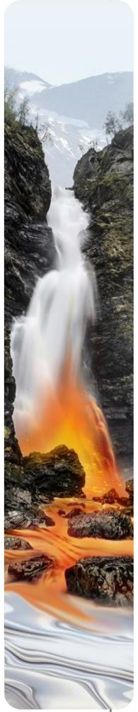


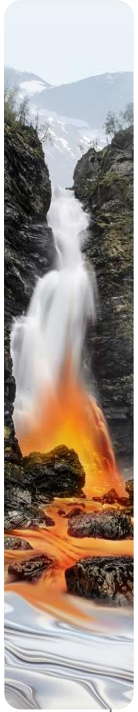
«The importance of Silicon to Society»

Professor Leiv Kolbeinsen, Dep. Mat. Sci. & Eng., NTNU

Including a short course in Process Metallurgy
- or rather "Resources, Energy & the Environment"

- Climate change has gone from **If** to **When** to **Now** (World Bank)
- Everyone is entitled to his/her own **opinion**, but not his/her own **facts**.

metal production



REE -Group

What/Who am I?

Metal production/-reduction/-oxidation:

- Liquid Slags and Metals
- Chemical reactions, Mass and energy transfer, Phase relations/transitions
- Process modeling

«Environmental metallurgy»:

- Recycling of metals/slags/dross/energy etc
- Reduction materials
- Waste material prevention
- Resource characterization and optimization

“Process symbiosis (Industry parks)” in cooperation with e.g. TSO Sustainability

Outline

3 Introductary postulates

Industrial overview

Resources, Energy & Environment

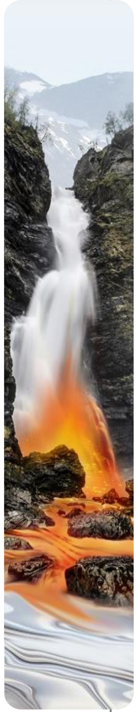
- About «Får-i-kål» & «Kransekake»
- Words on energy
- From Oxide to Metal
- Why CO_2-emission?

CE: Cirkular (Green) Economy

- Process metallurgy - A role i CE?
- Industrial symbiosis (Industry parks)

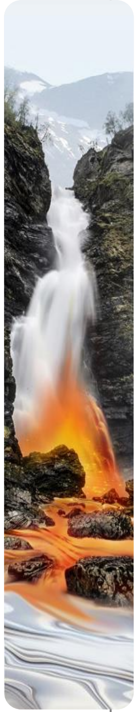
metal production

Three Postulates:



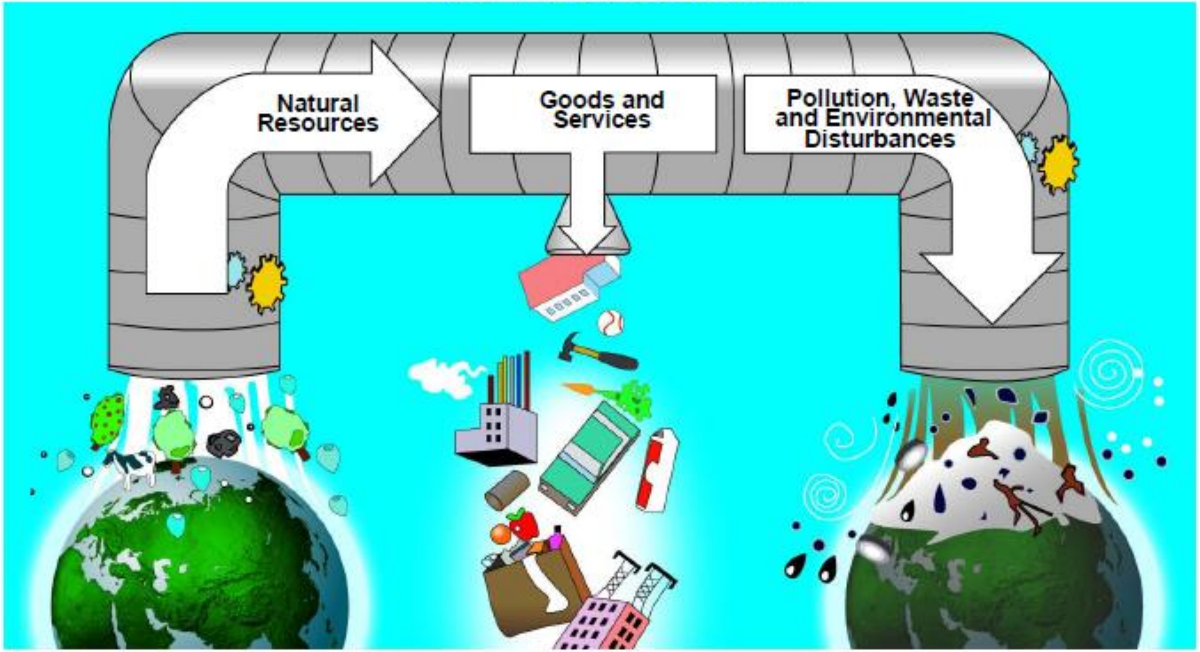
- The sources of materials obtained from the Earth's crust, though very large, are finite.
  - This is a fact
- The capacity of the Earth's ecosystem to cope with the wastes from human production and consumption is finite and by many measures is approaching the limit.
  - This has universal support from scientists and other professionals with deep knowledge of the issue.
- The neo-liberal economic model of unrestrained capitalism as practiced by developed and many developing countries, despite its obvious material benefits over the past decades, has resulted in social and environmental problems on a scale that cannot be solved by market forces alone.
  - This is a hypothesis although increasingly supported by empirical evidence.

W. J. Rankin «Minerals, Metals and Sustainability – Meeting Future Material Needs» CSIRO publishing, 2011



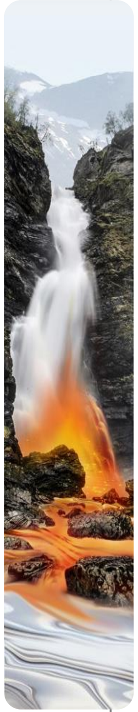
Resource Depletion and Waste

Approximately 10% of What Goes 'in the Pipe' Comes Out as Goods and Services, the Rest Is Waste



Source: wri.org

metal production



3 Introductary postulates

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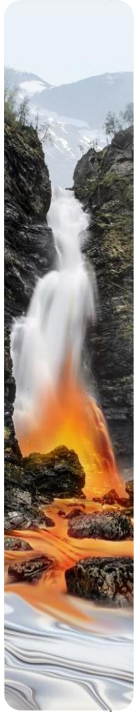
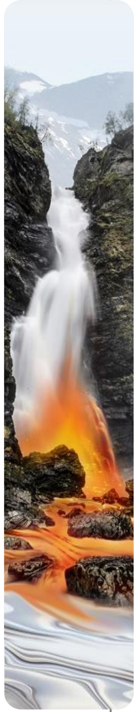
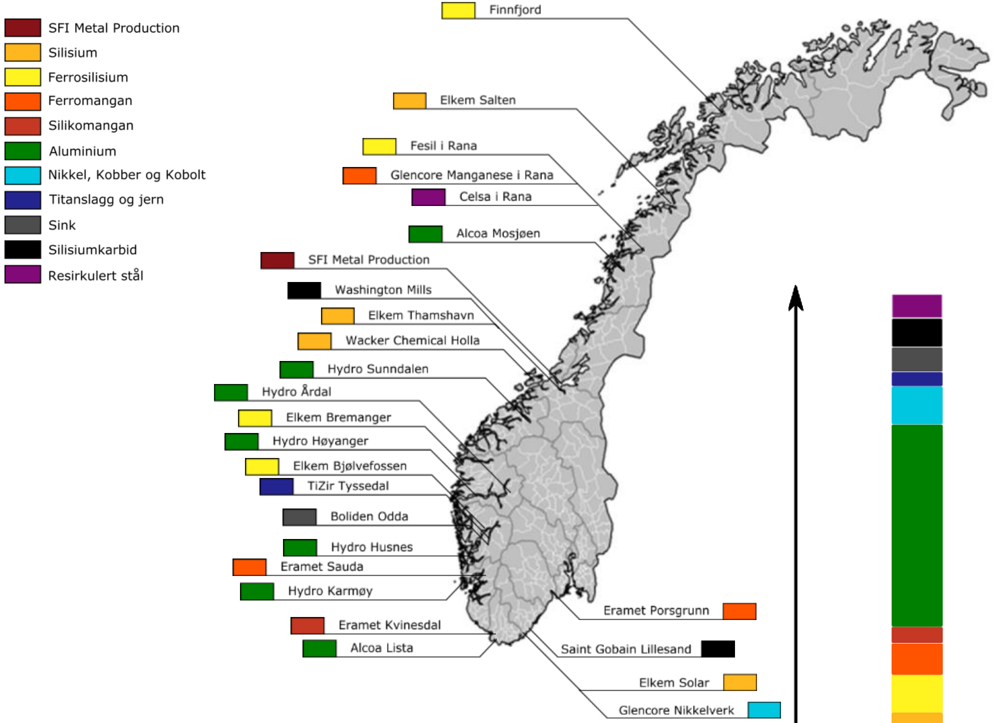


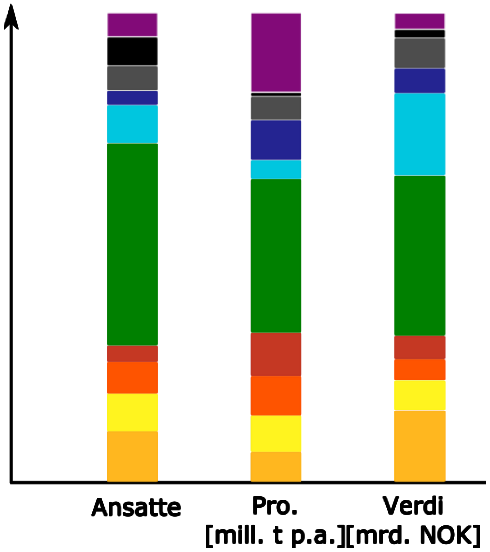
Position	Plant name when started	Year	Product started	Plant name today	Products today	Comments
1	Chistiania Spigerverk	1853	Iron		Closed 1989	Elkem 1972 Jernverket 1984
2	Meraker	1898	CaC2		Closed 2006	Owners: Union Carbide and Elkem
3	Hafslund	1899	CaC2 (1899 - 1967) FeSi (1908 - 2002)		Closed 2002	
4	Bjølvefossen Ålvik	1905	CaC2 Later FeSi and FeCr	Elkem Bjølvefossen	FeSi and Foundry Products	Elkem from 1986
5	Odda smelteverk	1906 (1924)	CaC2		Closed 2002	British Oxygen Company from 1937
6	Fiskaa Verk (1917)	1907	Fertilizers	Elkem Solar	Solar Si, carbon	Rebuilt 2005-2008
7	Vennesla	1908	Aluminium	Hydro Vennesla	Aluminium	Hydro Aluminium
8	Kristiansands Nikkelraffineringsverk A/S	1910	Nickel	Glencore Nikkelverket	Nickel, coppercathodes, cobolt, (gold, silver)	Falconbridge Nikkelverk A/S (1929) Xstrata (2006)
9	Arendal SiC	1912	SiC	Saint-Gobain Ceramic Materials	From 2005 only processing of SiC	
10	Eydehavn	1912	Aluminium		Closed 1975	
11	Sulitjelma smeltehytte	1912	Cu		Closed 1991	
12	Pea Porsgrunn	1913	FeMn/SiMn	Eramet Porsgrunn	FeMn	Eramet
13	Electric Furnace Products Com	1915	Mn	Eramet Sauda	FeMn SiMn	Union Carbide to 1981 Elkem 1981-99 Eramet from 1999
14	Tinfoss Jernverk AS	1916	Iron		Closed 1987	FeSi, SiMn and Silicon
15	Tyssedal	1916	Aluminium	TiZir Titanium and Iron	Titania slag and Iron	Repurposed in 1988 from Al
16	Elkem Bremanger	1917	Iron	Elkem Bremanger	FeSi, Silgrain	
17	Det Norske Zinkkompani A/S	1924	Zink	Boliden Odda As	Zinc / AlF	
18	Lilleby smelteverk	1927	FeSi		Closed 2002	
19	AS Tafjord Smelteverk	1930	FeSi		Closed 1962	
20	Orkla Metall	1931	Cu and S FeSi from 1964	Elkem Thamshavn	Si + microsilica	Orkla to 1986 - Elkem 1986 -
21	Norsk Jernverk	1946	Iron/Steel	Celsa Armeringsstål, FeSil, Glencore Manganese	Steel FeMn FeSi SiMn	Started 1955 Restructured 1988
22	Årdal	1948	Al	Hydro Aluminium AS Årdal	Al	Hydro Aluminium
23	Sunndal	1954	Al	Sunndal Primary Production	Al	Hydro Aluminium
24	Mosal Mosjøen	1958	Al	Alcoa Mosjøen	Al, carbon	Elkem/Alcoa - Alcoa 2009
25	Fesil Nord	1960	FeSi	Finnfjord Smelteverk	FeSi	Finnfjord Smelteverk from 1983
26	Holla verk	1962	FeSi	Wacker Chemicals Norway As Holla Metall	Silicon	FESIL sold to Wacker 2010
27	Husnes	1962	Al	Hydro Husnes	Al	Rio tinto / Hydro
28	Orkla Exelon	1962	SiC	Washington Mills AS	SiC	Washington Mills 2004
29	Hydro Karmøy	1963	Al	Karmøy Primary Production	Al	Hydro Aluminium
30	Elkem Salten	1967	FeSi	Elkem Salten	Si FeSi	
31	Elkem Lista	1971	Al	Alcoa Lista	Al	Elkem/Alcoa - Alcoa 2009
32	Tinfoss Øye	1974	SiMn	Eramet Kvinesdal	SiMn	Eramet from 2008

Production

Overview

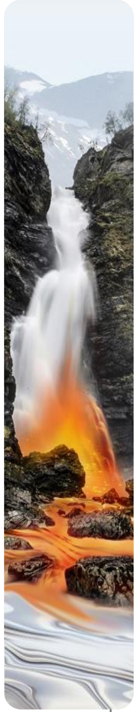


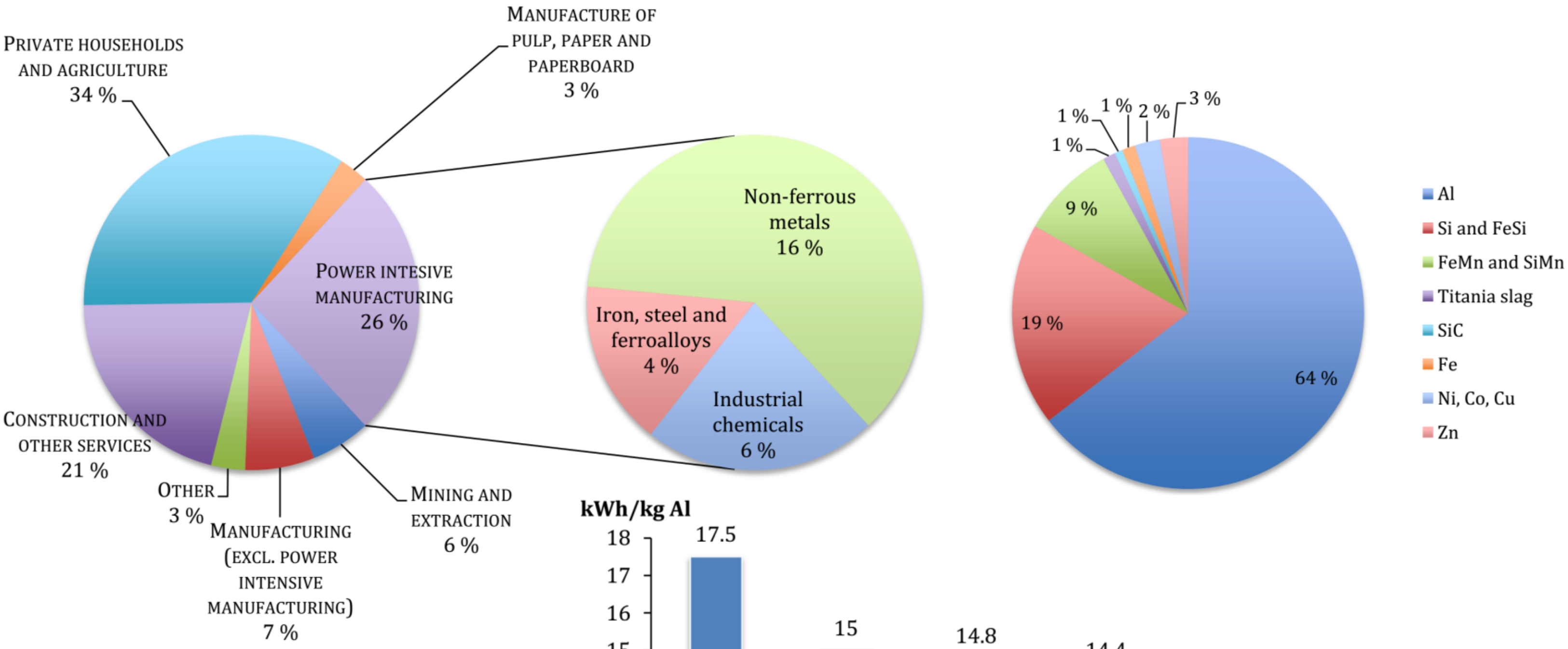


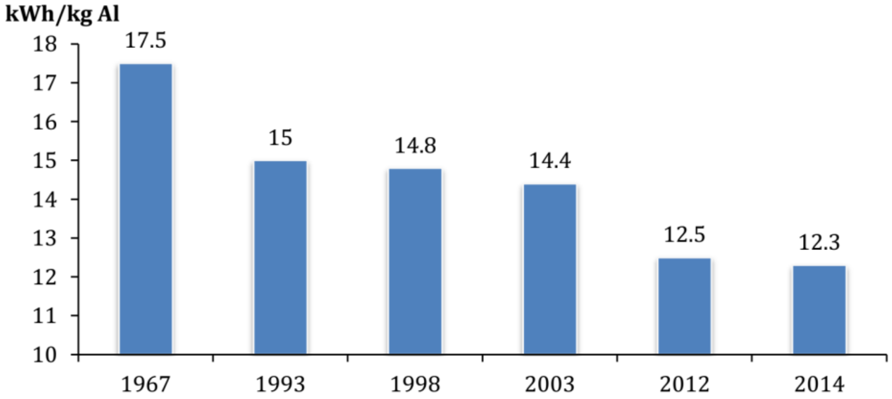


metal production

Net consumption of electricity in Norway.

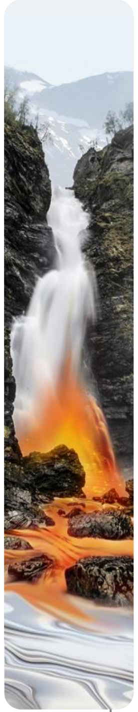


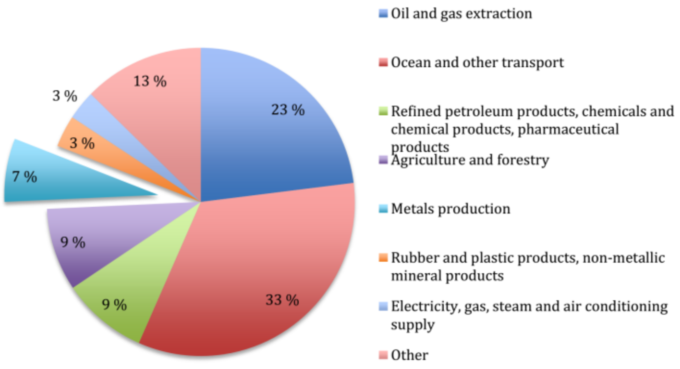


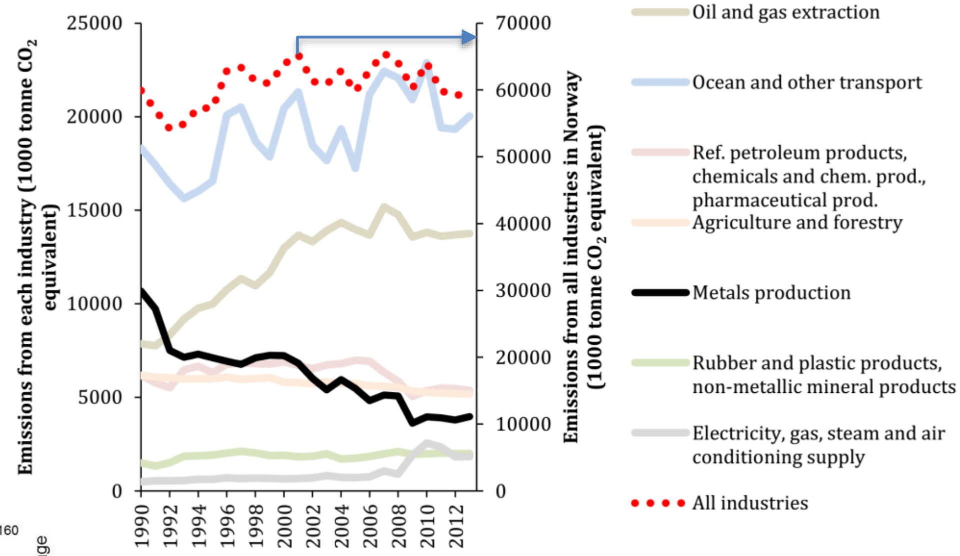


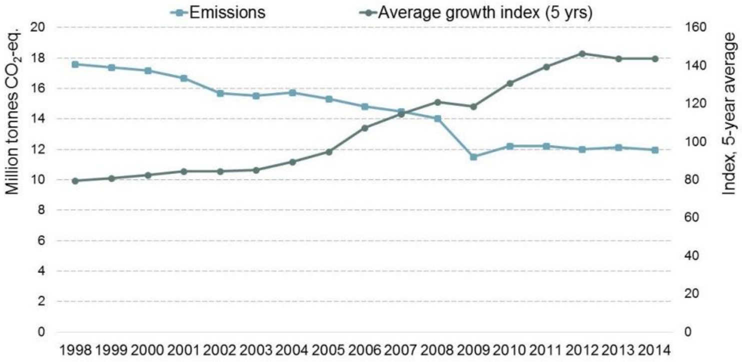
metal production

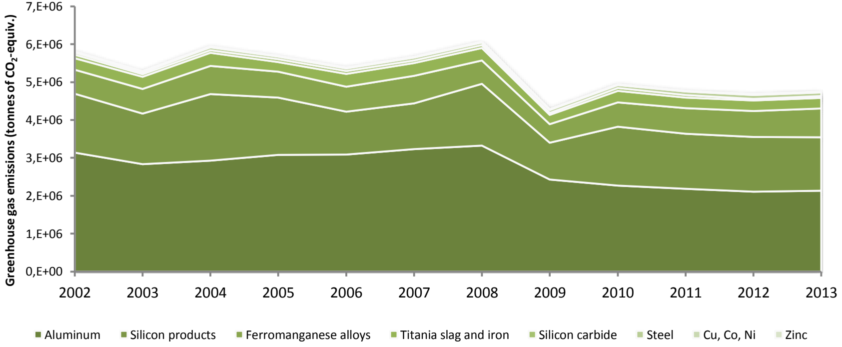
Greenhouse gas emissions by industry in Norway in 2014



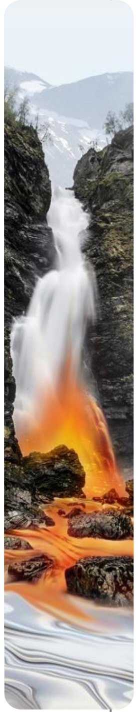








www.norskindustri.no/veikartforprosessindustrien



3 Introductary postulates

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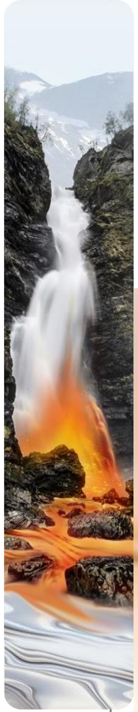


Får-i-kål (Mutton [Sheep] in Cabbage)

Without Salt and Pepper?

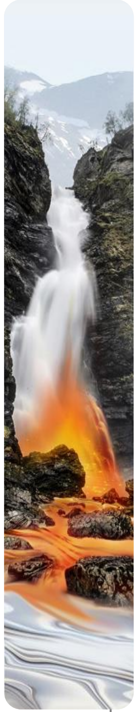
Will I still be fårikål?

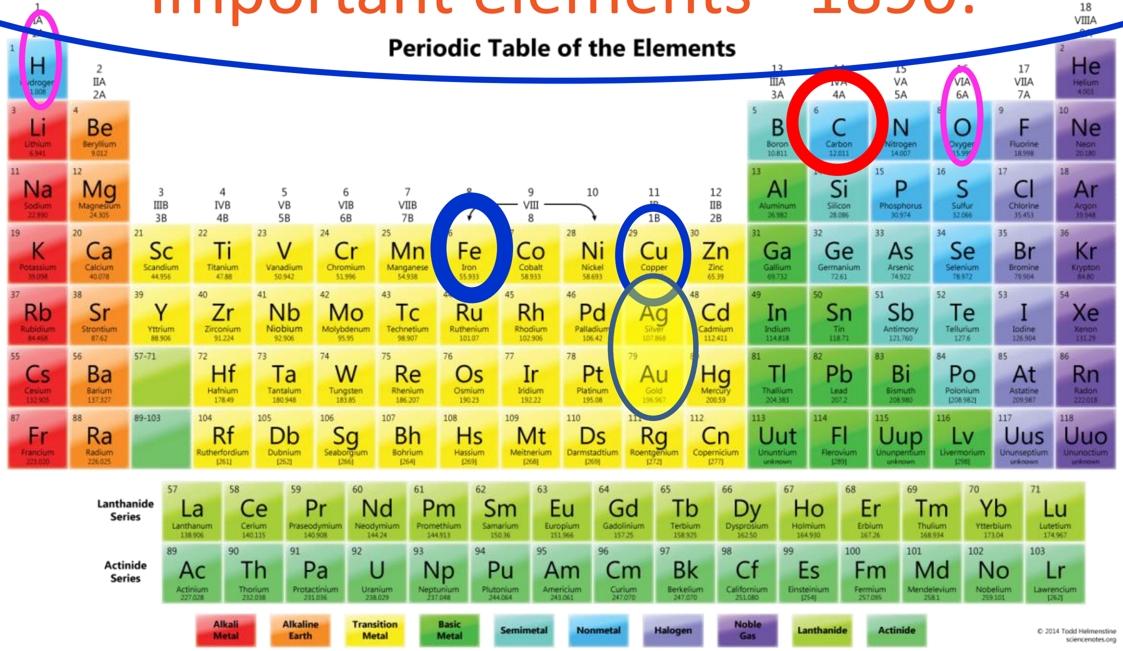
Kransekake (Almond Tower cake)

Using an almond-grinder is cumbersome; food-processor is much easier? (Is that so?)

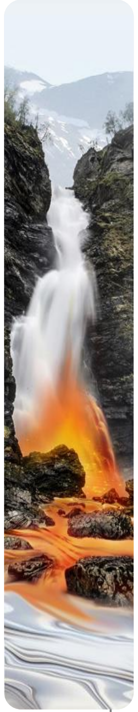
metal production

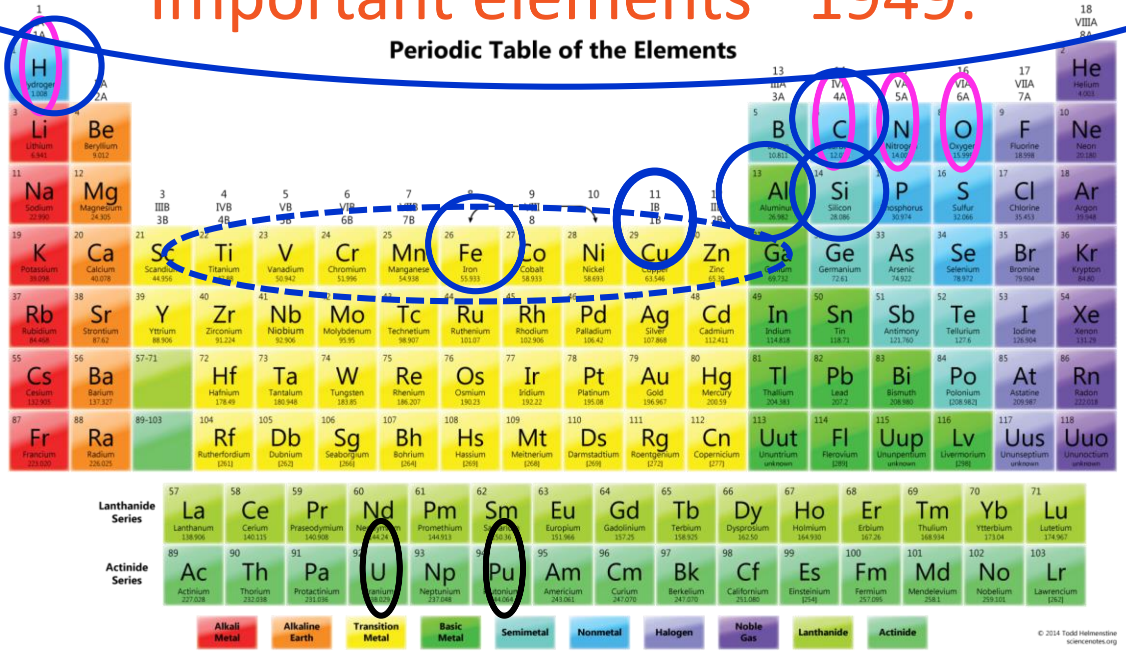
Food, Energy & Material use
Important elements ~1890:





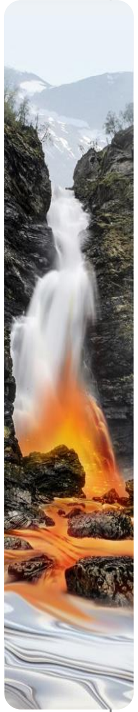
Food, Energy & Material use
Important elements ~1949:

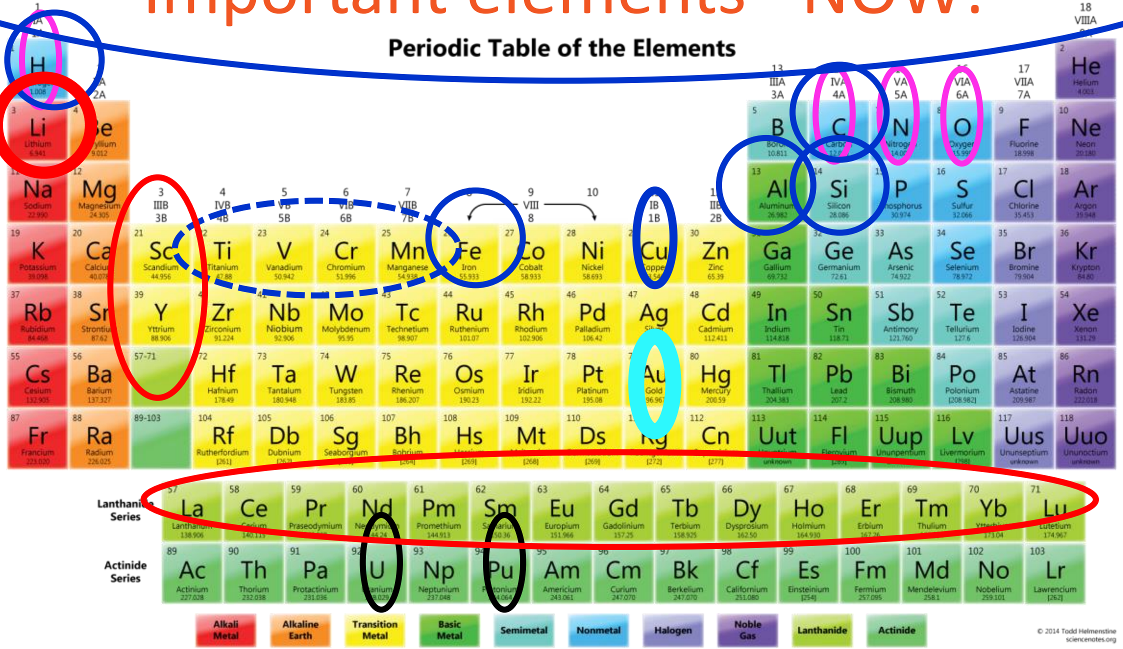




metal production

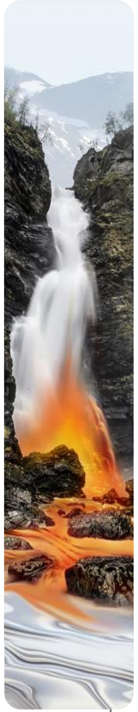
Food, Energy & Material use
Important elements ~NOW:

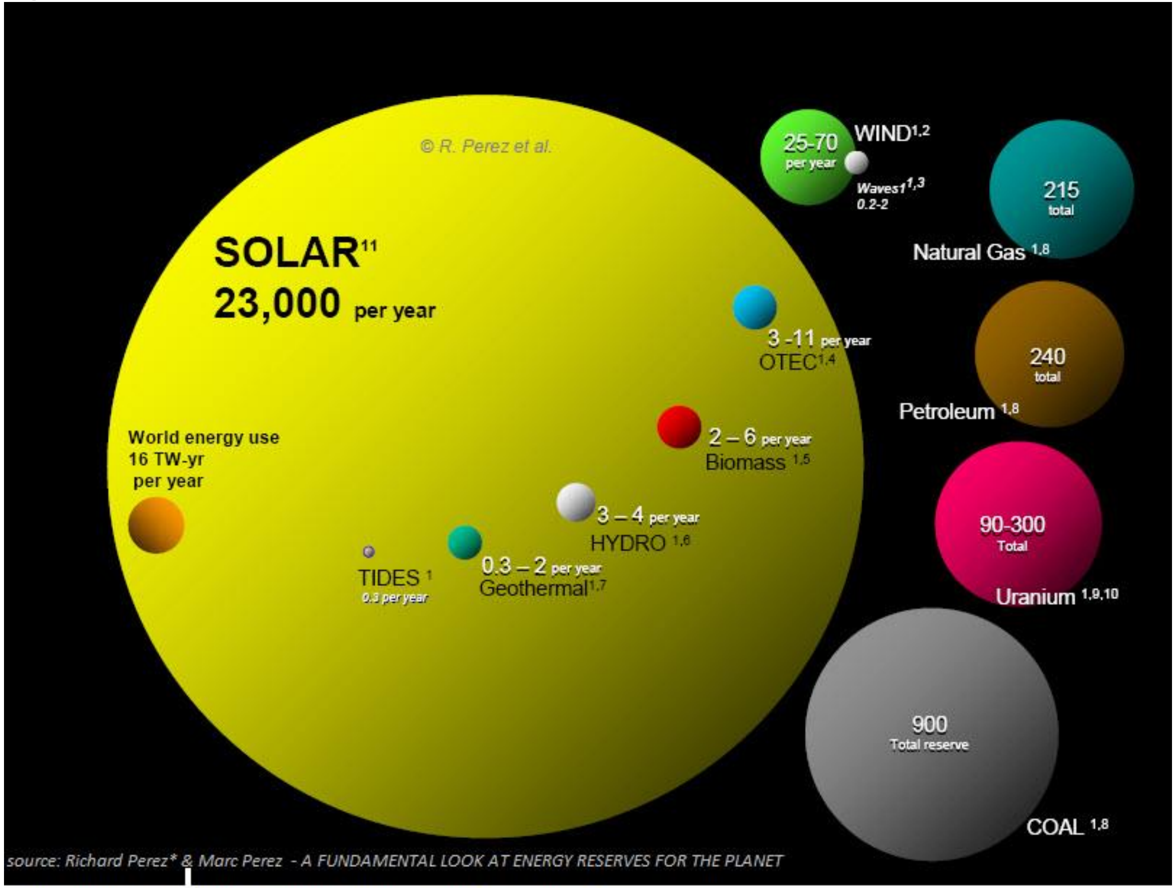




metal production

Energy Crisis?



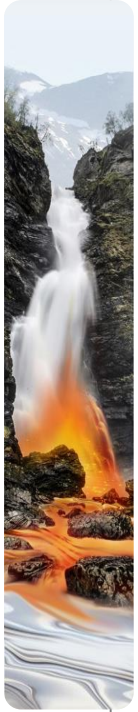


Comparing finite and renewale planetary energy reserves)Terawatt-years).
Total recoverable reserves are shown for the finate resources.

The **annual global energy consumption**, for 2009, was estimated at 16 TW-yrs (or 140,160,000,000 KW-hrs) illustrated by the orange sphere on the left-most side

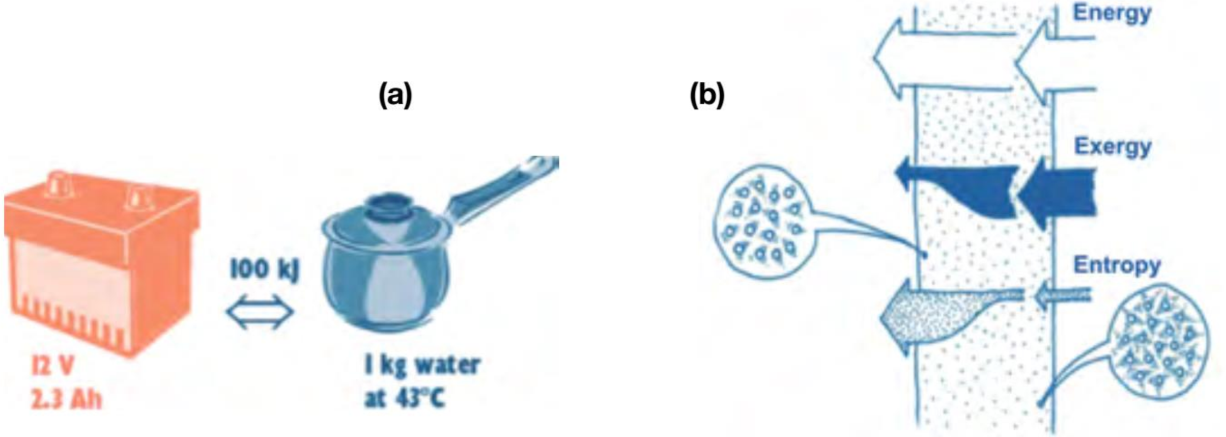
Energy quality – Energy – Exergy

(what is good use of renewable energy?)



Massflows are usually also Energy flows

- Exergy = f(T, P, a_i) – Quality & amount: **Ability to perform work**
- => Exergy is what people usually mean when they say «Energy»

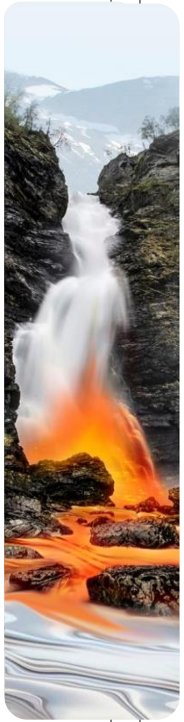


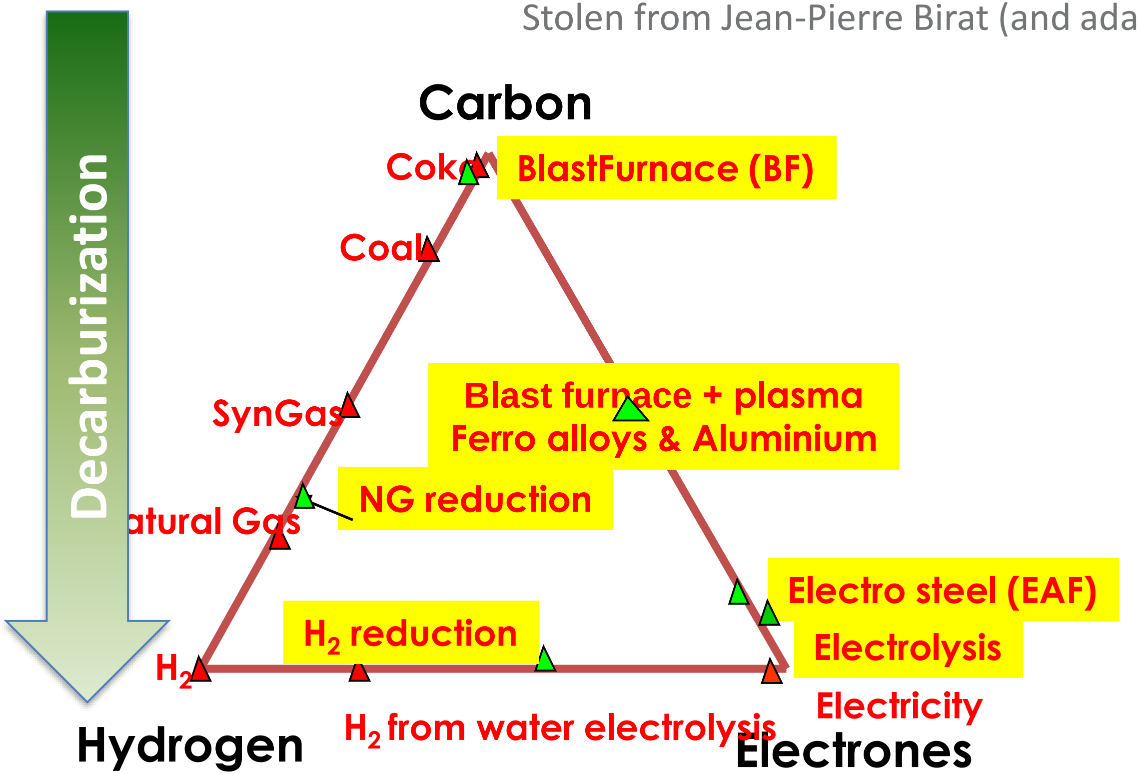
It is wise to distinguish between:

- Heat
- Fuel
- Reducing agent
- Electricity

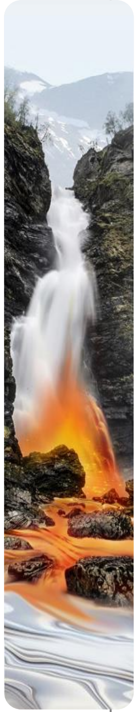
Metal production: Reductants/Energy sources

Stolen from Jean-Pierre Birat (and adapted by me)





metal production



Copper-like (chalcophile) e

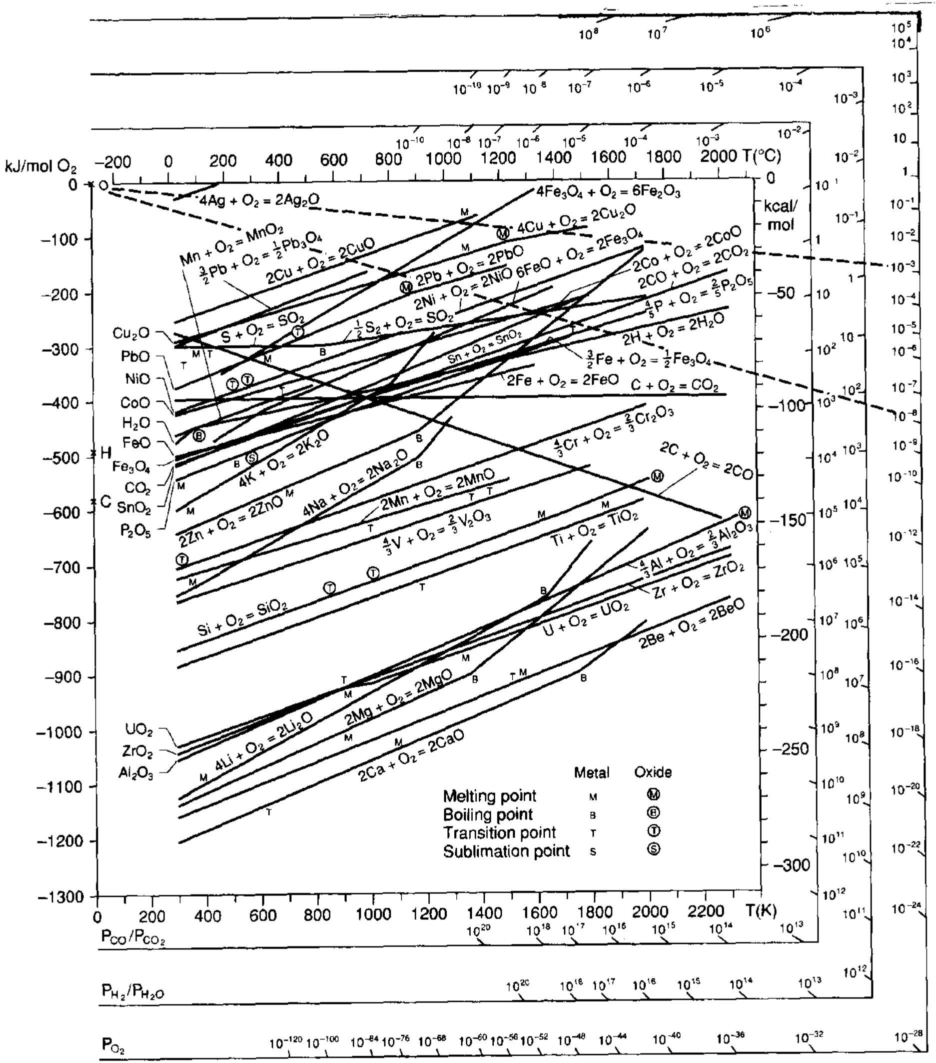
- Occur primarily in
  can be utilised as f
  the other hand the
  caused environme
  problems by diluti
  stacks are blatant e
  when ill formulate

Strong oxide forming (lith

- Silicon, Aluminum,
  abundant in natur
  require large amou
  or indirectly for ge

Iron-like (siderophile) elem

- This group also inc
  important additive
  10 times higher th
  most recycled (>40
  the amount of scra



metal production

$MeO_x + xR = Me + xRO$

[Me = Metal, MeO_x = metal oxide;

R = Reducing gas (H_2 or CO) - RO = Oxidized Reducing gas (H_2O or CO_2)

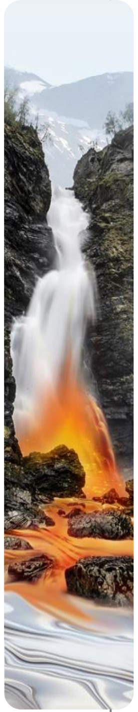
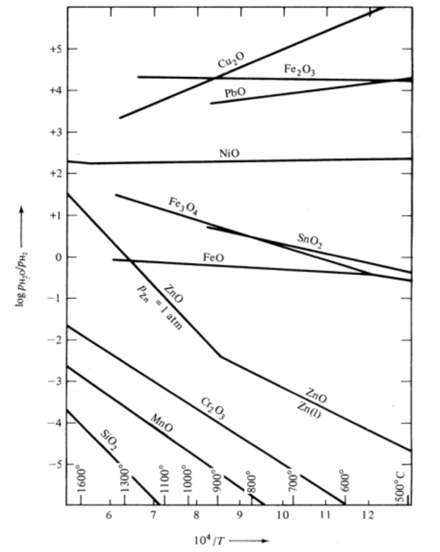


Figure shows dependance of $\log(P_{RO}/P_R)$ on temperature for the equilibrium $MeO_x + xR = Me + xRO$ when R equals H_2.



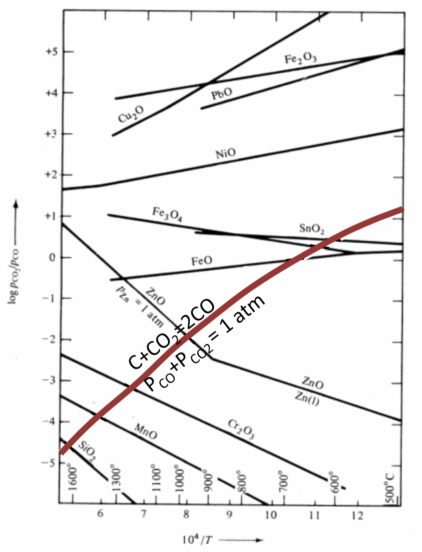


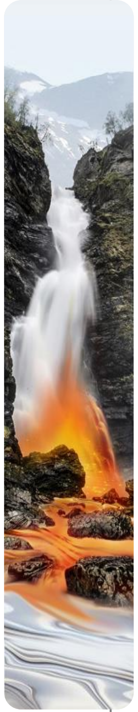
Figure shows dependance of $\log(P_{RO}/P_R)$ on temperature for the equilibrium $MeO_x + xR = Me + xRO$ when R equals CO.

At first sight these two collection of curves look the same, but:

When solid carbon is present the CO_2 from reduction will react with C and form new CO gas that can reduce metal oxide once more.

Reduction with Hydrogen do not involve a similar function.

Reduce => Refine
vs.
Refine => Reduce



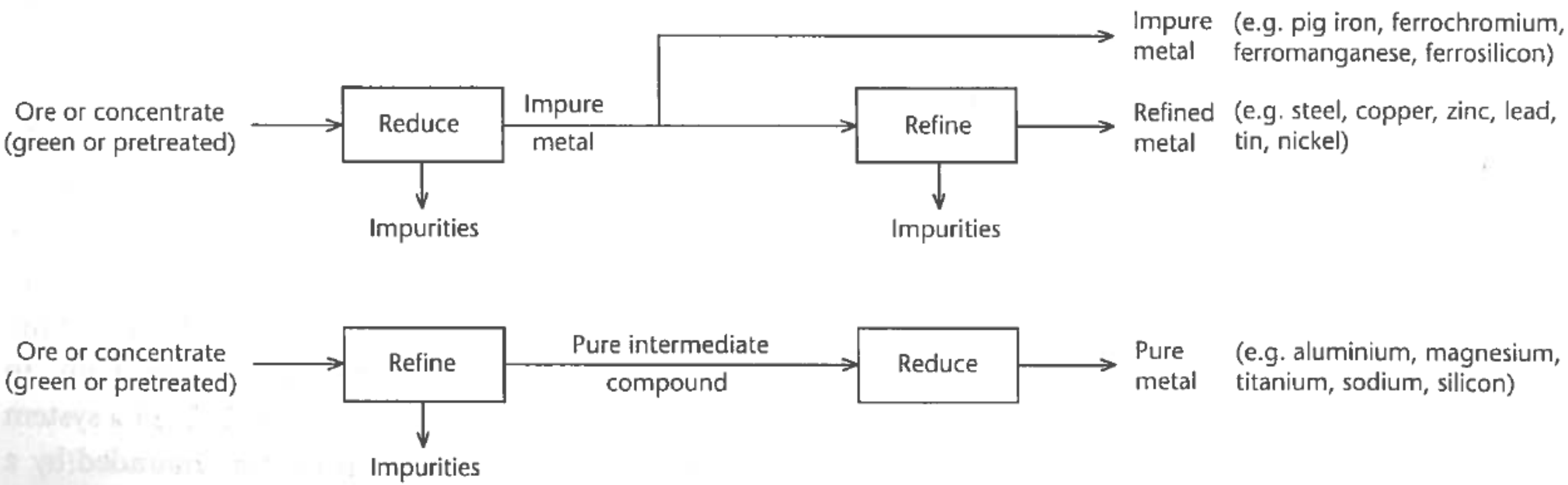
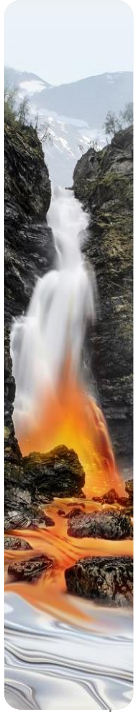


Figure 8.4: The reduce–refine and refine–reduce sequences for the production of metals.

W. J. Rankin «Minerals, Metals and Sustainability – Meeting Future Material Needs» CSIRO publishing, 2011

metal production

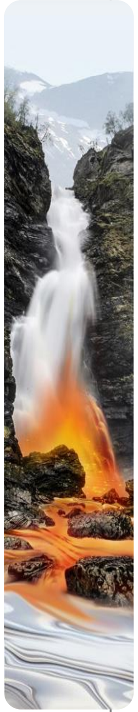
Silicon is used in a number of processes/applications



- **Ferrosilicon** is used both for removing oxygen from liquid steel and cast iron (de-oxidation), as well as being an alloying element. The end-users are the automotive and construction companies.
- **Silicon is mainly** used for alloying other metals, especially aluminium (about 45 % of global silicon production is for alloying purposes). As for ferrosilicon, the end-users are automotive and construction companies.
- **Silicon is also** used as feedstock for the silicone industry (about 40 %). The end products are typically cosmetics, construction, anti-foam, medical equipment, automotive parts, etc.
- **Silicon is an essential ingredient** in semiconductors and in the solar industry (about 10-15 % and growing). In electronic equipment, the amount of pollution elements must be as low as in the ppb (parts per billion) range. More than 90 % of all electronic components are based on silicon. Another important market for the industry is silicon used in solar cells. Here the pollution level is in the ppm (parts per million) range.

The Renewable energy leader globally

ICRIER Working Paper 329 Ashok Gulati, Stuti Manchanda, Rakesh Kacker: ***Harvesting Solar Power in India!*** Aug 2016



Germany – The Renewable energy leader in total cumulative installations globally and leads by a successful model. In 2014:

Country	Cumulative installed solar capacity [GW]	MW/million people
Germany	38	469
China	28	20
Japan	23	181
India	3	2.3

Germany's 38 GW accounts for nearly 21percent of total solar installed capacity in the world (2014). All this makes Germany a key leader in solar power.

There are 2 key elements in Germany's solar power success that have contributed to substantial rooftop installations:

guaranteed grid connection to renewable energy producers and

Feed-in-Tariffs (FITs)

By 2013,

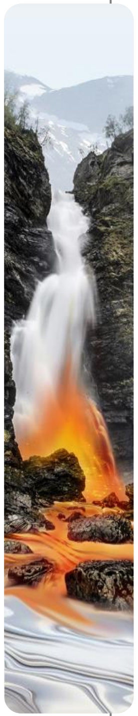
23 percent of global residential solar rooftops and

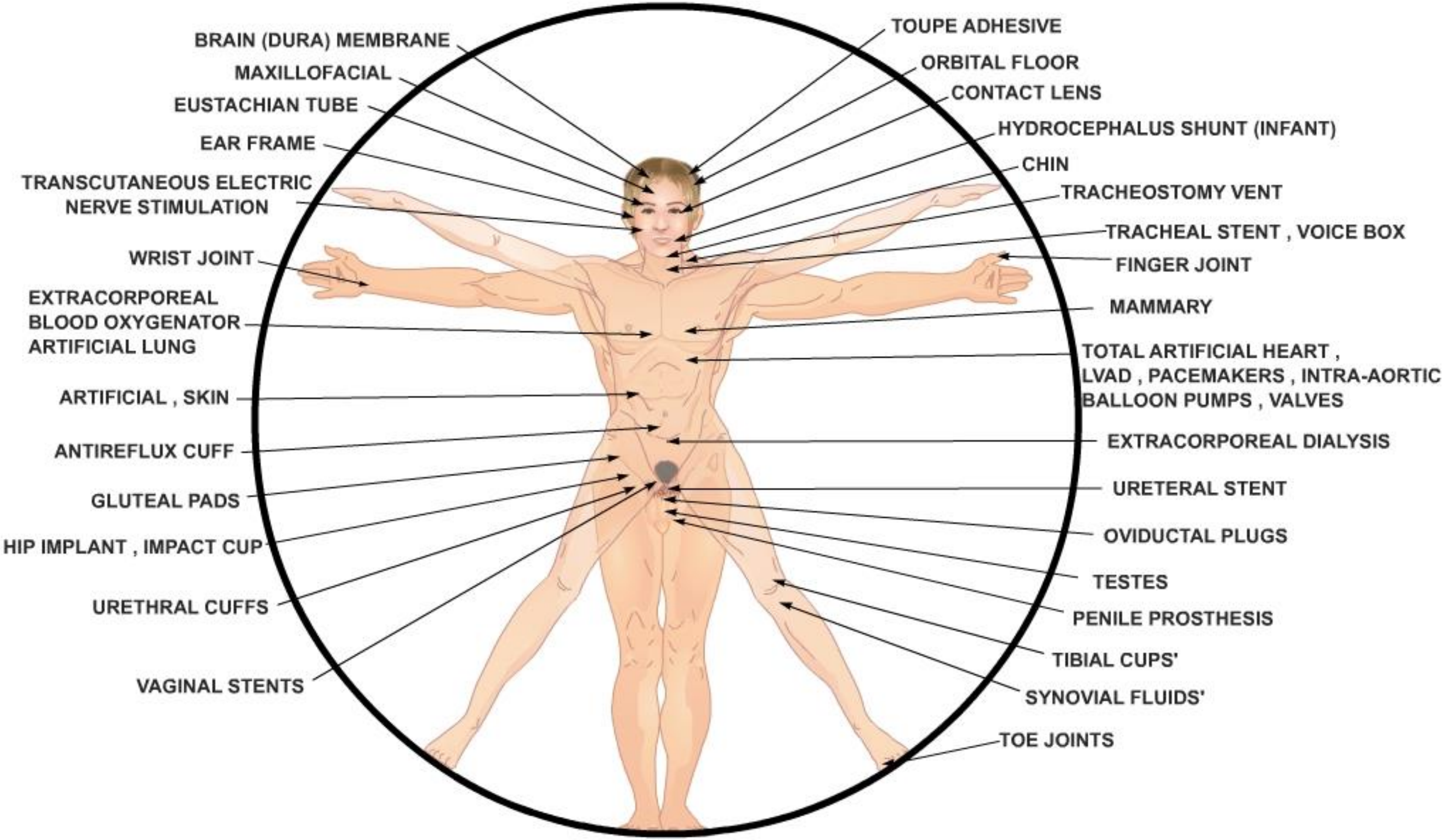
37 percent of global commercial solar rooftop

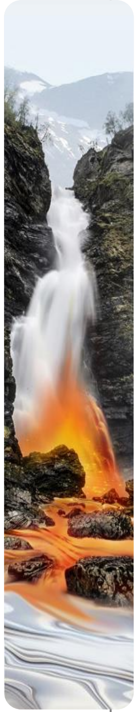
installations took place in Germany*. Governed by the Renewable Energy Sources Act 2000 (*Erneuerbare-Energien-Gesetz EEG)*, renewables including solar enjoy priority grid connection and are supported through Feed-in-Tariffs (FITs) in Germany. This has enabled even the small producers and farmers to connect to the grid and earn revenue by selling solar power.

* http://marketrealist.com/2015/02/german-rooftops-domniate-global-photovoltaic-capacity/ (Accessed: 6th June 2016)

Silicon in the human body







ELEMENTS OF A SMARTPHONE

ELEMENTS COLOUR KEY: ALKALI METAL · ALKALINE EARTH METAL · TRANSITION METAL · GROUP 13 · GROUP 14 · GROUP 15 · GROUP 16 · HALOGEN · LANTHANIDE

SCREEN

49 In Indium · 8 O Oxygen · 50 Sn Tin

Indium tin oxide is a mixture of indium oxide and tin oxide, used in a transparent film in the screen that conducts electricity. This allows the screen to function as a touch screen.

13 Al Aluminium · 14 Si Silicon · 8 O Oxygen · 19 K Potassium

The glass used on the majority of smartphones is an aluminosilicate glass, composed of a mix of alumina (Al_2O_3) and silica (SiO_2). This glass also contains potassium ions, which help to strengthen it.

39 Y Yttrium · 57 La Lanthanum · 65 Tb Terbium · 59 Pr Praseodymium · 63 Eu Europium · 66 Dy Dysprosium · 64 Gd Gadolinium

A variety of Rare Earth Element compounds are used in small quantities to produce the colours in the smartphone's screen. Some compounds are also used to reduce UV light penetration into the phone.

ELECTRONICS

29 Cu Copper · 47 Ag Silver · 79 Au Gold · 73 Ta Tantalum

Copper is used for wiring in the phone, whilst copper, gold and silver are the major metals from which microelectrical components are fashioned. Tantalum is the major component of micro-capacitors.

28 Ni Nickel · 66 Dy Dysprosium · 59 Pr Praseodymium · 65 Tb Terbium · 60 Nd Neodymium · 64 Gd Gadolinium

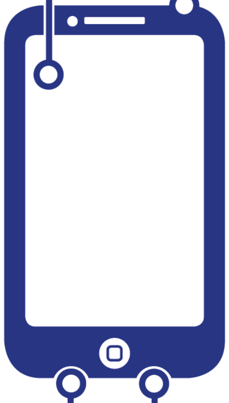
Nickel is used in the microphone as well as for other electrical connections. Alloys including the elements praseodymium, gadolinium and neodymium are used in the magnets in the speaker and microphone. Neodymium, terbium and dysprosium are used in the vibration unit.

14 Si Silicon · 8 O Oxygen · 51 Sb Antimony · 33 As Arsenic · 15 P Phosphorus · 31 Ga Gallium

Pure silicon is used to manufacture the chip in the phone. It is oxidised to produce non-conducting regions, then other elements are added in order to allow the chip to conduct electricity.

50 Sn Tin · 82 Pb Lead

Tin & lead are used to solder electronics in the phone. Newer lead-free solders use a mix of tin, copper and silver.



BATTERY

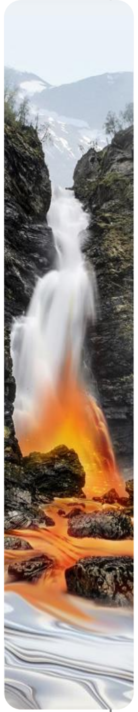
3 Li Lithium · 27 Co Cobalt · 8 O Oxygen · 6 C Carbon · 13 Al Aluminium

The majority of phones use lithium ion batteries, which are composed of lithium cobalt oxide as a positive electrode and graphite (carbon) as the negative electrode. Some batteries use other metals, such as manganese, in place of cobalt. The battery's casing is made of aluminium.

CASING

6 C Carbon · 12 Mg Magnesium · 35 Br Bromine · 28 Ni Nickel

Magnesium compounds are alloyed to make some phone cases, whilst many are made of plastics. Plastics will also include flame retardant compounds, some of which contain bromine, whilst nickel can be included to reduce electromagnetic interference.

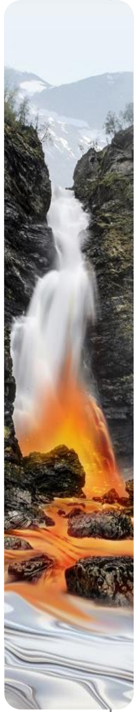


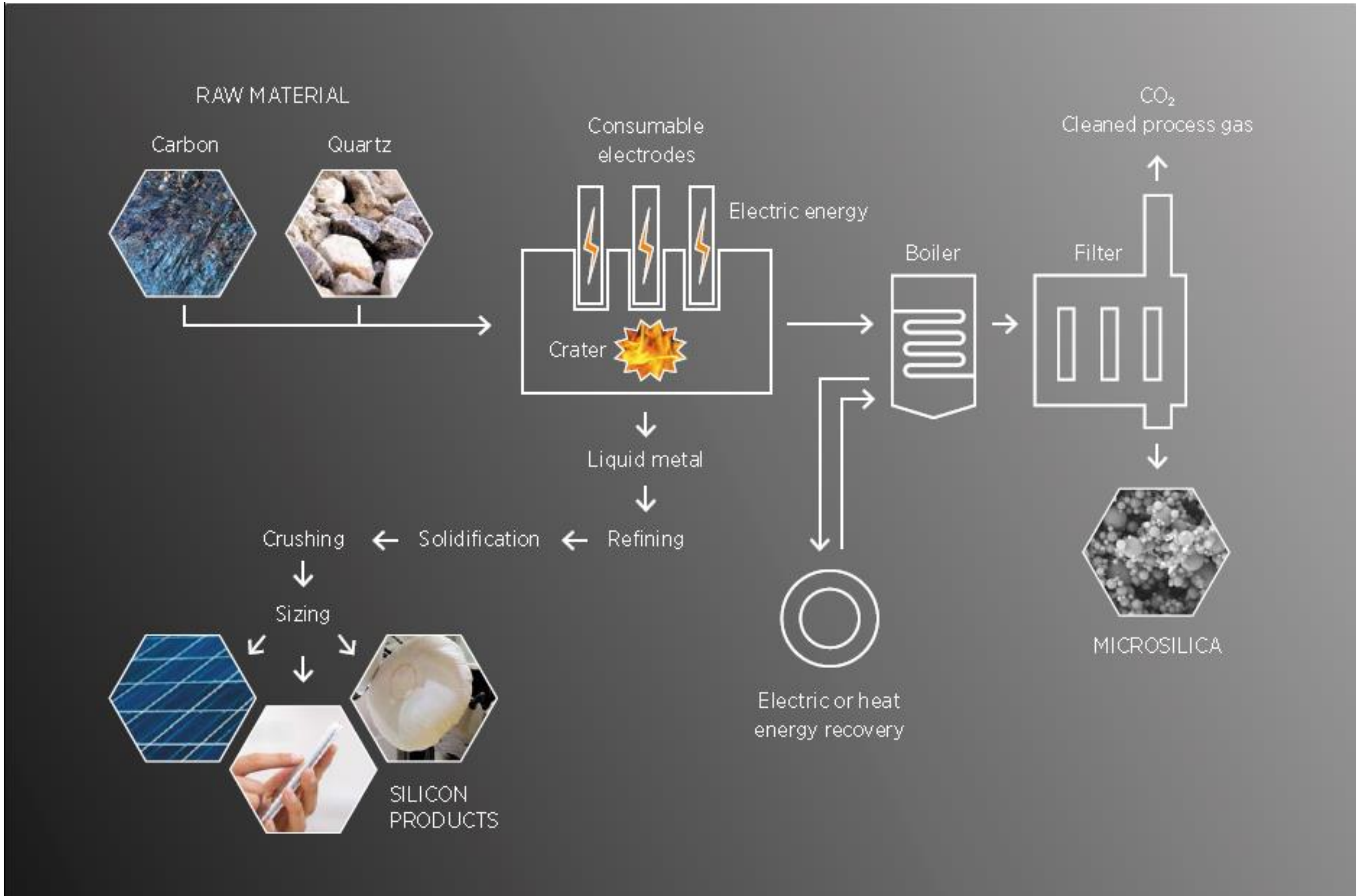
The Needle in a Haystack

Not easily found – Unpleasant

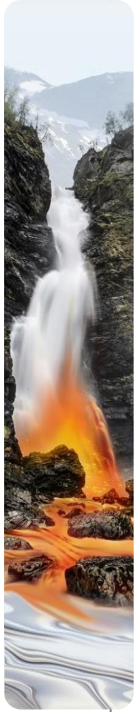
Trace elements

Dilution - poisoning




RAW MATERIAL
Carbon
Quartz
Consumable electrodes
Electric energy
Crater
Liquid metal
Refining
Solidification
Crushing
Sizing
SILICON PRODUCTS
Boiler
Filter
CO_2
Cleaned process gas
MICROSILICA
Electric or heat energy recovery

metal production

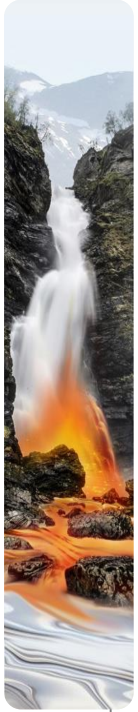


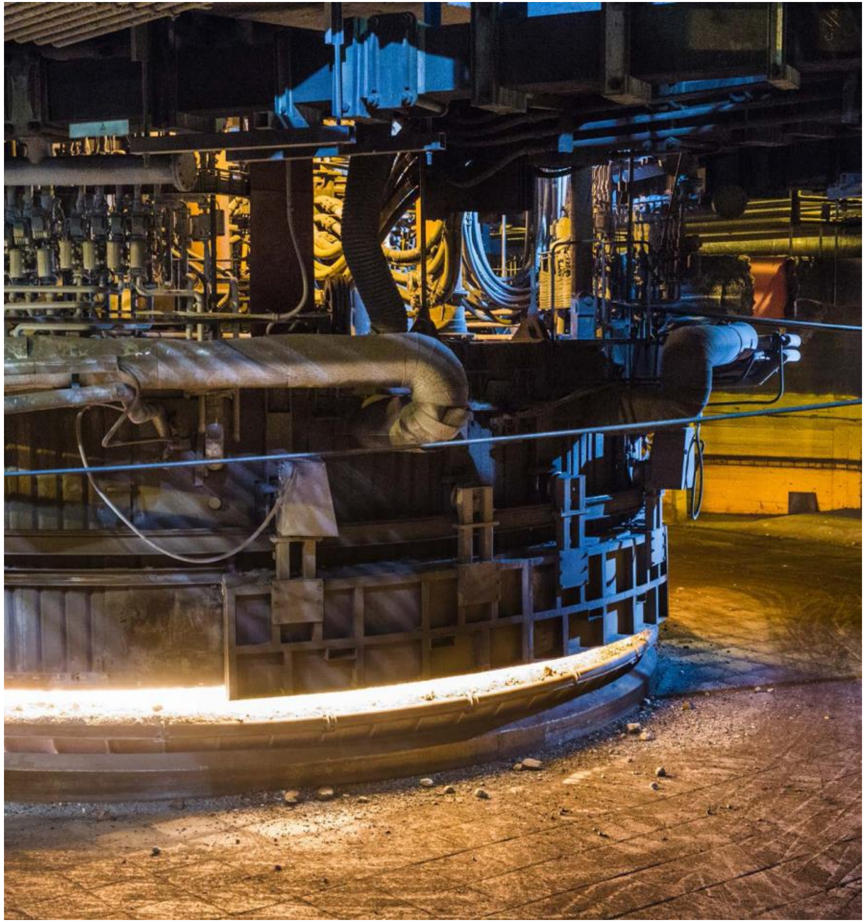
Si production and CO_2 emissions

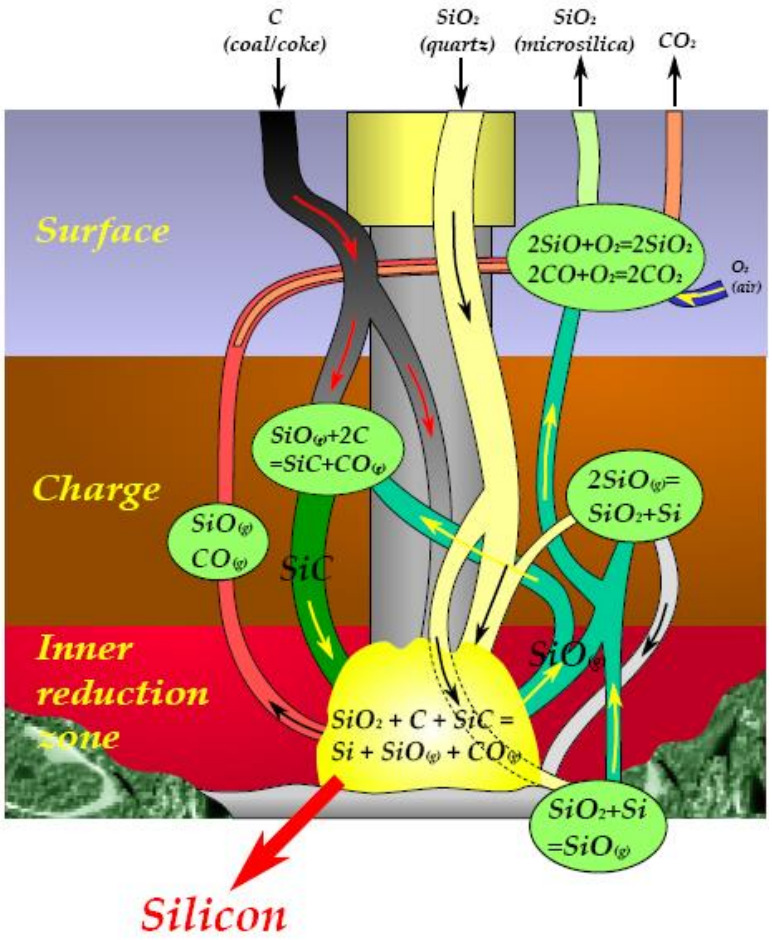
$$SiO_2(s)+(1+x)C(s) = xSi+(1-x)SiO(g)+(1+x)CO(g)$$

Electricity source	Total spec. CO_2 (kg CO_2/kg Si)
Theoretical C - free	[1.6 (1CO_2/Si)] – 3.2 (2 CO => 2CO_2/Si)
Hydro/Nuclear	4.3
Gas Power	10.6
Coal power	17.7

metal production

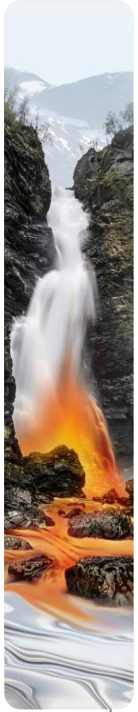


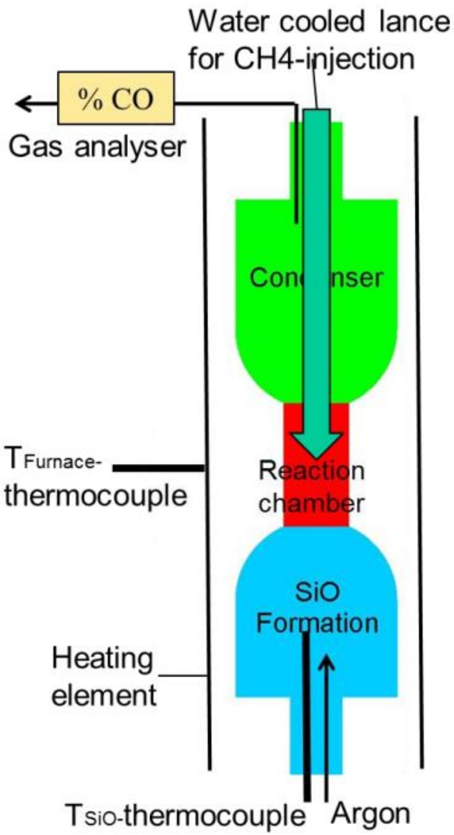




Main steps in the Si-process (Elkem)

What happens when cold CH_4 (g) meets hot SiO (g)?





<u>Condensation chamber, and on the lance:</u>

$2\ SiO\ (g) = SiO_2\ (s) + Si\ (s)$ (4)

$3\ SiO\ (g) + CO\ (g) = 2\ SiO_2\ (s) + SiC\ (s)$ (6)

<u>Reaction chamber</u>

$SiO\ (g) + 2\ CH_4\ (g) = SiC\ (s) + CO\ (g) + 4\ H_2\ (g)$ (2)

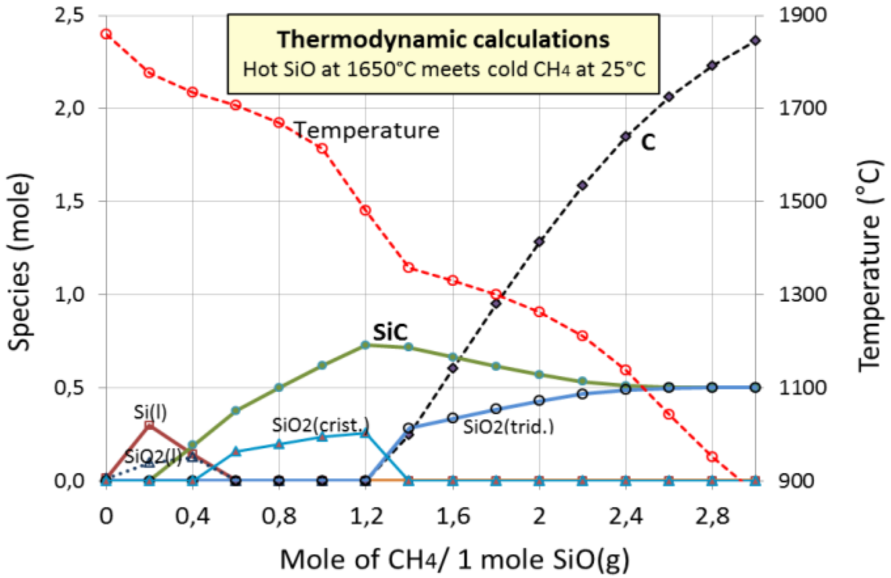
$CH_4\ (g) = C\ (s) + 2\ H_2\ (g)$ (3)

<u>SiO generator (SiO formation chamber)</u>

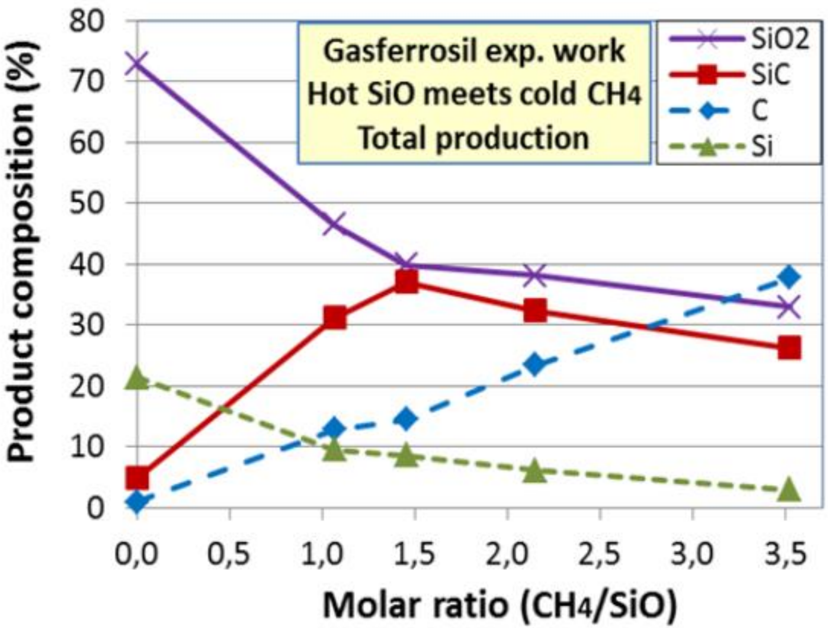
$2\ SiO_2\ (s) + SiC\ (s) = 3\ SiO\ (g) + CO\ (g)$ (5)

Based on a paper by B. Monsen, L. Kolbeinsen, S. Prytz, V. Myrvågnes, and K. Tang at the INFACON conference in Kazakhstan June 2013

Theory



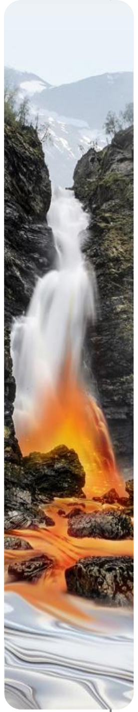
Practice

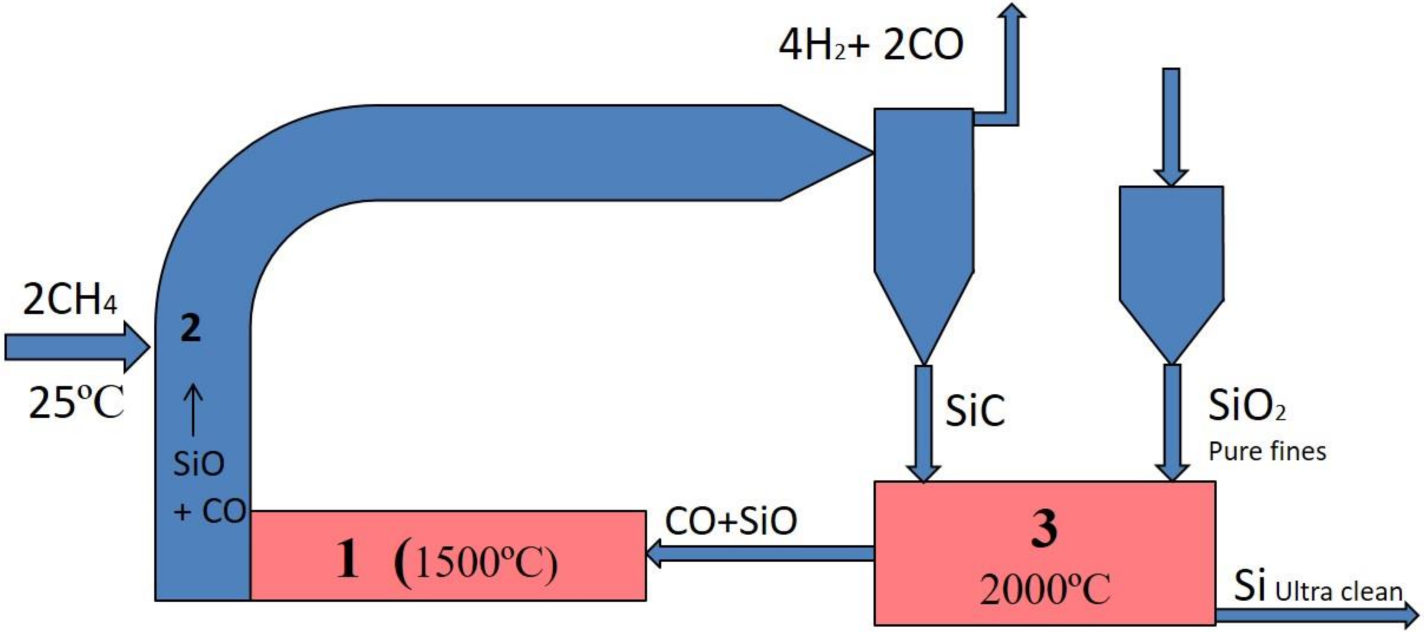


Based on a paper by B. Monsen, L. Kolbeinsen, S. Prytz, V. Myrvågnes, and K. Tang at the INFACON conference in Kazakhstan June 2013

GasFerroSil project

Oxygen in Silica is used to convert CH_4 to “Syn Gas” (H_2 + CO) with Si as bi-product

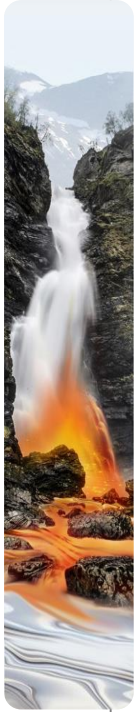




Start up with bought SiC.
Si-production with self-produced SiC.

metal production

Waste Hierarchy



3 Introductary postulates

Industrial overview (Norway)

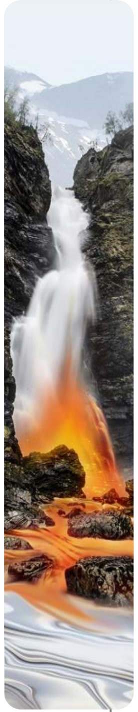
Resources, Energy & Environment

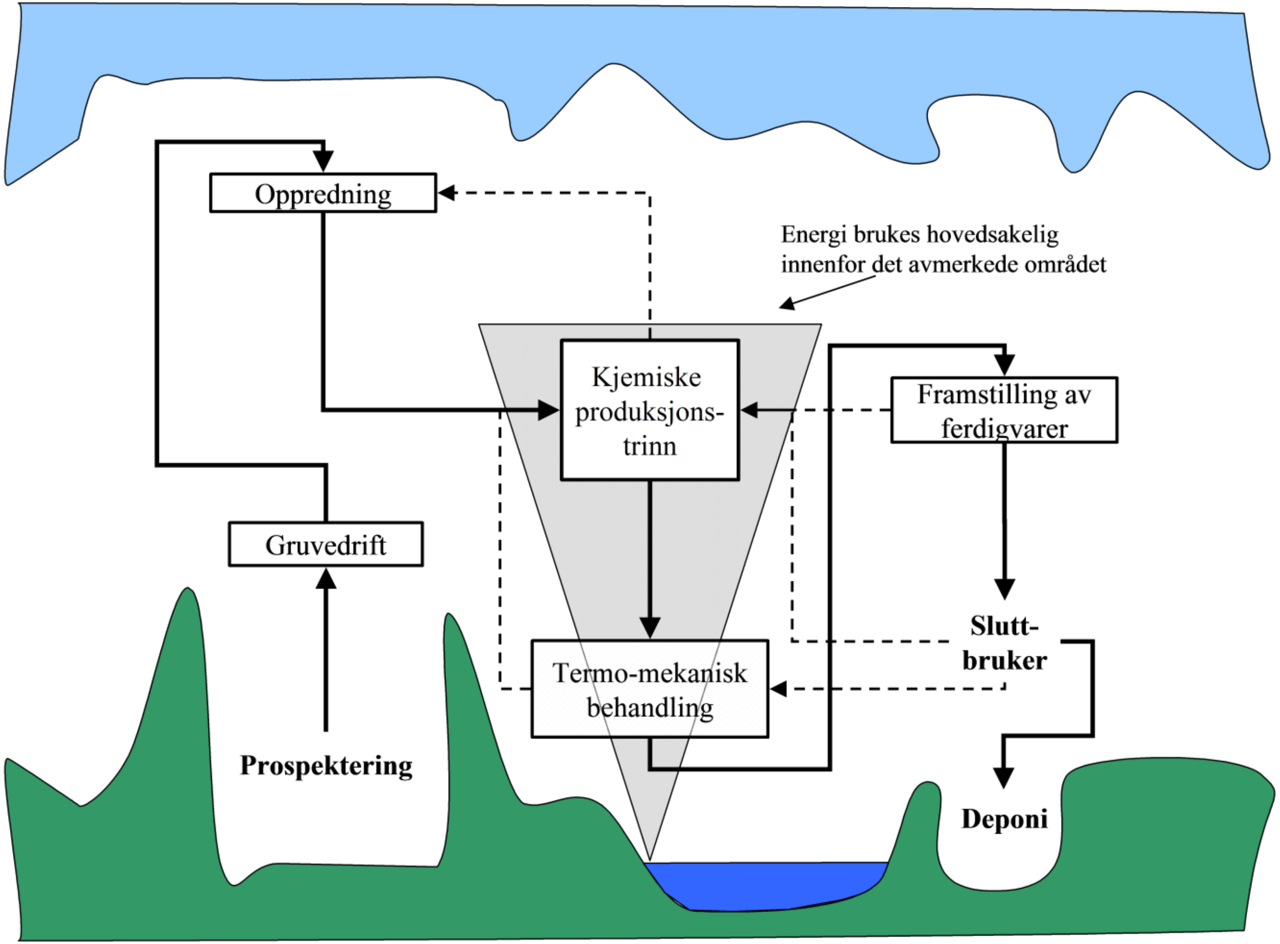
- About «Får-i-kål» & «Kransekake»
- Words on energy
- From Oxide to Metal
- Why CO_2-emission?

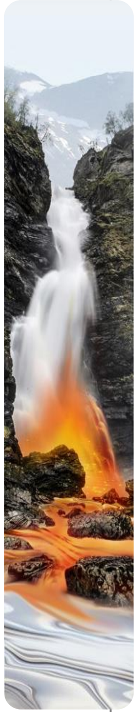
CE: Cirkular (Green) Economy

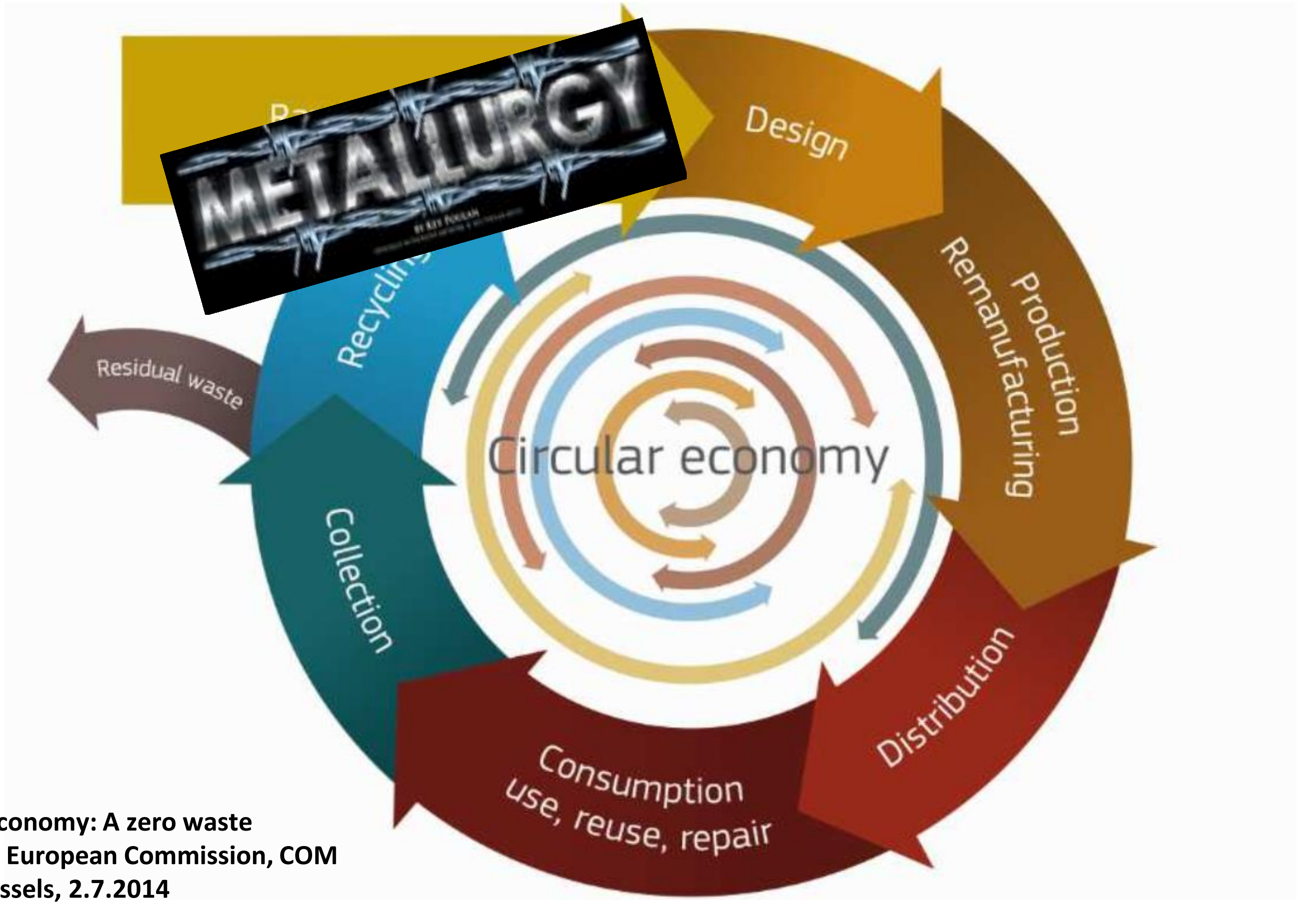
- Process metallurgy - A role i CE?
- Industrial symbiosis (Industry parks)

From “Introduction to Materials” – last century



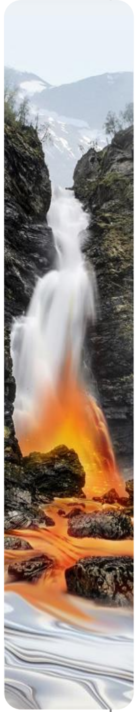




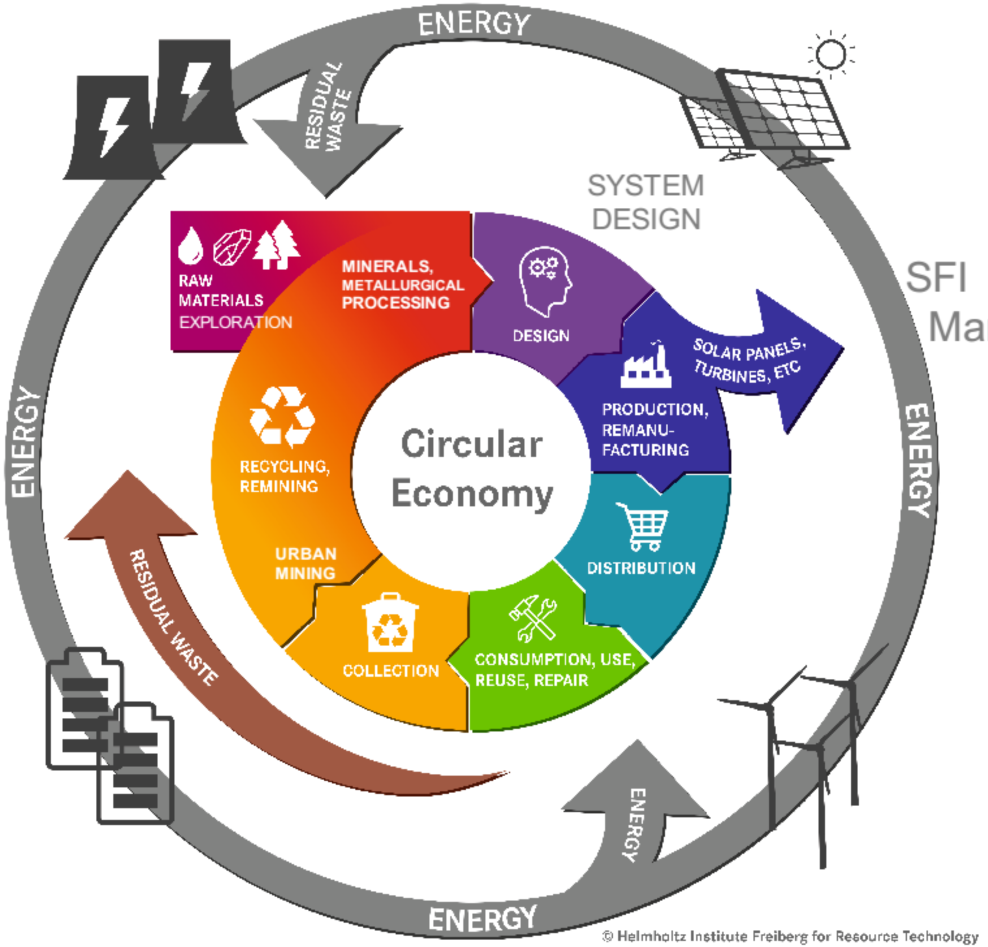


Towards a circular economy: A zero waste program for Europe, European Commission, COM (2014) 398 final, Brussels, 2.7.2014

metal production

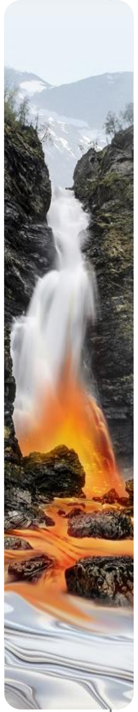


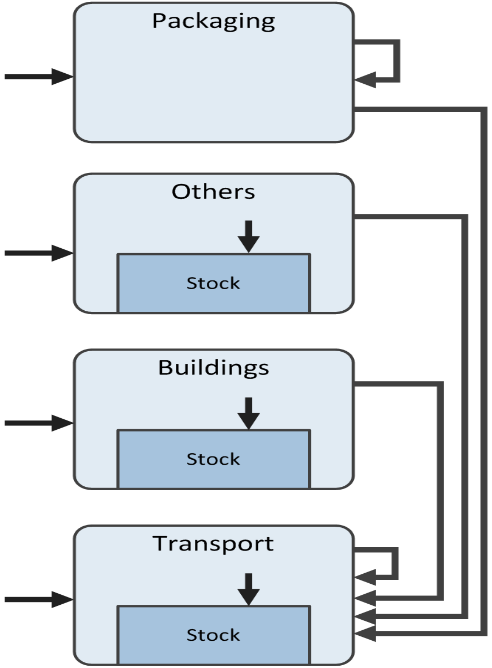
SFI
Metal
Production



SFI
Manufacture

Today's aluminium recycling system: cascading use



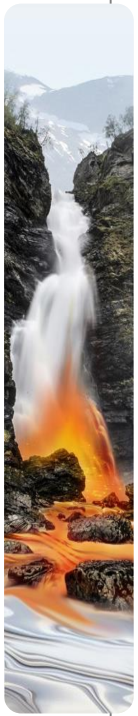


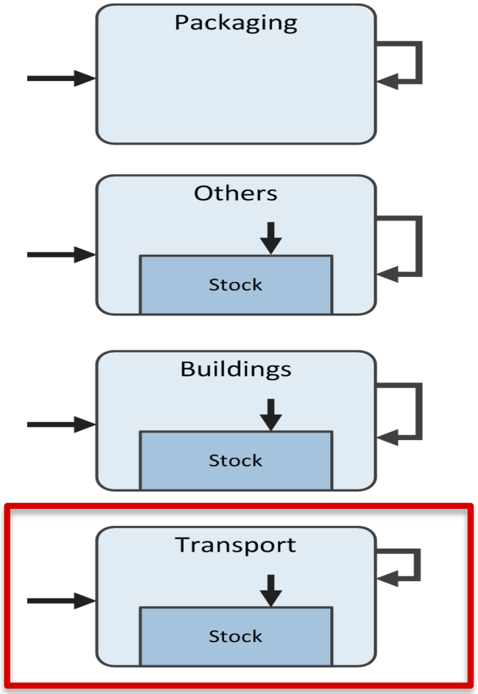
- The bottom reservoir is formed by automotive secondary castings (mainly engine parts).

- **Today, the cascading system is economically and ecologically meaningful.**
  → It makes use of all the metals (aluminium, alloying elements, other elements)
  → This saves alloying elements for secondary casting

- **In the future, the same system with the same resources may become unsustainable.**
  → Increasing amounts of scrap
  → Limited capacity of engine parts to absorb this scrap
  → Scrap surplus?

Tomorrow's aluminium recycling system: Closed alloy cycles?





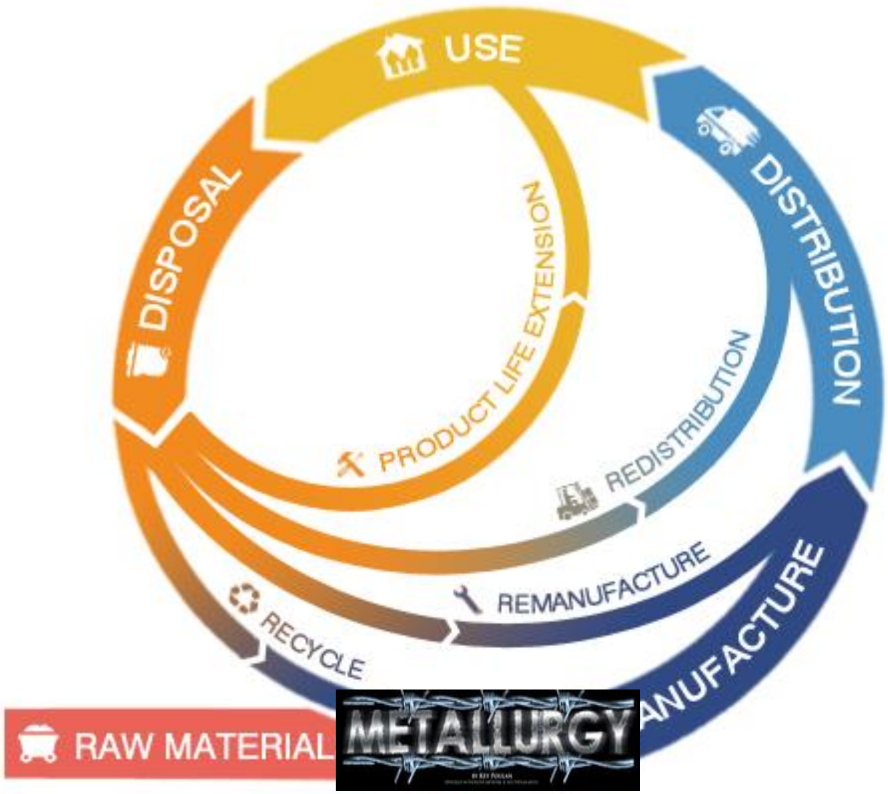
- A closing of alloy cycles would reduce the amount of scrap to be absorbed by automotive secondary castings.
  → Use scrap for alternative applications (sinks)

How could this be achieved in the transport sector?
→ Currently, there is a cascading use of about 200 aluminium alloys used in vehicles.

metal production

Illustration of the circular economy, Ellen MacArthur Foundation

Where does this company sit within the circular economy?



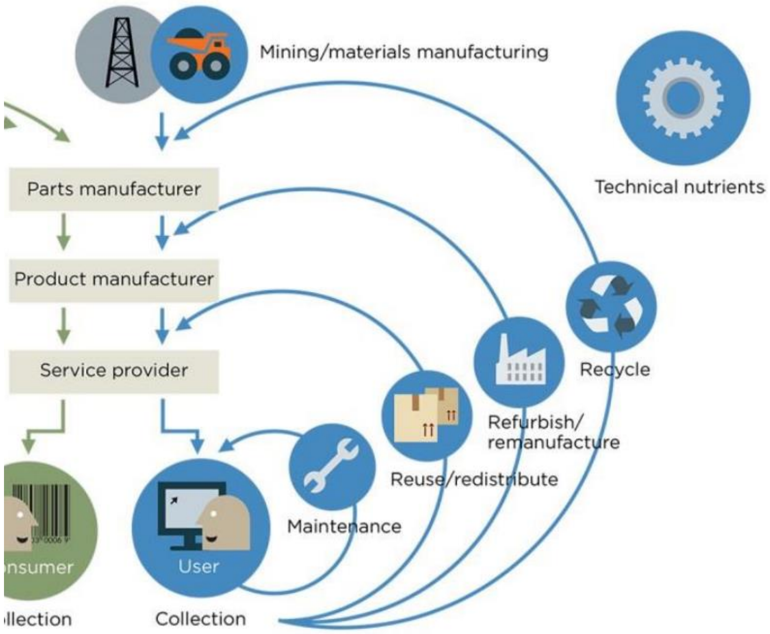
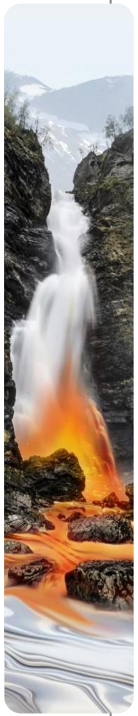
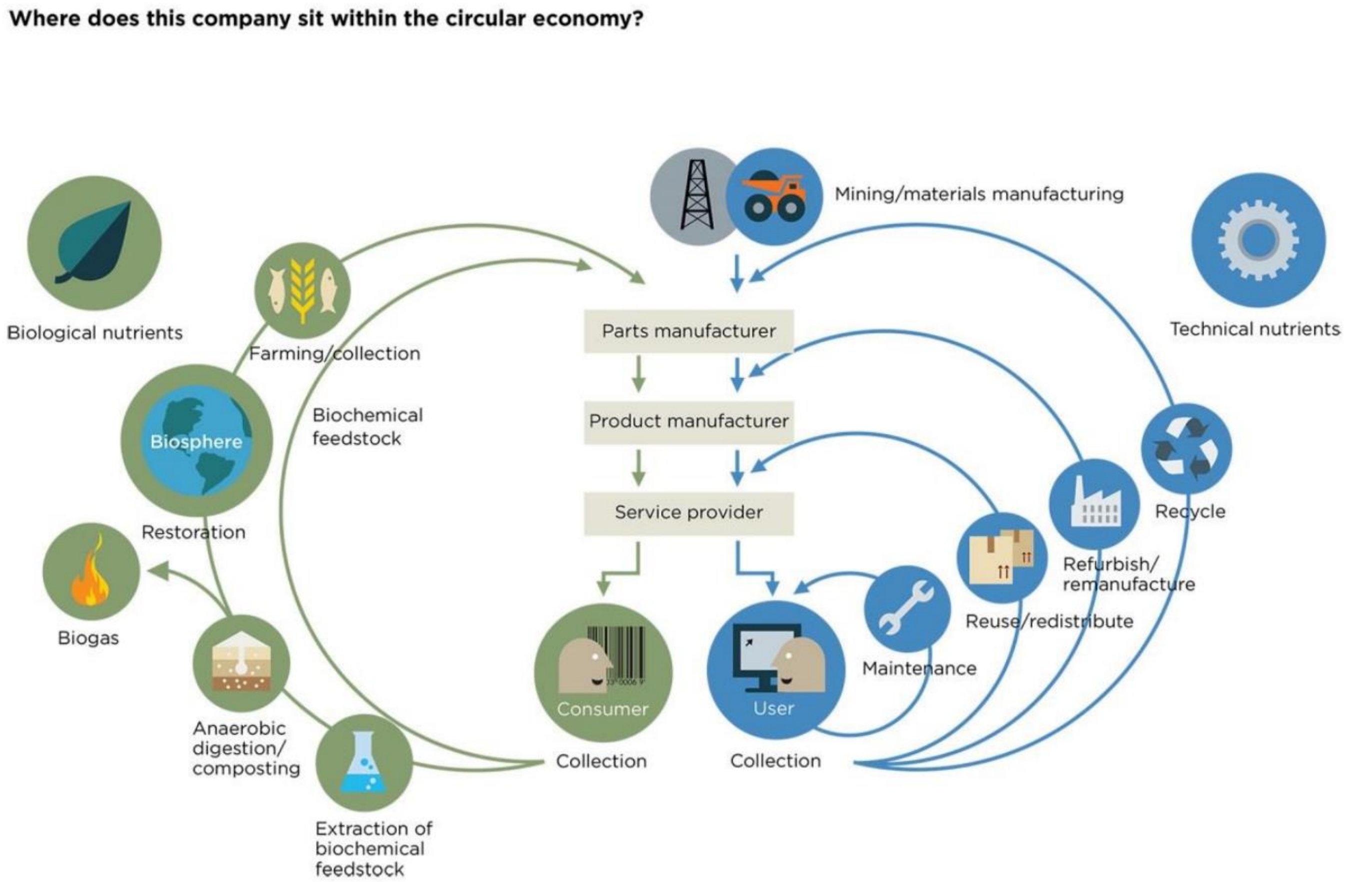
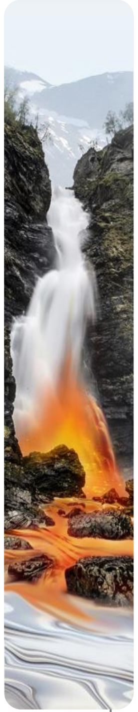


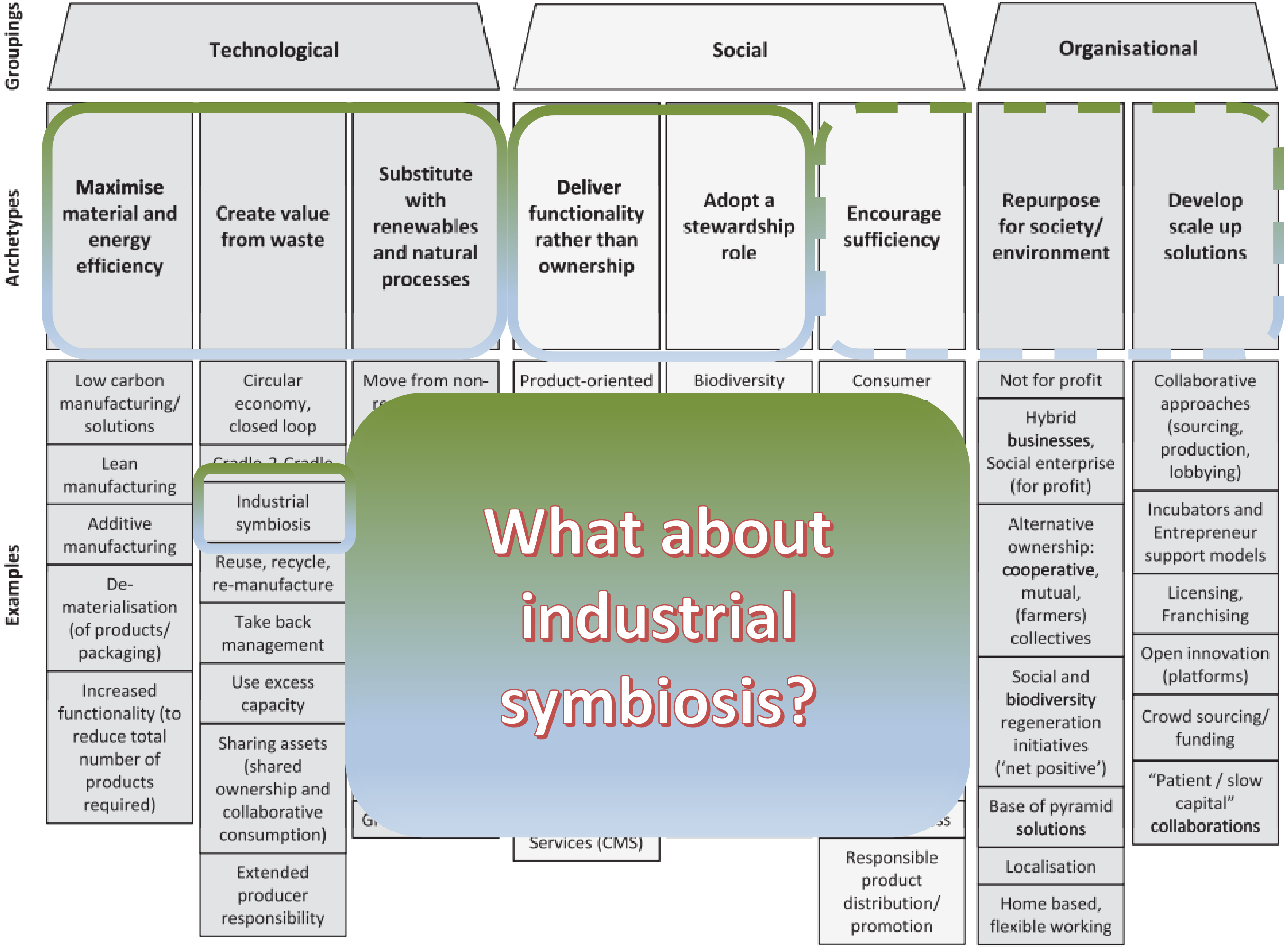
Illustration of the circular economy, Ellen MacArthur Foundation





metal production





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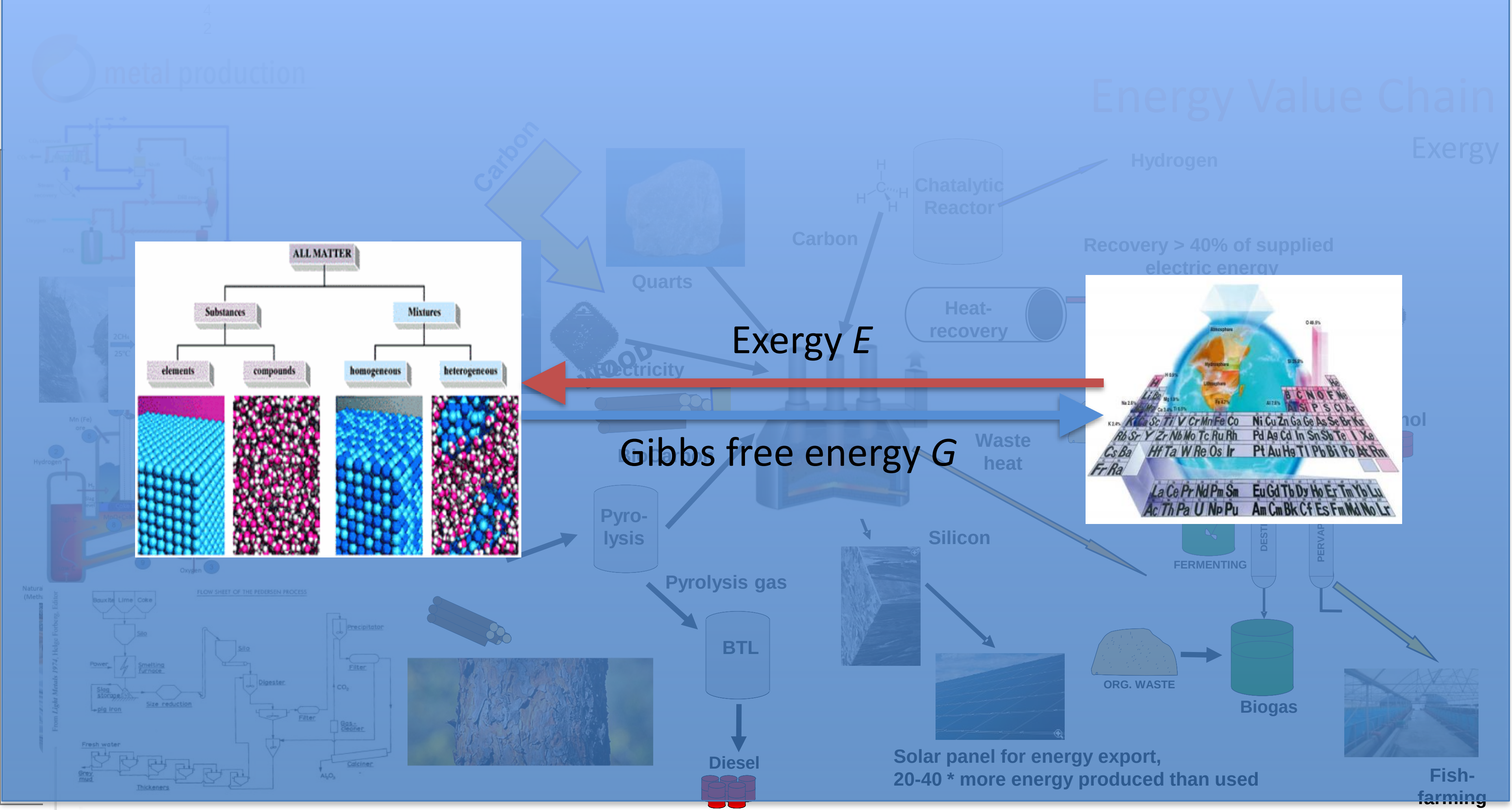
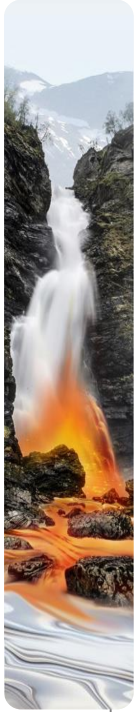
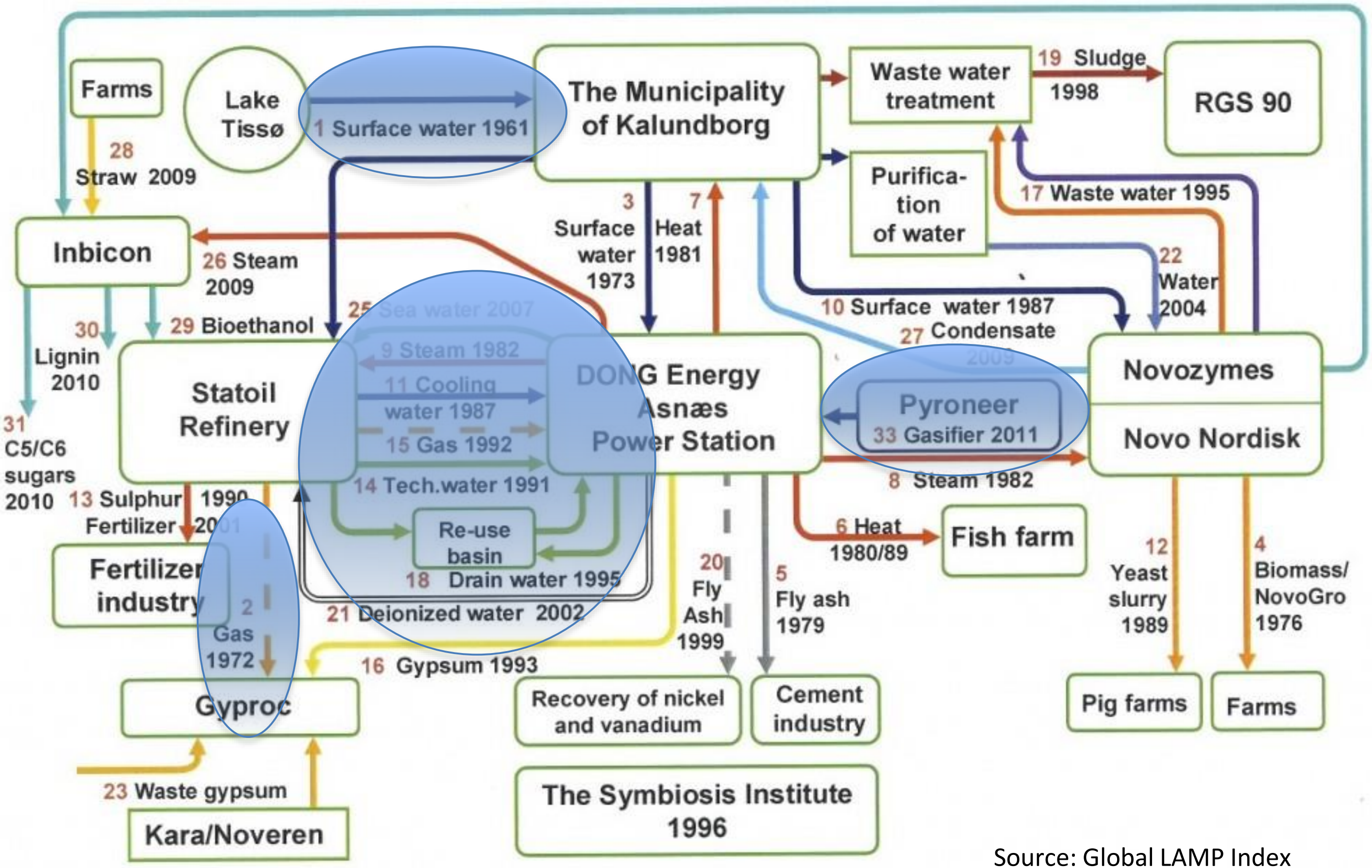
N.I 2–56



Exergy E
Gibbs free energy G
ALL MATTER
Substances
Mixtures
elements
compounds
homogeneous
heterogeneous
metal production
Energy Value Chain
Exergy
Hydrogen
Chatalytic Reactor
Carbon
Quarts
Recovery > 40% of supplied electric energy
Heat-recovery
Waste heat
Pyro-lysis
Pyrolysis gas
BTL
Diesel
Silicon
FERMENTING
ORG. WASTE
Biogas
Solar panel for energy export,
20-40 * more energy produced than used
Fish-farming

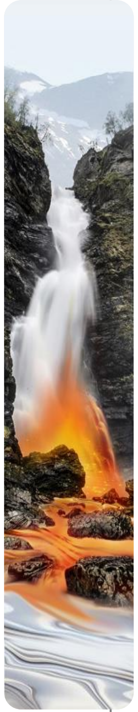




Source: Global LAMP Index

metal production

Organizing Self-Organizing Systems



Industrial symbiosis: cooperative manage-ment and exchange of resource flows - particularly materials, water, and energy - through clusters of companies.

Businesses have become increasingly attentive to the price and availability of these resources, the notion of interfirm coordination and management remains underdeveloped and collaborative opportunities are continually overlooked.

This article[1] describes a theory of industrial symbiosis examining the development of what have been called, industrial ecosystems or industrial networks, drawing on a mix of biology and ecology, complex systems-, and organizational theory.

[1]Chertow and Ehrenfeld, *Organizing Self-Organizing Systems:Toward a Theory of Industrial Symbiosis* Journ. Industrial Ecology Volume 16, Issue 1 February 2012 pp 13–27

DOI: 10.1111/j.1530-9290.2011.00450.x

Industrial Symbiosis: Main Development Stages

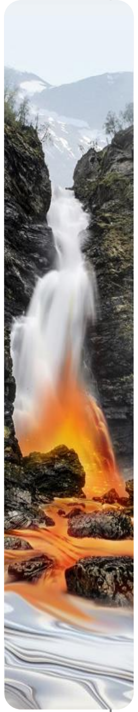
1) Sprouting: Firms begin to exchange resources on a random basis for a variety of reasons. A limited network of interlinked flows takes shape as "kernels" of industrial symbiosis that face a market test and, even when successful, may or may not lead to further exchange activity.

2) Uncovering: The realization that some networks have created positive environmental externalities becomes consciously revealed or "uncovered".

3) Embeddedness and institutionalization: In addition to self-organization, further expansion of the network becomes intentionally driven by an institute-ional entity created at an earlier stage that becomes more deeply established during this stage. As for how long this might last, we have evidence that industrial symbioses can persist over many decades, as is the case of Kalundborg, Denmark, and Kwinana, Australia

Industry-parks/-symbiosis

“Business Models”



B&R (Build & Recruit): Public or private developers create an industrial park or zone and then seek compatible tenants to whom land can be leased or sold. Often an “anchor tenant” is already known; sometimes attracting such a tenant becomes the linchpin for additional development.

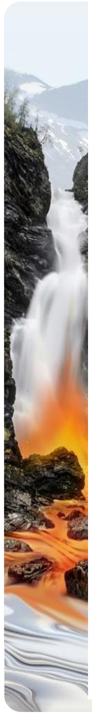
PE-IP (The Planned Eco-Industrial Park): draws most directly from the build and recruit model. It adds another step, which is a directed effort to identify companies from different industries with a plan to locate them together so that they can share resources across and among themselves. Versions of the PE-IP model ***have proven to be the least successful*** of the various approaches so far, particularly in Europe and North America

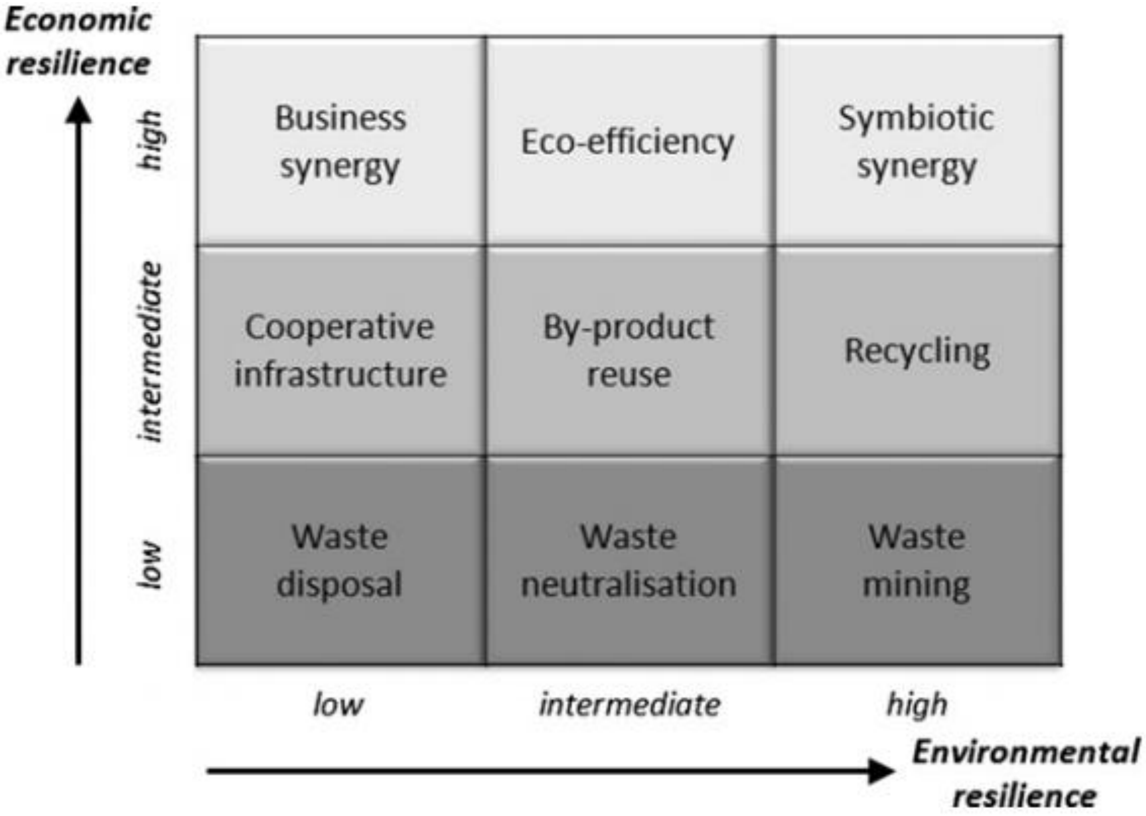
In the **SOS (The self-organizing symbiosis)** model an industrial ecosystem emerges from decisions by private agents economically motivated to exchange resources to meet goals such as cost reduction, revenue enhancement, or business expansion.

The **RIP model (Retrofit Industrial Park)**, existing industrial parks are targeted for conversion to eco-industrial parks ***after*** build and recruit has occurred. Success is likely to hinge on the degree to which firms in these parks come to accept the norms and values that enable collaboration and interfirm exchange.

The **CEE-IP (Circular Economy Eco-Industrial Park)** model is a new form emerging in China associated with the implementation of the Circular Economy Promotion Law in 2009. So far more than 20 existing sites have been designated as “demonstration eco-industrial parks” as part of the circular economy preparations. Most are retrofits rather than build and recruit models, although many are significant expansions closer in concept to the PE-IP model. Theory suggests that a very positive context for the evolution of symbioses in China now exists.

Economy vs. Environment

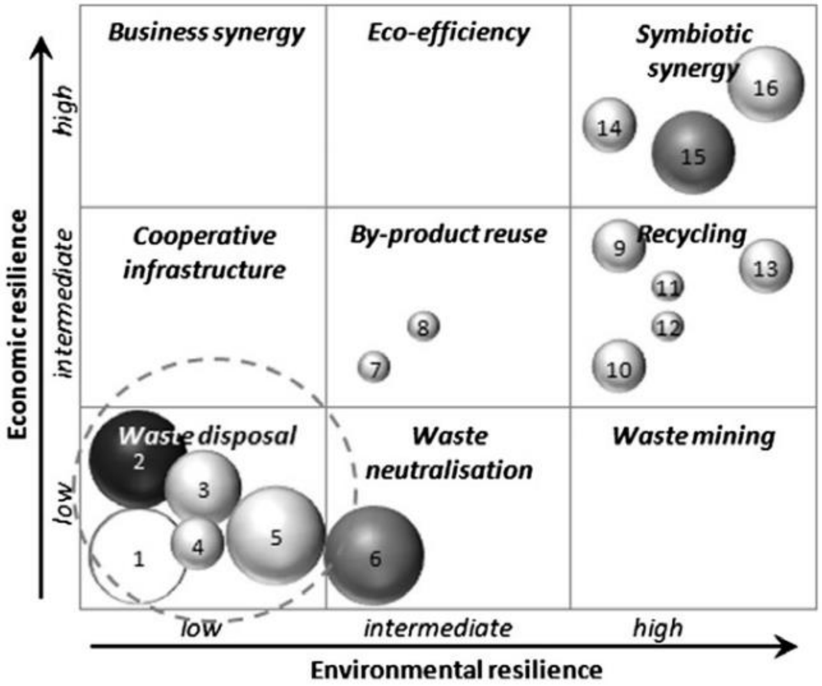


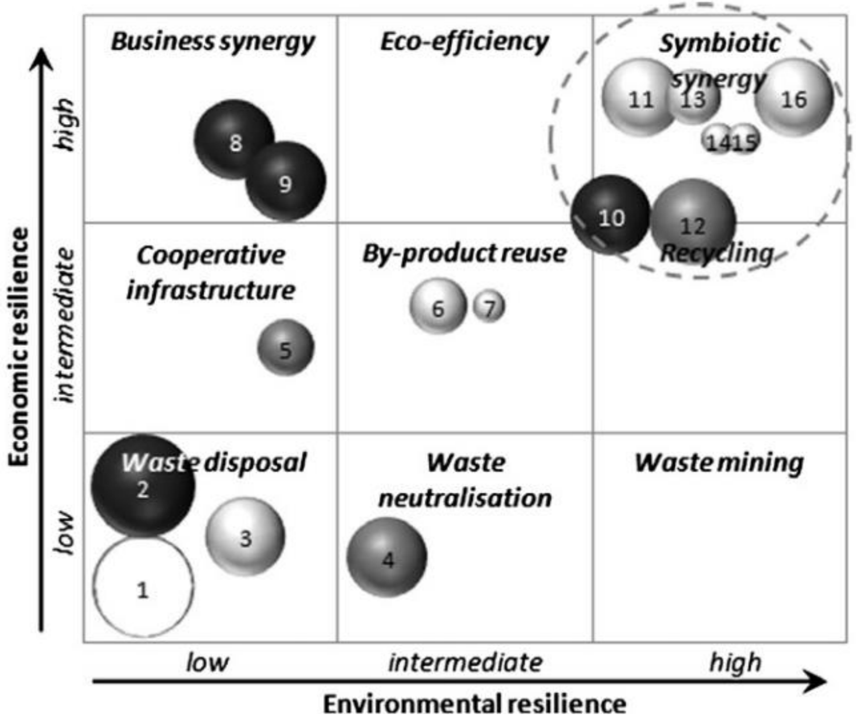


Source: Artem Golev & G.D. Corder «Developing a classification system for regional resource synergies» Minerals Engineering 29 (2012) 58–64 doi:10.1016/j.mineng.2011.10.018

Resilience is here the system's ability to absorb disturbances before it changes the variables and processes that control behavior

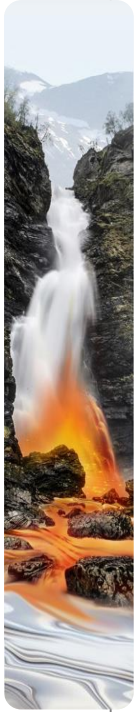
Gladstone (Australia) & Kalundborg (Denmark)





metal production

The 2052 Forecast: What will happen? How can metal production contribute?

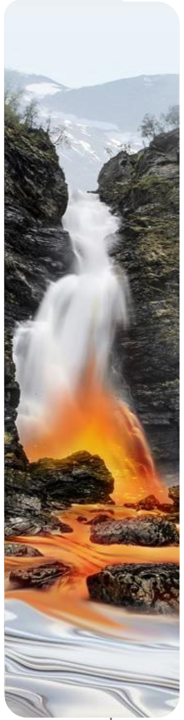


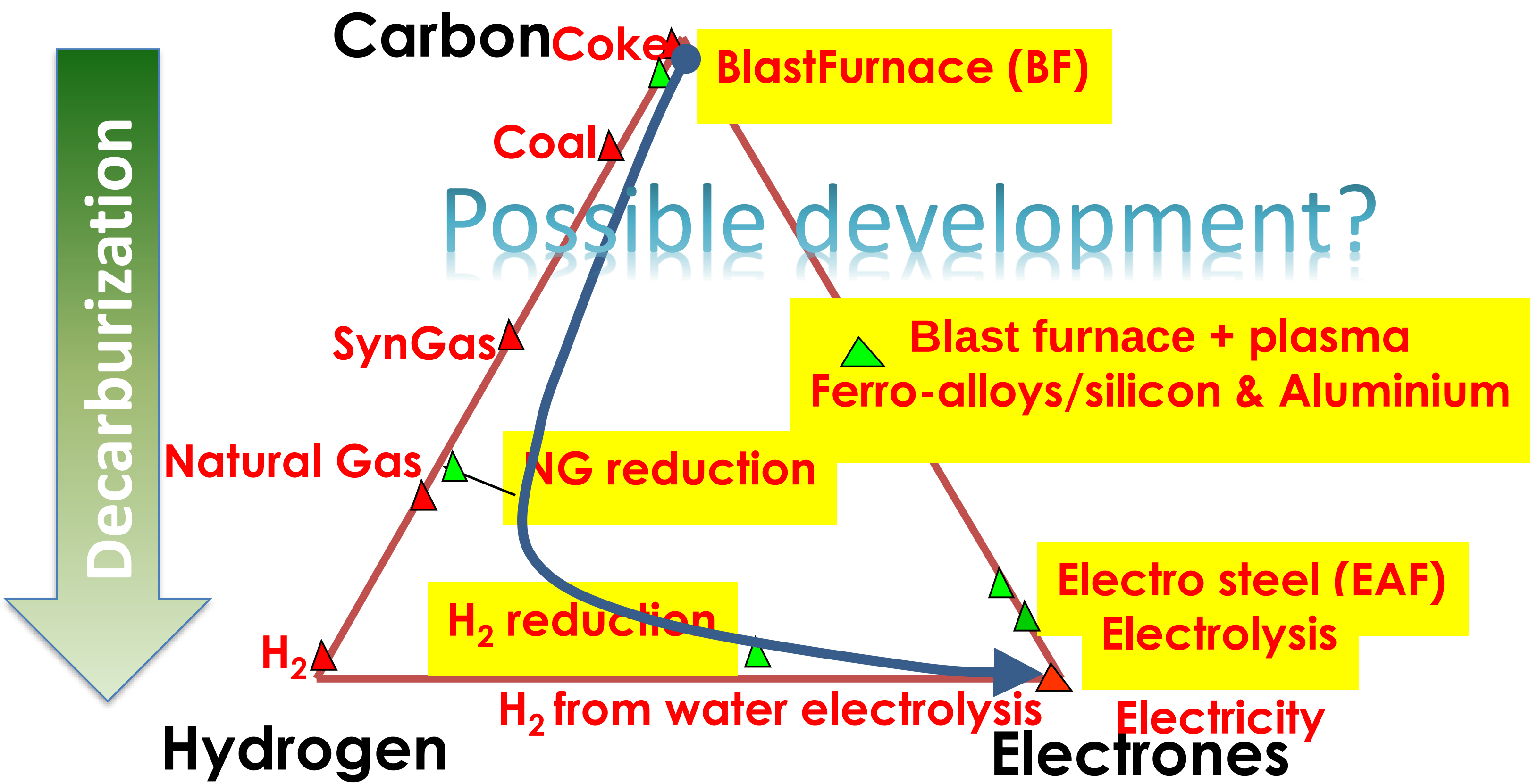
Jorgen Randers Professor Emeritus Climate Strategy BI Norwegian Business School

1. **Make sure production does not include any fossil inputs**
2. **Make sure process is suited for solar power – i.e. direct current and intermittent power**
3. **Make sure there exist technologies (like CCS) to neutralize greenhouse gas emissions (e.g. CO_2 and CH_4)**
4. **Work for a global ban on metals made from fossil fuels – or at least labelling of climate friendly metals**

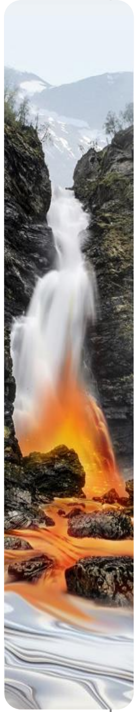
Metal production: Reductants/Energy sources

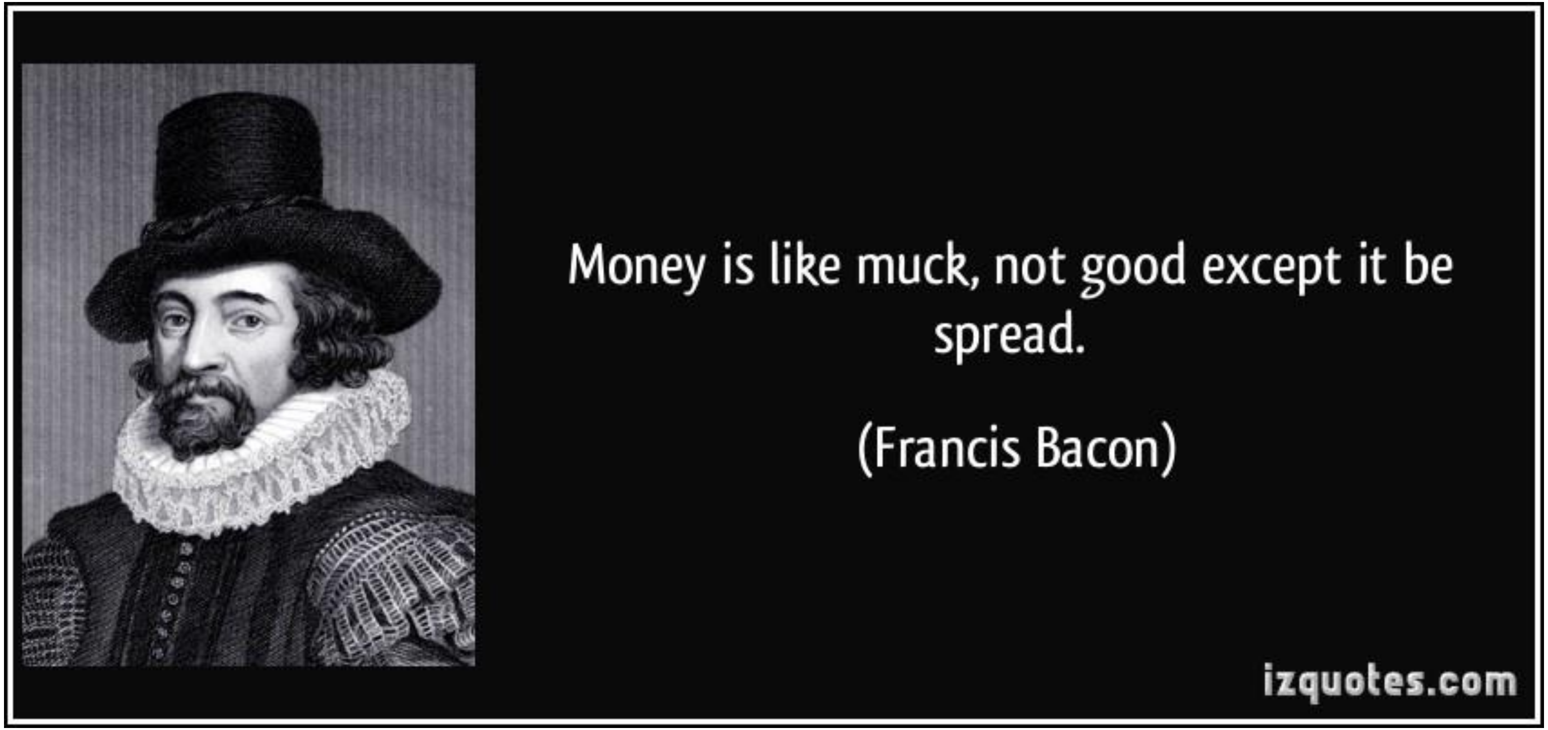
Stolen from Jean-Pierre Birat (and adapted by me)





metal production



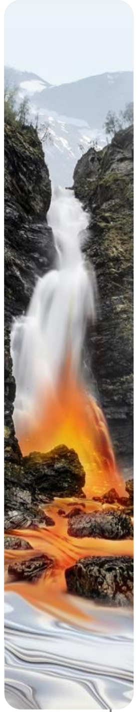


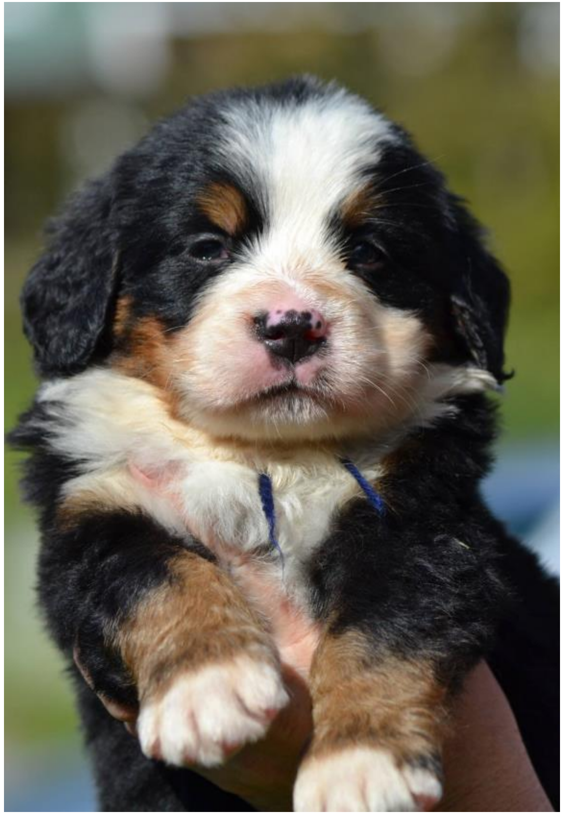
It is time to act – decisively!

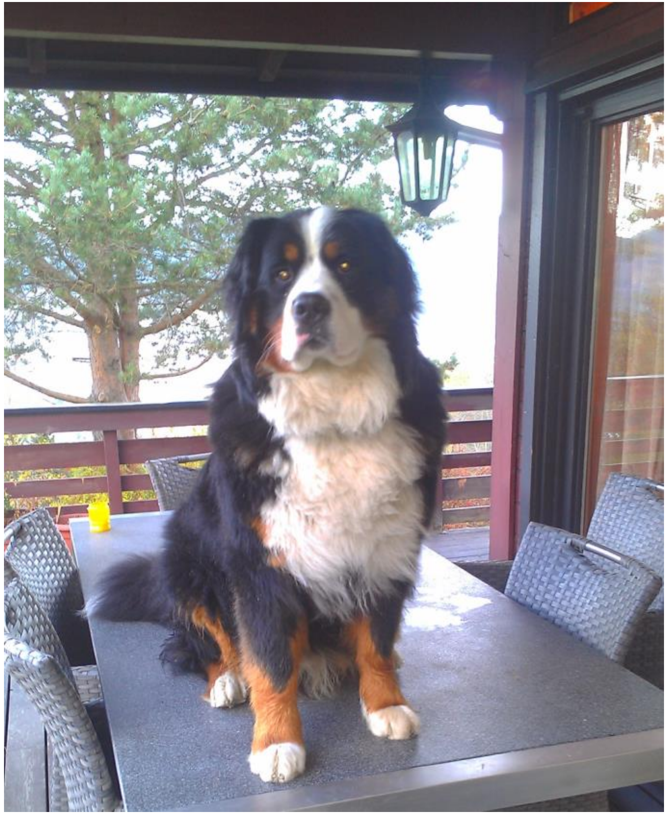
jorgen.randers@bi.no

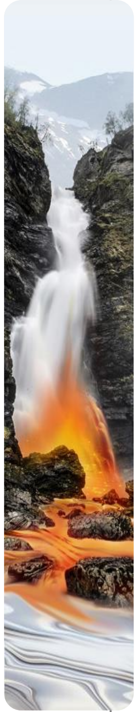
www.2052.inf
o

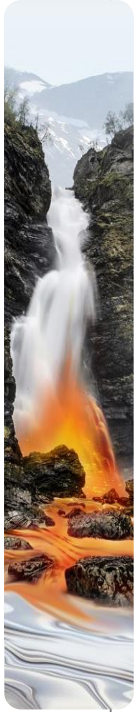
metal production





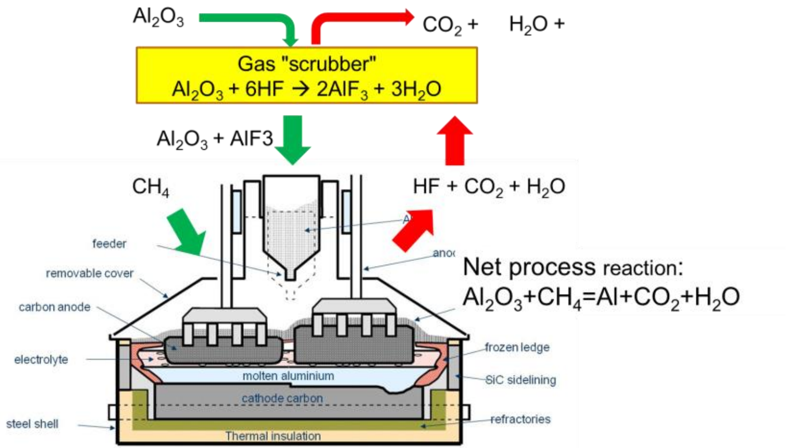






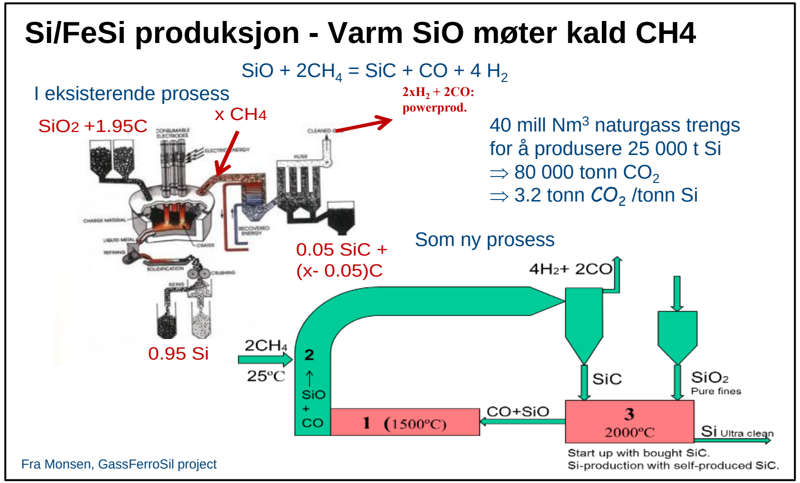
CO_2 fra aluminiumproduksjon

Alternativ C fra CH_4 (Natur- eller Bio-gass)

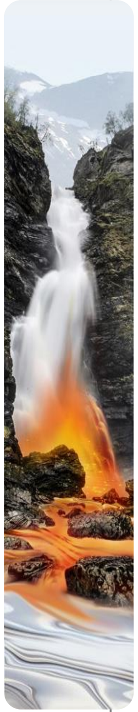


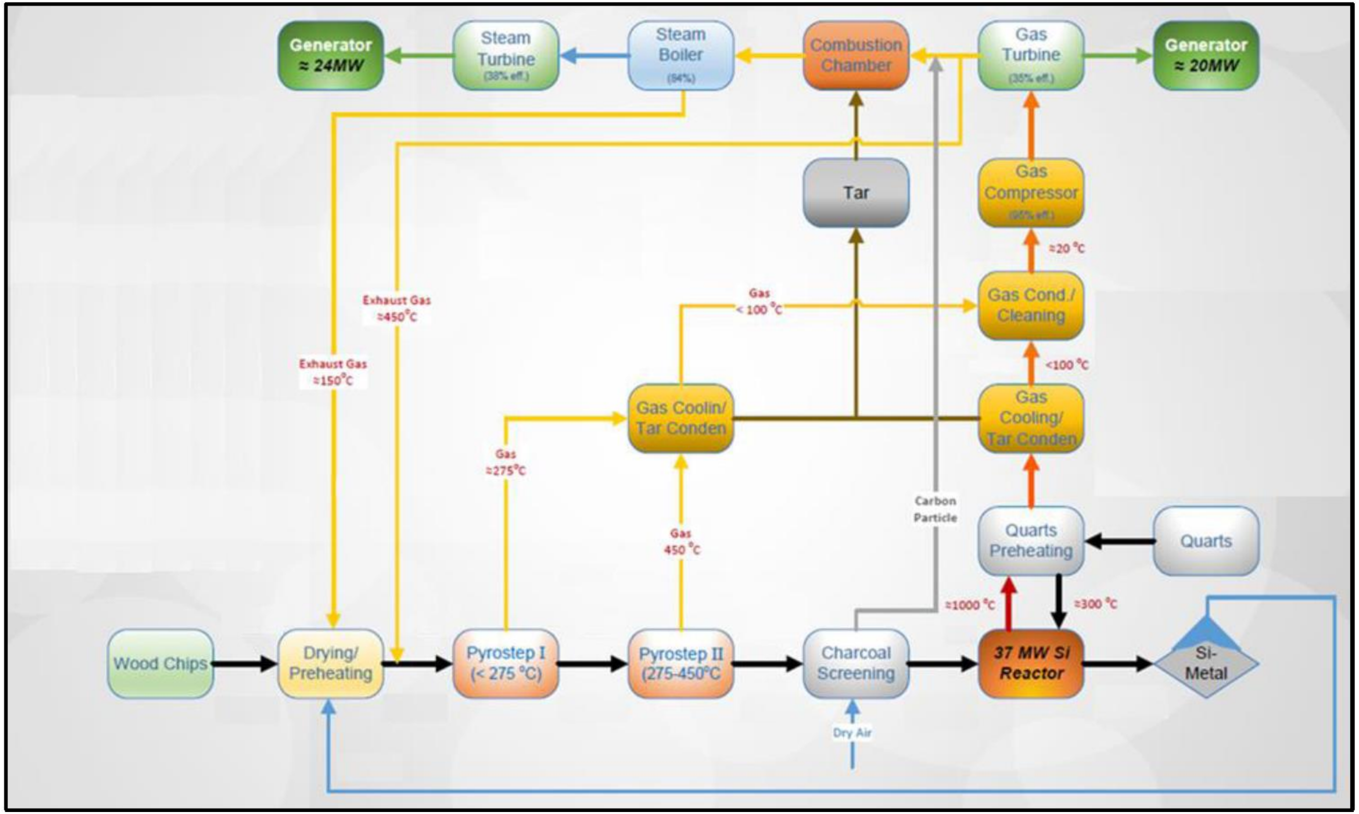
CO_2 fra silisiumproduksjon

Alternativ C fra CH_4 (Natur- eller Bio-gass)



Elkem: Carbon Neutral Metal Production (CNMP)

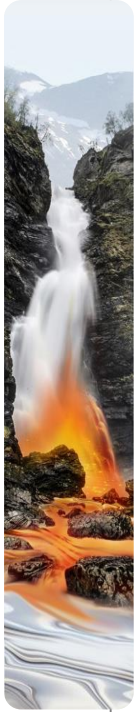


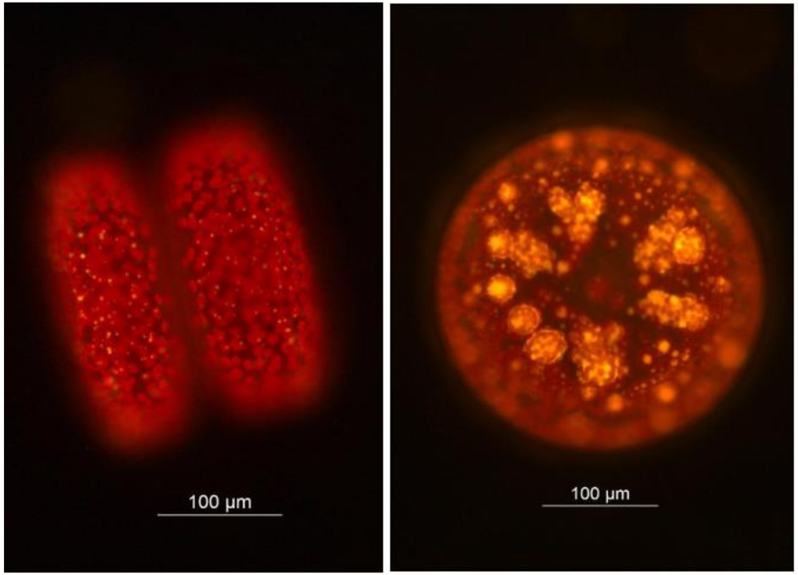


metal production

FINNFJORD

- We´ve got the power

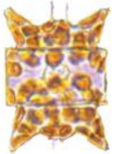




Bioolje

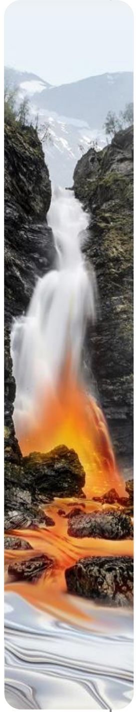
Laksefor

Kosttilskudd



Medisiner

metal production



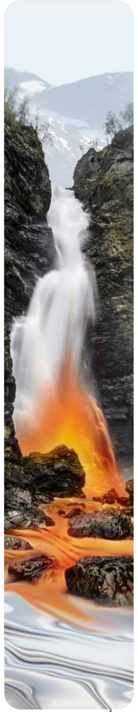
Finnfjord Vision

World’s largest ferrosilicon produce
without CO_2 emissions

FINNFJORD

VISJON

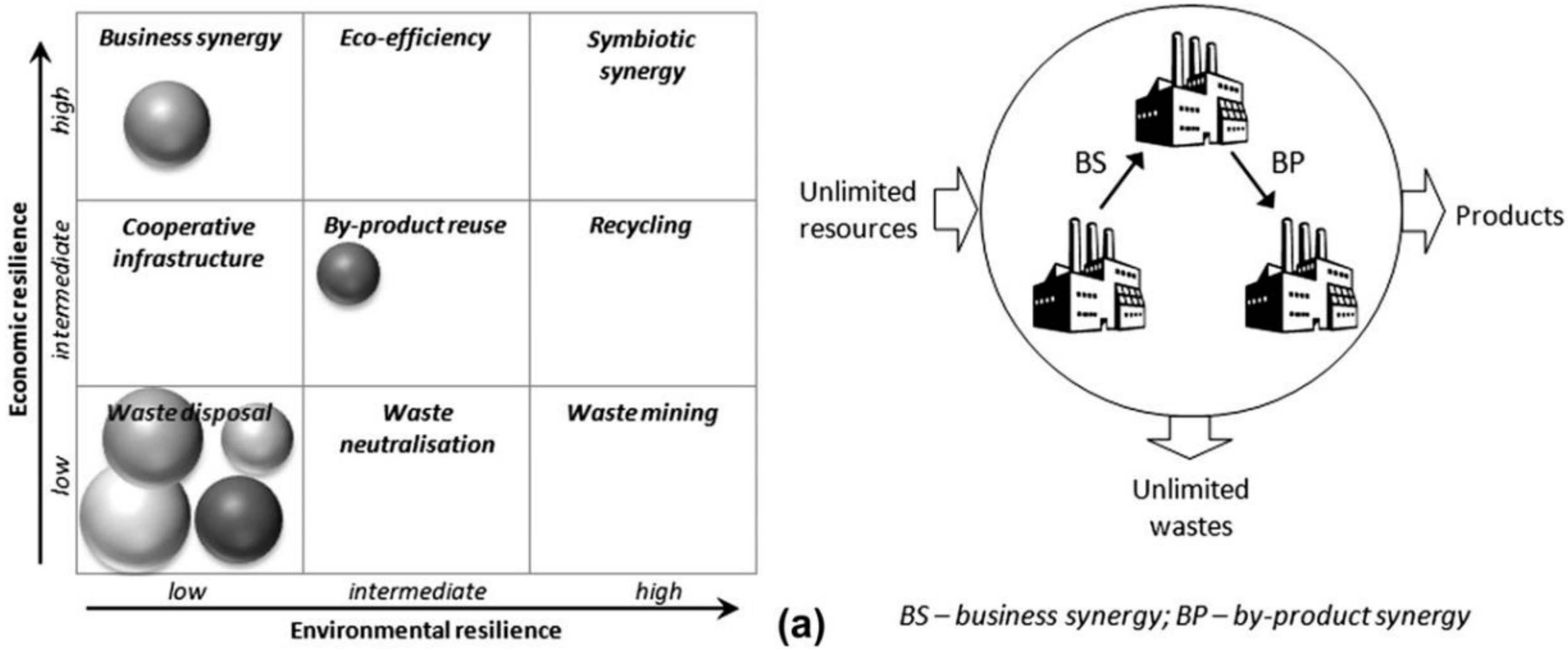
Finnfjord - verdens første ferrosilisiumprodusent uten CO_2 u



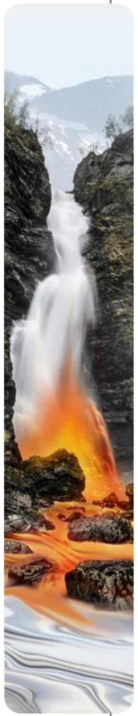
Ambitious

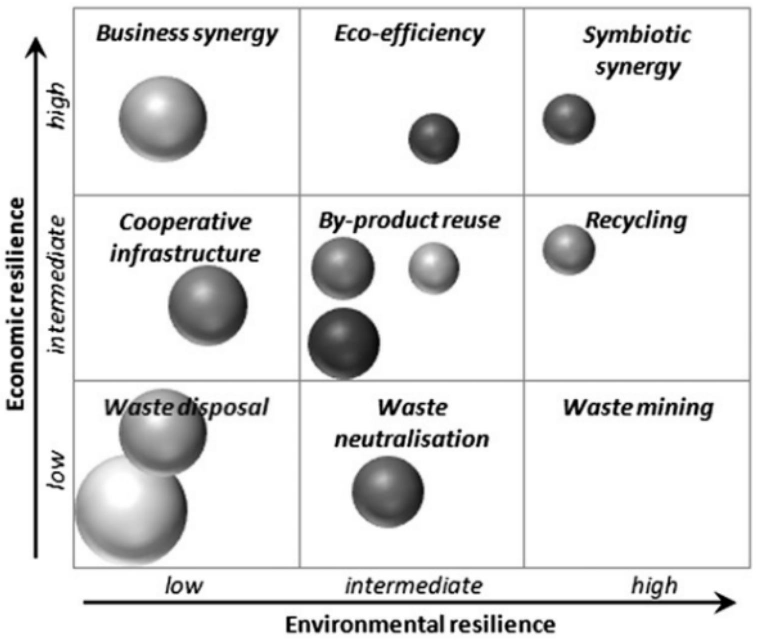
Remote

Type I industrial eco-system (linear material flows)

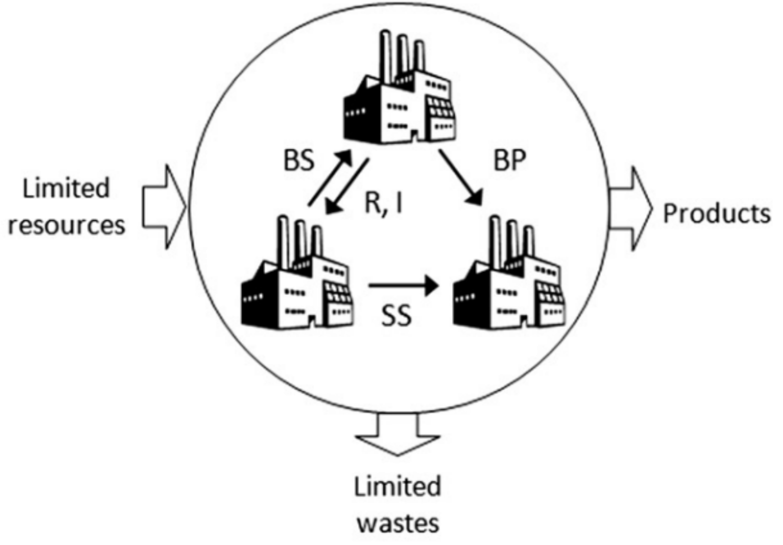


Type II industrial eco-system (quasi-cyclical).





(b)



R – recycling; I – cooperative infrastructure; SS – symbiotic synergy

Type III industrial eco-system (cyclical).