Metals scarcity: A sobering perspective
Part I: Our predicament

Delft University of Technology, Faculty Industrial Design Engineering,
The Netherlands, December 2, 2009
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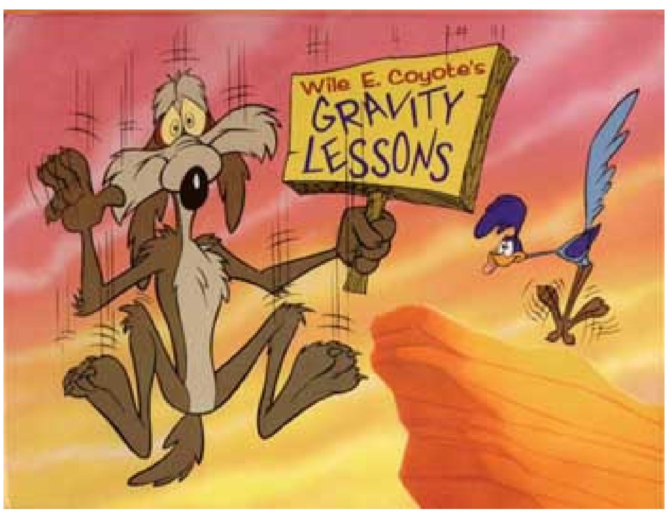
The core message is included in slide 22 and accompanying text.

Slide 1
Scarcity is of course something of all times. A prominent difference with the past however is the global scale of our current predicament. From the perspective shown here, Earth is just one giant Easter Island.

“The free market will solve it”, not to worry?

Slide 2
The free market has given us tremendous benefits, but it is by no means a cure for all trouble (witness e.g. the current financial crisis). Moreover, financial products are human abstractions without physical limits, whereas raw materials and the products and services built on these raw materials do have physical limits.

Is unlimited growth possible?



Slide 3
The law of gravity is quite obvious. But the second law of thermodynamics is less obvious and is being violated frequently in proposals and schemes to enable continued growth in energy and materials consumption. That 2nd law means amongst others that energy conversions will always be accompanied by losses. It takes energy to concentrate energy and if the rate and scale of energy consumption continue to be kept well above ambient levels, we’ll soon hit physical limits.

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- **Consequences of metals scarcity**
  - Forget painless transition towards sustainable economy
  - Bottleneck dead ahead
  - Will technology save us?
- **Solution framework with intrinsic value (preview to Part II)**
  - Amongst others the **Elements of Hope**

Slide 4
This presentation (Part I) can be quite alarming to the unprepared mind and could serve as a wake-up call for the many unaware, but is in no way meant to invite pessimism or defeatism. Part II of this presentation will explore meaningful actions to (try to partially) adapt to a world which is less affluent with energy and metals.

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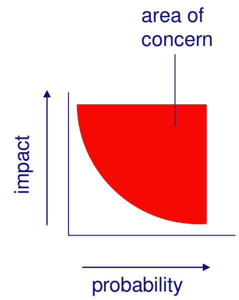
Slide 5
Awareness at the level of business and government can be raised by approaching metals scarcity (and scarcity in general) as a matter of risk assessment.

Way ahead: which decisions to take?

- Reality too complex to fully understand
  - inherent limitations on predictability of the future
  - keep wide safety margin
  - allow for “black swans” 

- Multiple futures or opposite scenario’s
  - which options have intrinsic values either way (least regret options)?
  - which options “hedge” against risks (probability x impact)?



Slide 6

A helpful way of evaluating what decisions best to take is to draw a roadmap. In part II I’ll propose a preliminary (and very incomplete) roadmap which gives specific measures of performance to be realized within a specific timeframe in order to stimulate discussion. The roadmap can be based on multiple futures scenario planning which is not so much about predicting the future (which is virtually impossible) but about making the correct choices today to reduce risks. The best choices to be identified are the so-called “least-regret” choices which work both ways (in the worst- and best-case scenarios) as these choices have intrinsic values.

Balance between F.E.A.R. (Fake Evidence Appearing Real) and Blind Optimism

Threats:

- Energy crisis
- Financial crisis (if energy can't grow, debt can't grow)
- Resource crisis (including metals, water, agricultural products)
- Natural disasters, environmental degradation and climate change
- Armed conflicts and war (including cyber warfare)
- Political instability and extremism
- Pandemics
- ......

These threats are interrelated
and partly have the same drivers

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Slide 7

Risk assessment has to strike a balance between fear (called sometimes Fake Evidence Appearing Real) and blind, unfounded optimism. What are the main threats to our civilization, urging us to make a transition towards sustainability? These are the interrelated crises of energy, finance, resources, natural disasters (together with environmental degradation and climate change), armed conflicts & war (including cyber warfare) and pandemics. I probably forgot a few ;).

These threats partly have the same drivers like population growth and consumption growth. Earlier this year, the IMF (within the context of the current financial crisis) stated that a "healthy" world economy should grow by 3% or more annually. Sustained growth of 3% per year means a doubling time of consumption every 24 years. Compare this with the average growth of China's economy during the last 15 years and associated growth in metals consumption: 10% or more per year, meaning a doubling time of 7 years (or shorter). How long do you think this is going to last without problems? What do you think of the likelihood of the global economy resuming and then maintaining an average annual growth rate of at least 3%?

What is the estimated timing of these events, so what's the urgency? See the following slide:

Big Trouble ahead

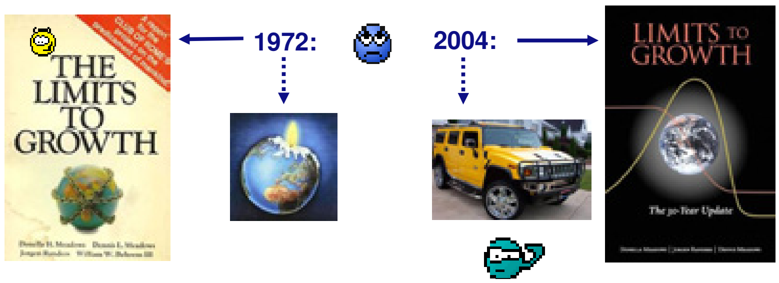
- **Energy scarcity: coming decade**
  peak regular oil: right now, peak all fossil fuels ±2020?
- **Financial crisis: right now**
  no return to “business as usual”?
- **Metal minerals scarcity: coming decade**
  driven by energy scarcity
- **Scarcity of water and agricultural products: increasing**
  scary in the long term
- **Environmental degradation: right now**
- **Armed conflicts and war: increasing**
  man’s natural tendency to compete for scarce resources
- **Political instability and extremism: coming decade?**
  demographic time bombs in Middle East and Northern Africa, populism in Western World
- **Pandemics, (accelerating) climate change, World War III**
  probability? impact? **possibly far-reaching consequences**

Slide 8

Metals scarcity, the subject of the remainder of this presentation, is only one of several major challenges coming our way. The most pressing problem in the longer run will probably be water and food scarcity: you could make a living with (much) less energy and (much) less metals, but we can’t survive without water and food. Many scarcity problems could be dwarfed by the potentially very disruptive effects of pandemics, climate change or global war, but we’ll face already enough challenges without this category.

Too late to prevent painless transition

Weren't we warned ?!



Inertia is not just a law of physics
- "Hope for the best, prepare for the rest"
  - Not so much crisis prevention but **crisis management**

Slide 9

We have wasted valuable time and lost a valuable opportunity of meaningful actions some 30 years ago. People like Jimmy Carter apparently were too far ahead of the crowd, just as the authors of Limits to Growth.

Military wisdom is partly applicable to society as a whole, e.g. "better safe than sorry" or "hope for the best, prepare for the rest". Do we wait until we have 100% proof of trouble with no fall-back strategy at that moment in time? Will we start constructing a fire engine for a yet-to-be-established fire brigade only until some major fire breaks out in town?

It is important to understand that we are already in overshoot (like Wile E. Coyote in slide 3), it's too late for crisis prevention. It's never too late though for proper actions. That doesn't mean that our current predicament is a "problem" with a "solution", it's more a collection of dilemmas, but nevertheless it's much better to strive for improvements, if only to mitigate part of the effects.

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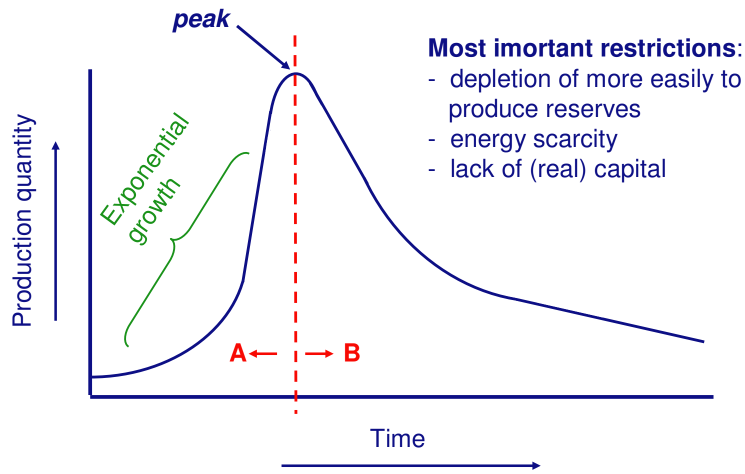
Slide 10
Metals scarcity is strongly linked with energy scarcity (some people call mining "a way of converting energy into metals").
To make a distinction between the word "mineral" and the word "metal", I would like the example of the metal aluminium which is being concentrated from the mineral bauxite (which contains aluminium oxide).

Resource scarcity

- Resources can indeed get scarce within a **problematic short timeframe**
- Of course elements don't disappear, but what does disappear at an accelerating rate are the producible higher **concentrations**
- Conventional measures neglect the required **timeliness** in combination with the required **scale**

Slide 11
The first bullet is not obvious and will be explained further on. The lack of time is also a dominant factor with other scarcities and their associated transitions.
The second bullet will be explained in further detail.
Third bullet: timelines and ability to scale are amongst the most important benchmarks to evaluate the feasibility of proposed solutions.

What matters is production *rate*

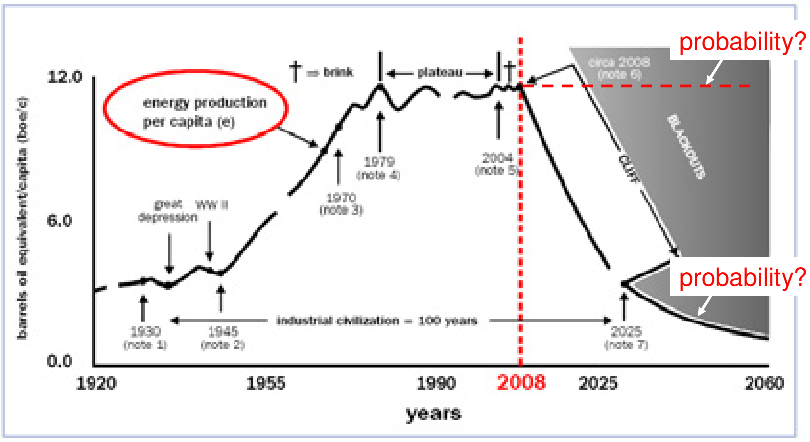


Slide 12
What is meant by peak production?
After a period of accelerated production growth the law of the diminishing returns sets in, after which a (small or broad) plateau is reached where production can no longer grow. The graph illustrates this and the top of the graph is called the production peak. It's quite possible that more production will take place after the peak (part B of the graph) than before the peak (part A of the graph), but the maximum production in a given year is much more important than the stuff left under the ground for future production.
I would like to lend a phrase from the peak oil community and apply it to mineral resources as well: it's not the size of the well that matters but the size of the tap.

In reality a production profile will of course have ups and downs superimposed on the smooth curve shown here, but this is the common (simplified) picture.
You can already have scarcity (defined as demand exceeding supply) in part A of the curve. I will give examples with slide 22.

The most important factors determining this styled production curve are the depletion of the more easily to produce reserves (the "low hanging fruit", see also slides 15 and 16), energy scarcity (slide 13) and lack of real purchasing power (as opposed to pseudo purchasing power). People who want to understand the meaning of pseudo purchasing power are invited to google the words fractional reserve banking and fiat currency. Money is a paper promise for future products and services. Where do you think the "real" value of money is heading to in a world with increasing amounts of (mostly digital, abstract) money, while supply of products and services based on primary, physical goods (like energy and metals) is not able to keep up with the money supply?

Decreasing energy production per capita



Source: The Olduvai Theory, Richard C. Duncan, 1989 and 2006

Slide 13

If we look at history (left of the vertical dotted red line) we see that the energy production relative to the global population hasn't been able to grow for quite some time. During the 30 years of this "plateau", global energy production has grown but so has global population. And the world's population will continue to grow for a while. What's the probability of continuation of this plateau for years to come (horizontal red dotted line)? What's the probability of a steep decline in energy per capita according to the black line? For the coming decades, reality will probably lie somewhere inbetween these lines, meaning a declining energy availability per capita. This graph is pretty scary if you think about its implications. It's even worse than a zero sum game: even zero growth at one part of the globe will inevitable cause shrinkage at another part of the globe.

This wouldn't have to be such a big issue if we would have a less energy intensive economy, but we are still far away from that.

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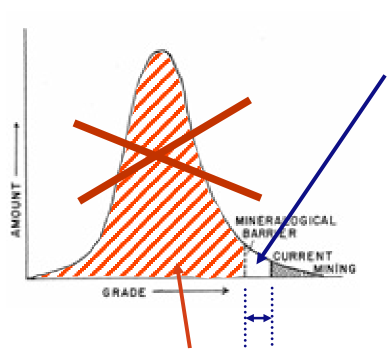
Slide 14
There are some striking similarities between energy production curves and metal minerals production curves, but also a number of distinct differences. An important difference is the likelihood of a much more asymmetric production profile compared to fossil fuels, resulting in a long fat tail after the production peak.

Mineralogical barrier for elements ≥ 0.1% (mass) earth’s crust



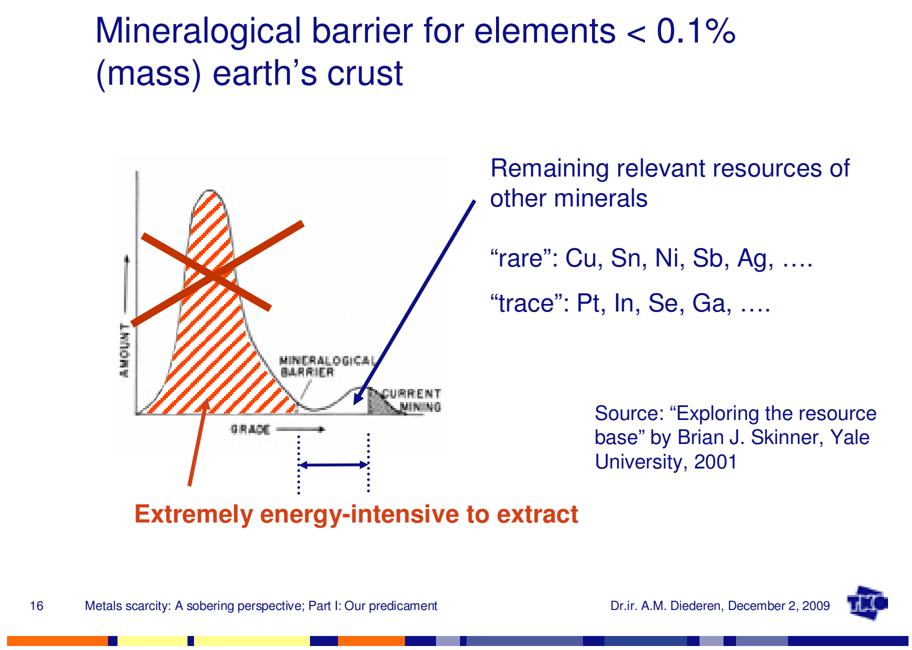
Remaining relevant resources of **aluminum, iron, silicon, magnesium, titanium, …..**

Source: “Exploring the resource base” by Brian J. Skinner, Yale University, 2001

Extremely energy-intensive to extract

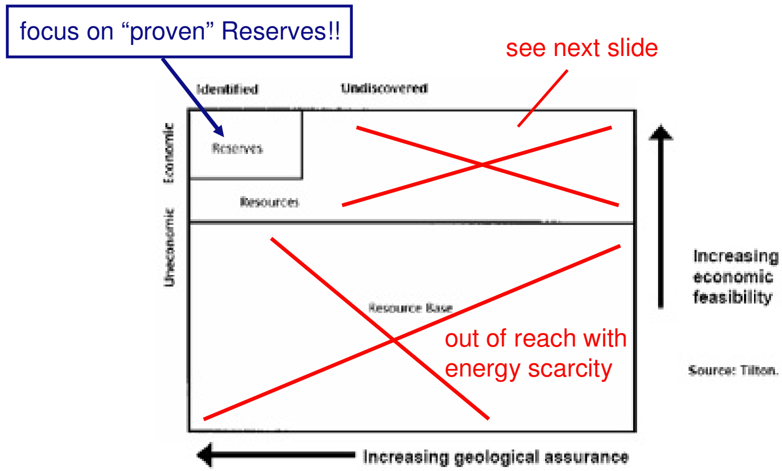
Slide 15
In an energy constrained world the vast majority of resources is out of reach and it is becoming increasingly more difficult to sustain or even grow current production rates of metals.
The absolute amounts of various metal minerals in the earth’s crust are large beyond imagination, but the bulk of it might as well not be there because it’s out of reach because of the required energy involved in extraction. Most of the minerals occur in practically useless

low concentrations: below the so-called mineralogical barrier (a certain low ore grade), essentially you should pull the source material (e.g. a piece of rock) chemically apart to extract the individual metals.
Again I would like to use the saying “it’s not the size of the well that matters but the size of the tap”. About a quarter of the earth’s crust consists of silicon, yet we are already short (for years) on pure enough silicon to make high efficiency solar cells. Of course we can purify the less favourable sources of silicon (as we indeed do), but this takes (lots of) energy.



Slide 16
This graph might be valid for all non-abundant metal minerals and it shows that the situation here might be even less favourable than with the more abundant metal minerals because there’s a dip in the graph at lower ore grades. This may aggravate metal minerals scarcity.

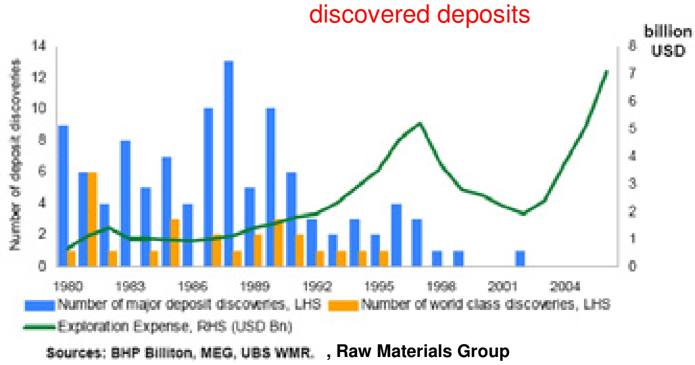
“Reserves” will not continue to be replenished



Slide 17
A typical critique on stating that we are running into metals scarcity is the notion that the free market (the laws of demand and supply) will upgrade parts of the resources or the resource base into reserves once reserves start to get tight. This has been the case for decades when there was cheap and abundant energy available. However with energy scarcity, the big lower part of the graph on slide 17 is out of reach (red crossed lines at the bottom). We should also let go of the notion that vast amounts of rich ore deposits lie waiting somewhere to be discovered (red crossed lines at the top), see slide 18.
So we should focus on reserves and not on the huge amounts of resources and the vast resource base. Of course there are many cases to be made to argue that the boundaries of the reserves may be stretched in favour of larger quantities; however there are as many cases to be made to argue that with an energy crisis not even the currently stated reserves remain within our reach to be exploited.
More importantly, what is often overlooked is the decrease in quality of reserves. Again a typical critique is that the reserves to production rates of most metals have remained more or less constant during the last decades. However, not only the quantity but also the quality should be taken into consideration. Many reserves today are much harder to produce than reserves a couple of decades ago. Extremely put: would you prefer a rich open pit deposit near your processing factories or a low ore grade deposit buried deep beneath rock and soil in a remote and inhospitable area? The extractable quantities of metals could be the same in both cases (“the same reserves” in quantity), but at different energy consumption (and other consumables) and at different investment cost.

Discovery rate of major mineral deposits

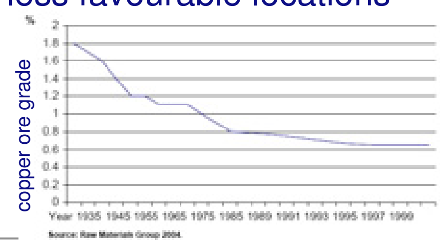
low expectations of yet to be discovered deposits

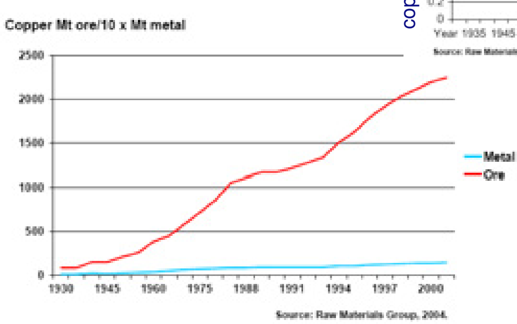


Slide 18
In analogy with scarcity of conventional oil: it’s unlikely that we will find another “Saudi-Arabia” or another “North Sea” of rich mineral deposits.

Decreasing quality of reserves: lower ore grades and less favourable locations

example: copper



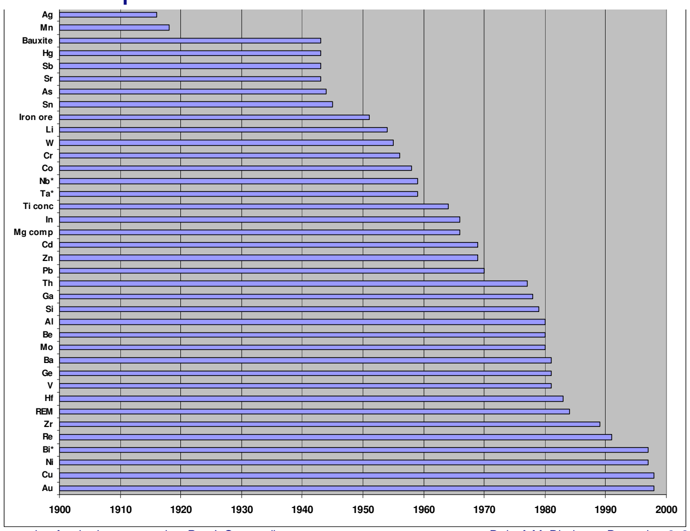


The production of 1 ton of copper is associated with 250 tonnes of solid waste

(Monash University, 2007)

Slide 19
A typical critique on stating that we are running into metals scarcity is the notion that “you will find 300 times more ore as you lower the ore grade with a factor of 10”. This misses the point that you need much more energy to keep extracting the same amount of metal. Lower ore grades increase energy expenditures because of the increasing amounts of solids which have to be processed to keep up the production rate of concentrated metal. But even when the ore grade is more or less stable (example: copper over the last few decades), you still need increasingly more energy to extract the same amount of copper because you have to go to more remote locations (often at less favourable conditions) and dig deeper to get to the ores.

In the USA primary production of most metals peaked before the 1980s



Source: Chris Clugston, "Continuously less and less", October 2009

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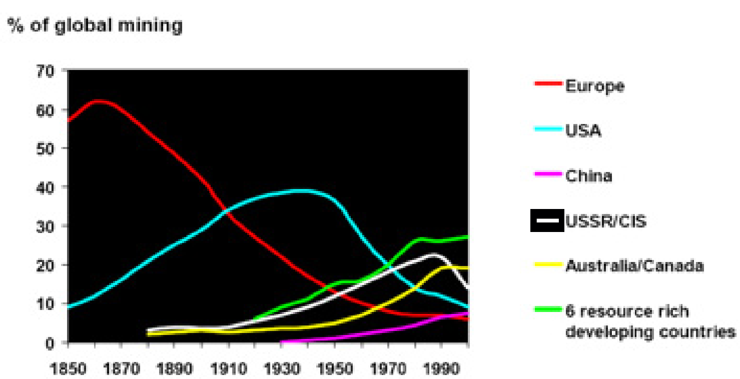
Slide 20
The United States of America, in fact half a continent in size, have had their peak in primary production of most metals some 30 years ago (primary production is production from ores and excludes recycling). These include not only silver (1916) but also widely applied metals like manganese and zinc. This does not mean of course that you couldn't mine and produce manganese and zinc anymore in the USA, but it means that it's partly not worthwhile anymore to do this in the USA. A similar picture of peak production, in another order and timing than shown here for the USA, will manifest itself globally.

Europe and the US have already depleted a significant part of their accessible resources



Sources: Raw Materials Data, Stockholm 2004, Sames, Raw Materials Group

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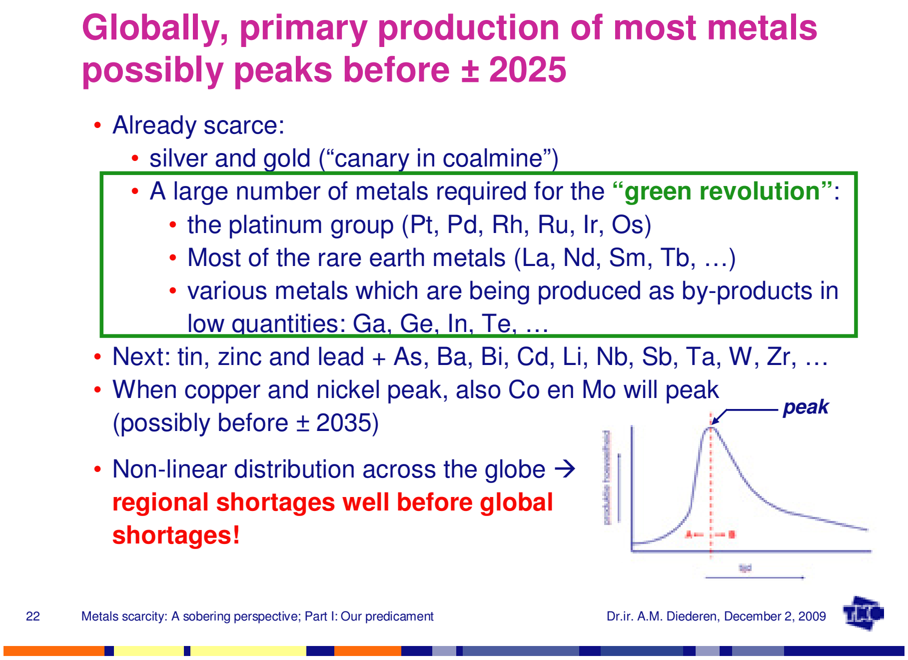
Slide 21
As with oil and gas, global (or average) metals scarcity will be preceded by spot shortages due to the non-linear distribution and non-linear depletion of metal mineral resources across the globe. The industrial revolution started in Europe and later the US became an industrial giant,

so it comes as no big surprise that both Europe and the US have depleted a large part of their accessible resources. Metals are obtaining geopolitical meaning, as fossils fuels already do have, and can and will be used as a means of power politics.



Slide 22

The peak in primary production of most metals may be reached no later than halfway the 2020s. According to my personal opinion it may be much sooner, around a decade or so sooner, meaning that most metals will have a primary production profile (see right bottom corner of this slide) with a longer and fatter tail than would be the case with a later peak. This will be caused by (amongst others) the ongoing depletion of the more easily to be exploited metal mineral reserves, (approaching and reaching) peak energy production and a lack of sufficient real capital to satisfy increasing investment requirements to grow or just maintain global primary production of metals.

I would like to emphasize (to prevent being misinterpreted) that we are not running out of metals in 2015 or in 2025, quite the contrary: humankind will produce more metals than ever before in the near to mid-term future. But primary production of most metals will probably no longer be able to grow a half or one-and-a-half decade from now and will decline after that. We will still be producing metals in the long term (especially common metals like iron and aluminium), but mostly no longer in the quantities we have grown accustomed to.

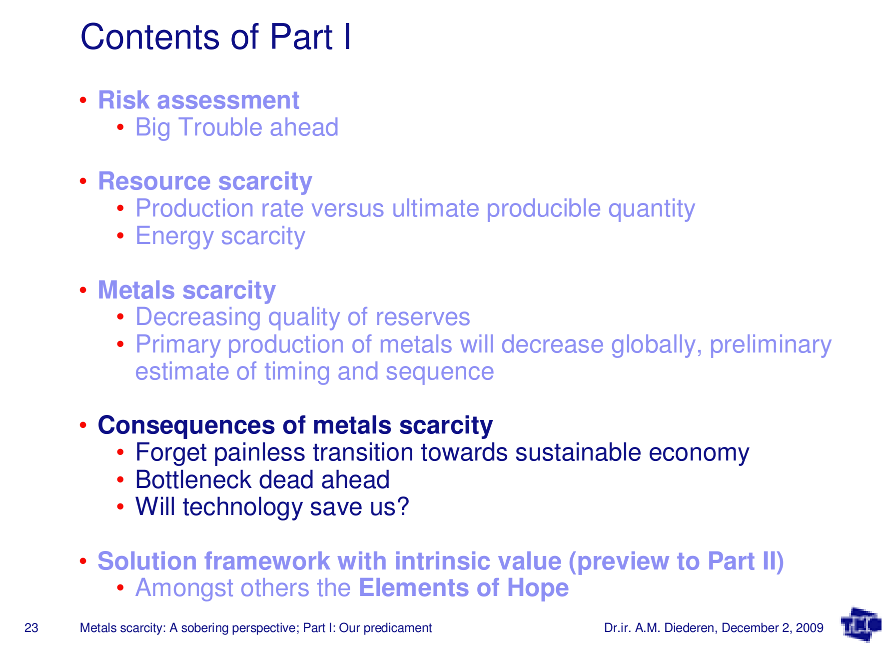
Precious metals like silver and gold are already scarce right now (scarce meaning that demand exceeds supply). Gold is the proverbial canary in the coalmine in this respect: we are going to great lengths to produce gold, we process on average 200,000 tons of solids to concentrate 1 ton of gold. Despite demand for gold being much larger than supply, primary production couldn't grow for almost a decade now.

Good examples of metals becoming scarce despite not yet having reached or surpassed peak production (production still in part A of the graph at the right bottom corner of this slide) are various metals which are necessary for the "green revolution", i.e. the transition towards a more sustainable economy. These include the platinum group metals, most of the rare earth metals (the rare earth metals are all 15 lanthanides plus yttrium plus scandium) and various minor metals like gallium, germanium, indium and tellurium which are mostly dependent on other (base) metals for primary production. We are not able to increase primary production of

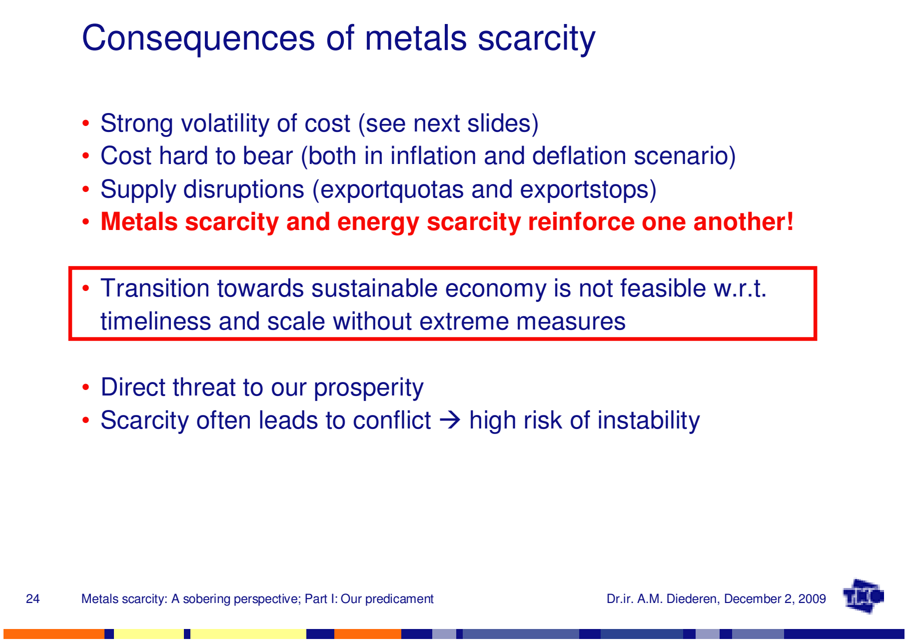
these metals fast enough to satisfy surging demand. Their applications include high efficiency solar cells, permanent-magnet drives and generators (wind mills, hybrid cars, electric cars), catalysts for cars and for petrochemical cracking, fuel cells, batteries and various electronic devices (from touch screens and harddrives to energy saving lighting).
In the medium term the base metals tin, zinc and lead will reach peak primary production and so will a number of metals associated with primary production of these base metals plus some other metals. This large group of metals includes those necessary for the green revolution as well, like many metals required for different types of batteries (zinc, lead, cadmium, lithium) and tantalum required for compact capacitators in mobile electronic devices like mobile phones. But the consequences of metals scarcity will be serious for established sectors like the automotive and the chemical industries as well. An example is tungsten, with many applications in (amongst others) machining and steels.
No later than halfway the 2030s the base metals copper and nickel and their associated by-products cobalt and molybdenum may also reach their primary production peak. The meaning of an end to the production growth of a metal as important for our industrial civilization as copper should be obvious. At this point, primarily we have metals like aluminium and iron (and possibly magnesium) left at our disposal to sustain or even continue growing their primary production.

The situation pictured above would be alarming even if it were only valid for a handful of these metals.
Yet the problem is even more serious and urgent, because the timing pictured above involves a global mean derivative. In reality spot shortages will occur well before global shortages hit. More often than not, the largest part of global primary production takes place in just a few countries. The geopolitical ramifications of this could turn out to be severe.

Metals scarcity wouldn’t have to be such a big issue if we would have a less material intensive economy, but we are still far away from that.



Slide 23
Take away message here is: without a shift from scarce to less scarce metals, a large-scale transition towards a more sustainable economy (large-scale meaning at current or growing consumption levels) doesn’t stand a chance.



Slide 24

Scarcity will manifest itself in one way or the other in cost (see also slides 25 and 26). But the absolute cost level in itself is probably an insufficient indicator of scarcity. First the absence of price stability is probably much more important than the absolute price level: uncertainty is not very helpful in making investment decisions. Secondly, scarcity can also manifest itself at low price levels, meaning during a period of deflation. In the third place, money is rather useless of it can't buy you the necessary items, see the 3rd bullet in this slide. For a number of the rare earth metals, China is already using export quotas (since 2004) and considering export stops in the near future.

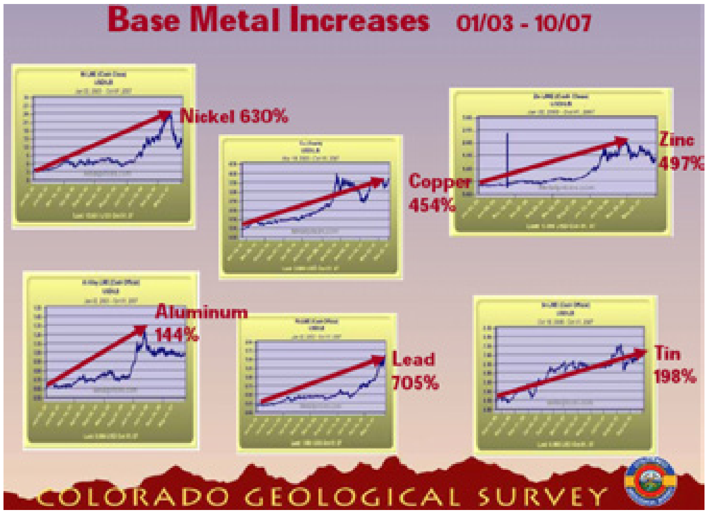
Because the energy sector is one of the largest metals consumers, metals scarcity will aggravate energy scarcity and energy scarcity in turn will aggravate metals scarcity. The energy sector uses lots of metals within its whole chain of exploration, production, storage and distribution up to conversion into the desired forms of energy.

It will be obvious by now that we cannot let things take their course if we want to realize a timely and extensive transition towards a sustainable economy.

Metals scarcity (like energy scarcity) poses a direct threat to our prosperity. Resource poor countries like The Netherlands and Japan have to import most of the material input for their domestic industry.

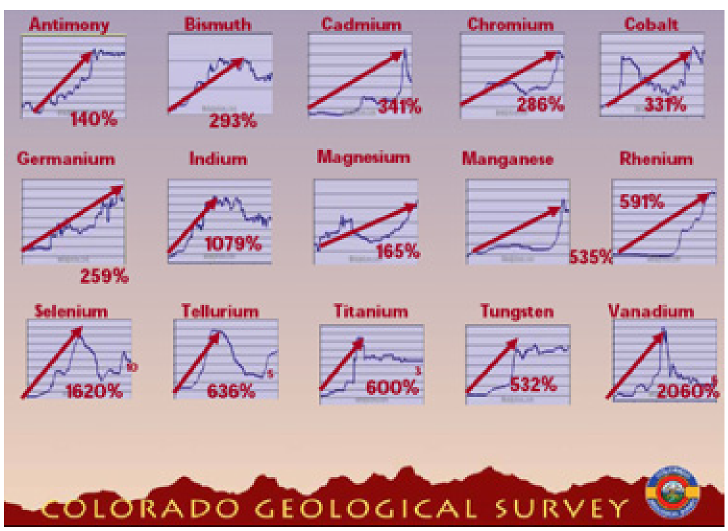
History shows us that scarcity of various kinds often leads to conflict. It's no longer sufficient to look at the global geopolitical situation from the perspective of the availability and distribution of fossil fuels, water and food; we should add metals to this list.

High price volatility prior to current crisis (1 from 2)



Slide 25
Price levels of a number of base metals rose between 144% and 705% (measured to peak levels) during the period 2003-2007.

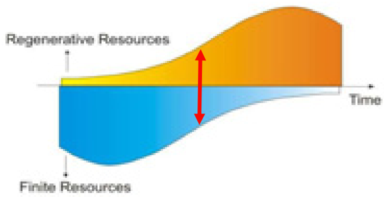
High price volatility prior to current crisis (2 from 2)



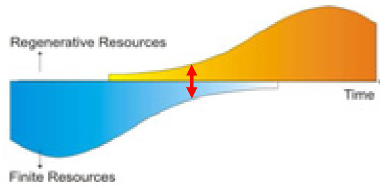
Slide 26
Price levels of many metals showed high spikes during the period 2003-2007. An extreme example is given by vanadium which price temporarily rose by 2060%.

Passing through the bottleneck: Weight Watchers or extreme surgery?

Proper and timely action:



Denial, disbelief and blind optimism:



Graphs: Armin Reller, 2009

Slide 27
I think it's rather obvious that we'll have to go through a difficult transition the coming decades. The blue production in the graph (any resource like energy, raw material, water, food) could be interpreted as "business as usual" and overall production might grow for some time but will hit a maximum level and decline thereafter. The orange production could be interpreted as "sustainable". The message is that we have to take timely action to prevent us from having to squeeze ourselves in future through the bottleneck as illustrated at the right side of slide 27. This right hand part sketches a situation you don't want to react upon, you'd rather like to anticipate to such a situation. In the right hand situation you might have to resort to notional amputation to fit through the bottleneck, at the left side we might get away with a rigorous diet if and when we start early enough (and keep up with it).

Wat does this mean (globally)?

- Globally we'll loose, regionally there will be winners
- Access to resources:
  - by owning them
  - by buying them (with real purchasing power)
  - by force

Slide 28

So I think it's rather obvious that we'll have to go through a difficult transition and we'll end up with a world facing a situation worse than a zero sum game. But as always, there will be winners and losers.

Access to raw materials will then primarily be realized by 3 options: (1) by owning (part of) the production chains, (2) by using surplus of other products and services to be able to buy raw materials and associated products and (3) by taking them by force. Option 1 could imply repatriating (part of) the manufacturing industries back to developed countries.

Resource poor countries have to utilize even more than now their inventiveness and creativity. A country like The Netherlands will also have to put more emphasis on agriculture (food as well as non-food products) and a more intense use of its continental shelf in the North Sea to be more self-sufficient and create more surplus of domestic goods and services (option 2) to trade for non-domestic goods like metals and associated products.

Technology softens the consequences, don't expect miracles

- Timeliness?
  (think in decades, not years)
- Economic scaleability?
- Are we making the right choices?

Slide 29
You cannot beat the second law of thermodynamics (see text with slide 3) using technology. As with the free market (slide 2) technology has given us tremendous benefits and with technology the magic box of tricks is far from being depleted, but it is by no means a cure for all trouble. Timelines and ability to scale are amongst the most important benchmarks to filter feasible propositions. Besides this, we should also ask ourselves if we should resort to technology: sometimes behavioural change is much more effective (and maybe also much more difficult).

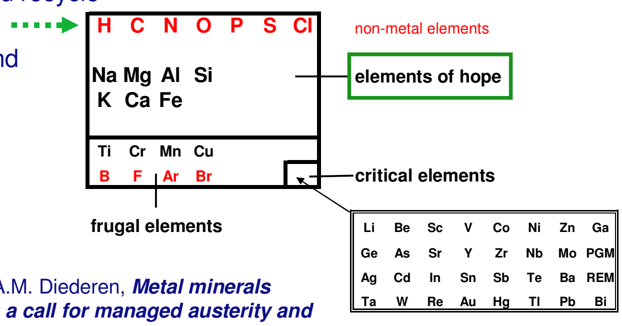
Contents of Part I

- **Risk assessment**
  - Big Trouble ahead
- **Resource scarcity**
  - Production rate versus ultimate producible quantity
  - Energy scarcity
- **Metals scarcity**
  - Decreasing quality of reserves
  - Primary production of metals will decrease globally, preliminary estimate of timing and sequence
- **Consequences of metals scarcity**
  - Forget painless transition towards sustainable economy
  - Bottleneck dead ahead
  - Will technology save us?
- **Solution framework with intrinsic value (preview to Part II)**
  - Amongst others the **Elements of Hope**

Slide 30
One of the most holistic approaches to connect metals scarcity with the transition towards a more sustainable society is using the elements I baptized "Elements of Hope", see part II.

Solution framework with intrinsic benefits, applicable to energy as well as metals

1. Use less (sounds like …..)
2. Longer life
3. Re-use and recycle
4. Substitute
5. Product and process (re)design
6. Buffers



Source: A.M. Diederen, ***Metal minerals scarcity: a call for managed austerity and the elements of hope***, March 10, 2009

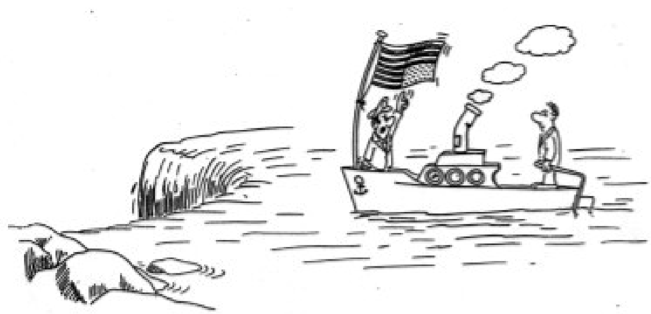
Slide 31

There are six solution directions to diminish our dependence on scarce metals: using less, longer product lifetime, more intensive recycling, substitution with less scarce metals, a new product design philosophy and adapted inventory management. These are "least regret" solution directions because they are meaningful no matter how the future is going to unfold, they are solution directions with intrinsic value. They are applicable to energy scarcity as well as metals scarcity.

Realization of this solution framework challenges people's ingenuity and creativity and offers meaning and purpose. "Using less" requires nothing less than some form of managed austerity. Also technology can play an important role by enabling dematerialization (like film tapes which have been replaced by digital photos). A number of solution frameworks are facilitated by reducing complexity in order to enhance quality and diminish waste.

I will elaborate on this in Part II of this presentation.

Let's prevent this from happening:



CREW, you fixed the burgee upside down !

32 Metals scarcity: A sobering perspective; Part I: Our predicament Dr.ir. A.M. Diederen, December 2, 2009

Slide 32
Metals scarcity is real and urgent. Proper and interconnected solutions take time to develop and implement. Let us prevent going back to the order of the day after hearing or reading this information and let us prevent thinking this is something to worry about later.

See also my March 10, 2009 paper "***Metal minerals scarcity: A call for managed austerity and the elements of hope***", published (with 198 comments) at the website TheOilDrum.com on May 4, 2009 (http://europe.theoildrum.com/node/5239) and as a paper (pdf) at http://www.materialscarcity.nl/Downloads.aspx.

Recommended further reading:

- Bardi, U., Pagani, M., ***Peak Minerals***, ASPO-Italy and Dipartimento di Chemica dell'Università di Firenze, posted October 15, 2007 at the website The Oil Drum: Europe, http://www.theoildrum.com/node/3086
- Bardi, U., ***The Universal Mining Machine***, posted January 23, 2008 at the website The Oil Drum, http://europe.theoildrum.com/node/3451
- Angerer, G., et. al., ***Rohstoffe für Zukunftstechnologien*** (in German), Fraunhofer-Institut, Germany, 2009, ISBN 978-3-8167-7957-5, downloadable as pdf from the internet (http://publica.fraunhofer.de/eprints/urn:nbn:de:0011-n-910079.pdf)
- Clugston, C., ***Continuously less and less***, October 2009, downloadable as pdf from the internet (http://www.wakeupamerika.com/PDFs/Continuously-Less-and-Less.pdf)
- Bol, D., Wouters, H., ***Material Scarcity – An M2i Study***, Materials innovation institute, Delft, The Netherlands, November 2009, downloadable as pdf from the internet (http://www.m2i.nl/images/stories/m2i%20material_scarcity%20report.pdf)

Metals scarcity: A sobering perspective
Part II: Crisis management: technology & beyond

Delft University of Technology, Faculty Industrial Design Engineering,
The Netherlands, December 2, 2009
Dr. A.M. Diederen, MengSci (andre.diederen@tno.nl)

Slide 1
Where Part I focuses on our predicament, Part II deals with ways of easing the consequences of scarcity and ways to change into the direction of sustainability.

Contents of Part II

- **Solution framework with intrinsic value**
  - Amongst others the **Elements of Hope**
  - Roadmap towards sustainability?
- **The huge pitfall of suboptimization**
  - Context dropping
  - Technology worship
  - Human behaviour
- **Let sound engineering knowledge and practice be your base guide**
  - You can't beat the laws of nature using technology
  - "All models are wrong, some are useful"
- **Creativity and inventivity are "without limit"**
  - Let nature inspire you
  - Out of the box thinking

Slide 2
As already mentioned in Part I of this presentation, discussion of our predicament is in no way meant to invite pessimism or defeatism. As I will show you in this Part II of the presentation, working on viable solution directions challenges people's ingenuity and creativity and offers meaning and purpose.

Contents of Part II

- **Solution framework with intrinsic value**
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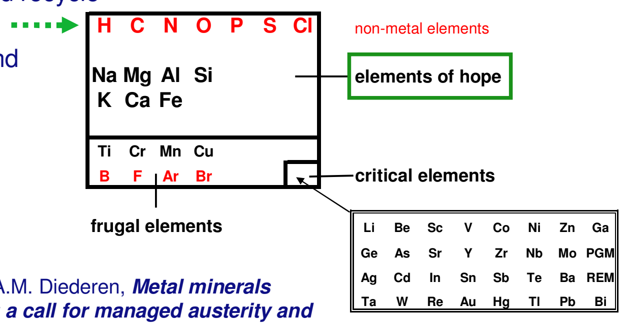
Slide 3
A particularly powerful solution direction is the substitution of scarce metal elements by the most abundant elements, the so-called Elements of Hope.
I'll propose a preliminary (and very incomplete) roadmap which gives specific measures of performance to be realized within a specific timeframe in order to stimulate discussion.

Solution framework with intrinsic benefits, applicable to energy as well as metals

1. Use less (most important solution but reluctant human behaviour leads to low priority)
2. Longer life
3. Re-use and recycle
4. Substitute
5. Product and process (re)design
6. Buffers



Source: A.M. Diederen, ***Metal minerals scarcity: a call for managed austerity and the elements of hope***, March 10, 2009

Slide 4

There are six solution directions to diminish our dependence on scarce metals: using less, longer product lifetime, more intensive recycling, substitution with less scarce metals, a new product design philosophy and adapted inventory management.

1. Use less or "managed austerity"

"Technical" solutions:

- Efficiency gains
  beware of Jevon's paradox!
- Useful products instead of disposables
  - basic necessities
    temperature (shelter), water, food, clean air, sanitation
  - human relations
    example: telecommunication
  - useful luxuries
    example: musical instruments
- Localisation and less complexity
  reduced distribution and transmission losses, more resilient and robust

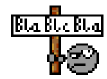
Slide 5

Using less can also be combined with one or more of the other solution directions, leading to efficiency gains and "dematerialization". Dematerialization often boils down to replacing a large quantity of one material by a much smaller quantity of another material (in fact a combination of using less and substitution). An example is the replacement of film tapes by digital photography. Please keep in mind that "dematerialization" still involves materials: you still need physical substrates to store the digital information and people still like to make prints. In order to have benefit from efficiency gains and dematerialization solutions, care should be taken to avoid the pitfall of Jevon's paradox, e.g. more kilometers per year travelled in a more fuel efficient car or making more photo prints or using digital photo frames running on batteries instead of framing a print. Jevon's paradox is the proposition that technological progress that increases the efficiency with which a resource is used, tends to increase (rather than decrease) the rate of consumption of that resource. So, technological progress on its own (without 'control') will only accelerate the depletion of reserves.

More a behavioural change than a "technical" solution is to focus on essential goods and services, i.e. basic necessities as opposed to short-lived luxuries. People should (re)learn the difference between inconvenience or discomfort on the one hand and real (even life-threatening) problems on the other hand.

The third main bullet may be phrased "keep it smart and simple".

1. Use less or “managed austerity”



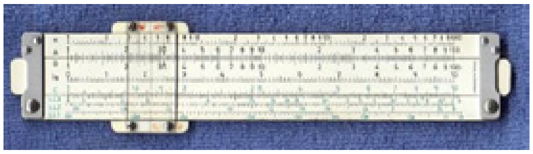
Policy solutions:

- Sound advice to decision makers
  Politicians are inclined to postpone decisions on disputed items
- Education of the population
- Living “here and now” and acting accordingly
  it’s easier to make noble plans for the future than taking real action now
- Frugality (using less) as opposed to greed
  nature doesn’t maximise but optimises within its very broad system boundaries
- How to “measure” wealth and prosperity?
  Include human arts and preserved nature as ways of providing well-being?

Slide 6
I think one of the few real options to avoid an unguided (gradual?) collapse of industrial civilization is to use less. This would require some form of “managed austerity”. As Nate Hagens pointed out earlier this year, chances of this going to work without taking into account human behaviour are close to zero (see http://www.theoildrum.com/node/5519).

2. Longer product lifetime

- **End planned and perceived obsolescence**
- Reduce complexity for improved quality



"transparent technology"

- Design for maintenance and repair

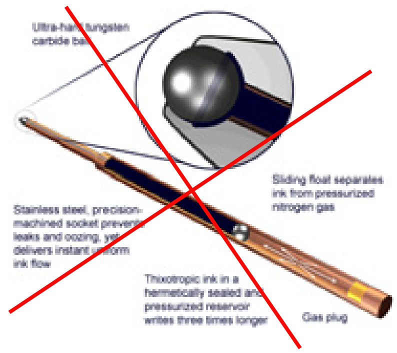
Slide 7

The first thing to abandon is planned and perceived obsolescence, especially applicable to various consumer products. Planned obsolescence is the strategy to make products with such a poor quality that the rate of consumption is maximized whilst the quality is marginally sufficient to prevent the products from remaining unsold. Perceived obsolescence is making people believe (using marketing) that they should buy new stuff to prevent them from being seen as morons or to be more successful etcetera.

Longer product lifetime is facilitated by reducing complexity (transparent technology is helpful here) and by design dedicated to easy maintenance and repair.
A slide-rule is a wonderful example of transparent technology: it's much easier to comprehend how calculations are being performed than using a calculator (do you know how the microchip works in detail?). Moreover, the calculator needs batteries and its lifetime is much less than a durable (non-plastic) slide-rule.
Cars used to have space left under the hood (sober designs), amongst others making it easy to change a light. Many modern cars (often luxury designs compared to the past) have to be taken to a workshop for a simple task such as changing a light.

3. Recycling and reuse of materials

- Design for reuse and intense recycling
- Reduce complexity to diminish waste

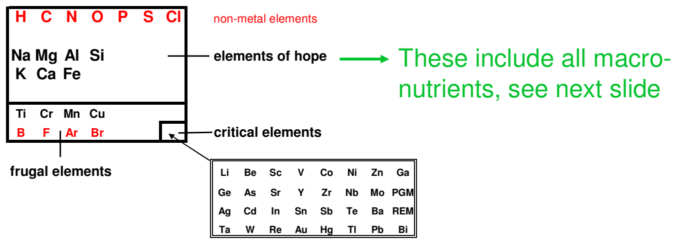


Slide 8

Recycling the current and constantly growing inventory of metal elements in use in various compounds and products is the obvious choice in order to buy time and avoid or diminish short- to medium-term supply gaps. Although recycling is nothing new, generally the intensity could be further enhanced. We should keep in mind though that recycling has inherent limits, because even 100% recycling (which is virtually impossible) does not account for annual demand growth. At the present course we need to continue to expand the amount of metal elements in use in order to satisfy demand from developing countries like China and India whose vast populations wish to acquire a material wealth comparable with the standard of living of the industrialized western world. Furthermore, recycling also costs lots of energy (progressively more with more intense recycling) and many compounds and products inherently dilute significant parts of their metal constituents back into the environment owing to their nature and use. So even with intense recycling, we will need a continued massive primary production to continue our present collective course.

4. Substitution of materials

- Substitute scarce metals using the "Elements of Hope"



- Design for use of Elements of Hope

- Dematerialisation (e.g. digital photography)
  beware of Jevon's paradox!

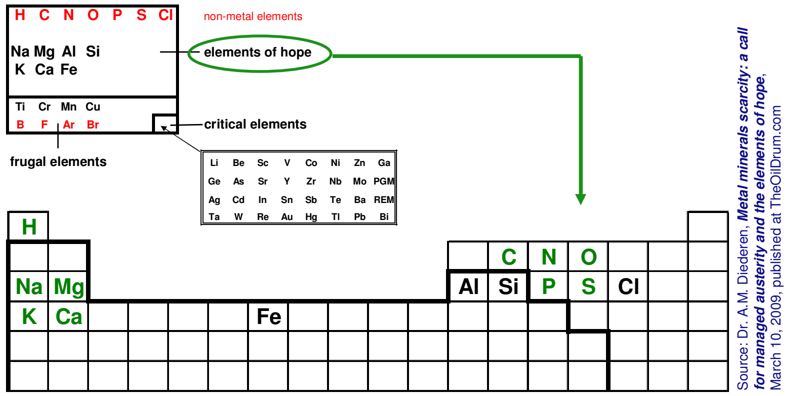
Slide 9
It is self-evident that - at our current level of technology - substitution of scarce metals by less scarce metals for major applications will lead to less effective processes and products, lower product performance, a loss in product characteristics, or will lead to less environmentally friendly or even toxic compounds. An important and very challenging task is therefore to realise the desired functionalities of such products with less scarce elements and to develop processes for production of these products at an economic scale. The best candidates for this sustainable substitution are a group of abundantly available elements, that I have baptised the 'Elements of Hope'. These are the most abundant elements available to mankind and can be extracted from the earth's crust, from the oceans and from the atmosphere. They constitute both metal and non-metal elements.

We can look at the remaining producible global reserves of metals as a toolbox for current and future generations.
The largest part of the toolbox is reserved for the elements of hope.
Another part of our toolbox is reserved for less abundant but still plentiful building blocks, the 'frugal elements'. These elements should be used predominantly for those applications for which there is no substitute with current technology (example: chromium for stainless steel). In this way their remaining reserves will last longer (most notably copper and manganese). For the sake of completeness, also the non-metals belonging to this category are included.
Finally a small corner of the toolbox is reserved for all other metal elements combined, the 'critical elements', which should be saved for essential applications where substitution with less scarce elements is not possible.

Solution direction no. 4 (substitution) is also linked to product and process (re)design (solution direction no. 5, slide 11).

I already covered dematerialization with slide 5 ("use less").

Elements of Hope: can be inherently environmentally friendly



the green elements are macronutrients

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Slide 10
Not coincidentally, all macronutrients of nature (all flora and fauna including the human body) are found among the elements of hope: nature either uses these elements (metabolism, building blocks) or has shown to be tolerant to these elements (in their abundant natural forms). Substitution based on the elements of hope therefore can be inherently environmentally friendly, they lack any heavy metal.
Hydrocarbons for production of materials (including plastics) could be extracted progressively more from biomass, albeit at a much lower extraction rate than from concentrated (fossilized) biomass (oil, natural gas and coal). The feasible scale size of biomass materials production is limited by amongst others water availability, competition with food requirements, availability of usable land (with proper replenishment of soil nutrients) and available energy.

5. Develop adapted/new products and processes

- Learn from the past when society was much less energy intensive, when we were much less affluent in a material sense
  example: low alloy steels from 1930s

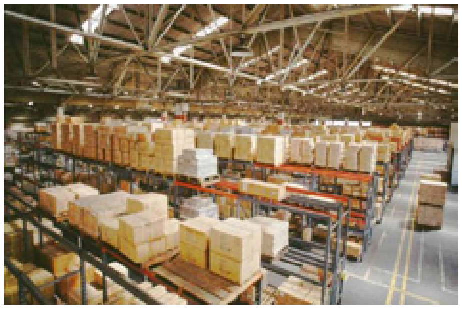
- Make much more products fit for replacements or upgrades of components
  example: retrofit of ships and airplanes

Slide 11
Not coincidentally, important material technology breakthroughs from a less energy-intensive and less material-intensive past may point towards material developments which are suitable for a less abundant future. An example is given by low alloy steels developed during the 1930s which are viable only recently for reliable and quality-consistent mass production owing to modern process technology.
The example of replacement of components or upgrades of components could be taken to extremes and thus include smaller items like household appliances and consumer products by making labour much less expensive relative to materials. It will (again) make more sense to repair things or replace subcomponents instead of discarding complete subassemblies or complete products.

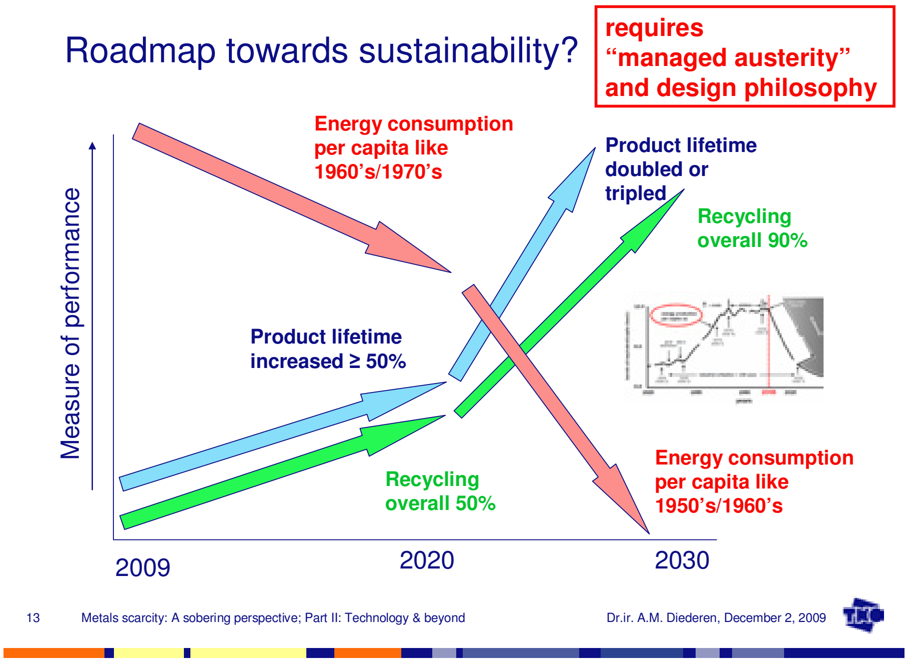
6. Buffers / stockpiles

- Keep buffers to cope with supply disruptions and to enable peak shaving

Simplest and easiest to realize solution, however not sustainable in itself



Slide 12
With the arrival of the age of scarcity industrialism (the term "scarcity industrialism" has been coined by John Michael Greer, see his extensive work at http://thearchdruidreport.blogspot.com/) a lot of common wisdom arisen in times of plenty might need some revision! One of them might be the "just in time" philosophy to minimize cost and maximize turn-around rates and profits. In times of scarcity with associated high price volatility it might be profitable again to have buffers to be able to cope with supply disruptions and to have the luxury to temporarily stop purchasing raw materials and products at unfavourable high cost during price peaks.
On a larger scale, national stockpiles of strategic metals, like the USA used to have during the Cold War, might be reinstated.



Slide 13

Because of the urgency and severity of the interrelated threats as discussed in Part I of this presentation, the goals in this roadmap are quite challenging; we should drastically reduce our energy use per capita. Maybe we should be lucky if we could maintain an energy per capita use (global mean value) by 2030 similar to the mid-1950s which is shortly after abandoning rationing in Europe after World War II. We have to drastically increase product lifetime and we have to recycle much more intensively. Of course, this roadmap is far from complete. Maybe some of you readers feel challenged to propose additions to this roadmap.

I order to realize the proposed roadmap, the six solution directions mentioned before and their combinations are useful. To recapitulate a few:

- Reduce complexity (if we’re going to (gradually?) collapse, complexity will be reduced anyway) in order to improve quality, reduce waste and facilitate a design philosophy enabling longer product lifetime, more intense recycling and dedicated substitution with less scarce materials.
- Try to dematerialize as much as possible.
- Learn from Mother Nature, who has learned to optimize rather than maximize (see slides 28 and 29).

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  - Out of the box thinking

Slide 14

One of the big pitfalls is to solve scarcity on a piece of paper or on a page in the blogosphere by notionally putting all of our attention, focus and means on solving a particular problem. For instance "an Apollo program to ramp up lithium production for electrification of all automobiles". Problem solved. The next problem is equally solved ("an Apollo program" to massively expand installed windpower or solar power generation and so on). Then, extremely put, these separate issues are summed up as if they were independent and all problems seem solved.

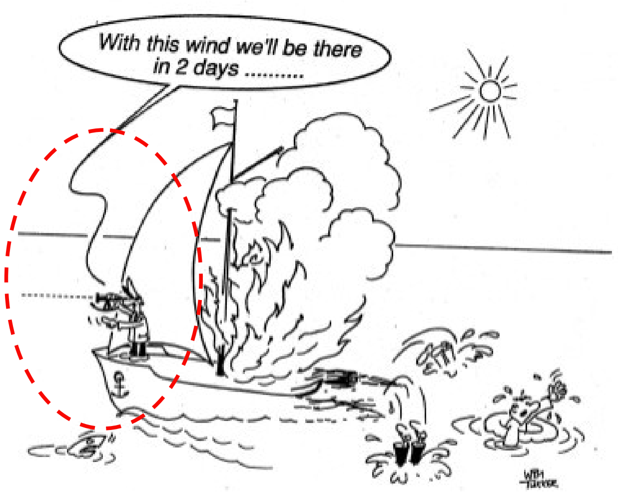
Of course we can only afford to spend a finite amount of effort and resources to the various problems in a given time.

The huge pitfall of suboptimization

"well intended actions can have unintended consequences"

Slide 15
This dark humour says it all. The situation with biofuels from corn comes to mind. Or farm fishing to "save" the wild fish, while these fish farms consume around one third of all wild fish harvested worldwide to feed the "tame" fish.

Context dropping



Slide 16
Of course we have to make abstractions from the complex reality in order to be able to make sense of it all, but the danger of abstraction is choosing the wrong boundaries, i.e. leaving essential parts out of the area of concern.

Context dropping

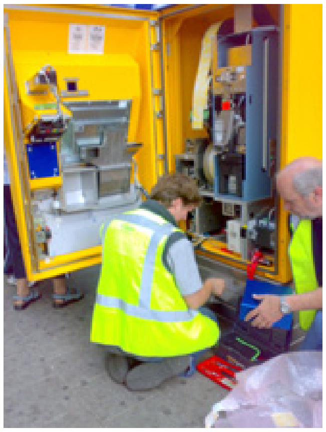
Scientific American, November 2009

Slide 17

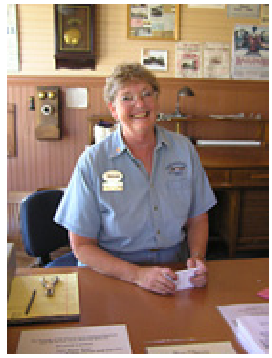
Leaving out essential parts from the area of concern may cause pipe dreams like this sympathetic plan (Scientific American, November 2009) to replace ALL fossil fuels by 2030. The plan includes construction of 490,000 1MW tidal turbines, 5,350 100MW geothermal plants, 900 1,300MW hydroelectric plants, 3,800,000 5MW wind turbines, 720,000 0.75MW wave converters, 1,700,000,000 0.003MW rooftop photovoltaic systems, 49,000 300MW concentrated solar power plants and 40,000 300MW photovoltaic power plants. They don’t explain where and how they are going to get the metals to construct all this (except put most of their hopes to recycling). They only mention a possible “materials hurdle” for a few already obviously constrained materials like neodymium, indium, tellurium and platinum.

Technology worship

Example: tickets for public transport



or



?

Technology worship

eyeball Mark I

or

?

Slides 18 and 19

Why do we apparently prefer sophisticated complex machines to take over normal-complexity jobs (no university degree required)? Not to mention the benefits of the human factor?

Why do we prefer sophisticated complex sensors to our own “eyeball Mark I”? Not to mention the fact that most people prefer live police officers in their neighbourhood?

Human behaviour

How to catch a monkey

Humans focus more on what they don't want to loose than on what they want to gain; see next slide!

Recommended reading:
Nate Hagens: ***The psychological and evolutionary roots of resource overconsumption revisited***, www.theoildrum.com, June 25, 2009

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Slide 20
Nate Hagens used a similar slide during the Oil Drum/ASPO Conference at Alcatraz, Italy in June 2009 to illustrate human behaviour. No solution framework is complete if it doesn't address human behaviour.

People want "solutions" without making (perceived) sacrifices

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Slide 21
The terms "green" and "sustainable" are often abused to legitimize "business as usual", i.e. faking feeling passionate for good stewardship of our planet while being focussed on maximizing profit. That does not mean of course that sustainability and profitability would be mutually exclusive. But try to make a distinction between the black, the white and the various grey shades here. If you don't want to be fooled, then stop fooling yourself. People want to hear "solutions" without making any real sacrifices.

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Slide 22
To quote Warren Buffet in this context: "You're neither right nor wrong because other people agree with you. You're right because your facts are right and your reasoning is right – and that's the only thing that makes you right. And if your facts and reasoning are right, you don't have to worry about anybody".

The 2nd law of thermodynamics

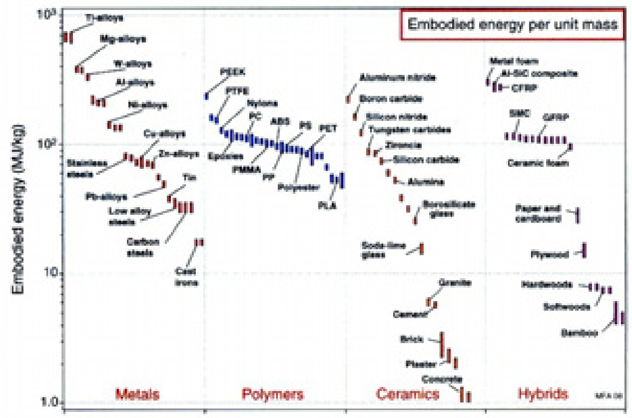
- Energy conversions are always accompanied with losses (not in quantity but in quality)
- It is much more easy to mix pure salt and pure pepper than to separate the mixture back into its separate ingredients

- Essence of the 2nd law of thermodynamics (within the context here): **it costs energy to concentrate energy**

Slide 23
Energy can neither be created nor destroyed, and left to itself, it always flows from higher concentrations to lower concentrations and this means that you can't concentrate energy without using energy to do it. A system that has energy flowing through it can develop eddies in the flow that concentrate energy in various ways. Living things like we humans (and the human body) are such eddies: we take energy from the flow of sunlight through the system of the earth in various ways (as food but also as stored sunlight in the form of fossil fuels), and

use it to maintain concentrations of energy above ambient levels. It takes energy to concentrate energy. If the rate and scale of our energy consumption keeps continuing well above ambient levels (with stored energy being rapidly depleted), we'll soon hit physical limits.

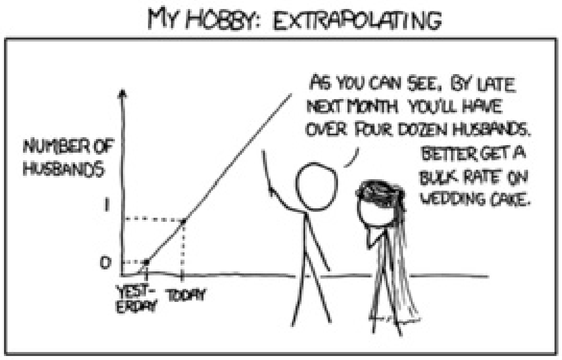
Embedded energy in materials



Source: Michael F. Ashby,
Materials and the environment – Eco-informed material choice, 2009

Slide 24
The graph taking from the book from Ashby (2009) gives an impression of the energy embedded in various materials. Please be aware of the fact that the values of embedded energy are NOT constant: a few decades ago the energy embedded in metals was often higher (see for instance "Tomorrow's Materials" from Ken Easterling), now it's on average lower thanks to efficiency gains / technology progress and a few decades from now the energy embedded in metals will probably again be higher on average (see part I of this presentation).

Your greatest assets: skills, experience, knowledge and sound judgements



Most models are descriptive, not predictive

Correlations can be wrong; correct correlations are applicable to the PAST but don't necessarily predict the future

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Slide 25
People often confuse the descriptive quality of models with their perceived predictive power. Models are always abstractions of (real or perceived) reality and therefore should always be applied using common sense.

Contents of Part II

- **Solution framework with intrinsic value**
  - Amongst others the **Elements of Hope**
  - Roadmap towards sustainability?
- **The huge pitfall of suboptimization**
  - Context dropping
  - Technology worship
  - Human behaviour
- **Let sound engineering knowledge and practice be your base guide**
  - You can't beat the laws of nature using technology
  - "All models are wrong, some are useful"
- **Creativity and inventivity are "without limit"**
  - Let nature inspire you
  - Out of the box thinking

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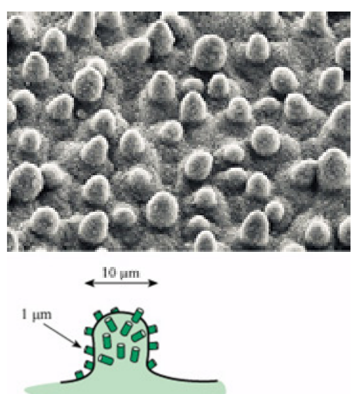
Slide 26
The resource-poor future pictured in this paper strongly appeals to the ingenuity and creativity of engineers and scientists as well as many other people to cope with a limited choice and availability of resources. Fortunately, unlike fossil fuels and metal mineral resources, ingenuity and creativity are "unlimited".

Nature

- Nature has several billion years of experience finding out how to optimize processes instead of maximize them. The question is not whether we can beat nature, but if we can match nature.
- By the way: we are part of nature!
- Nature’s way of assuring resilience of ecosystems is biodiversity; lesson to be learned here: strive for multiple proper solutions instead of “monocultures”

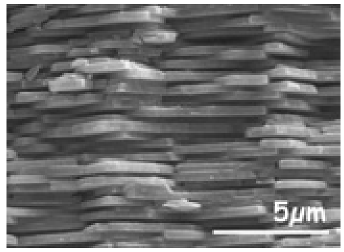
Slide 27
We are disconnected from nature. If you are driving in your car or are sitting on a boat, in a train or in an airplane, if you are working at your office (if that’s your job) or if you are at home, look around you. Besides bacteria and some other small stuff invisible to the naked eye, how many living things are around you? Most of the time, the only living things around you are other (disconnected) people. The rest is lots of dead stuff.

Nature

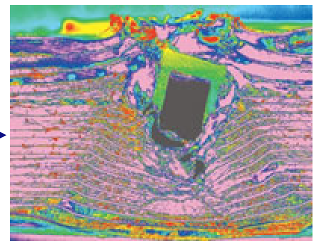


Water repellent surface of lotus leaf

Nature



Shell of the red abalone



Biomimicry using titanium and aluminium (stops high velocity fragment)

Source: University of California, San Diego

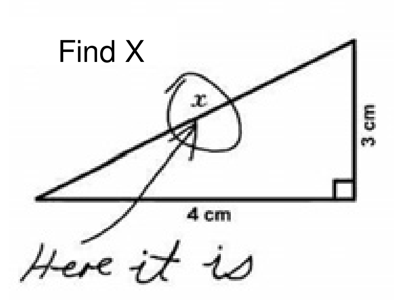
Slides 28 and 29

Nature has inspired humankind throughout history for its beauty and ingenuity. Where humans tend to maximize, nature has learned to optimize within its vast system boundaries. Some humans tend to measure and compare the efficiency of a leaf to that of a high-efficiency solar cell made from semiconducting materials. Those people miss the point that a leaf provides much more than just a way of converting solar radiation into another form of (partially stored) energy.

Humans have “nanotechnology” (often used for things on a microscale as well), whereas nature is capable of “engineering” on a molecular scale with far less energy and auxiliary materials then humans. The question is not whether we can beat nature, but if we can match nature.

The water repellent surface of the lotus flower is a well-known example. Another nice example is the shell of the red abalone which consists of a large number of small and hard but brittle lime platelets (97%), kept together by a kind of protein adhesive (3% of the shell). The University of San Diego has mimicked the shell of the red abalone by letting thin layers (approximately 1 mm) of aluminium and titanium react with each other. This results in hard layers of a titanium-aluminide intermetallic phase and ductile layers of titanium. The intermetallic phase of titanium aluminide is the complement of the abalone’s hard calcium carbonate phase, and the titanium alloy layer mimics the abalone shell’s compliant protein layers. This hybrid material is useful for impact resistant applications.

“If you don’t think out of the box, the box may become your coffin”



“Significant problems cannot be solved at the same level of thinking with which we created them” (Einstein)

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Ocean/sea energy harvesting and simultaneous primary metal production? (Mg?, Li?)

Energy islands (by Robert and Rudolf Das, 1999)

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Slides 30 and 31

Fine examples of “out of the box thinking” are provided by the Dutch Das brothers. In their beautiful and inspiring work “Visions of the Future – A New Golden Age for the Low Countries” (1999), among many things they envisage the construction of so-called energy islands in the North Sea. Combining their ideas with metals scarcity, it might be feasible on some scale in future to use excess electric power generation not for temporary storage in electric accumulators but instead use this for the primary production of metals from seawater. Magnesium has a relatively high concentration in seawater and possibly other valuable metals like lithium could be produced as well. Of course such primary production of metals from seawater would be (much) more expensive then current primary production on land, but nevertheless it might be interesting as an alternative (making by-products) to battery storage of excess electric power. A country like The Netherlands would then be able to have (to some extent) primary production of some useful metals using its own resources.

Our hope for the future includes **YOU**

Slide 32
I sincerely hope this second part of my presentation has motivated you to pursue proper and realistic solution directions and has inspired you to tap into your own unique resources of inventiveness and creativity.

Parts of this presentation have been presented earlier by me during the Oil Drum/ASPO Conference at Alcatraz, Italy on June 28, 2009 in a presentation titled "***Global Resource Depletion: A roadmap towards sustainability?***".

Part of the text used in this document has been published earlier this year in my March 10, 2009 paper "***Metal minerals scarcity: A call for managed austerity and the elements of hope***", published (with 198 comments) at the website TheOilDrum.com on May 4, 2009 (http://europe.theoildrum.com/node/5239) and available as pdf at http://www.materialscarcity.nl/Downloads.aspx.