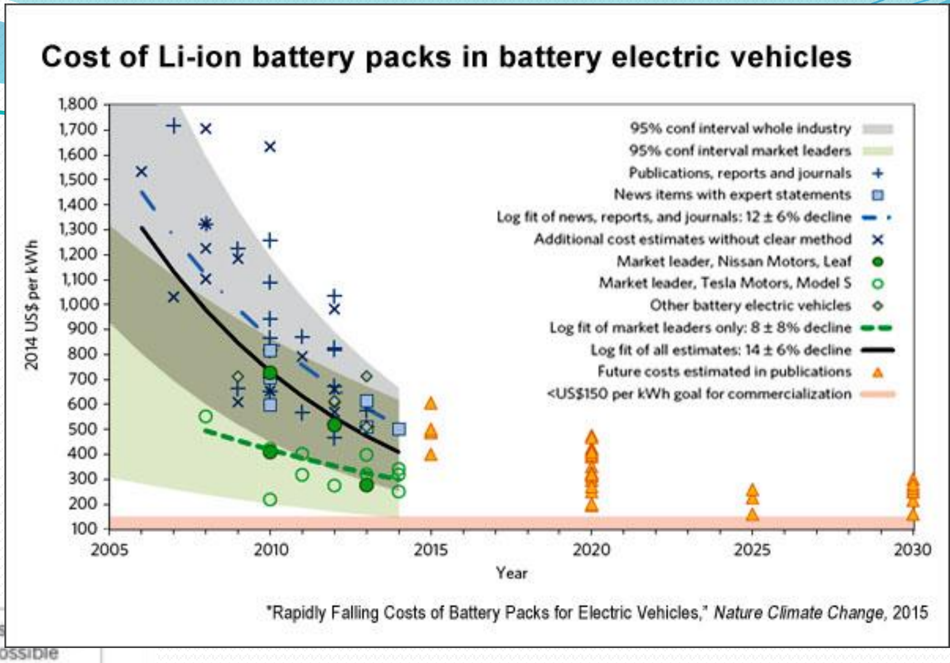
BATTERIES

- **“Tesla's Elon Musk says new car battery is a milestone”** **(24 August 2016 BBC News website).**

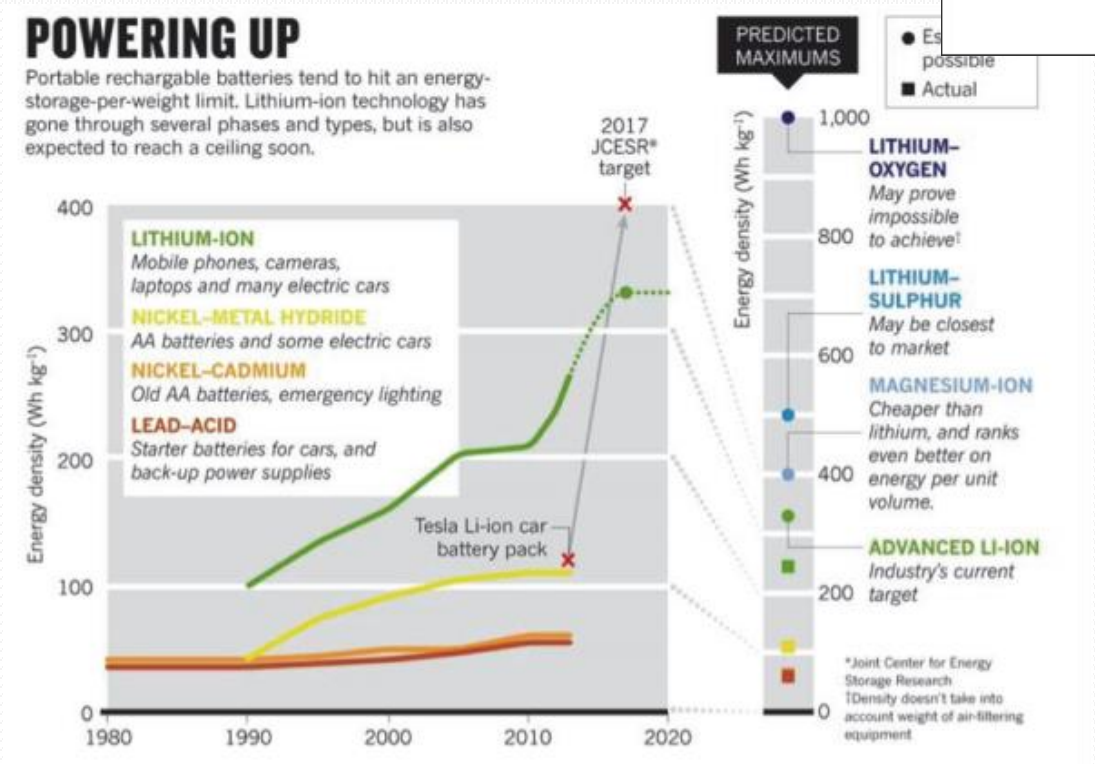


Tesla Model S
The world’s fastest accelerating EV

Lithium-ion



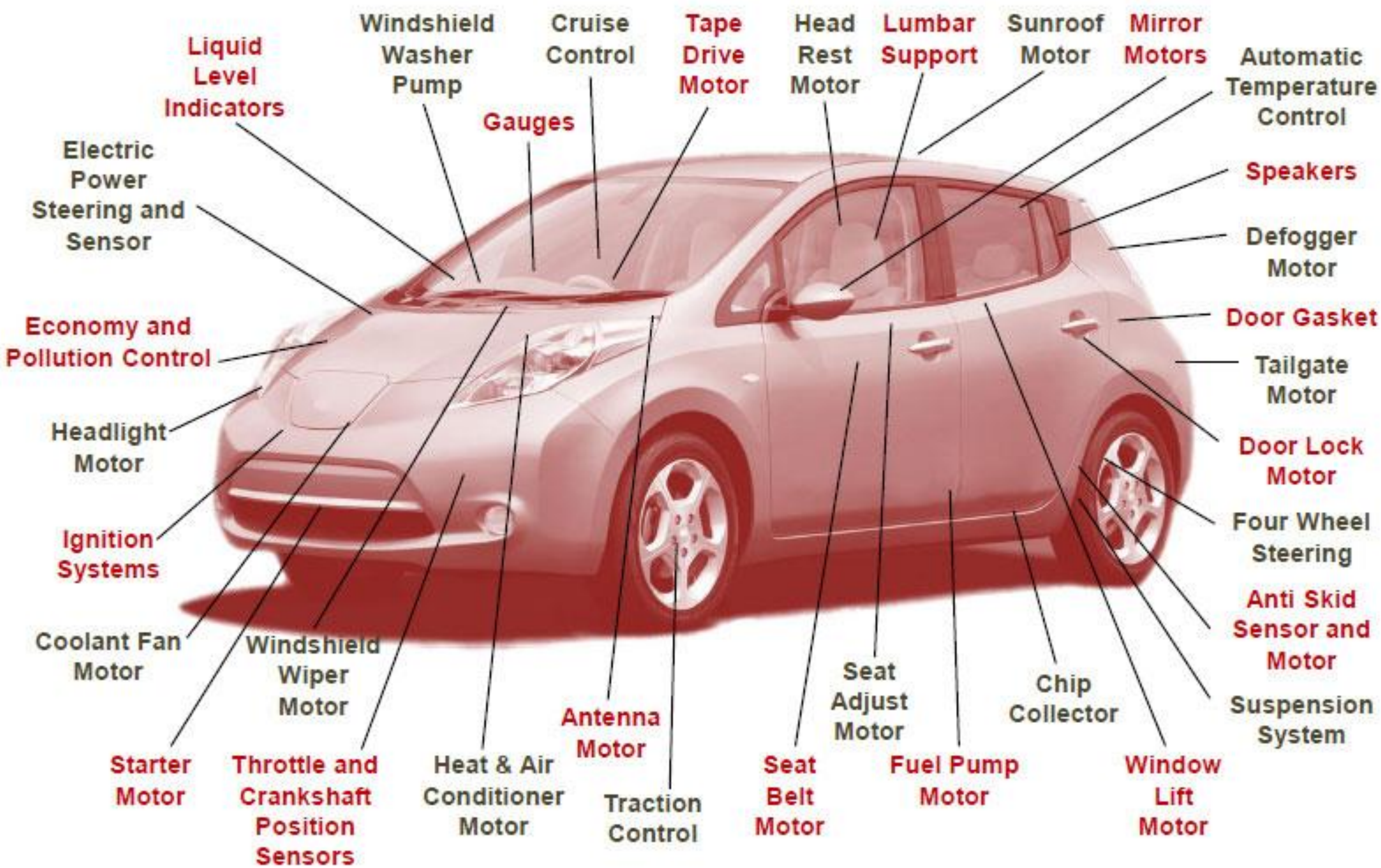
Cost of Li-ion battery packs in battery electric vehicles
2014 US$ per kWh
Year
95% conf interval whole industry
95% conf interval market leaders
Publications, reports and journals
News items with expert statements
Log fit of news, reports, and journals: 12 ± 6% decline
Additional cost estimates without clear method
Market leader, Nissan Motors, Leaf
Market leader, Tesla Motors, Model S
Other battery electric vehicles
Log fit of market leaders only: 8 ± 8% decline
Log fit of all estimates: 14 ± 6% decline
Future costs estimated in publications
<US$150 per kWh goal for commercialization
"Rapidly Falling Costs of Battery Packs for Electric Vehicles," Nature Climate Change, 2015



POWERING UP
Portable rechargable batteries tend to hit an energy-storage-per-weight limit. Lithium-ion technology has gone through several phases and types, but is also expected to reach a ceiling soon.
Energy density (Wh kg⁻¹)
LITHIUM-ION
Mobile phones, cameras, laptops and many electric cars
NICKEL-METAL HYDRIDE
AA batteries and some electric cars
NICKEL-CADMIUM
Old AA batteries, emergency lighting
LEAD-ACID
Starter batteries for cars, and back-up power supplies
2017 JCESR* target
Tesla Li-ion car battery pack
PREDICTED MAXIMUMS
possible
Actual
LITHIUM-OXYGEN
May prove impossible to achieve†
LITHIUM-SULPHUR
May be closest to market
MAGNESIUM-ION
Cheaper than lithium, and ranks even better on energy per unit volume.
ADVANCED LI-ION
Industry's current target
*Joint Center for Energy Storage Research
†Density doesn't take into account weight of air-filtering equipment

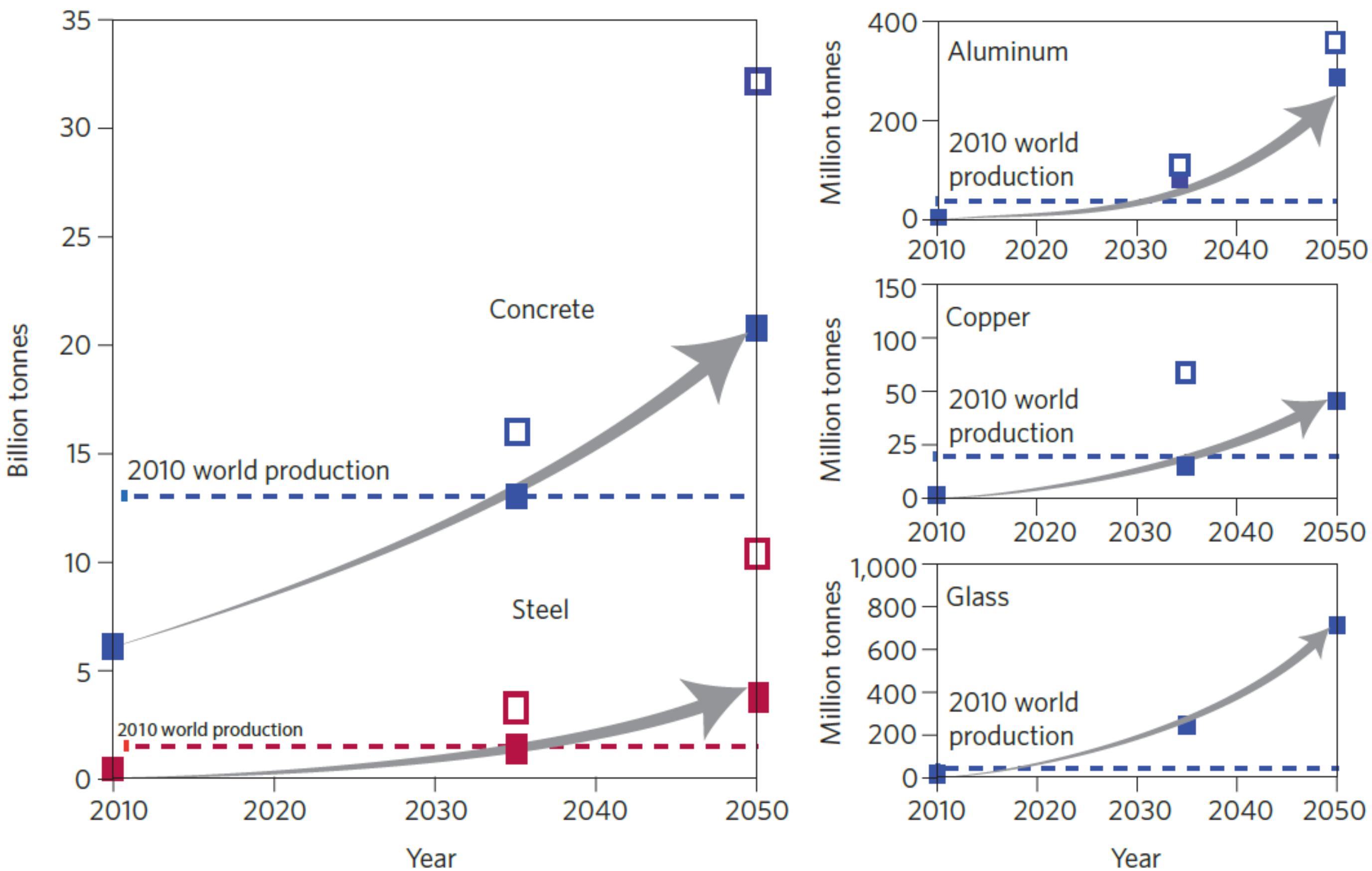
Expanding REE Consumption

Invisible Metals.......



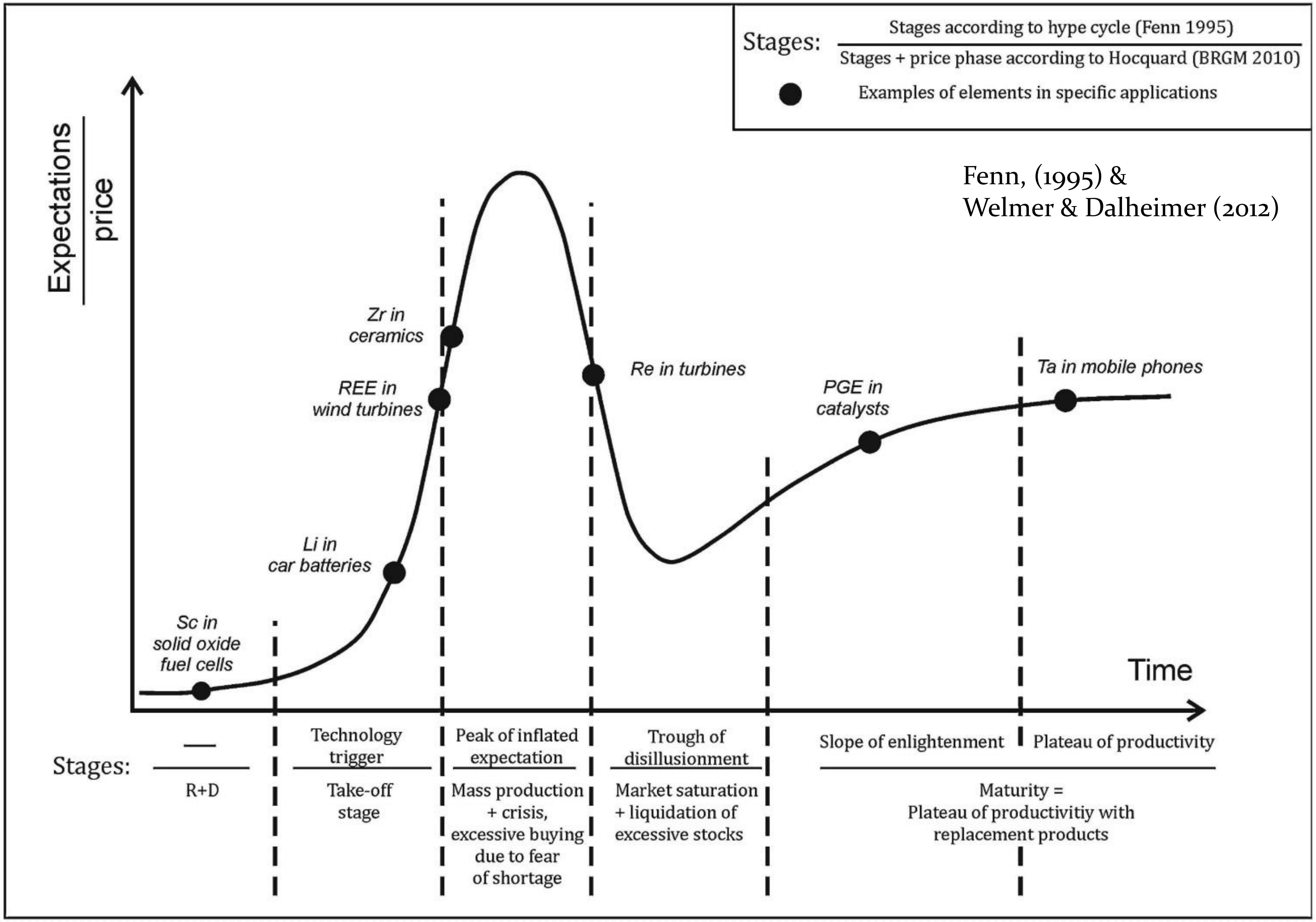
Source : Neo Materials

Are these Environmentally Friendly?



The drive to environmentally friendly energy will require increases in raw material consumption (Vidal et al, 2013)

The Hype Cycle



Current Reality: Profitability, markets

- Mining is a commercial activity undertaken in the main by mining companies.
- It is not undertaken by governments, NGO's or geological societies (people who discuss RFG!!)
- Decisions on whether it is commercially viable to mine a particular deposit / commodity ultimately depend on the board / shareholders and whether or not a profit can be made.
- Legislation can govern how mining and investment operates but it cannot make decisions on the behalf of shareholders.

When will we run out? Divergent Views

- Its going to be OK – Reduce – Reuse-Recycle
- Advanced technologies will help
- The planet is a finite resource – we are going to run out
- Cathles, L.M. 2015
  - “The world contains the energy and mineral resources needed to sustain 10.5 billion at a European standard of living for hundreds of centuries”.
  - However, its “largely in the world’s oceans”

Its not easy to provide definitive answers:

Mining oceans, asteroids

Stay concerned

Be (scientifically) informed: (balanced?)