Introduction to the Laws of Nature behind Strategic Sustainable Development

Physics and chemistry behind the logics of the Operative System

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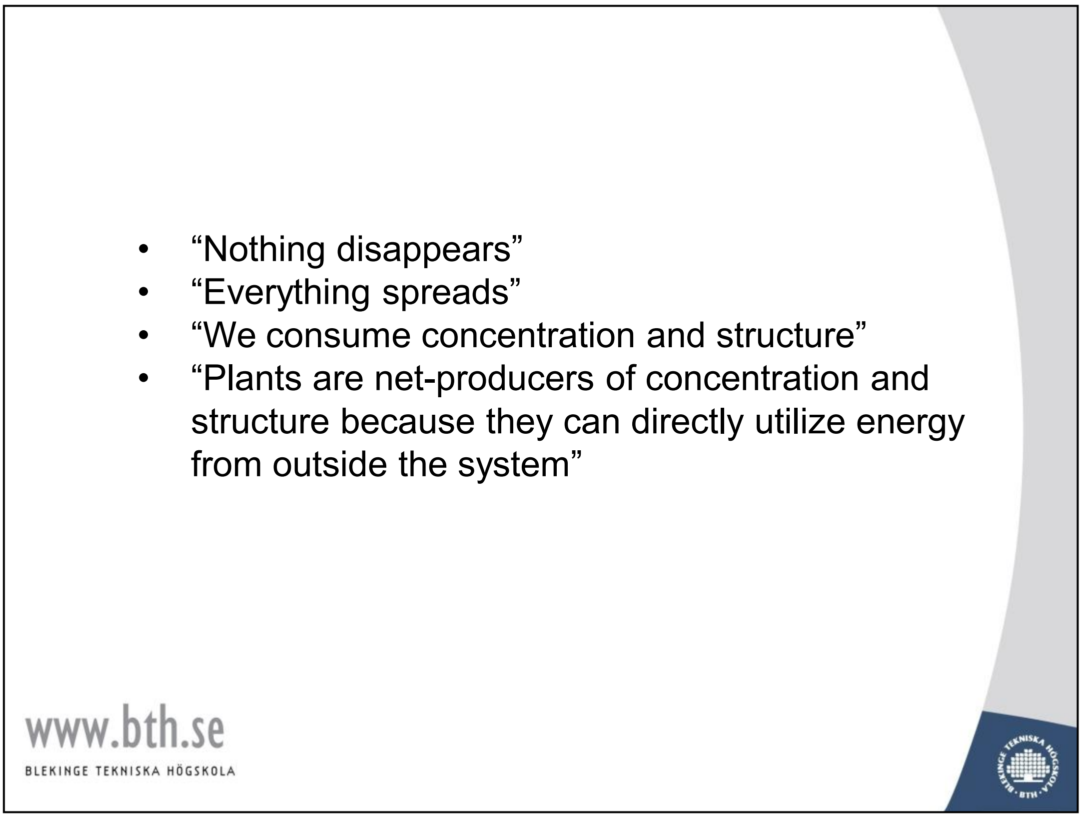
BLEKINGE TEKNISKA HÖGSKOLA

Karl-Henrik Robèrt in April, 2026

Would it be possible to move from understanding a disease in a patient, to understanding a disease for the whole world, threatening us all as some diseases do individuals? What are the basic health-principles for sustainability – a society that does not destroy nature and social systems?

To explore the principles for a sustainable civilization, we first need to understand the basic conditions for life on Earth viewed through a scientific lens.



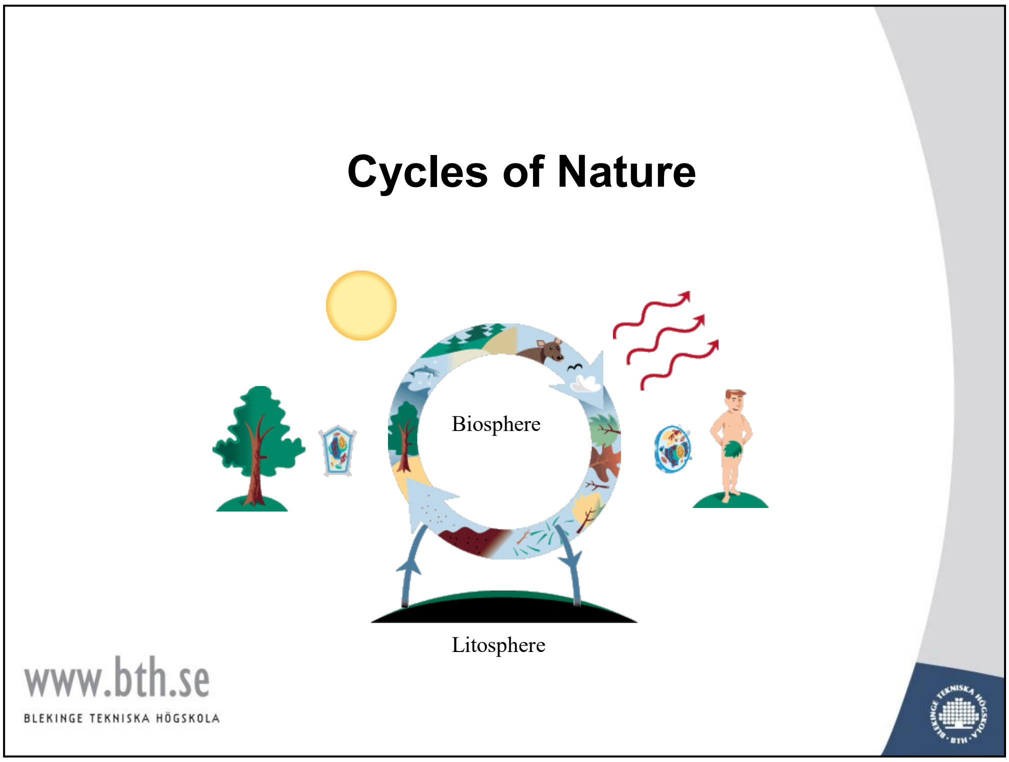
- “Nothing disappears”
- “Everything spreads”
- “We consume concentration and structure”
- “Plants are net-producers of concentration and structure because they can directly utilize energy from outside the system”

Those statements provide four cornerstones that are helpful for understanding the cycles of life on Earth.

- “Nothing disappears” is also called “the conservation-laws”. They are two, one law applying for (i) matter (the ‘matter-conservation law’) and the other for (ii) energy (the ‘first law of thermodynamics’). In all processes, including chemical reactions, the (i) atoms that enter the process are exactly the same as the ones coming out of it (though mostly in different combinations e.g. in valuable new chemicals as well as in side-products or waste). Likewise, the energy that is accompanying and/or driving a process is exactly the same that leaves it (though, again, in a different shape – some or all of the energy’s working capacity has been consumed, not the amount of energy per se, we will return to this).
- “Everything spreads”. This statement refers to the second law of thermodynamics, also called the entropy-law. It refers to matter as well as energy and means that the energy that accompanies all kinds of processes irreversibly end up as disperse heat and – when we talk about Earth – leaves the planet as heat-radiation with no remaining working-capacity. Likewise, matter also has a tendency to spread in all kinds of processes, e.g. when carpets turn to dust and cars to rust – never the other way around. Another example is when we burn a piece of wood and turn the concentrated energy in the wood to more and more disperse heat and ashes. Which brings us to the third statement.
- Since neither energy, nor matter, disappears in processes it is the *quality* of

energy and matter that is consumed. The piece of wood has a quality and structure that makes it usable as building material, or to help keeping us warm. Both qualities are consumed when we burn it, but both energy and matter per se is preserved though in a diluted and mixed state.

- The above three statements apply on Earth as well. So, in principle, why don't all life-forms and all things we evaluate end up as a huge garbage dump and as disperse heat into outer space? The answer is that plant cells create and/or sustain valuable concentration and structure of energy and matter on Earth. They don't need to burn wood or petroleum or food or any other source of energy for their lives, they manage to do the opposite: fueled by sun-energy, *that is free to enter the biosphere since the system is open to energy* they *consume* disperse junk from animal life and other processes, and concentrate it into the energy-containing structured materials of nature. This includes the food we and the other animal-species eat. Since *we* cannot make use of energy directly from the sun, we have to digest food, and breath oxygen to "burn" the food in our metabolism, turning food with chemical energy (with its origin in the sun) and materials into body-growth, disperse waste and body-heat that leave our bodies. The material waste from animals is re-concentrated and re-structured back into growing farm-fields and forests containing concentrated and structured matter and energy. Which brings us to the next slide – a simple graph of the natural cycles.



Cycles of Nature

Biosphere

Litosphere

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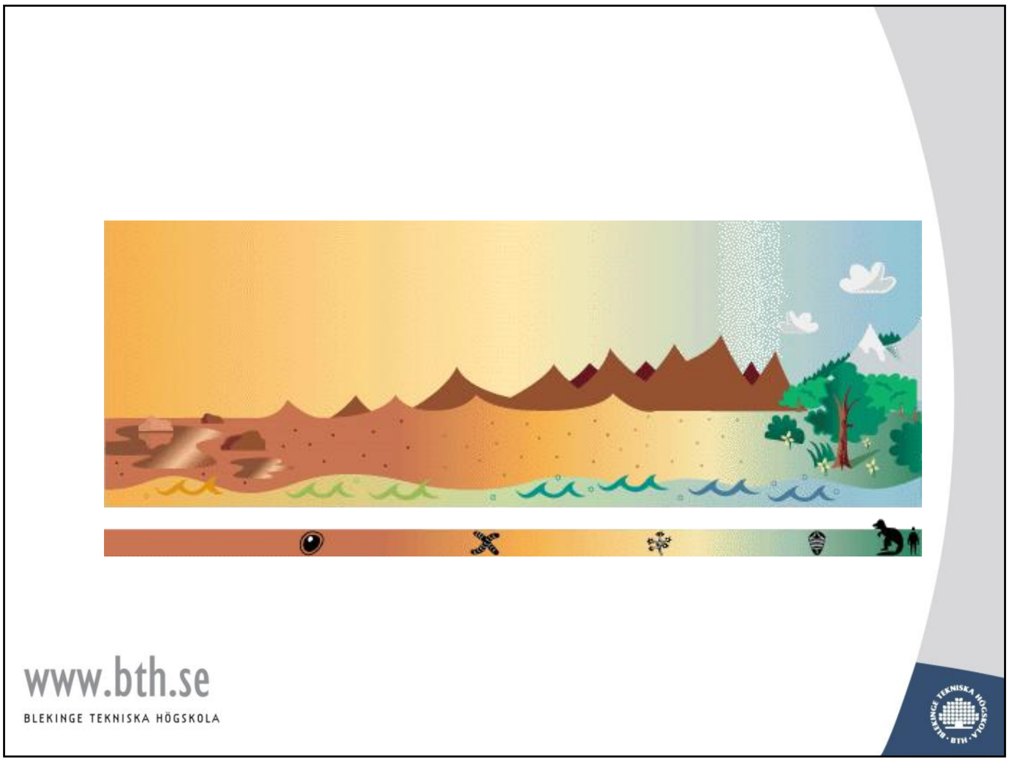
The four statements can now be put together for the understanding of natural cycles, or the ‘biogeochemical cycles of nature’. They operate like a huge heat-machine producing quality for life on Earth i.e. concentration and structure for energy and matter. The *primary* producers in this machine are the plant cells, and the reason for their specific capacity is photosynthesis, i.e. they know how to energize themselves without eating or using other forms of chemical energy such as fossil fuels. On the contrary, energized directly by the sun they digest what is waste from animal- and human bodies, and concentrate it back to new energy rich resources such as crop, forests, algae etc. This is called photosynthesis, i.e. 'building with light‘, or ‘primary production’ since it is the first order production on which other production forms on Earth relies on. There is another and much slower cycle as well – a very slow flow of matter is sedimented and mineralized into rock at the border between the biosphere and the earth’s crust (‘lithosphere’), and another flow brings matter back from the earth’s crust to the biosphere – volcano eruptions and weathering. Though small flows in relation to the hugh bio-cycles pumping matter and energy around every day, they still count over geological times. The creation of resources from waste (primary production with sun-energy) has, over geological times, exceeded the degradation of resources back to waste, making biological evolution possible. So in the tiny little space of the universe, where plants live, the biomass could grow and evolve to ever finer life-forms within the same amount of matter, and through a continuous consumption of high-quality energy from the sun. Due to the second law of thermodynamics this must happen with a cost. Loss of concentration and structure happens if we look at the whole system, namely as disperse irradiation-heat leaving the Earth into outer space, and as degradation of the sun. No worries though, the sun is calculated to last for another 2,5 billion years, providing the energy our cycles of nature need. Our worries are of another dimension, civilization’s current processes dissolve and pollute the biosphere faster than the cycles of nature can cope with. Which brings us to the next slide.



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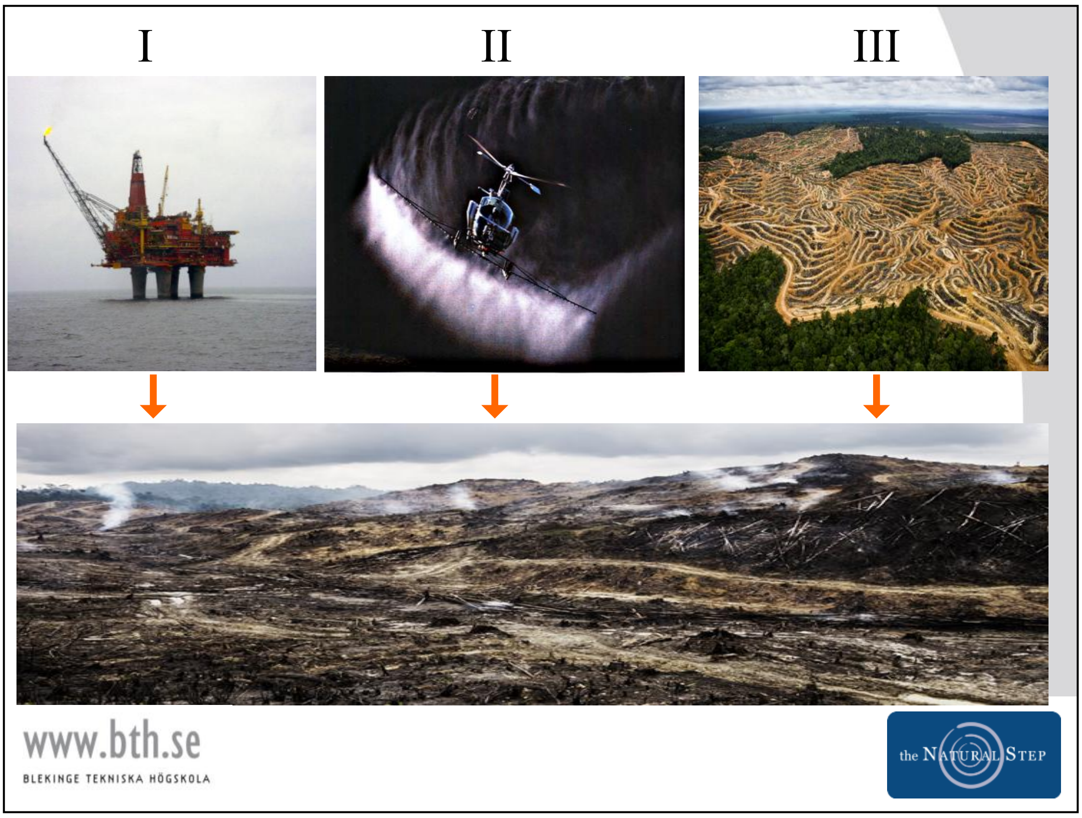
So, the natural cycle has served as the ‘engine’ by which evolution in the biosphere (biological evolution, and lately, after humanity entered the scene, also cultural and technical evolution) has been possible in spite of the second law of thermodynamics. There is one billion (!) years between each biological event symbolized by the evolving species on the time axis in this picture. From the creation of Earth 4.5 billion years ago, it took around one billion years for the blue-green algae to appear. After another one billion years the biomass had grown a bit more, and also contained primitive colonies of one-cellular organisms. It took another one-billion years to create complex multicellular plants where the different cells plaid specified roles. After yet another one billion years the first primitive animal cell entered the scene, the amoebas which was the starting point for the high-metabolism life and mobility of animals. This triggered a boost in diversity, giving us what we refer to as ‘Nature’ within only 0.5 billion years. The big Cycle of Nature, the heat-machine for production of life-quality, has thus – in 3.5 billion years – created ‘Nature’ from a worthless mixture of disorganized matter in the primeval atmosphere. What are the basic mechanisms, by which civilization with its organizations destroy this “quality-machine”?


I

II

III

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the NATURAL STEP

The laws of nature *would* allow human civilization to live like a huge animal amongst other animals, on the same conditions as them. I.e. consuming resources into waste, but not systematically more than nature’s cycles can cope with. This picture denotes three overriding mechanisms by which ecosystems can be destroyed. The end-result is the same – destruction. It is important to understand the basic difference of those mechanisms, in order for us to ”design” the problem out of the system: The global ecosystem can be destroyed by…

I. Ever larger concentrations of substances from materials that society drills or mine for, e.g. fossil CO2, or pollution from heavy metals e.g. Cd, Zn, Ag etc.

II. Ever larger concentrations of substances than society produce, i.e. compounds such as NOx, or PCB, or endocrine disruptors.

III. Ever larger areas that we destroy by physical means, e.g. through more and more asphalt on land, too large fishcatches or too large areas of clear cutting.

IV

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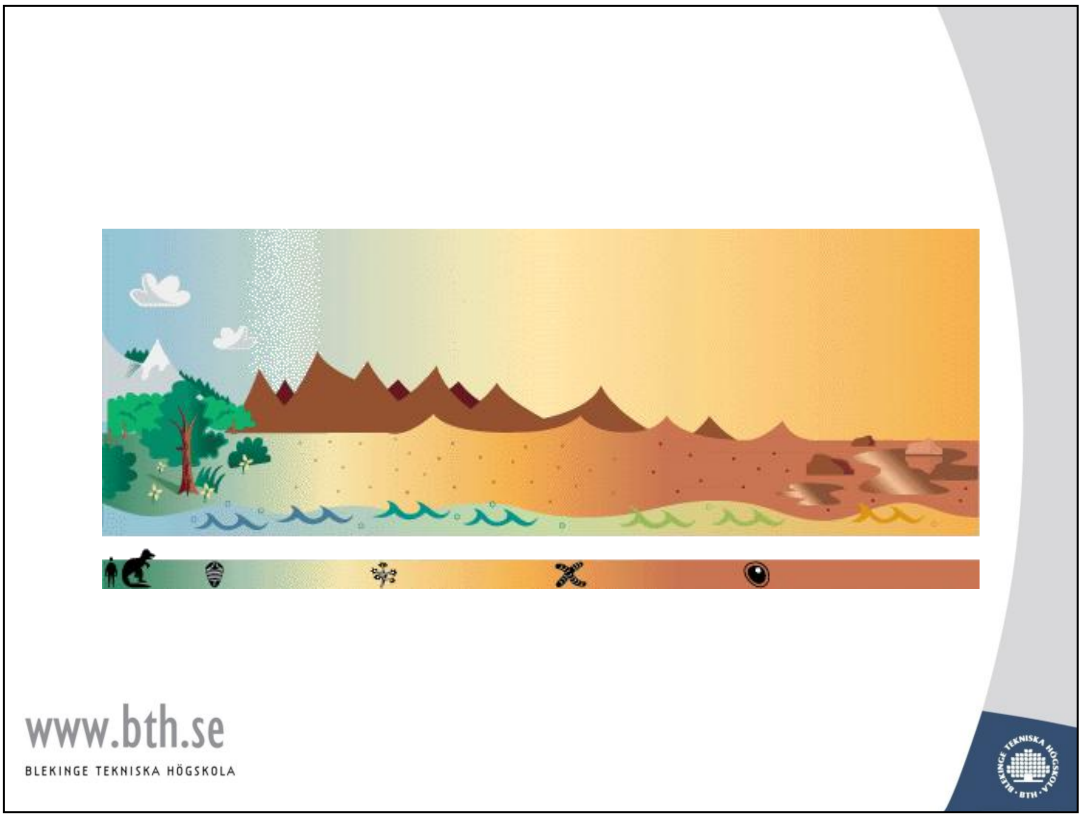
But we must not forget the other of the two systems that support civilization, the social system. By studying also this system enough, we have understood that trust between people, and between people and their institutions, is the key element. It is with a sense of general trust in a community, people can be effective and deal with big problems together.

Social sustainability, sustaining trust, means that the leadership (at all levels in society) sets no barriers to people’s health (mental and physical e.g. regarding wages and working hours), influence (e.g. voting or having a say at the work place), competence (e.g. the right to learn and grow), meaning-making (e.g. having a sense of joint mission for communities and organizations) and impartiality (all people being treated equally regardless gender, nationality, belief-system etc.). We will return to this.



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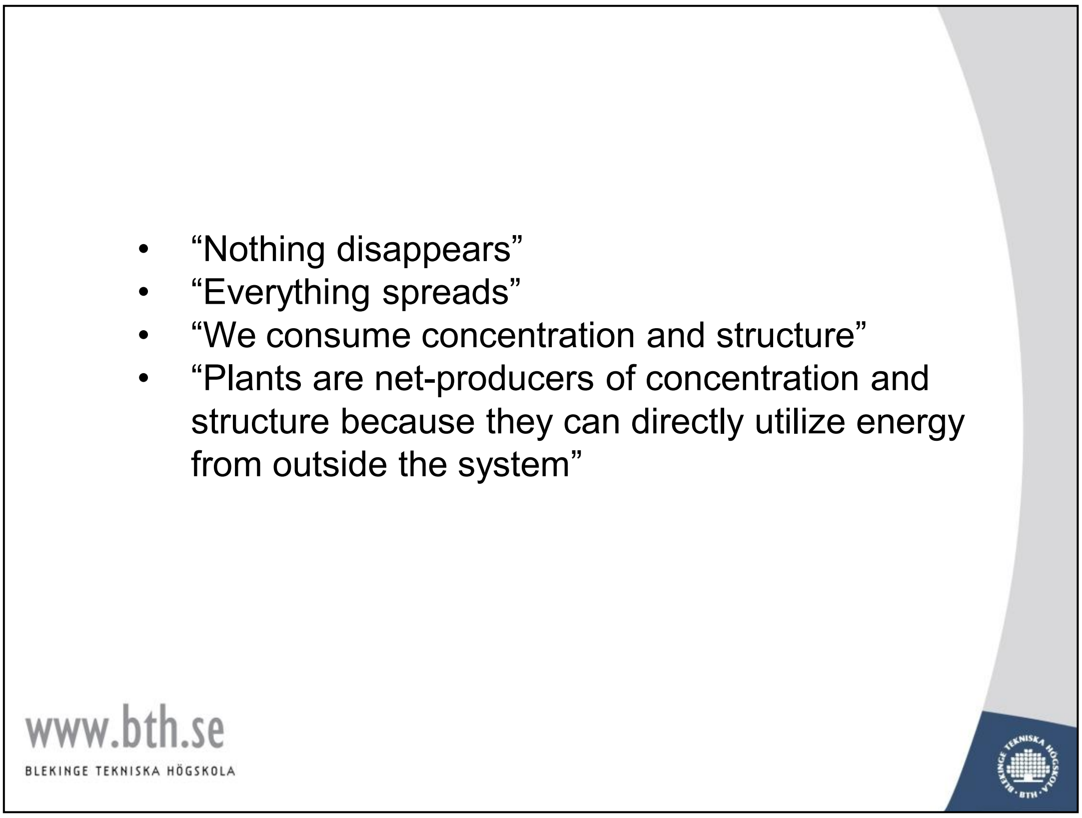
So, after a creation period of 3.5 billion years, human civilization with all its organizations, systematically run basic destruction mechanisms that allow forests and soils to become deserts, and the creation of waste to supersede primary production. As a consequence, resources are declining at the same time as inpurity and climate-change gases are increasing. We are going backwards in evolution, as if the 3.5 billion-year creation film is played in reverse. We have created a funnel of diminishing capacity to sustain civlization. The framework is outlined more in detail elsewhere in the program, but let us now proceed and go more in detail when it comes to the four statements on slide 4, serving as our mental ”building-blocks” to understand how nature works.



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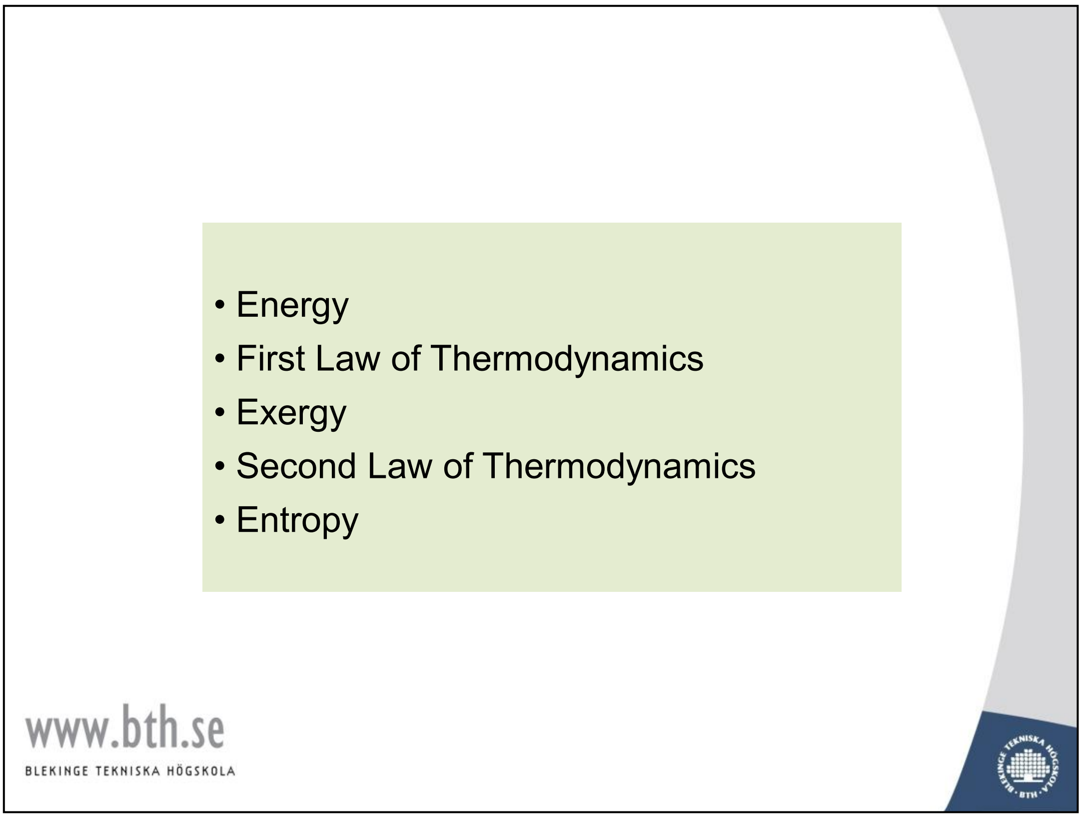
Let us go a bit deeper in science to understand the four statements and their meaning a bit more.



- Energy
- First Law of Thermodynamics
- Exergy
- Second Law of Thermodynamics
- Entropy

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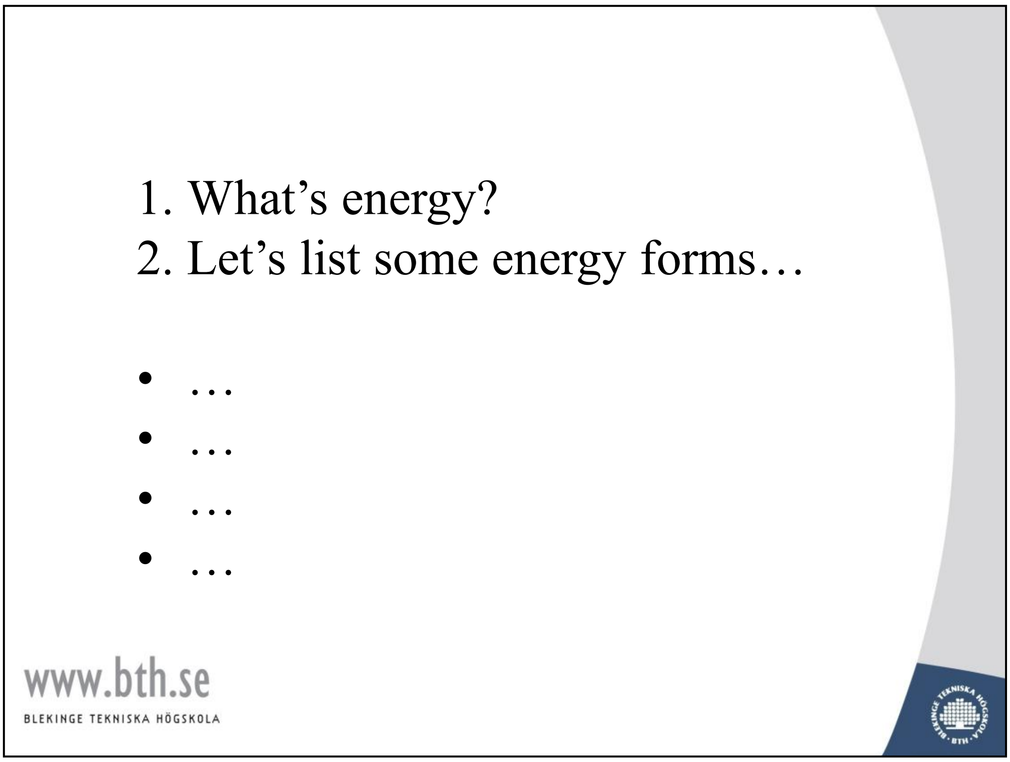
- Energy means motion. Anything that has motion of any kind, from sun-beams moving here from the sun, through the motion of atoms and molecules moving faster and faster the hotter something is, to kinetic energy e.g. when a car is moving ahead. We also talk about “potential energy”, i.e. energy harboured or contained somehow until it can be released in a process. Examples of the latter are the energy of food, which belongs to the group “chemical energy” since it is about food-matter containing energy that originally was captured from sunlight in the photosynthesis of plants. Another example of potential energy is the water in a dam high up, which can be released to a turbine further down in the gravity field.
- First law of Thermodynamics. We have already said what this is, energy cannot be consumed but is conserved. All the potential energy within the dam in the example above is released as we empty the dam, and turned to kinetic energy as the water falls down, which turns to kinetic energy in the spinning turbine, which turns to electric energy flowing in a cable to a city. In myriad processes more and more worthless and diluted waste heat is produced in the series of energy-conversions. Waste-heat in the turbines, city light, computers, electric cars, elevetors – *all* the energy eventually turns up as disperse heat that eventually leaves the atmosphere into outer space as heat irradiation. The amount of energy, ‘motion’, is the same. But in the last stages of quality it is distributed to so many disperse particles that it can no longer perform any work for us. Which brings us to the next term.
- Exergy is a term for the value or quality of energy, i.e. what proportion of it that can actually perform work – making something else move. An example

can be a certain amount of electric energy, e.g. 60 kilowatt-hours from the grid to our house; the amount of energy needed to make a 60 watt lamp burn for one 1 hour. Electric energy is an example of energy that has a very high exergy value, *all* of electric energy can in principle be put at use. **60 kilowatt-hours of electric energy, is 60 kilowatt-hours of exergy.** An example of the opposite is the disperse heat from the lamp that eventually leaves the Earth – *none* of the heat-energy that is diluted that much can be put at any use at all, the exergy of it is then zero. But the amount of energy of the disperse heat is still 60 kilowatt-hours. **60 kilowatt-hours of disperse heat leaving the Earth, is 0 kilowatt-hours exergy**.

- Again, the second law of thermodynamics, also called the entropy law, means that in all processes, the working capacity of energy, exergy, is *irreversibly* lost.
- Entropy is a dimension put on the *degree of exergy loss* or “disorder”, in the process. In an insulated system consuming a certain amount of exergy in a process, *all* of that exergy is eventually turned to entropy. If the system is not insulated for energy, it can receive exergy from outside the system to create structure and order again, and the entropy can be exported out of the system.



1. What’s energy?
2. Let’s list some energy forms…

- …
- …
- …
- …

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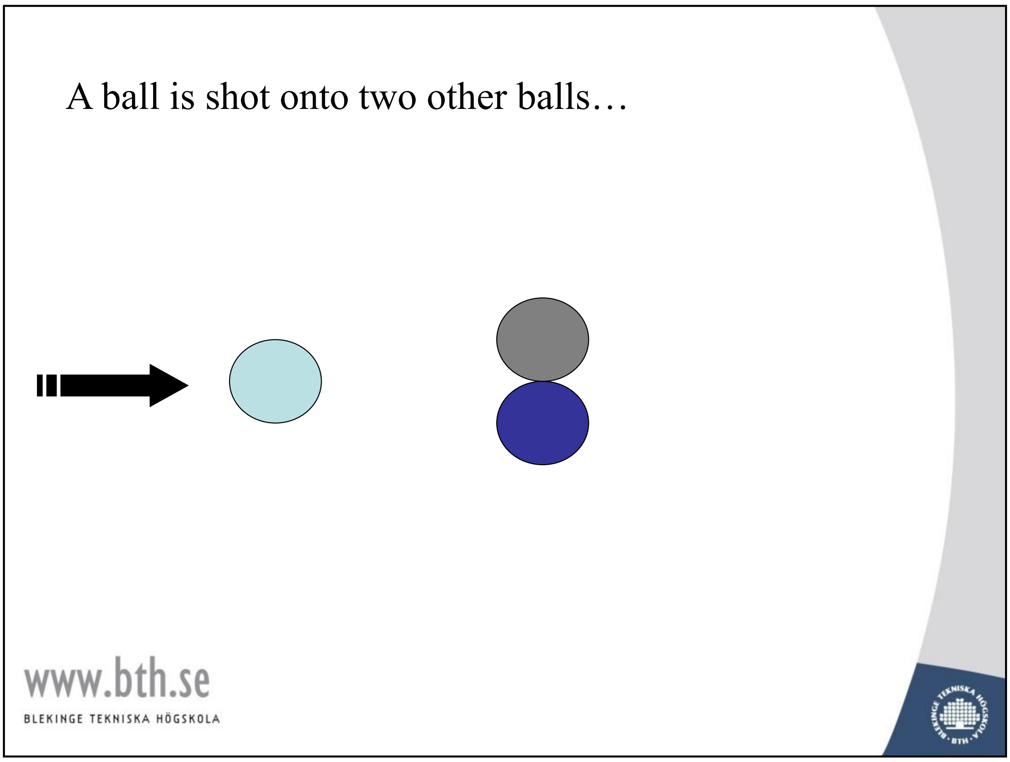
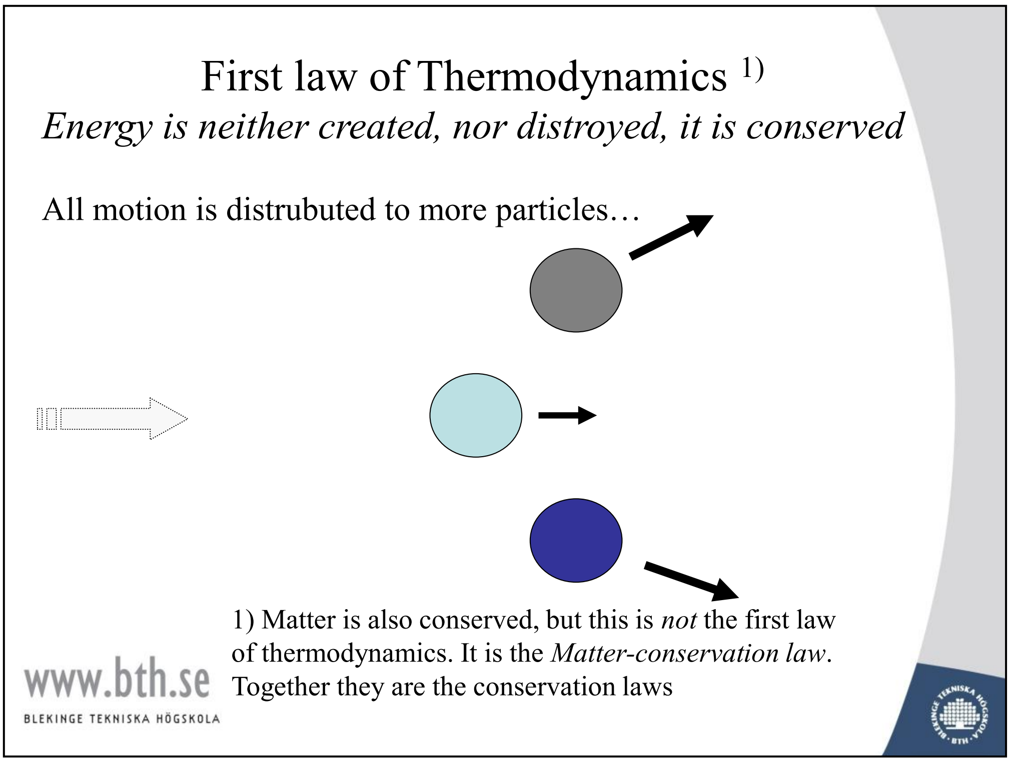
What energy-forms can you think of? For any of them, what does the “motion” refer to, what is it that moves? Think of some examples of heat-energy, chemical energy, kinetic energy, radiation-energy, potential energy.



A ball is shot onto two other balls…

Making use of the above knowledge, let us imagine a game of billiards.



First law of Thermodynamics 1)

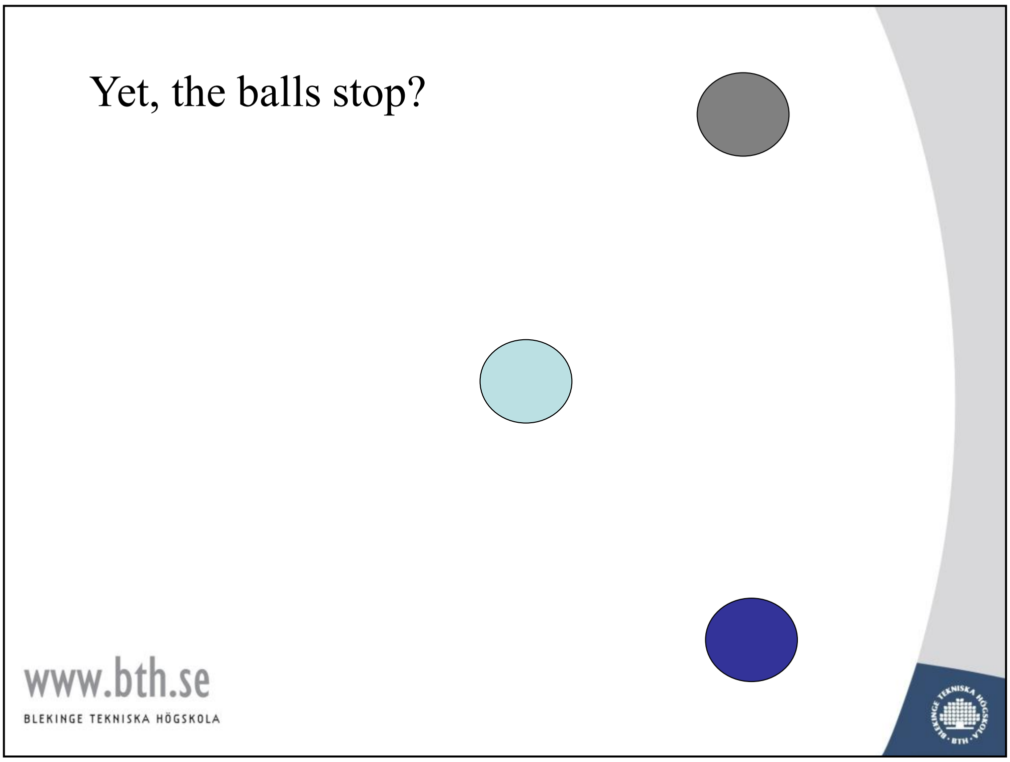
Energy is neither created, nor distroyed, it is conserved

All motion is distrubuted to more particles…

1) Matter is also conserved, but this is *not* the first law of thermodynamics. It is the *Matter-conservation law*. Together they are the conservation laws

Two particles, balls, receive kinetic energy from the first ball (that, in turn, originally got it from sun-light creating chemical energy in the food turned to kinetic energy of the arm moving the que-stick that creates the motion of the ball – yet a form of kinetic energy).

All motion is preserved, but directly after the hit of the first ball into the two other balls, the energy it is now distributed to *three* balls moving. Neither of them has as much energy or motion as the first ball had originally, only together they do.



Yet, the balls stop?

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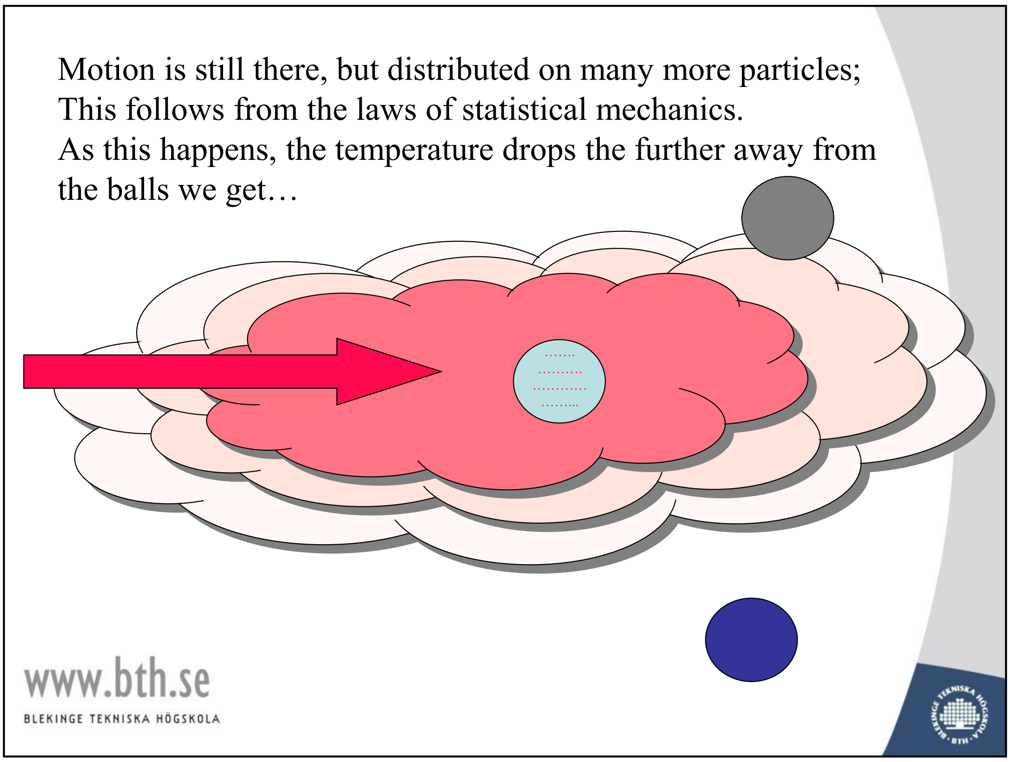
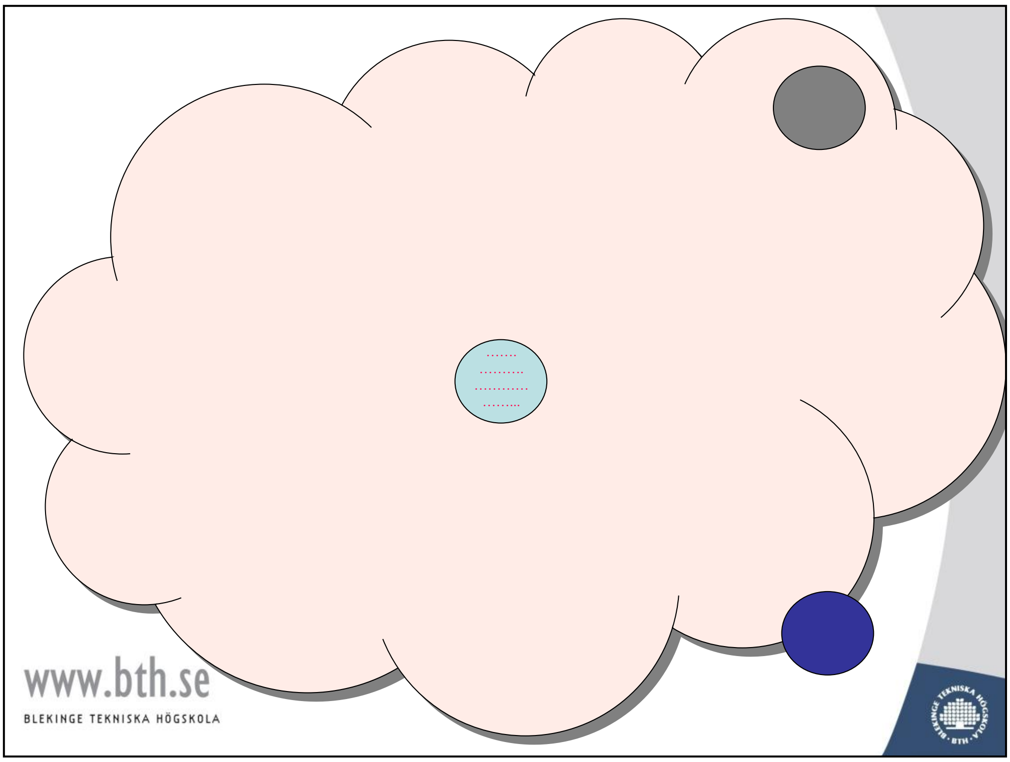
So, if all motion is preserved, why don’t the balls continue to roll and bounce in this system, the billiard table, for ever? We have already said that all the energy in a process like this is eventually leaving Earth as heat-radiation. What is it that got a bit hotter from the above process, distributing energy (motion) to more and more disperse particles moving at relatively slower pace? Can you think of examples how this could happen?



Motion is still there, but distributed on many more particles;
This follows from the laws of statistical mechanics.
As this happens, the temperature drops the further away from the balls we get…



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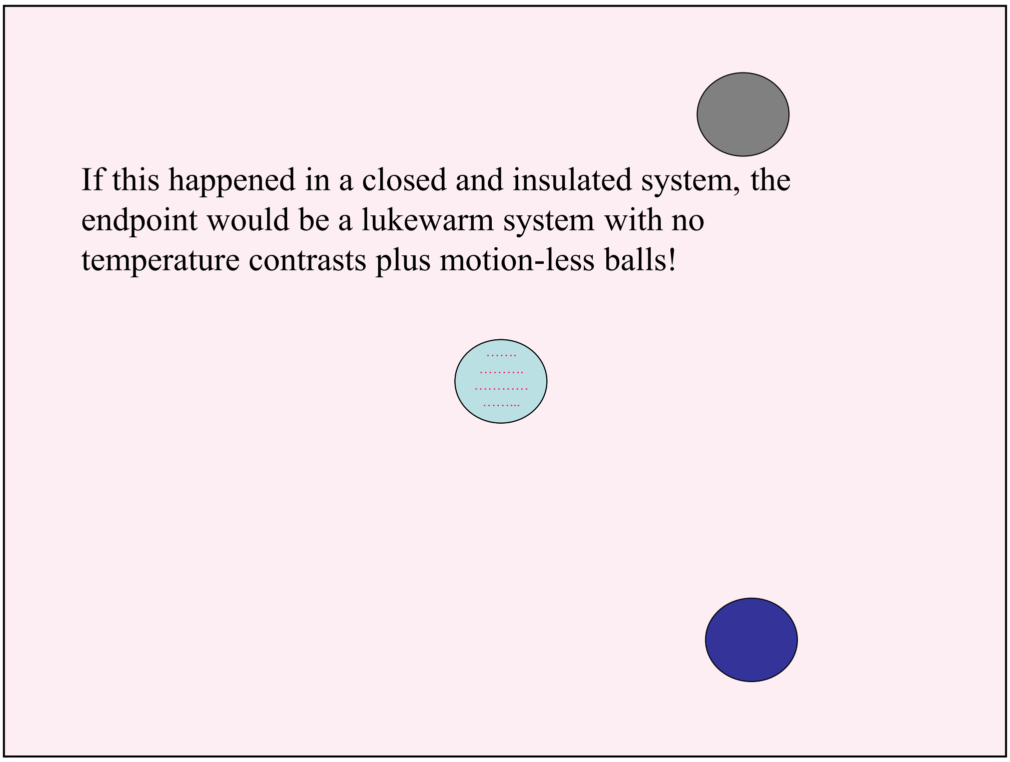
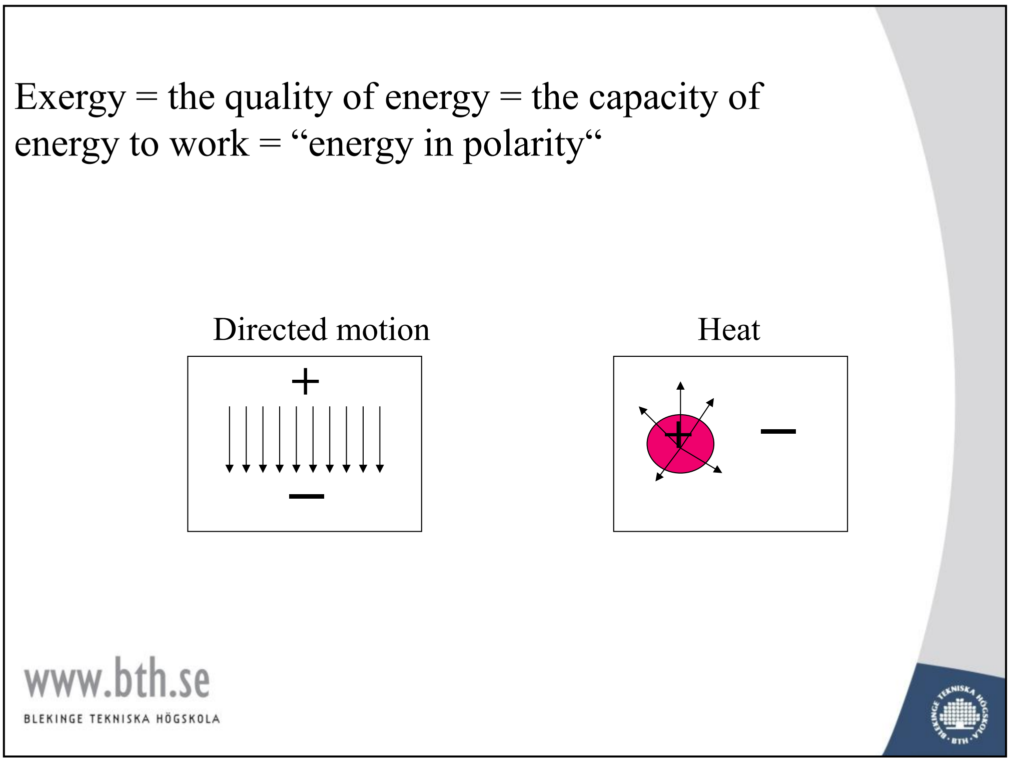


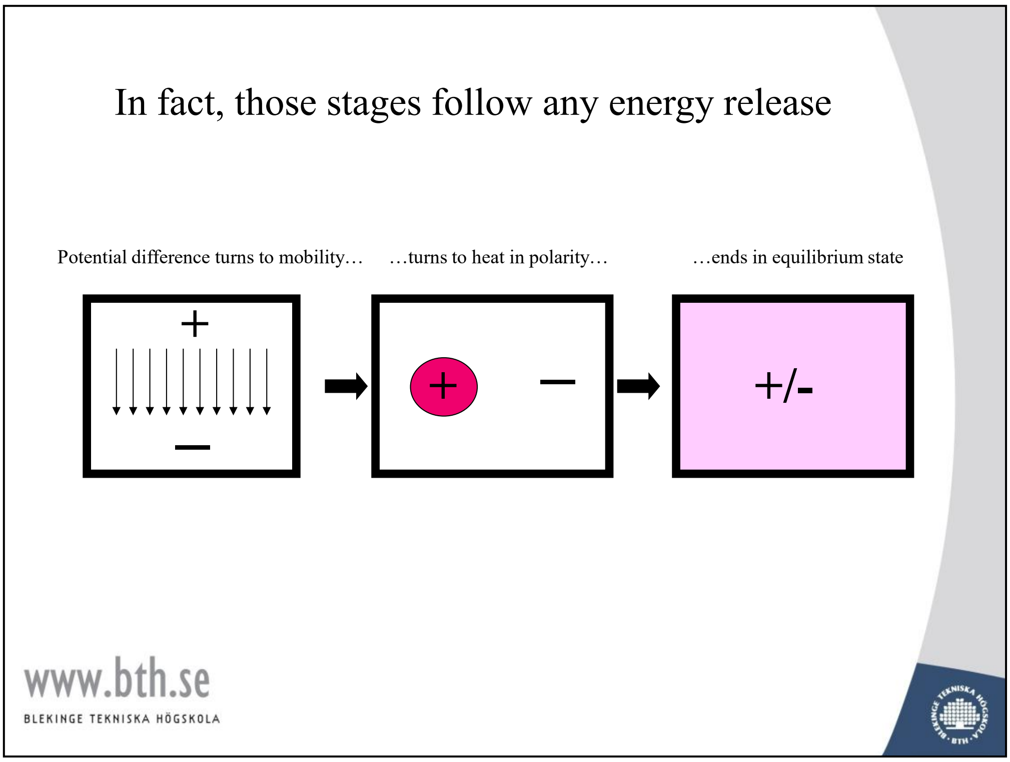
If this happened in a closed and insulated system, the endpoint would be a lukewarm system with no temperature contrasts plus motion-less balls!

The atoms and molecules of all the balls, and the table of billiards, is slightly hotter than before the process began. If the table would be perfectly isolated in a perfect thermos, no energy could leave the table. All the particles of such a sealed-off table would move slightly more than before the ball-strike, and would continue to do so for ever. But there would be no contrasts of temperature in the system. So we cannot lead a systematic low of energy from a hotter place to a cooler place and thereby make something else move e.g. a turbine. This is called “thermodynamic equilibrium”, sometimes also called “heat-death”. The slightly hotter, but use-less-for-work stage, follows from the first and second law of thermodynamics, see above.



Exergy = the quality of energy = the capacity of energy to work = “energy in polarity“

This figure displays two different situations where we have the possibility to extract work from an energy flow. In both cases we can see a polarity, expressed as a plus and a minus sign. The first example displays something that flows regularly in one direction e.g. a wind, solar energy, a waterfall or a sea-current. The second example is a place that is hotter than its surrounding, e.g. the heat within a steam-engine. In the latter case the energy is not distributed in a parallel motion, but particles are moving around and bumping in random directions, though more intensely in the concentrated area of the tank. This means that if the two examples contain exactly the same amount of energy, the heat-example cannot even theoretically be transferred to the same amount of motion elsewhere, e.g. into kinetic energy of the train propelled bythe steam-engine. There is an inevitable loss of exergy *upfront* as the heat in the steam-engine is turned to kinetic motion of the train. This is not the case in an electric train, where the efficiency is much higher – a parallel motion of electric current is turned to a one-direction motion of the train.



In fact, those stages follow any energy release

Potential difference turns to mobility… …turns to heat in polarity… …ends in equilibrium state

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This picture displays a general flow of energy-conversations when a process (i) begins with high-exergy motion of some kind. That motion is eventually (ii) transferred to heat in polarity which is (iii) inevitable transferred to heat with no polarity i.e. the heat is transferred to all particles in the system moving randomly in all directions (but slightly more than they did before i.e. the system has a slightly higher temperature).

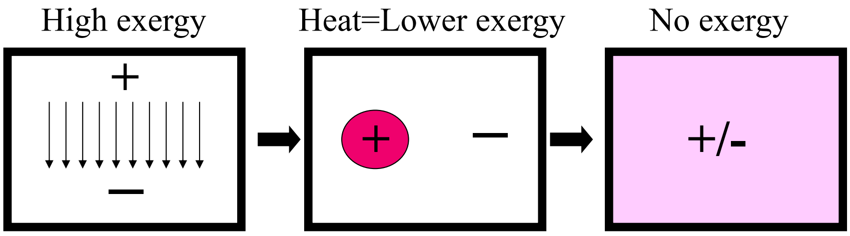
As an imagined example, say that those energy-conversions would happen in a sealed-off region e.g. Karlskrona within a perfect thermos. Further, that the energy-transformation process pictured in the three boxes begins with a huge electric battery attached to a likewise huge lamp within the Karlskrona box (the box far left). The light-energy from the lamp makes wood grow in a park in Karlskrona. The wood is put as biofuel into a steam-engine of a train, look at second box where the water-vapor in the tank is much hotter than around it. It means that the high-exergy from the battery was first turned to high-exergy chemical energy of the wood, and the wood was then transformed to heat in the steam-engine. The polarity in the steam-engine has considerably less exergy than the battery (because of the random motion of heat in the steam-engine).

After all the exergy from the heat-polarity in the steam-engine has been consumed in the motion of the train, and it stops, *all* the motion still remains in the system! More and more particles are bumping randomly into each other from friction in the rail, and from the wind-turbulence surrounding the train, etc. Until *all* of the original energy from the battery and the wood is evenly distributed as heat within the Karlskrona thermos. That is symbolized by the third box. The original exergy from the battery has now, in the end stage of energy-conversations, been consumed until zero exergy remains, and *all* of the original exergy exists as entropy.

If we now *open* the thermos and let out the entropy, i.e. let the worthless disperse heat out into space, we can allow the sun to perform the work of the lamp. The system is now still closed regarding matter, because matter is kept in Karlskrona by gravity, i.e. does not leave into outer space even when we have opened the box. But the disperse matter from the exhaust of the steam-engine *can be turned back to biofuel* – the system can be perpetual for ever.

There we are – by opening up the box we have a biosphere where the sun is continuously feeding energy into biomass, we make use of it in different ways e.g. food, fuels, timber, and the heat dispersion from each process – the entropy – is systematically exported into outer space which can be regarded as an eternal sink for entropy i.e. disperse heat from all energy-transformations in the universe.

Exergy is consumed, not energy!

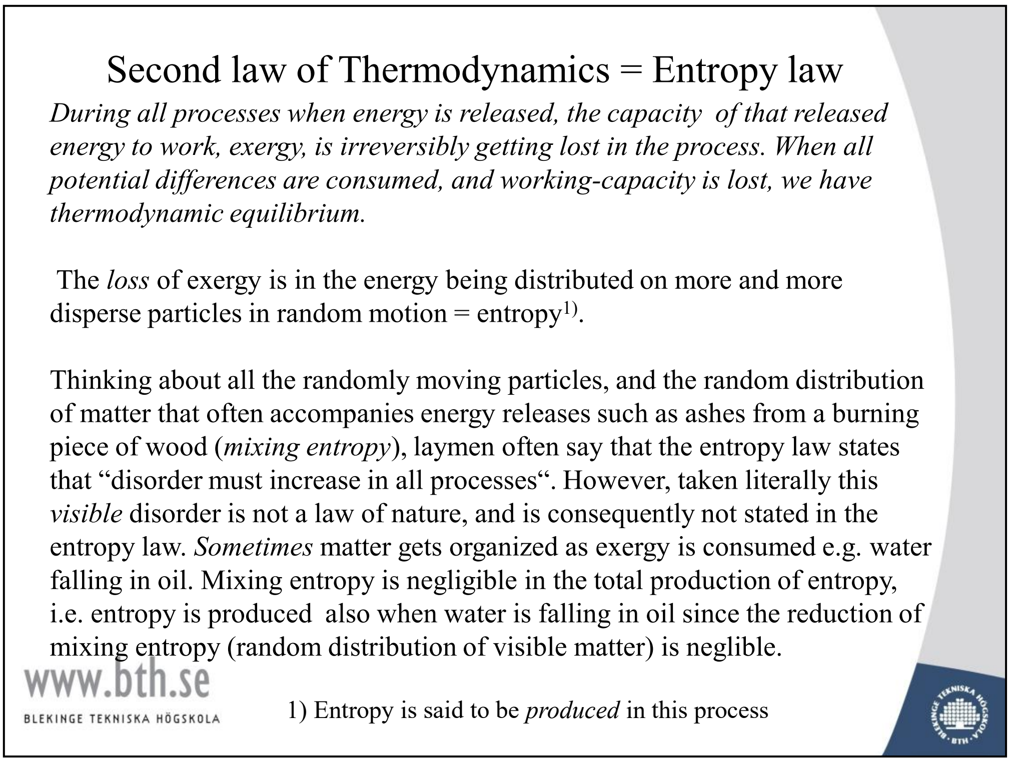


High exergy

Heat=Lower exergy

No exergy

The fact that potential differences in any system strive to be discharged, leads us to…



Second law of Thermodynamics = Entropy law

During all processes when energy is released, the capacity of that released energy to work, exergy, is irreversibly getting lost in the process. When all potential differences are consumed, and working-capacity is lost, we have thermodynamic equilibrium.

The *loss* of exergy is in the energy being distributed on more and more disperse particles in random motion = entropy1).

Thinking about all the randomly moving particles, and the random distribution of matter that often accompanies energy releases such as ashes from a burning piece of wood (*mixing entropy*), laymen often say that the entropy law states that “disorder must increase in all processes“. However, taken literally this *visible* disorder is not a law of nature, and is consequently not stated in the entropy law. *Sometimes* matter gets organized as exergy is consumed e.g. water falling in oil. Mixing entropy is negligible in the total production of entropy, i.e. entropy is produced also when water is falling in oil since the reduction of mixing entropy (random distribution of visible matter) is neglible.

1) Entropy is said to be *produced* in this process

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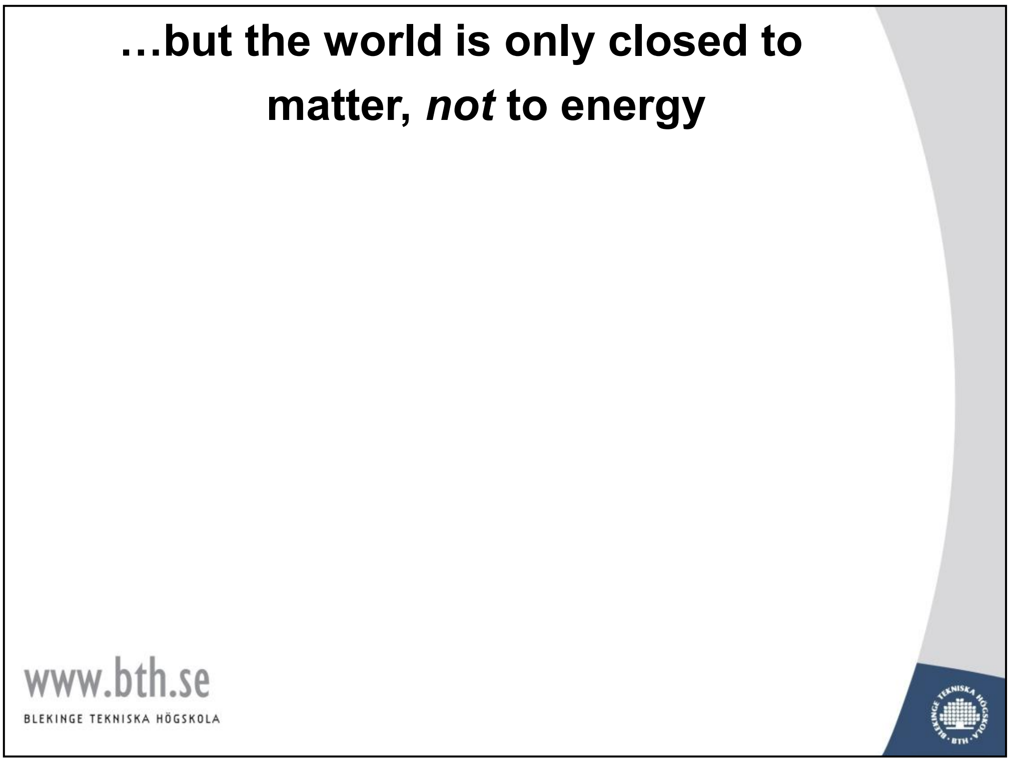

…but the world is only closed to matter, *not* to energy

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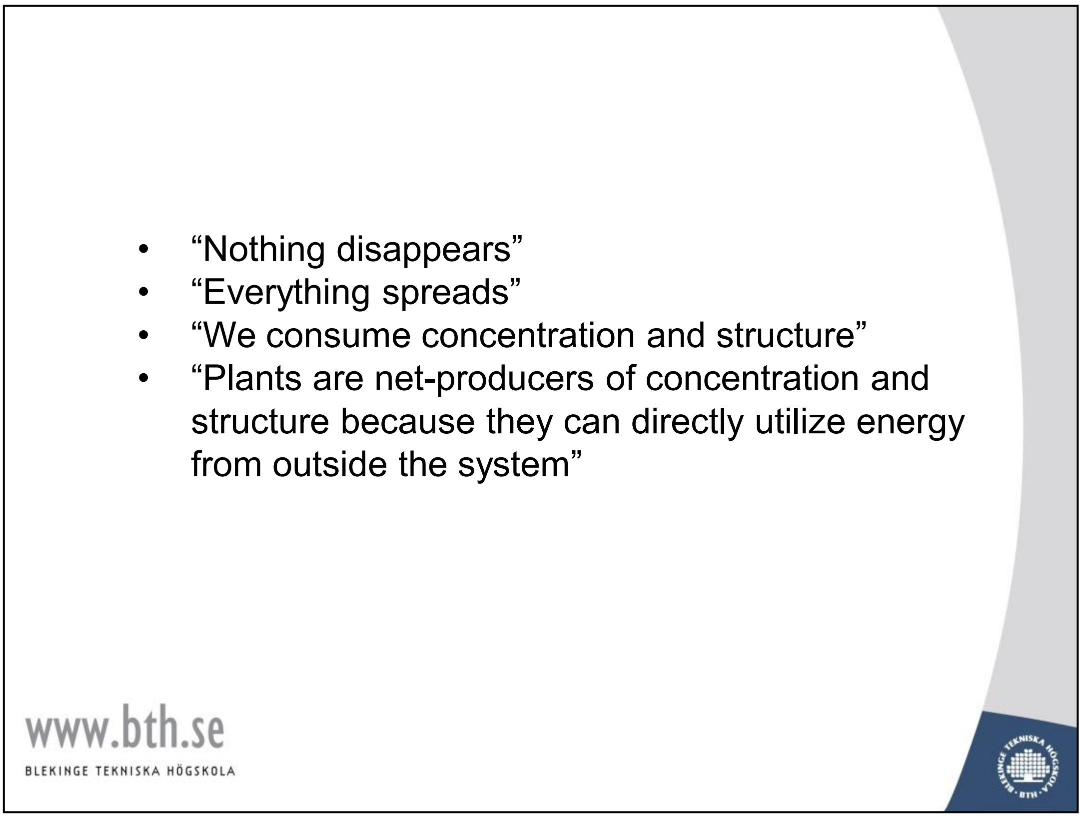
“Value”, seen as ’concentration, structure and purity’, can “flow upstream” in the biosphere. This is because exergy is imported into the system (sun-energy), entropy is exported out from the system (non-polarity heat into the cold universe), and the potential-difference between the two can be directly used by plants. The entropy is not a problem to the biosphere, however the disordering of matter is (S.P. 1-3). The latter is dangerous and destructive, but in entropy terms (”mixing entropy” is a number we can put on disperse and mixed matter just like we put entropy-numbers on disperse heat) it is a relatively *very* small number. Though the effect on sustainability may be huge. *Explaining* the mixing and dispersing of matter to far away, may call for the second law of thermodynamics. For instance that the entropy-law explains the existence of flame-retardents in the milk of polar-bears. But the *amount* of total entropy on Earth is a dimension of no value to explain un-sustainability.The number we can put on the ”mixing-entropy” of flame-retardants leaking from a computer is so small that nobody sane would bother calculating it. But it is a *huge* sustainability problem that we violate SP2 in this way! **Random heat is exported away from Earth, gravity makes sure that disperse junk is not.**



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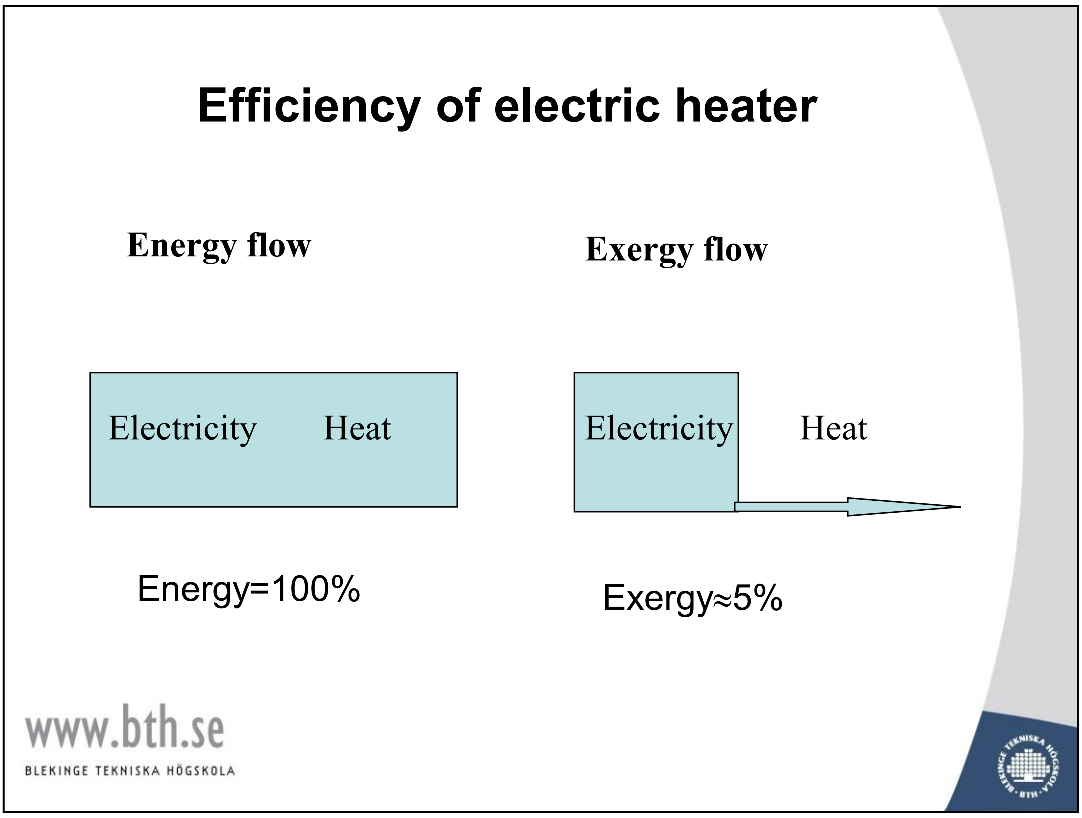
So, let us return the four notions again. Have you managed to extract some deeper understanding of them by the overview of thermodynamics pictured above, and what they mean as regards the conditions for life on Earth?



Efficiency of electric heater

Energy flow

Electricity Heat

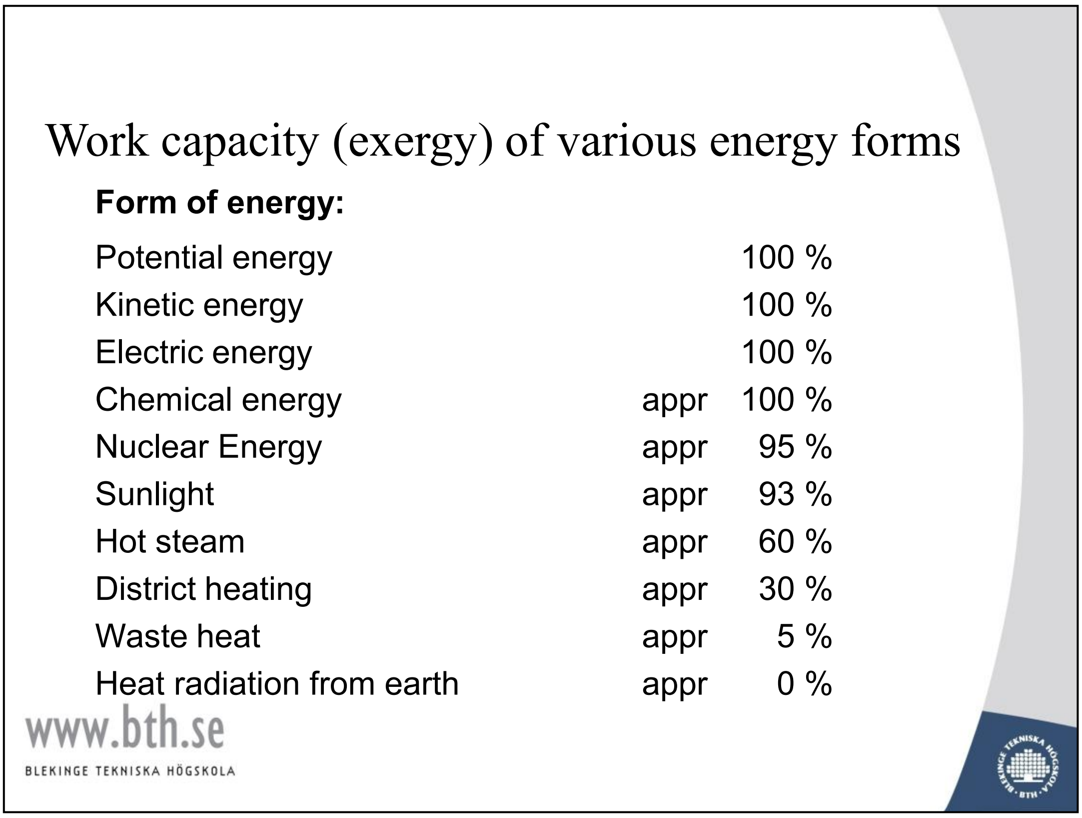
Energy=100%

Exergy flow

Electricity Heat

Exergy≈5%

By use of the above knowledge, you can understand this slide.



Work capacity (exergy) of various energy forms

Form of energy:		
Potential energy		100 %
Kinetic energy		100 %
Electric energy		100 %
Chemical energy	appr	100 %
Nuclear Energy	appr	95 %
Sunlight	appr	93 %
Hot steam	appr	60 %
District heating	appr	30 %
Waste heat	appr	5 %
Heat radiation from earth	appr	0 %

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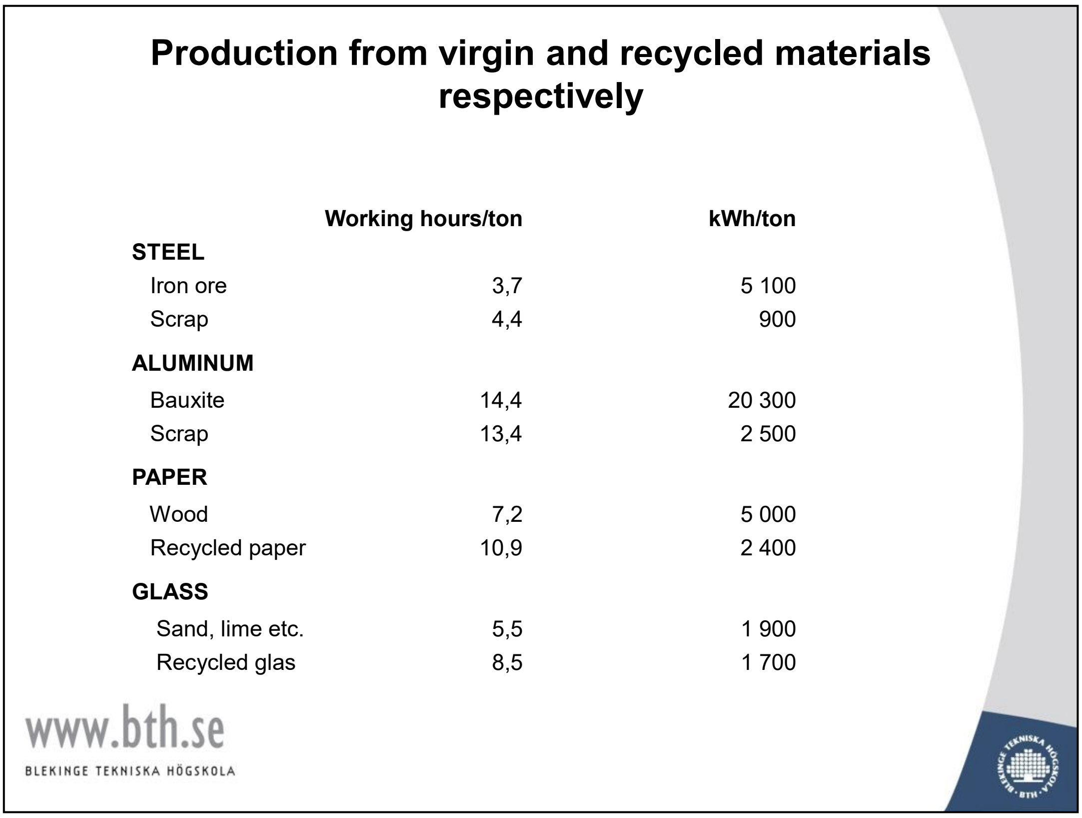
And this. The reason behind the small deviations from 100% exergy that you may notice for chemical energy, nuclear energy and sun-energy, is that it is theoretically impossible to make use of *all* of it as motion in a perfect parallel flow. We do not explain this further here. But you can also notice that even a very hot steam-engine cannot even theoretically make use of more than around 60% of its energy – all the particles in the steam move around randomly, though at high speeds (high temperature) in polarity to the cooler surrounding. As heat is distributed to more and more particles, temperature drops until there are no more contrasts in the heat radiation from the Earth.

Exergy contents in materials

Material	**MJ Exergy/kg**
Iron in Earth’s crust	0
Iron ore	appr 0,5
Iron	appr 7
Iron Scrap	appr 7

We can actually go one step further – ”exergy analyses” can also be used as a relevant measure for materials and material flows. If we put energy (e.g. electricity and chemical energy in fossil fuels) into a mining process to extract pure iron, we can calculate the actual exergy-cost to get a certain amount of pure metal from the ore. We can do the same if we begin with iron-scrap, and show that the exergy cost for the same amount of metal is *much* lower – in this example . In this way we can get a good picture of how much exergy we can save if we – in this case – recycle iron instead of using virgin iron. In fact we can save 14 times more exergy this way!



Production from virgin and recycled materials respectively

	Working hours/ton	kWh/ton
STEEL		
Iron ore	3,7	5 100
Scrap	4,4	900
ALUMINUM		
Bauxite	14,4	20 300
Scrap	13,4	2 500
PAPER		
Wood	7,2	5 000
Recycled paper	10,9	2 400
GLASS		
Sand, lime etc.	5,5	1 900
Recycled glas	8,5	1 700

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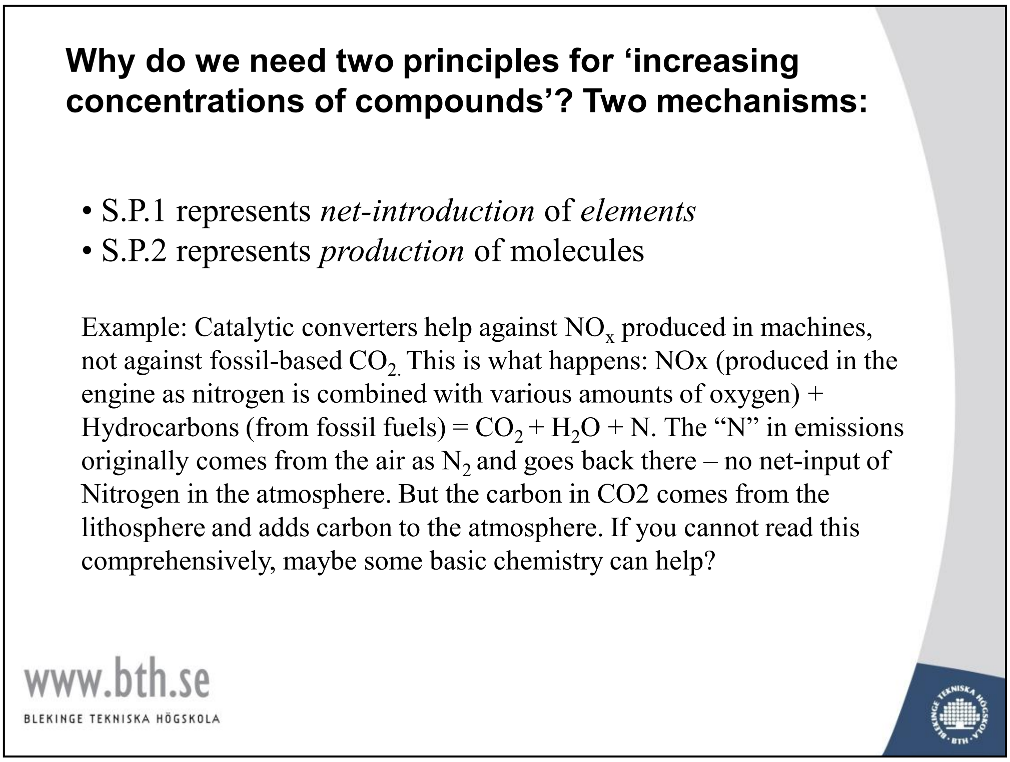
This is another example of exergy-analysis, applied for production of materials, to make the point. The table displays very large differences in exergy-expenditures when we compare production through recycling vs. virgin materials. Since there is a cost attached to the exergy needed, why are not materials recycled more in society than they are? The answer is to be found in the left column – its about the design of our economic system. This is the reason behind the discourse ontax-shifts, to increase taxes on energy and other resources, while decreasing taxes on labor.



Why do we need two principles for 'increasing concentrations of compounds'? Two mechanisms:

- S.P.1 represents *net-introduction* of *elements*
- S.P.2 represents *production* of molecules

Example: Catalytic converters help against NO_x produced in machines, not against fossil-based CO_2. This is what happens: NOx (produced in the engine as nitrogen is combined with various amounts of oxygen) + Hydrocarbons (from fossil fuels) = $CO_2 + H_2O + N$. The "N" in emissions originally comes from the air as N_2 and goes back there – no net-input of Nitrogen in the atmosphere. But the carbon in CO2 comes from the lithosphere and adds carbon to the atmosphere. If you cannot read this comprehensively, maybe some basic chemistry can help?

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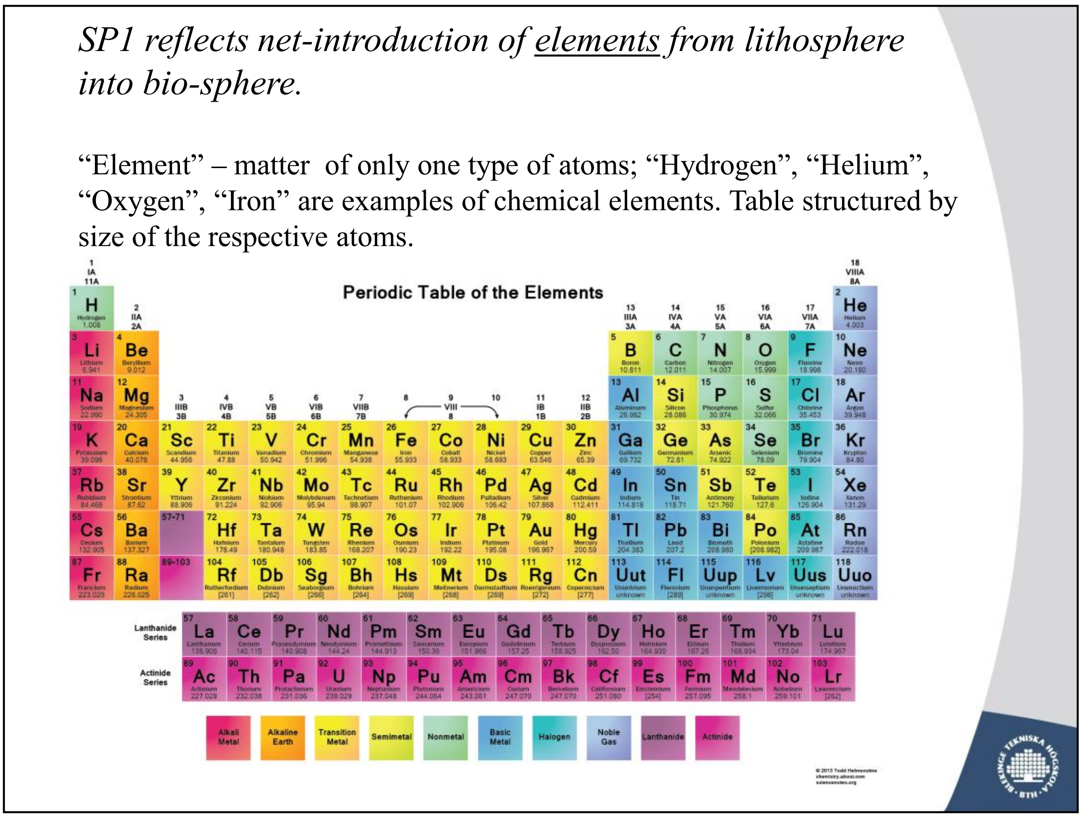
Nitrogen: Chemical element essential for the growth of plants and animals; a gas constituting 79% of the atmosphere.

NOx: Gases consisting of one molecule of nitrogen and varying numbers of oxygen molecules. Nitrogen oxides are produced in the emissions of vehicle exhausts and from power stations. In the atmosphere, nitrogen oxides can contribute to formation of photochemical ozone (smog), can impair visibility, and have health consequences; they are thus considered pollutants.

This brings us to chemistry as an important area for the understanding of how nature works, including how it is threatened by pollution.

Chemistry is the study of matter and energy and the interactions between them. Chemistry tends to focus on the properties of substances and the interactions between different types of matter.



SP1 reflects net-introduction of <u>elements</u> from lithosphere into bio-sphere.

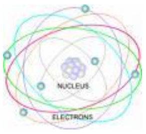
“Element” – matter of only one type of atoms; “Hydrogen”, “Helium”, “Oxygen”, “Iron” are examples of chemical elements. Table structured by size of the respective atoms.

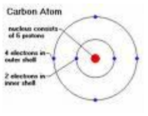
Let us begin with the elements, i.e. atoms of various kinds. The gas Hydrogen (H =first element of the periodic chart), and the metal iron (26:th element) are, like all the other elements or atoms, constituted by only one type of atoms.

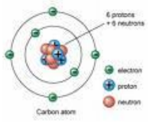
The next slide displays how the different atoms of the chart are given their respective numbers.

The Periodic chart displays how many electrones (−) = number of protones (+) an element has; it’s “atomic number”.

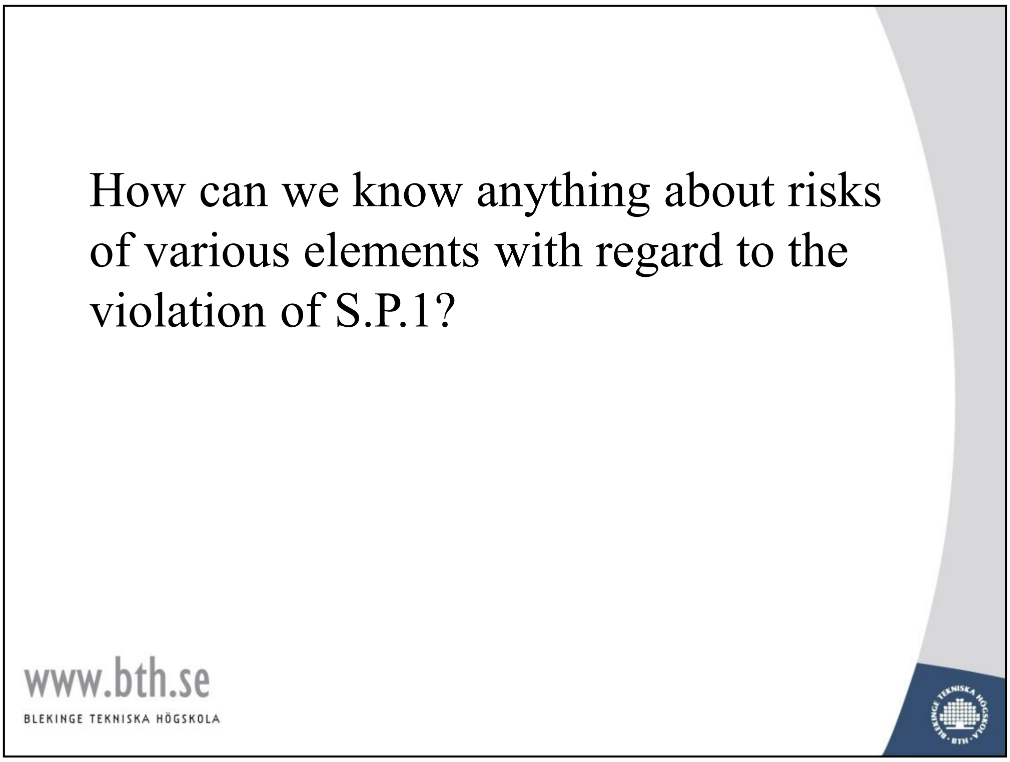
The first, smallest atom is hydrogen with one electrone and one protone, but carbon has six of each plus “neutrones” increasing the mass of the atom:



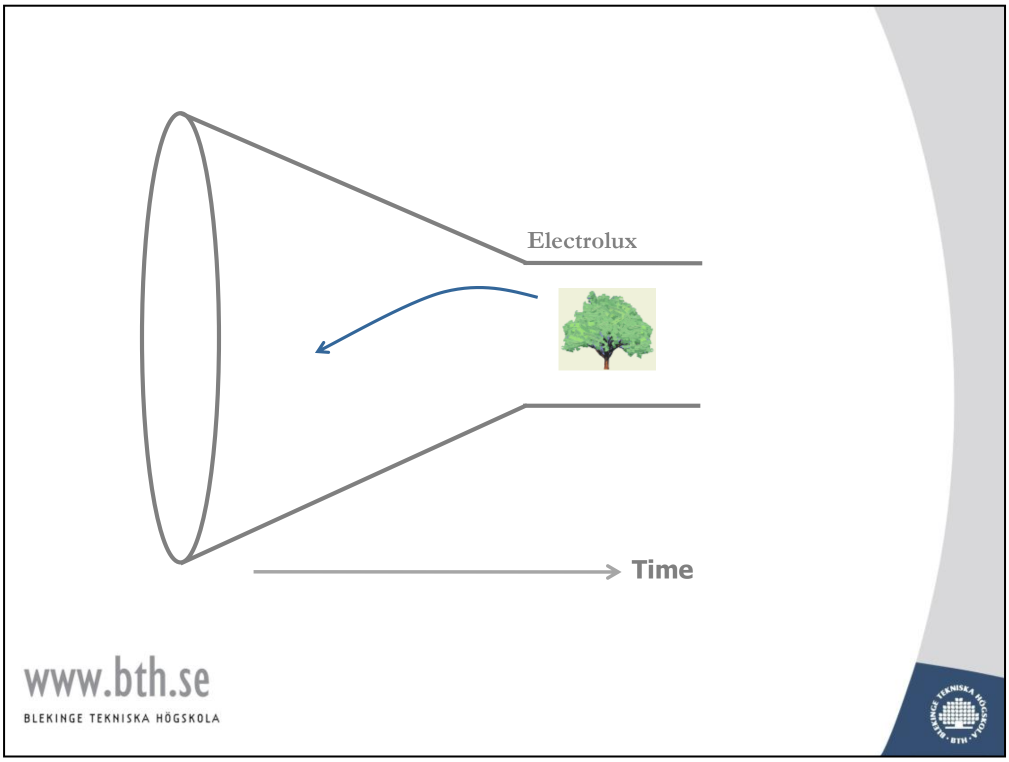




Atoms cannot be split chemically (but compounds made of many atoms can)

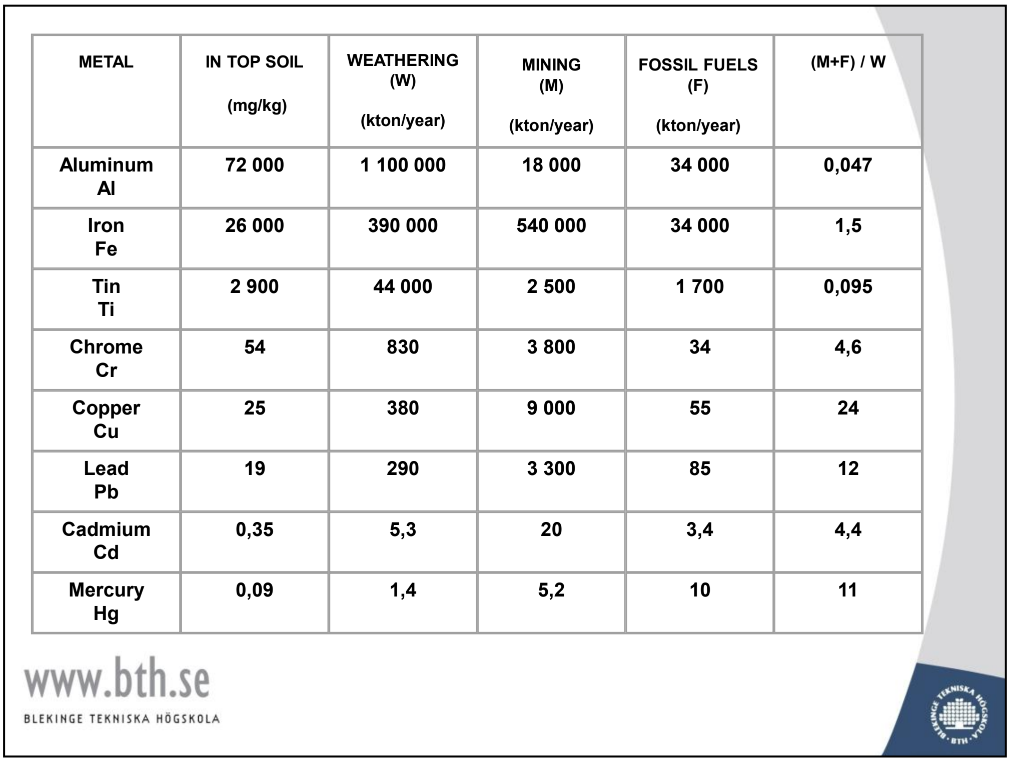


How can we know anything about risks of various elements with regard to the violation of S.P.1?



Electrolux provides an example of how to apply the FSSD to *foresee* risks with the use of metals. Since the SP 1 is about risks of concentrations-increases, logical questions to ask are: how abundant is this metal normally in the soils and biota of the biosphere? How much do we use of this metal, and how much of that use is contained in society and how much of it do we allow to leak out into nature? The higher the natural amounts of a certain metal in nature, the less influence small leakages of that metal from society to nature will have on concentrations. And vice versa. If amounts of a metal are very low in nature, and if our technical and economic systems allow large emissions and leakages of that metal into nature, the result will be high concentration-increases i.e. violations of the SP1.

Electrolux wanted to foresee which metals would be dangerous to use in refrigerators and other white-ware products. How abundant were metals normally in nature and – in relation to this – how much did society use of the respective metals? Since the second law of thermodynamics (entropy-law) tells us that metals erode and rust and eventually find their ways to nature, the CEO of Electrolux wanted to foresee which metals have the greatest risk of becoming alarm-reports in the headlines of future newspapers. They asked the question to scientists thinking like Electrolux i.e. “backcasting from future situations”. The scientists responded by providing data in response to the essential questions, see next slide.



METAL	IN TOP SOIL (mg/kg)	WEATHERING (W) (kton/year)	MINING (M) (kton/year)	FOSSIL FUELS (F) (kton/year)	(M+F) / W
Aluminum Al	72 000	1 100 000	18 000	34 000	0,047
Iron Fe	26 000	390 000	540 000	34 000	1,5
Tin Ti	2 900	44 000	2 500	1 700	0,095
Chrome Cr	54	830	3 800	34	4,6
Copper Cu	25	380	9 000	55	24
Lead Pb	19	290	3 300	85	12
Cadmium Cd	0,35	5,3	20	3,4	4,4
Mercury Hg	0,09	1,4	5,2	10	11

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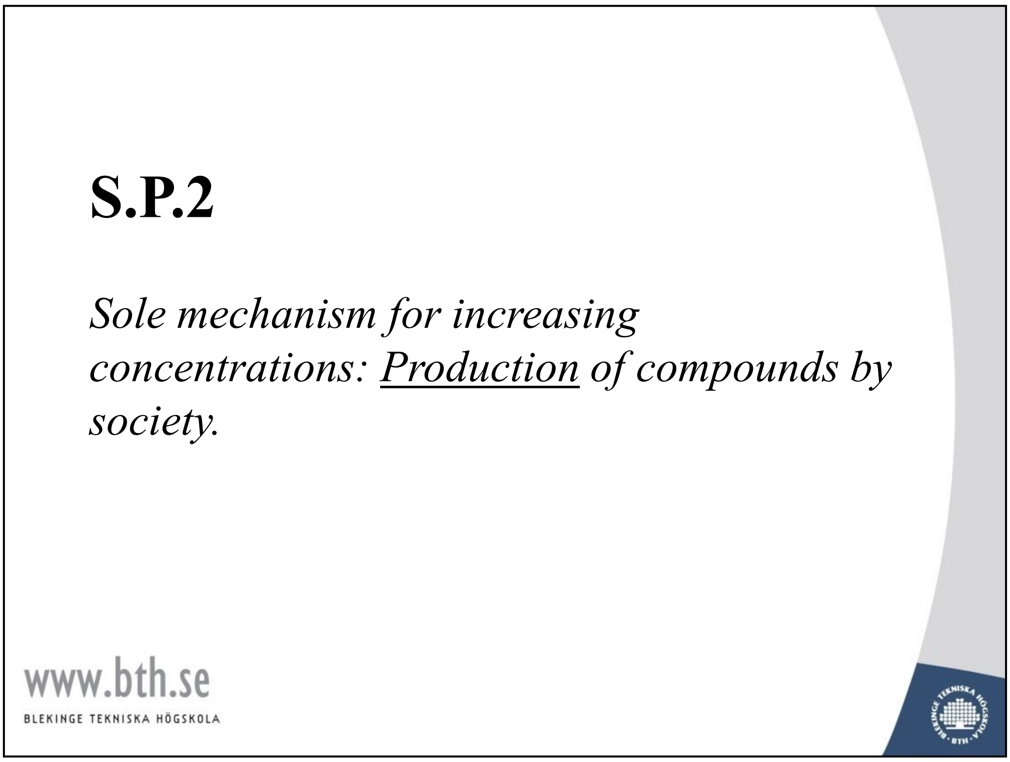
In the left column we find some metals and their acronyms from the periodic chart. In the next column we see numbers for the corresponding metal's natural abundancy in top-soils of nature. The next column shows how large abounts of that metal that are naturally brought from the Earth's crust (the litosphere) to nature (the biosphere) – i.e. the sum of weathering and volcano-eruptions. The column after that shows how much metals that are brought up by society from the Earth's crust in various mining-processes. The comparison of those two 'litosphere to biosphere' flows reveals the answer about future risks of using a certain metal. Even if we would *want* to pollute nature by increasing the concentrations of aluminium there, we wouldn't stand a chance. Due to the naturally huge flows of aluminum from the Earth's crust, it would be like trying to pollute an aquarium by putting more water into it. The index-column to the far right shows the relationships. Society's flows of aluminum from the litosphere to the biosphere are but 0,047 of natural flows. Compare this with, say, copper. Society's flows are 24 times higher than natural flows. Given the combined effect of the 'principle of matter-conservation' (matter does not disappear), and the second law of thermodynamics (matter has a tendency to disperse over time), the right column gives us a nice sense of "future-contamination-factor". There is also another risk with metals that are normally very scarce in soils, over and above the number per se: the species of nature has evolved with very low back-ground levels of such metals, e.g. *zero* amounts of plutonium in nature. Nowadays, nuclear power and nuclear arms have allowed small amounts of this metal to enter the biosphere. It is the most toxic matter we know of are increasing substantially in concentrations.

So a sustainable use of metals that are normally very scarce in nature, require rigorous and tight technical loops to avoid but minimal leakages of the corresponding metals into nature. We can, for instance, not have them in consumer-goods unless we organize leasing-systems to guarantee close to 100% recycling.

As a result from Electrolux understanding the chart of indicators, they decided to move away from copper in their productions, and instead use aluminium that works as well – including in electric wires.

Having said this, it is important to look also at other risks regarding SP1 for various uses of metals – when we mine by use of fossil fuels we violate this principle as well. There are aspects around the other SPs as well. Think of intergenerational justice for instance, if we would waste metals with the low contamination numbers of the right column.

A conclusion from all of this is: we can use indicators like this to get a brief overview of relative risks from violating SP1 regarding metals, but if we backcast from a future sustainable society all metals are either changed for other materials or are rigorously recycled.

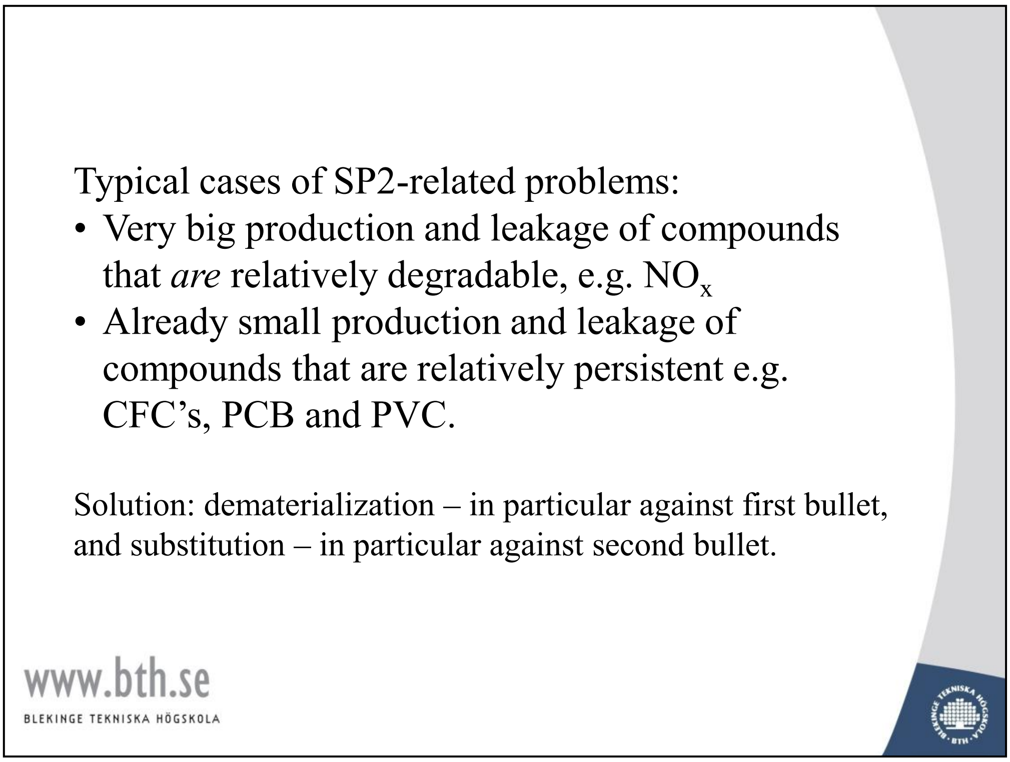


S.P.2

Sole mechanism for increasing concentrations: Production of compounds by society.

SP2 is different from SP1. (You may recall that SP1 refers to risks of concentration-increases from elements i.e. a *net-input* of various kinds of atoms. Atoms, unlike compounds of atoms, never degrade. So we have to cautiously look at the natural abundance of the respective metals in use, and compare it with how much society uses and loses. In line with the previous chart, this gives us a nice estimate of the corresponding risks for concentration-increases).

SP2, on the other hand, is about another factor: how fast does the corresponding compound or molecule (combinations of atoms) *degrade* once it has found its way into nature (in emissions and/or leakages). The more stable a compound is, and the more foreign to nature it is, the greater the risk to use it. We can compare the SP2 risk of using such substances outside of tight technical loops, say CFCs (“freons”), to – say – the SP1-related risks of using cadmium. CFCs degrade very slowly, and cadmium not at all. And we can compare compounds that degrade very fast into atoms and molecules that are normally very abundant in nature with, say, aluminium. In both cases something that is abundant in soils is finding its way there – no or very small concentration-increases.



Typical cases of SP2-related problems:

- Very big production and leakage of compounds that *are* relatively degradable, e.g. NO_x
- Already small production and leakage of compounds that are relatively persistent e.g. CFC's, PCB and PVC.

Solution: dematerialization – in particular against first bullet, and substitution – in particular against second bullet.

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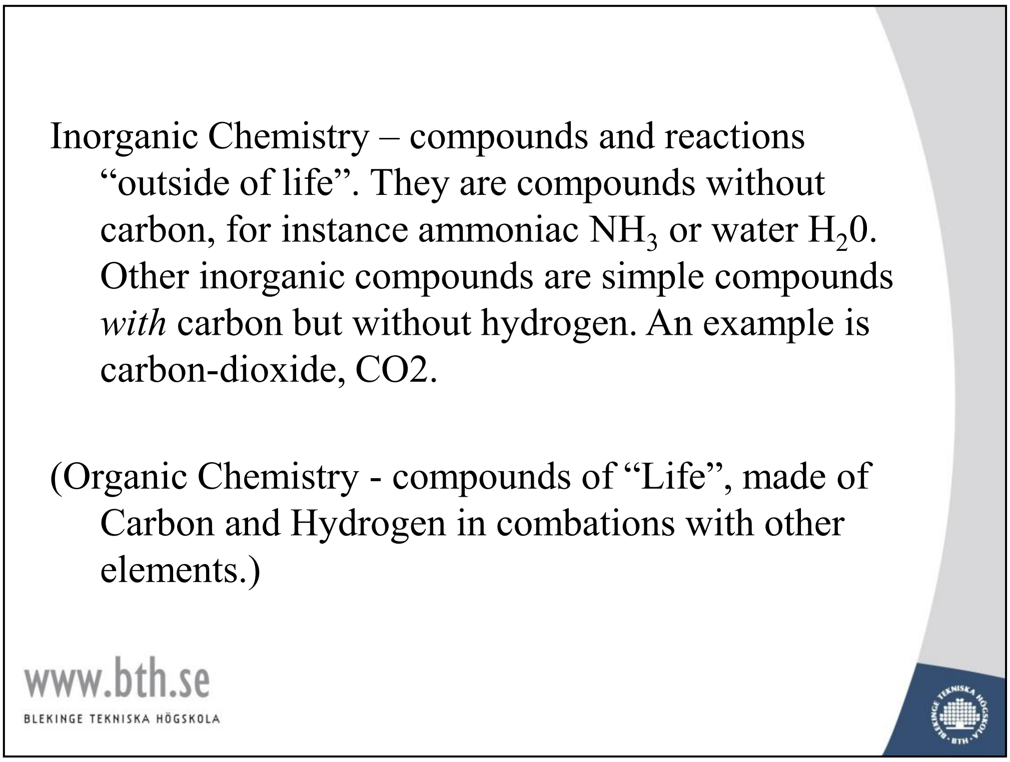
Examples of some chemicals (molecules, or compounds):

- **PCB, Polychlorinated Biphenyl**, a synthetic, organic chemical once widely used in electrical equipment, specialized hydraulic systems, heat transfer systems, and other industrial products. Highly toxic and a potent carcinogen. Any hazardous wastes that contain more than 50 parts per million of PCBs are subject to regulation under the Toxic Substances Control Act. Given that this substance does not normally appear in nature, and given how very persistent it is (it needs very long time to degrade in natural systems), it should never have been introduced for use outside of tight technical loops. Large amounts have now been leaking from various technical products in society, and criminal organizations continued to use it also after toxic thresholds had been exceeded, the growing damage in various species were known, and it was announced a crime to continue using it.

- **CFC's.** Chlor-fluor-carbons. These are compounds containing two of the so called halogen's of the periodic chart, and used for many technical purposes including as coolants and insulation in refrigerators. Like PCB, some of the CFC's are very persistent compounds, a given amount needs around 100 years to be degraded to 50%. They are relatively very non-toxic, and they don't accumulate in plants or the bodies of animals (are not bio-accumulative). However, given that they don't exist normally in nature, and given their relative persistence, they should never have been introduced outside of very technical loops. So they kept leaking from refrigerators and other types of products, and eventually reached concentrations in the atmosphere high enough to catalytically destroying the ozon-layer. We are lucky that Nasa detected how the ozone-layer was shrinking, and we are lucky that Nobel-prize winner Sherwood Rowland and colleagues eventually understood the CFC-related chemistry behind the shrinking. This story puts emphasis on how to use the FSSD for upstream-thinking, already when we design products, organizations and societies: substances that are scarce in nature, and relatively persistent, should not be introduced for use outside of very tight technical systems. Even if they are considered to be "non-toxic" and "non-bioaccumulative". Due to complexity, who can foresee what will happen if such substances are allowed to violate SP2?

- **PVC , Polyvinyl chloride**, commonly abbreviated **PVC**, is a widely used thermoplastic polymer. In terms of revenue generated, it is one of the most valuable products of the chemical industry. Globally, over 50% of PVC manufactured is used in construction. As a building material, PVC is cheap and easy to assemble and *recycle*. In recent years, PVC has been replacing traditional building materials such as wood, concrete and clay in many areas. Despite appearing to be an ideal building material, concerns were raised about the costs of PVC to the natural environment and human health. The complex story around PVC provides yet a dimension of understanding the applicability of FSSD for re-design of products and societies. Hard PVC as in water pipes and sewer systems, is so non-degradable or persistent that it can be regarded as an inert matrix. For such uses, it doesn't leak into nature per se. Nor would it provide any problems if we applied very tight technical loops to recycle the material, which is highly possible if we constrain its use to – for instance – pipes and building materials, and apply new business models – for instance – various leasing systems, to get all of the material back.

A number of SP related problems around PVC *can* be solved, which we will return to in the MSLS program.



Inorganic Chemistry – compounds and reactions "outside of life". They are compounds without carbon, for instance ammoniac NH_3 or water H_20. Other inorganic compounds are simple compounds *with* carbon but without hydrogen. An example is carbon-dioxide, CO2.

(Organic Chemistry - compounds of "Life", made of Carbon and Hydrogen in combations with other elements.)

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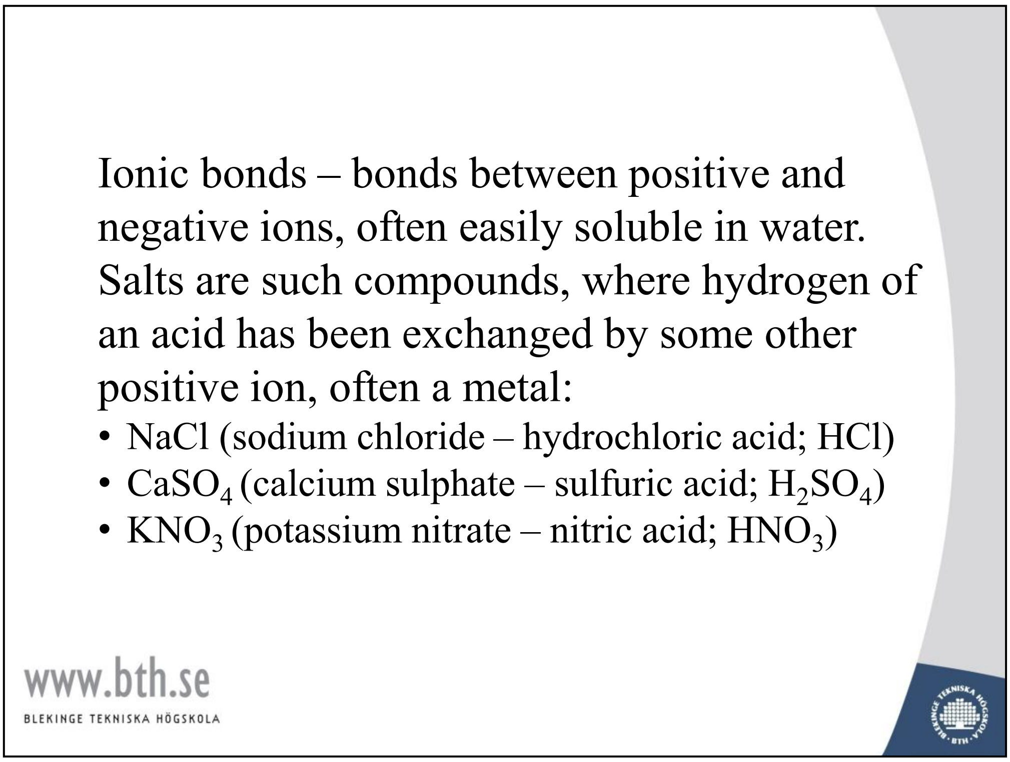
Inorganic and Organic Compounds

Compositions of matter can be broadly divided into the two classes: inorganic and organic compounds. Although inorganic compounds are numerous, organic compounds - compounds that contain carbon and hydrogen bonded to each other - are far more numerous, comprising the majority of all compounds known. The overlap between organic and inorganic chemistry is considerable.

Many inorganic compounds exist in organisms and are essential to life. Sodium, chloride, and phosphate ions are essential for life as are some inorganic molecules such as carbonic acid, nitrogen, carbon dioxide, and oxygen.

In the past it was believed that organic compounds are found only in living organisms. Today, however, the great majority of organic compounds are synthetic, they are *not* found in nature. And many, such as drugs and plastics, are important for our human health nonetheless.

All carbon compounds are sometimes erroneously considered to be organic; many compounds that contain carbon, however, can be defined as strictly inorganic: carbon monoxide, carbon dioxide, carbonates, fullerenes to name but a few. All these compounds have no hydrogen atoms bonded to the carbon.



Ionic bonds – bonds between positive and negative ions, often easily soluble in water. Salts are such compounds, where hydrogen of an acid has been exchanged by some other positive ion, often a metal:

- NaCl (sodium chloride – hydrochloric acid; HCl)
- $CaSO_4$ (calcium sulphate – sulfuric acid; H_2SO_4)
- KNO_3 (potassium nitrate – nitric acid; HNO_3)

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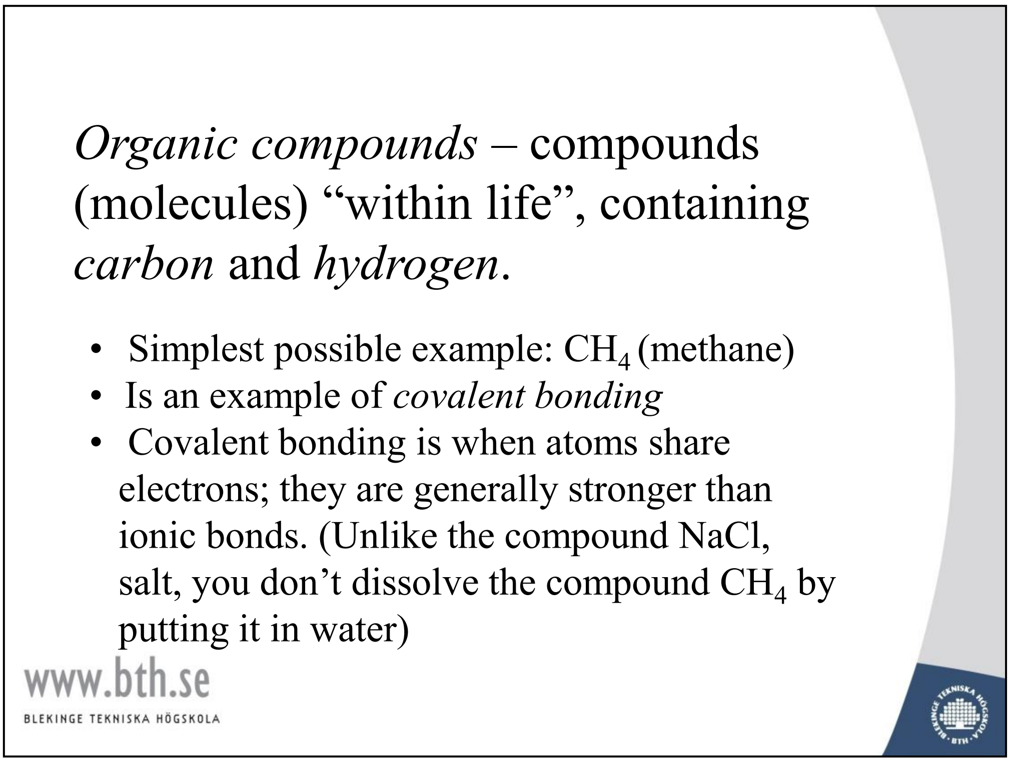
Ions and Ionic Bonds: Ionic bonds happen when **one atom gives** at least one **electron to another atom**. Once the electron gets handed over, the atoms are no longer atoms – **they become *ions***, and they each have a charge - one type of them are positively charged (+, positive) and the other are negatively charged (-, negative).

- Each atom to become part of a compound, started with enough (-) electrons to match each (+) proton in its nucleus. The atom that gets an extra electron ends up with a (-) charge and is called an *anion* (sounds like ann-eye-on). The atom that gives away an electron ends up with a (+) charge and is called a *cation* (sounds like cat-eye-on).
- These (+) and (-) charges have a strong attraction to each other - they sit next to each other and refuse to move. This is an **ionic bond** - the strong attraction between ions with opposite charges. On the table, salt is a good example of a common ionic compound. (Table salt is also called *sodium chloride*.) However, ionic bonds are not very strong in relation to covalent bonds (see below). Ionic bonds can be dissolved in various liquids, e.g. water. Think of table salt that is dissolved in water. All the atoms of the salt are still there, but in the shape of dissolved Na+ and CL- ions.

Molecules: So, atoms form bonds together to make molecules. One molecule of vitamin C is made up of 20 atoms (6 carbons, 8 hydrogens, and 6 oxygens - that's $C_6H_8O_6$). If you use the same type of atoms and bond them together in a different order, you'll have a totally different molecule that not only looks different, it acts different. For instance $C_6H_{12}O_6$, sugar. Changing which atom is bonded to which can change the properties of a molecule, that is, how it looks and acts - and that changes how a whole BUNCH of molecules hanging out together will look and act. For example, water is a liquid, hydrogen is a gas, and vitamin C is a solid.

NaCI: When elements join and become compounds, they lose their individual traits. Sodium alone is very reactive. But when sodium and chlorine combine, they form a non-reactive substance called sodium chloride (Salt, NaCl). The compound has none of the traits or the original elements. The new compound is not as reactive as the original elements. It has a new life of its own.



Organic compounds – compounds (molecules) “within life”, containing *carbon* and *hydrogen*.

- Simplest possible example: CH_4 (methane)
- Is an example of *covalent bonding*
- Covalent bonding is when atoms share electrons; they are generally stronger than ionic bonds. (Unlike the compound NaCl, salt, you don’t dissolve the compound CH_4 by putting it in water)

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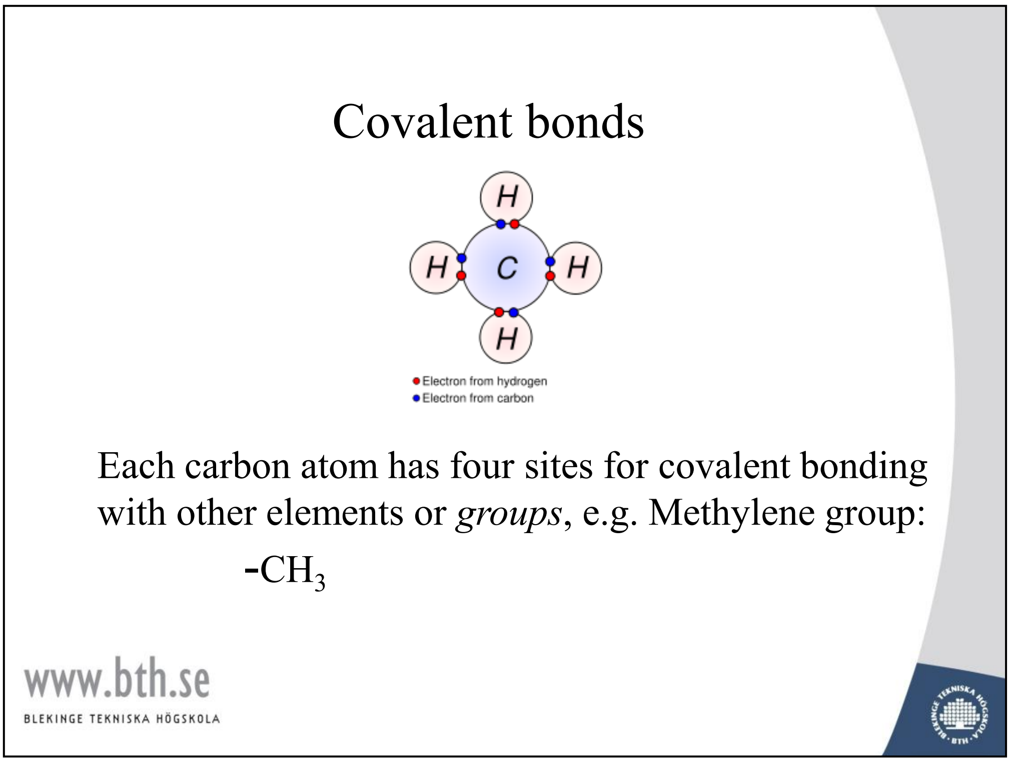
Methane (CH4) - made up of one carbon (C) and four hydrogens (H). There are four bonds and they are all *covalent*.

“**Covalent bonds** happen when **two atoms <u>share</u> electrons**. When at least 2 atoms get together by sharing electrons, they form a *molecule*.”

“Two major categories of compounds are ionic and molecular (covalent) compounds respectively. Molecular compounds contain covalent bonds, ionic compounds contain ionic bonds.

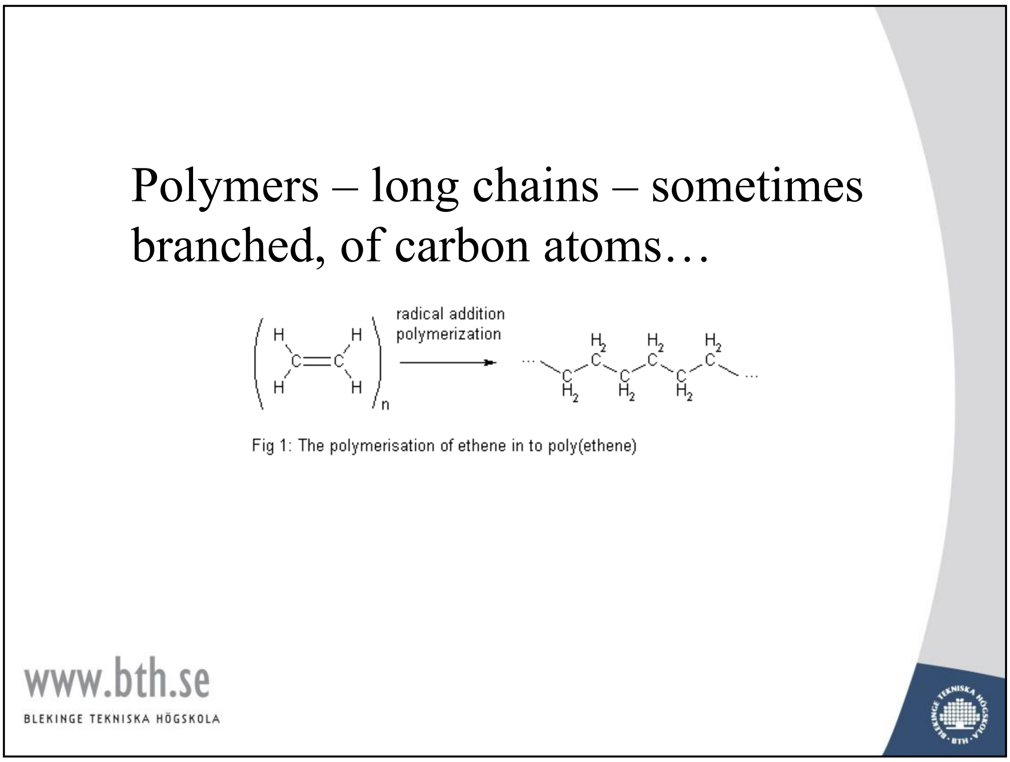


Covalent bonds

Each carbon atom has four sites for covalent bonding with other elements or *groups*, e.g. Methylene group:

-CH_3

Each type of atom typically forms the same number of bonds (they tend to be stubborn that way). For example, a hydrogen atom forms one bond, an oxygen atom forms two, and carbon forms four bonds. If you look at a molecule of water - each hydrogen has one bond, and the oxygen in the middle has two bonds.

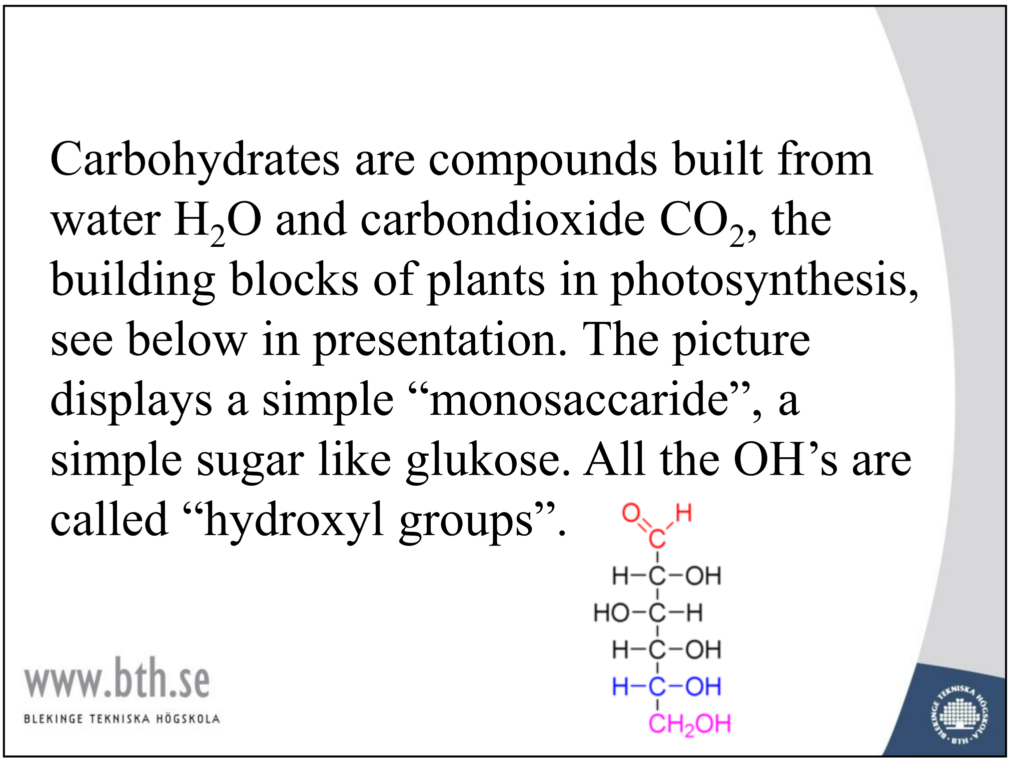


Polymers – long chains – sometimes branched, of carbon atoms…

Fig 1: The polymerisation of ethene in to poly(ethene)

Polymers are made up of many, many molecules all strung together to form really long chains (and sometimes more complicated structures, too).

How polymers act depends on what kinds of molecules they're made up of and how they're put together. The *properties* of anything made out of polymers really reflect what's going on at the ultra-tiny (molecular) level. So, things that are made of polymers look, feel, and act depending on how their atoms and molecules are connected, as well as which ones we use to begin with.



Carbohydrates are compounds built from water H_2O and carbondioxide CO_2, the building blocks of plants in photosynthesis, see below in presentation. The picture displays a simple “monosaccaride”, a simple sugar like glukose. All the OH’s are called “hydroxyl groups”.

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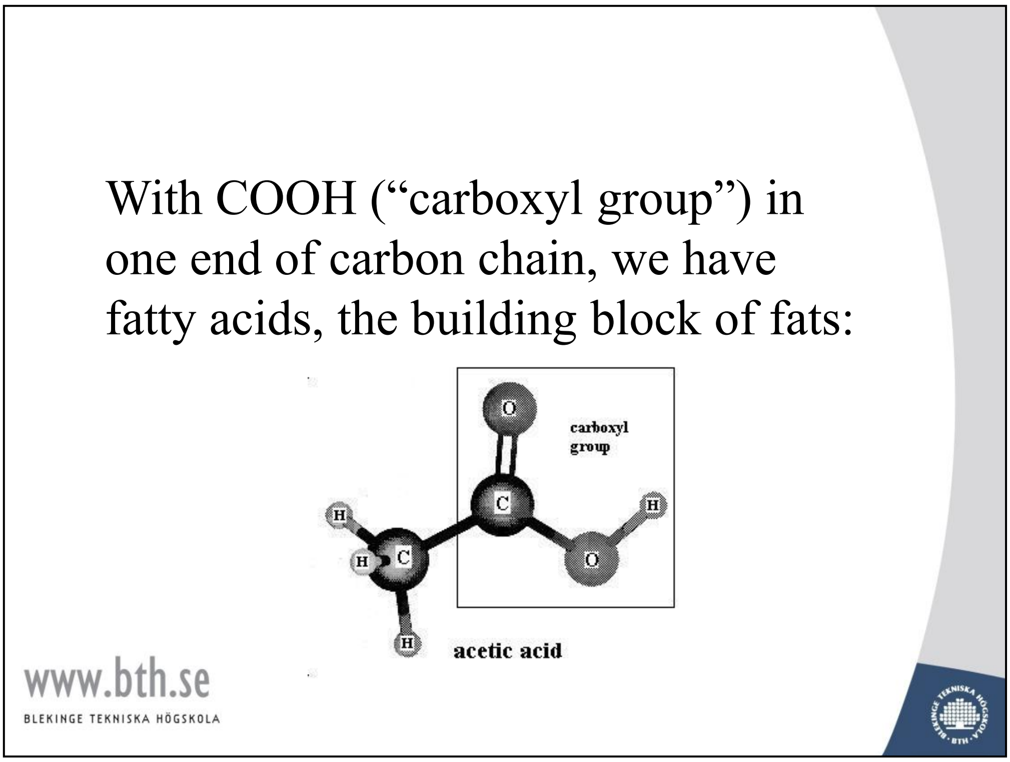
- $C_6H_{12}O_6$, sugar. Again, this molecule is made of the same atoms as vitamin C. But exactly how is the molecule constructed? The figure displays this. Carbon appears in a little chain, each carbon atom attaching to another, plus to other groups of atoms as well. Again, note that each carbon is attached to the other elements and groups through four covalent bonds.



With COOH (“carboxyl group”) in one end of carbon chain, we have fatty acids, the building block of fats:

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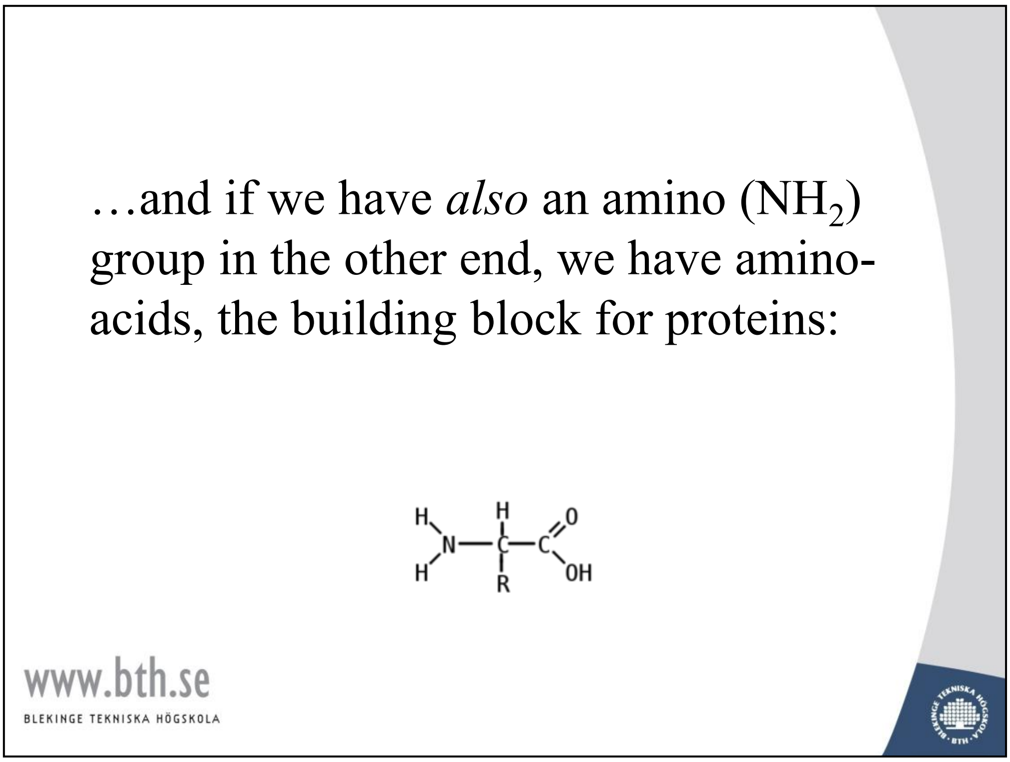
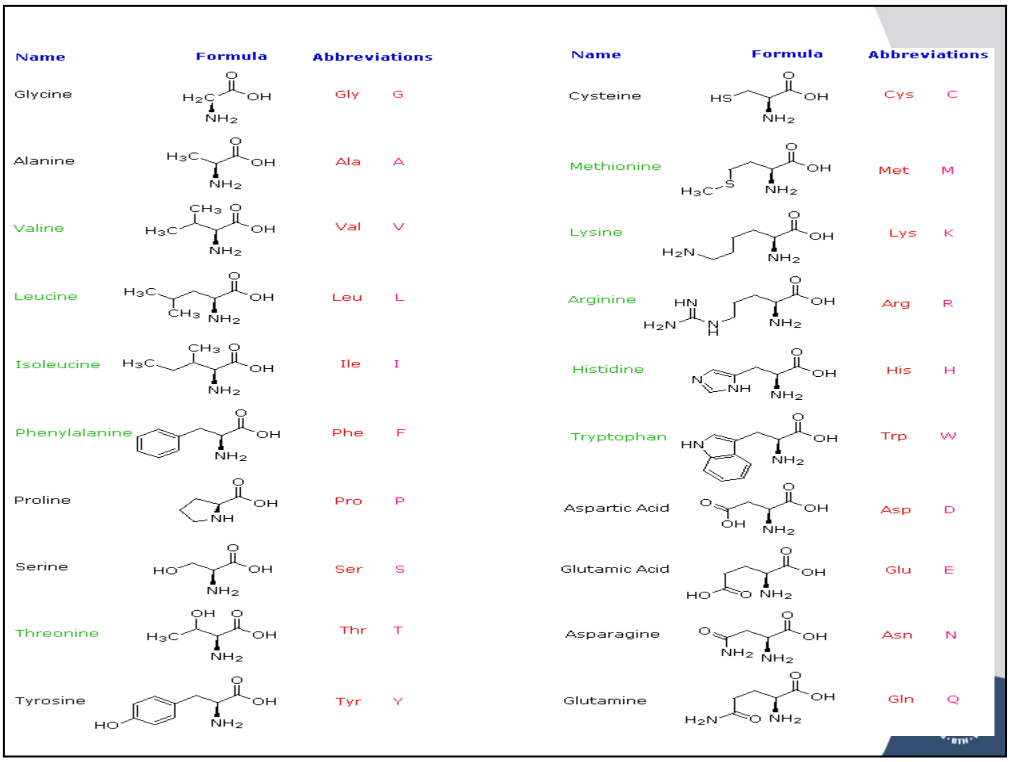
Fats are composed of fatty acids as building blocks. Though each acid is relatively small and composed of a small number of atoms, the combination of fatty acids in various kinds of fat-compounds may comprise large molecules.



…and if we have *also* an amino (NH_2) group in the other end, we have amino-acids, the building block for proteins:

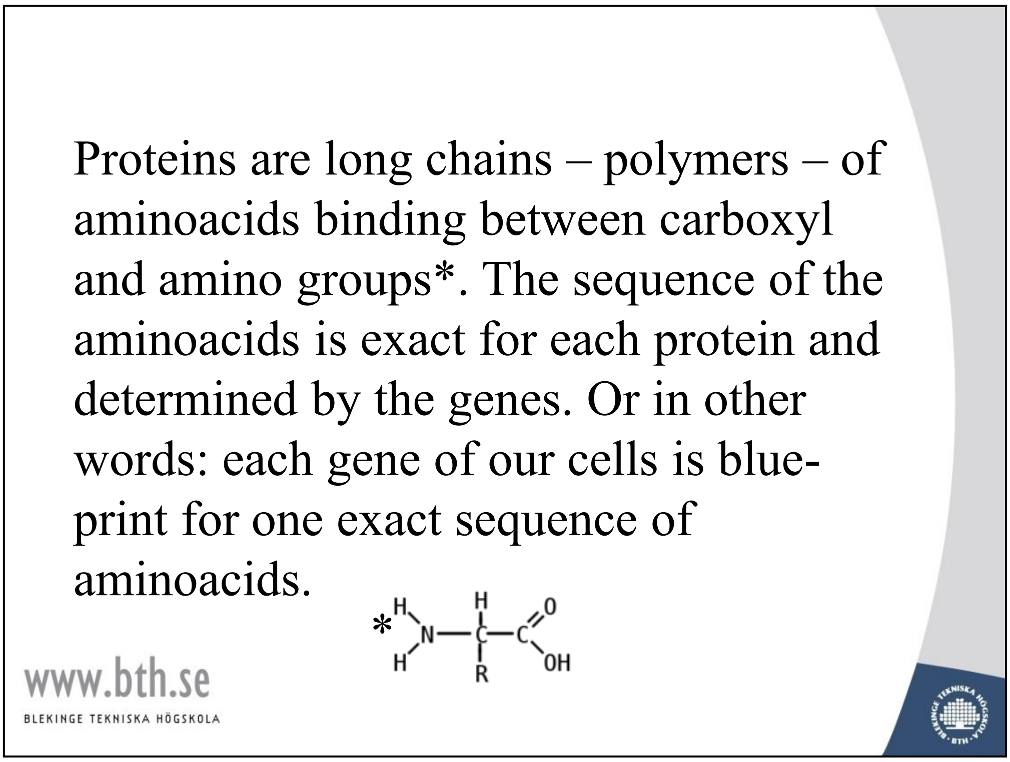
Amino acids contain also nitrogen, and the corresponding chemical group – one nitrogen and two hydrogens – attached at the end of a carbon chain, tells us we have an amino acid. The various kinds of amino-acids are combined together to comprise *proteins*.



Name	Formula	Abbreviations	
Glycine		Gly	G
Alanine		Ala	A
Valine		Val	V
Leucine		Leu	L
Isoleucine		Ile	I
Phenylalanine		Phe	F
Proline		Pro	P
Serine		Ser	S
Threonine		Thr	T
Tyrosine		Tyr	Y

Name	Formula	Abbreviations	
Cysteine		Cys	C
Methionine		Met	M
Lysine		Lys	K
Arginine		Arg	R
Histidine		His	H
Tryptophan		Trp	W
Aspartic Acid		Asp	D
Glutamic Acid		Glu	E
Asparagine		Asn	N
Glutamine		Gln	Q

This chart displays the 20 different types of amino-acids that are combined – in various amounts and combinations – to the complex world of protein-molecules. The amino-acids have different “magnetic” characteristics, are attracted to each other in specific ways. Or in chemical terms, they are isoelectrically different. We will return to this.



Proteins are long chains – polymers – of aminoacids binding between carboxyl and amino groups*. The sequence of the aminoacids is exact for each protein and determined by the genes. Or in other words: each gene of our cells is blue-print for one exact sequence of aminoacids.

* $\mathrm{H_2N-CHR-COOH}$

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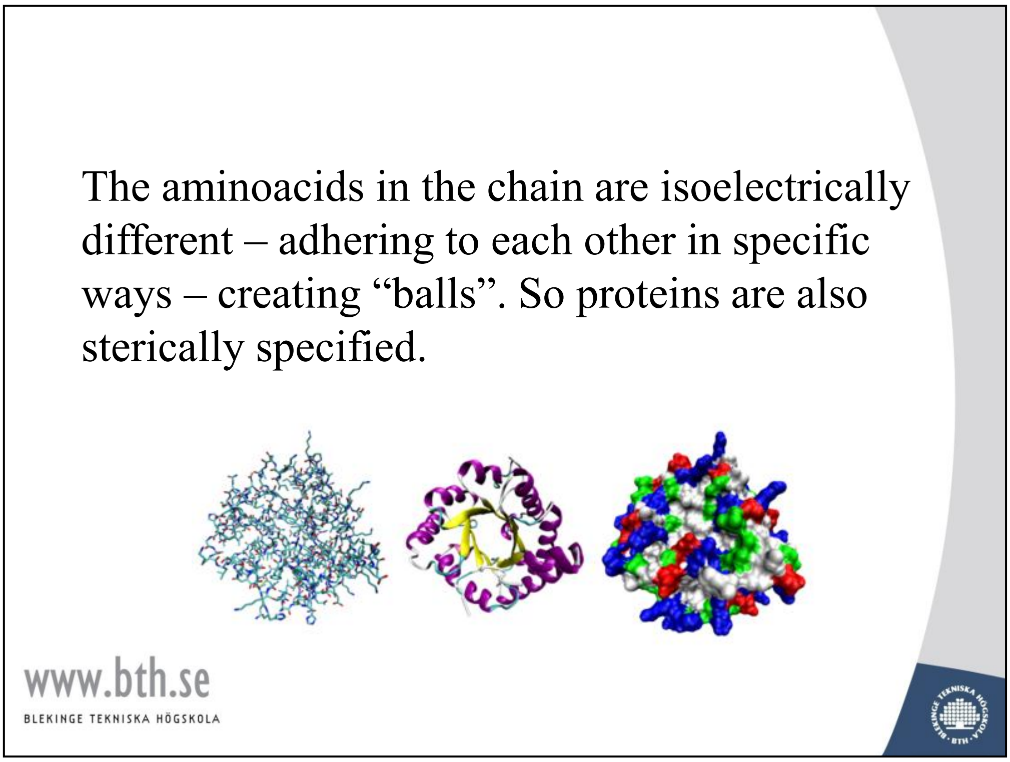
The amino-acids combine into various forms of proteins, where the ends of each aminoacid bonds to the next aminoacid into long chains. Our genes are the blue-prints for proteins, each gene corresponding to a given specific protein. Insulin is one example. Vitamin C is another. Vegetables and Dogs for instance, can produce their own vitamin C. But humans don’t have this gene – we have to eat vitamin C from a species that have this gene e.g. fruit and various vegetables.



The aminoacids in the chain are isoelectrically different – adhering to each other in specific ways – creating “balls”. So proteins are also sterically specified.

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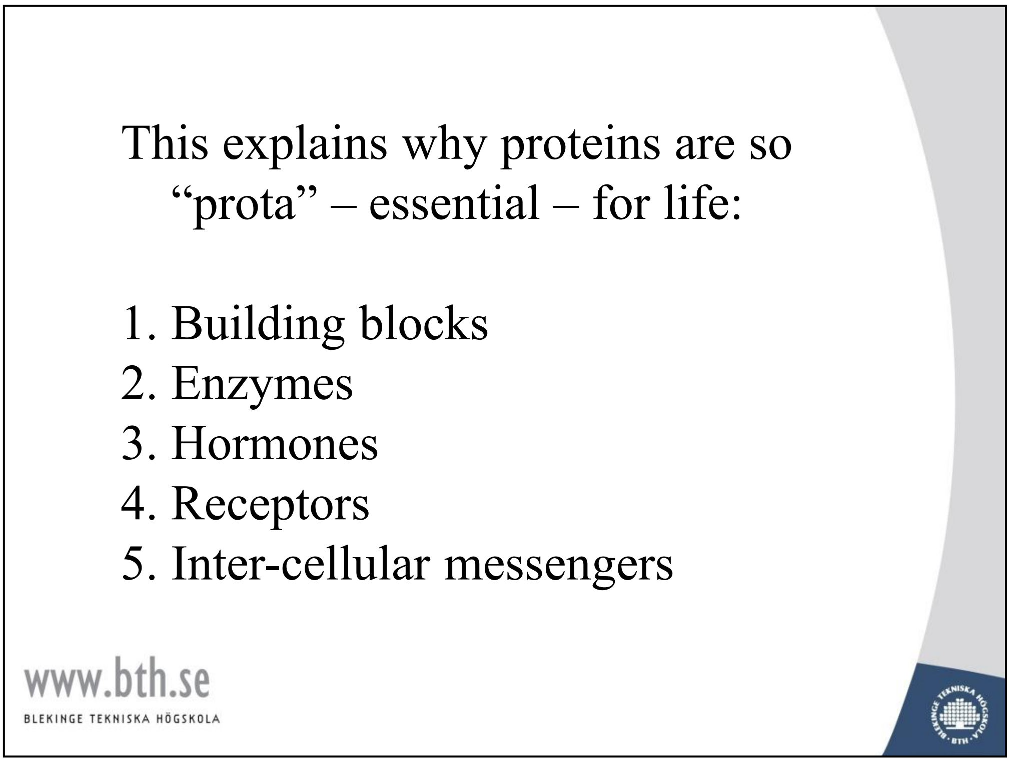
Now, if you picture a long chain with a specific sequence of various amino-acids for your inner eye, and then grab hold of the two ends and keeping the molecular-thread straight, you can see this sequence of the different amino-acids in front of you. But what happens if you let go of the ends? Thinking of the isoelectric attraction patterns, the thread will naturally form into small ball – this or that amino-acid attaching to this or that other amino-acid a bit further away on the thread. So each protein cannot only be defined by the sequence of different amino-acids, it is also *sterically* defined. So you can look at the properties of proteins also in this capacity, turning them around and watching them from different angles e.g. in a computer.



This explains why proteins are so “prota” – essential – for life:

1. Building blocks
2. Enzymes
3. Hormones
4. Receptors
5. Inter-cellular messengers

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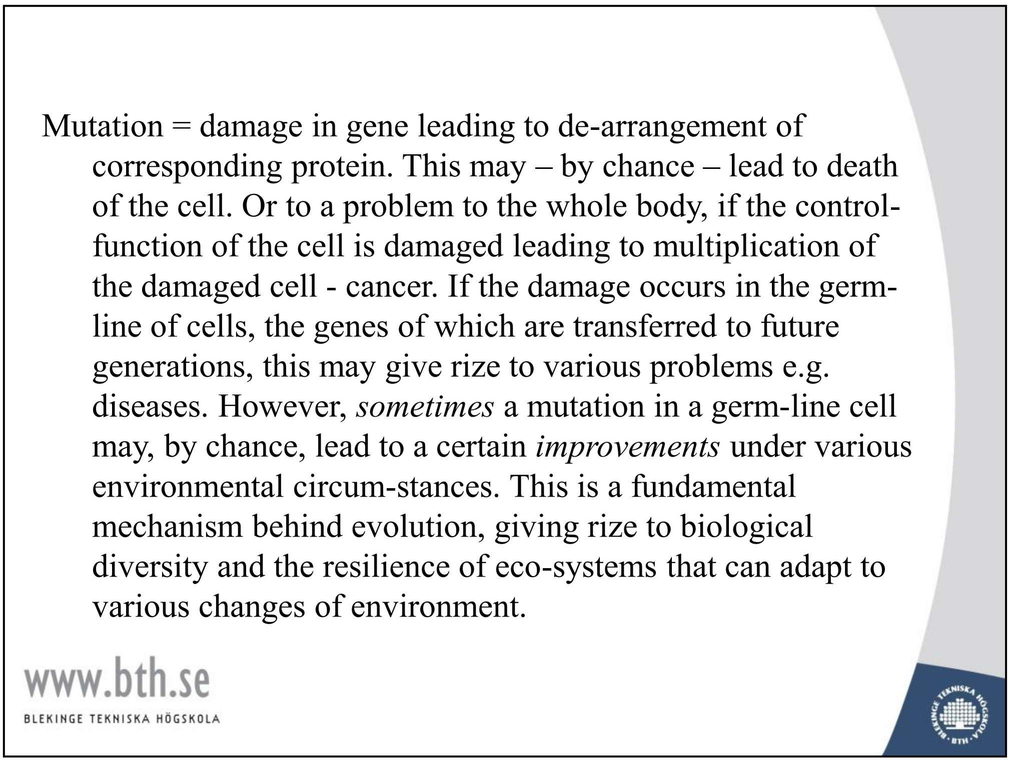
1. Cavities and spikes that fit each other between two proteins, explain how they can be like “lego-pieces” when tissues are formed.
2. The steric qualities also explain how molecules can be brought together through cavities, each fitting a specific compound that is thus “presented” to another compound in the cavity next to it, so that the two compounds can easier combine in a chemical reaction. When they react and combine, they are ripped away from the cavities that are then exposed for another pair of molecules to be combined. The protein thus “helps” the respective reactions, but is not changed or consumed in the process. We call such catalytic “helping chemical reactions proteins” *enzymes*.
3. Hormones are specific proteins with very strong influences for how bodies are developed and function. Estrogens vs. testosterones are good examples of this.
4. Cellular receptors are other proteins, exposed on the surface of cells. They fit the corresponding hormones or other inter-cellular messengers and receives them on the cell-surface, which trigger cellular reaction-responses. For instance cell-division in the breast-tissue of a young girl entering puberty, who has suddenly began to produce estrogen in her sex-glands.



Mutation = damage in gene leading to de-arrangement of corresponding protein. This may – by chance – lead to death of the cell. Or to a problem to the whole body, if the control-function of the cell is damaged leading to multiplication of the damaged cell - cancer. If the damage occurs in the germ-line of cells, the genes of which are transferred to future generations, this may give rize to various problems e.g. diseases. However, *sometimes* a mutation in a germ-line cell may, by chance, lead to a certain *improvements* under various environmental circum-stances. This is a fundamental mechanism behind evolution, giving rize to biological diversity and the resilience of eco-systems that can adapt to various changes of environment.

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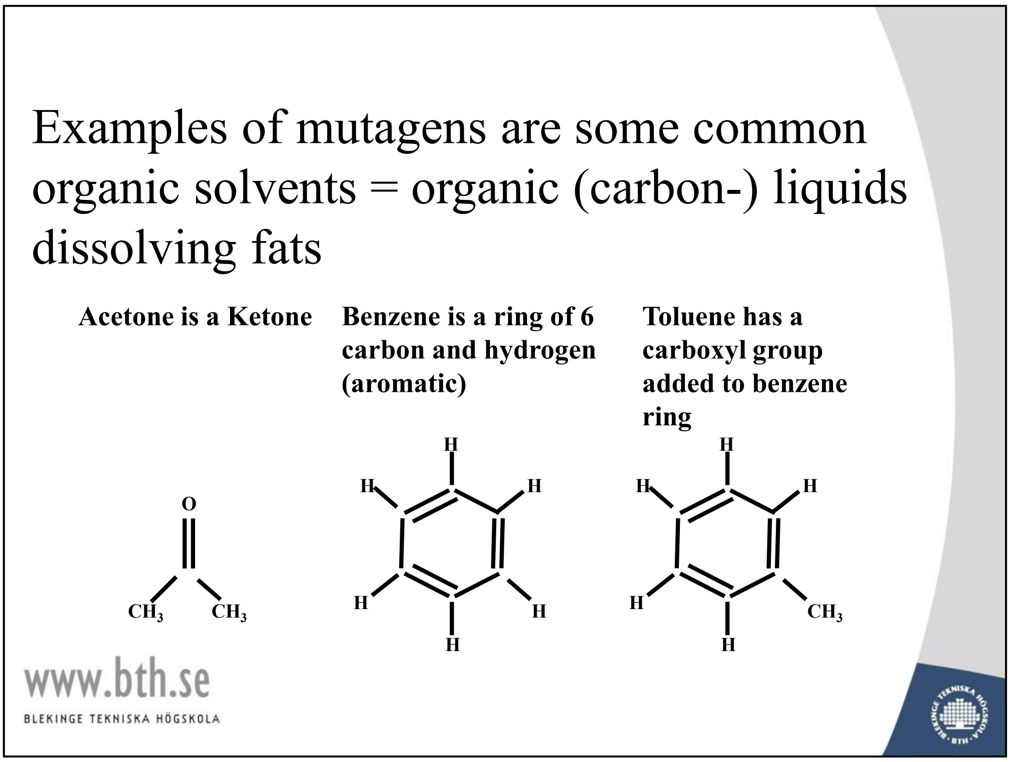
The above understanding explains why we are so concerned with pollution. The process of genes being blue-prints for proteins, and the proteins functioning in myriad complex interactions within and between cells, is naturally vulnerable to chemicals that shouldn't be there.

An example is various kinds of chemicals from our chemical societies, that cause damage to our genes. We call such damage a *mutation*. When the blue-print for a protein is destroyed, the outcome is generally a dysfunctional protein. But, by chance, and if the genetic change occurs in a sex-cell that will accompany all cells in the growing organism, the new quality may be helpful in certain circumstances. This has worked as an essential mechanism of evolution.



Examples of mutagens are some common organic solvents = organic (carbon-) liquids dissolving fats

Acetone is a Ketone

Benzene is a ring of 6 carbon and hydrogen (aromatic)

Toluene has a carboxyl group added to benzene ring

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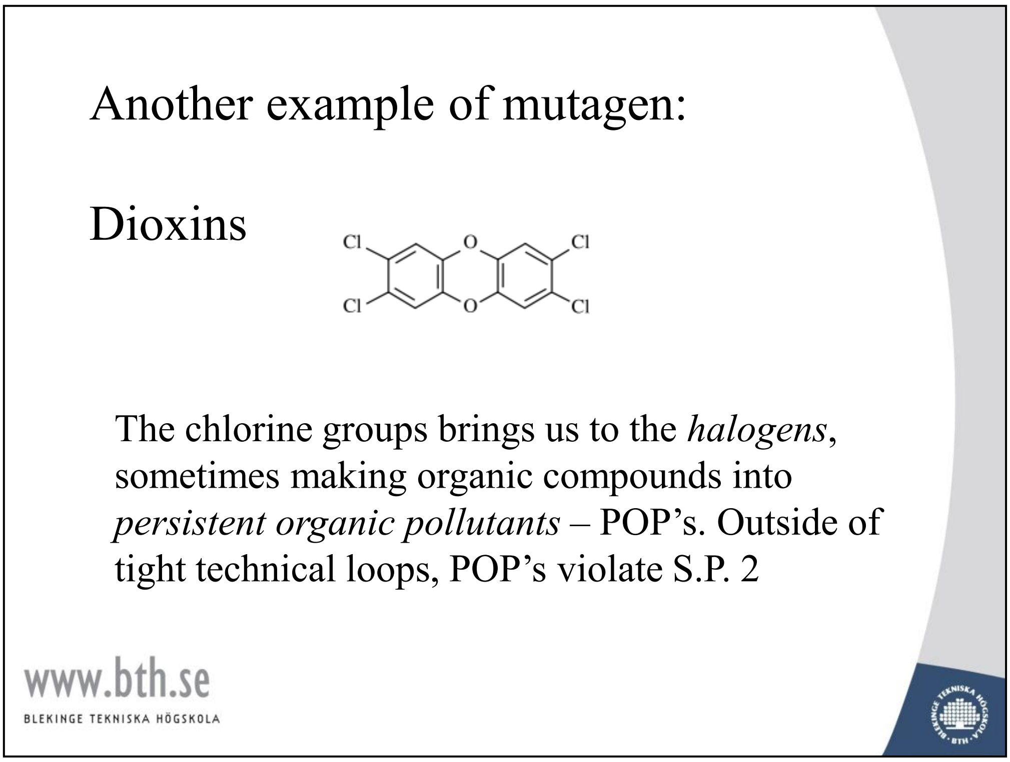
This slide gives some examples of various mutagens, cancerogenic substances. However, it is important to point out that though dangerous to individuals – say in a factory where workers may be exposed to those substances – they are not likely to violate SP1 but for very limited times and/or in very local environments where emissions may be temporarily large. The reason is that natural processes brake down those particular substances very fast into CO2 and H2O. So, they are mainly a concern around the social principles, e.g. the first one around health-aspects of different kinds of leadership. If leaders are allowing a number of employees to get cancer, it may not have serious effects on the environment. But its effect on the social system may be huge, e´mplyees losing faith in their leadership.

They are mutagenic and cancerogenic, but they don’t accumulate because they dissolve relatively easily in natural systems. Using them large-scale may, however, violate the social sustainability principles. And for this reason, the term ”toxic” does not tell the full ecological sustainability story. The SP2 related question is: is a ”toxic” substance persistent or not?



Another example of mutagen:

Dioxins

The chlorine groups brings us to the *halogens*, sometimes making organic compounds into *persistent organic pollutants* – POP’s. Outside of tight technical loops, POP’s violate S.P. 2

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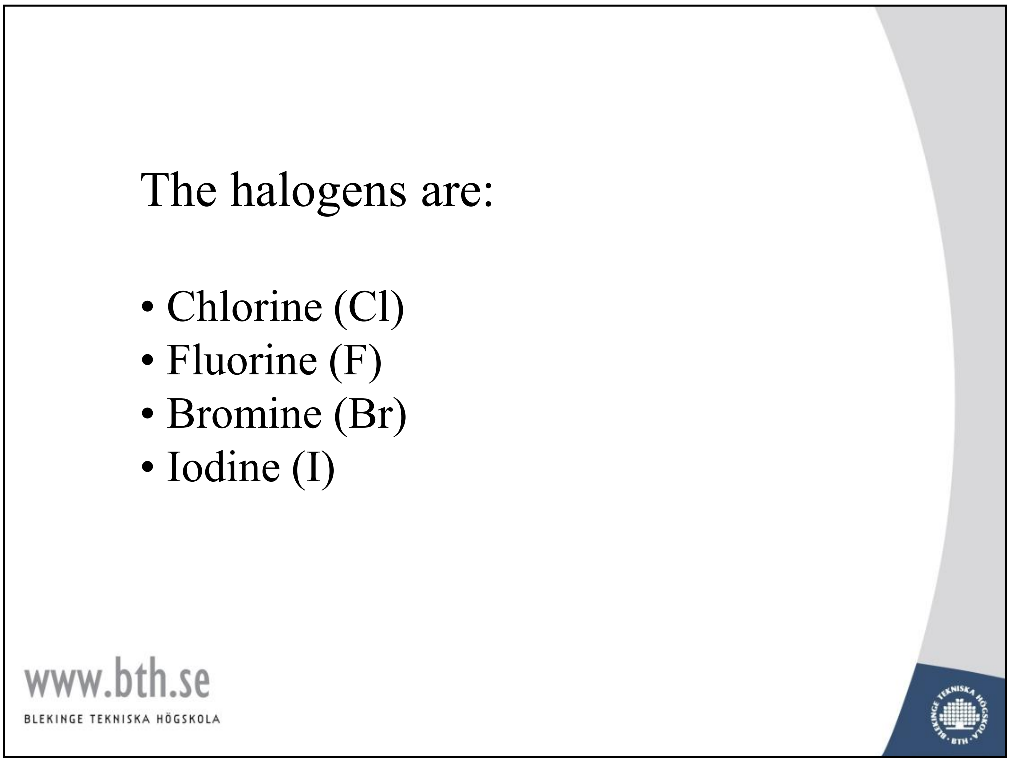
Dioxins: A group of generally toxic organic compounds that may be formed as a result of incomplete combustion (as may occur in incineration of compounds containing chlorine). A risk-factor here is the use of Poly Vinyl Chloride, PVC, in itself containing all the compounds needed to produce dioxins. To incinerate PVC without production of dioxins require very modern incinerators. But in a world of global trade – who can guarantee that PVC does not end up in poor incineration e.g. back-yard incineration?

- There are 75 known varieties of dioxin. Each known variety has a unique chemical structure. These chemicals can have effects at extremely low levels. Health problems related to dioxin exposure include: some types of cancer, immune disorders, lowered sperm counts, diabetes, malformations and other reproductive and developmental effects, and endocrine disruption (interfering with the body’s natural hormone signals). The largest current sources of dioxins are industries producing chemicals, pesticides and paper products.
- Dioxins are, *unlike* for instance the also toxic substance Acetone, also relatively very "*persistent*“. Such compounds which drift around the world, tend to accumulate in fatty tissues of animals and humans. 95% of typical human exposure comes through dietary intake of animal fats such as meat, dairy and eggs.

Halogens: The family of elements that includes fluorine, chlorine, bromine and iodine. Halogens are very reactive and have many industrial uses. They are also commonly used in disinfectants and insecticides. Many hazardous organic chemicals -- such as polychlorinated biphenyls (PCBs), some volatile compounds (VOCs) and dioxins contain halogens, especially chlorine

- Typically compounded into plastic materials to improve the flame retardants. When the materials are exposed to a high heat source, halogen gases are released, limiting the spread of flames but potentially causing a health hazard.



The halogens are:

- Chlorine (Cl)
- Fluorine (F)
- Bromine (Br)
- Iodine (I)

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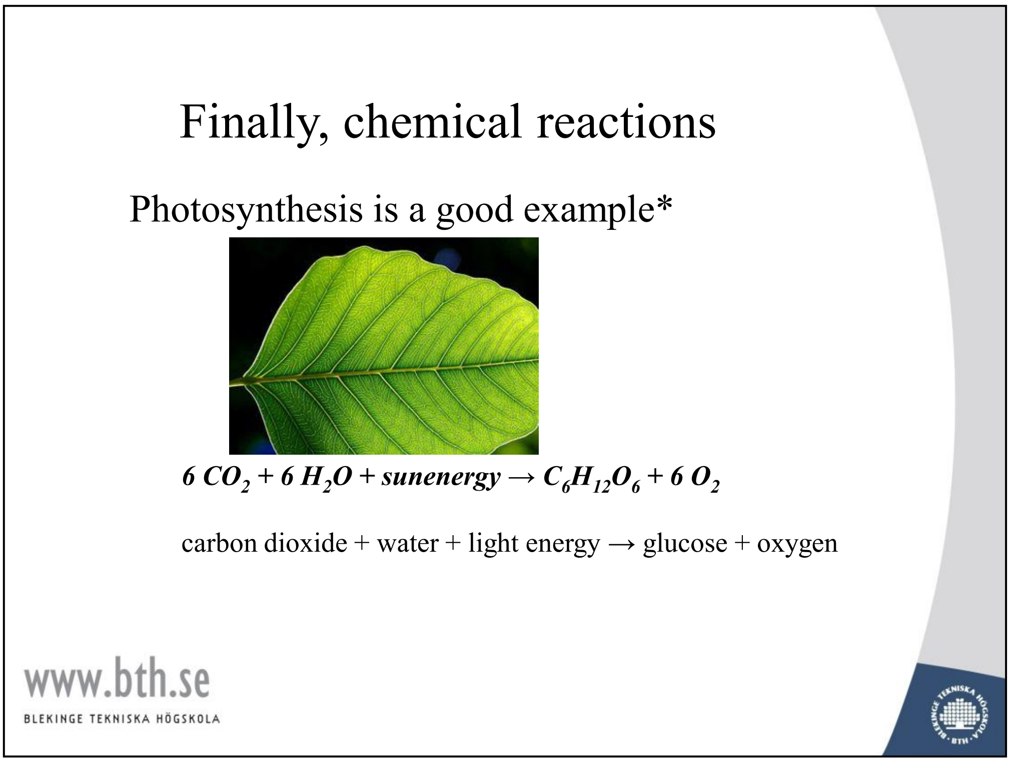
Persistent Organic Compounds: Persistent Organic Pollutants (POPs) are chemical substances that persist in the environment, bioaccumulate through the food web, and pose a risk of causing adverse effects to human health and the environment. Think of the matter-conservation law in combination with the second law of thermodynamics: With the evidence of long-range transport of these substances to regions where they have never been used or produced and the consequent threats they pose to the environment of the whole globe, the international community has now, at several occasions called for urgent global actions to reduce and eliminate releases of these chemicals. We know, for instance, that polar bears breast-feed their cubs with milk containing halogenated organic compounds in so called anti-flammables (used, for instance, in curtains and computers). http://www.chem.unep.ch/pops/

The Stockholm Convention on POPs: The Stockholm Convention is a global treaty to protect human health and the environment from persistent organic pollutants (POPs). POPs are chemicals that remain intact in the environment for long periods, become widely distributed geographically, accumulate in the fatty tissue of living organisms and are toxic to humans and wildlife. POPs circulate globally and can cause damage wherever they travel. In implementing the Convention, Governments will take measures to eliminate or reduce the release of POPs into the environment. http://www.pops.int/



Finally, chemical reactions

Photosynthesis is a good example*

$6\ CO_2 + 6\ H_2O + \textit{sunenergy} \rightarrow C_6H_{12}O_6 + 6\ O_2$

carbon dioxide + water + light energy → glucose + oxygen

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In consideration of the matter-conservation law, you can follow this reaction by counting the atoms of the participating compounds. 6 molecules of carbondioxide are combined with 6 molecules of water to give us the simplest sugar molecule – glucose – and a “waste” of pure oxygen. This is the basic reaction of life, explaining how the growth of the biomass (for the first billions of years only concerning plants) also oxygenated the atmosphere. So what do we have, if not a big chemical “battery”. What is the fuel of the biomass, surrounded by oxygen, if not a sort of battery? It can be discharged in a forest fire, turning the above reaction to a violent reverse. But it can also be discharged in a controlled fashion, when the food we eat is metabolized to give us energy to grow and live. When we run after a bus, we have to breath faster to burn the corresponding amount of food to give us that energy. The above reaction run in that direction, is called “respiration”. We breath in oxygen, use it to burn sugar as our fuel, while the jogging person exhales CO2 and water-vapor.

[redacted]

The biosphere, and the processes there, can now be understood at a deeper and more profound scientific level.

Sun-space battery…

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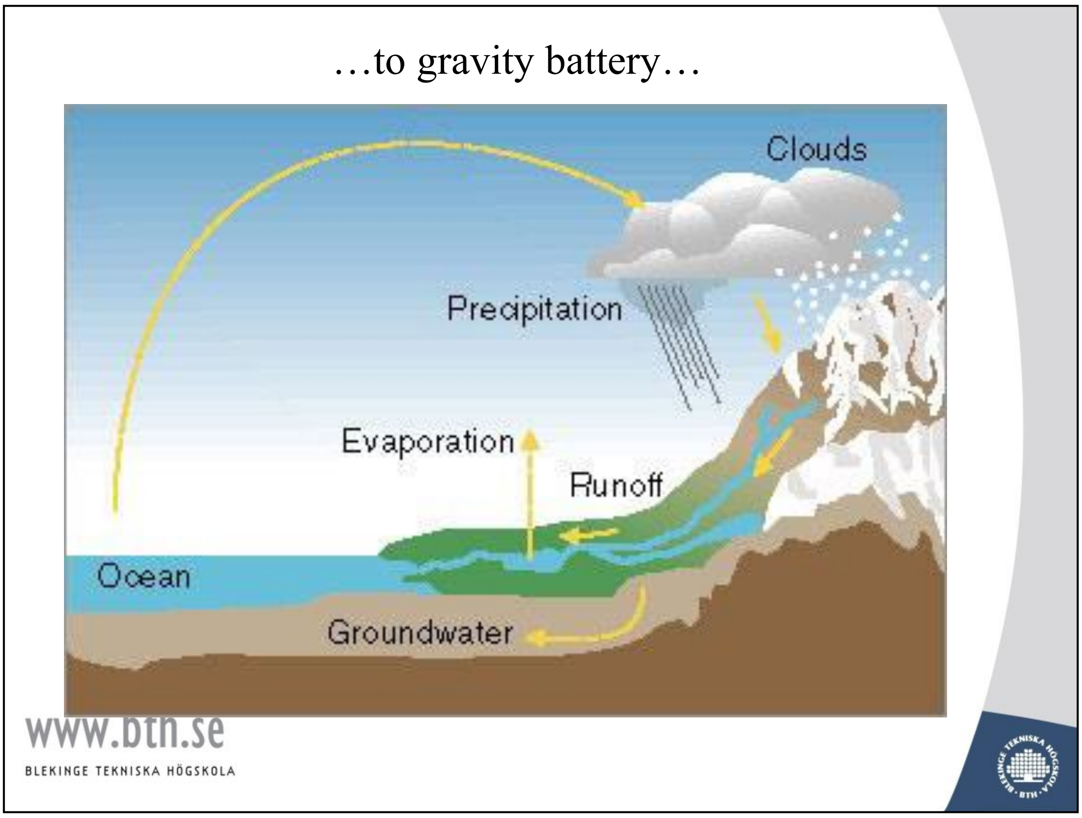
The sun-space battery, so called by physicians because the glowingly hot sun, surrounded by the ice-cold space, provides a contrast with a huge working capacity. If all of outer space would be ice-cold, we would not have any processes and no biosphere. And, likewise, if all of outer space would be hot like the sun there would be no contrasts either. The high-exergy light from the sun however, flowing out into the ice-cold outer space and hitting earth with its atmosphere, could be used to create what we refer to as nature or the ”biosphere”. Again, disperse junk in the virgin soup of the atmosphere, billions of years ago, was digested by the first primitive organisms – cyanobacteria. They used sun-light to grow at the cost of the junk they were composed of, the biomass increasing in volume and the junk decreasing correspondingly. We got oxygen into the atmosphere, animals could eventually develop from plants, the cycles of nature between plants and animals were started, and…



…to gravity battery…

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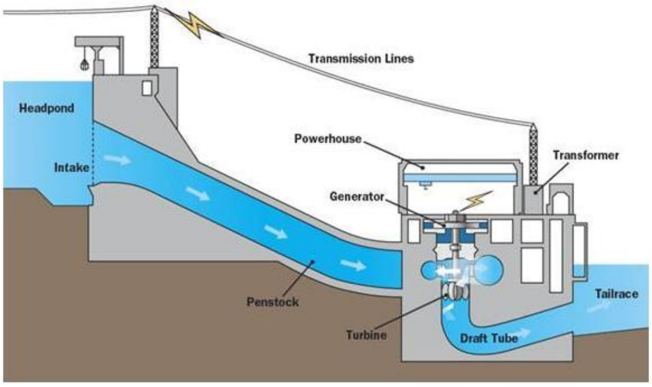
…we can use the same understanding also for other experiences we all have. For instance that it rains every now and then; the heating-up of waters from the sun leading to evaporation, followed by condensation higher up, and then rain falling as the water-containing air's temperature drops which lowers the air's capacity to contain water. Which may give us lakes or dams high up, helping us to create electric turbines.

What does this mean? Well, the sun-space battery has *charged* a gravity battery that charges electricity production in a turbine that charges a battery in a car that we may have attached to the grid.

…to electricity in turbines.



…to chemical battery…

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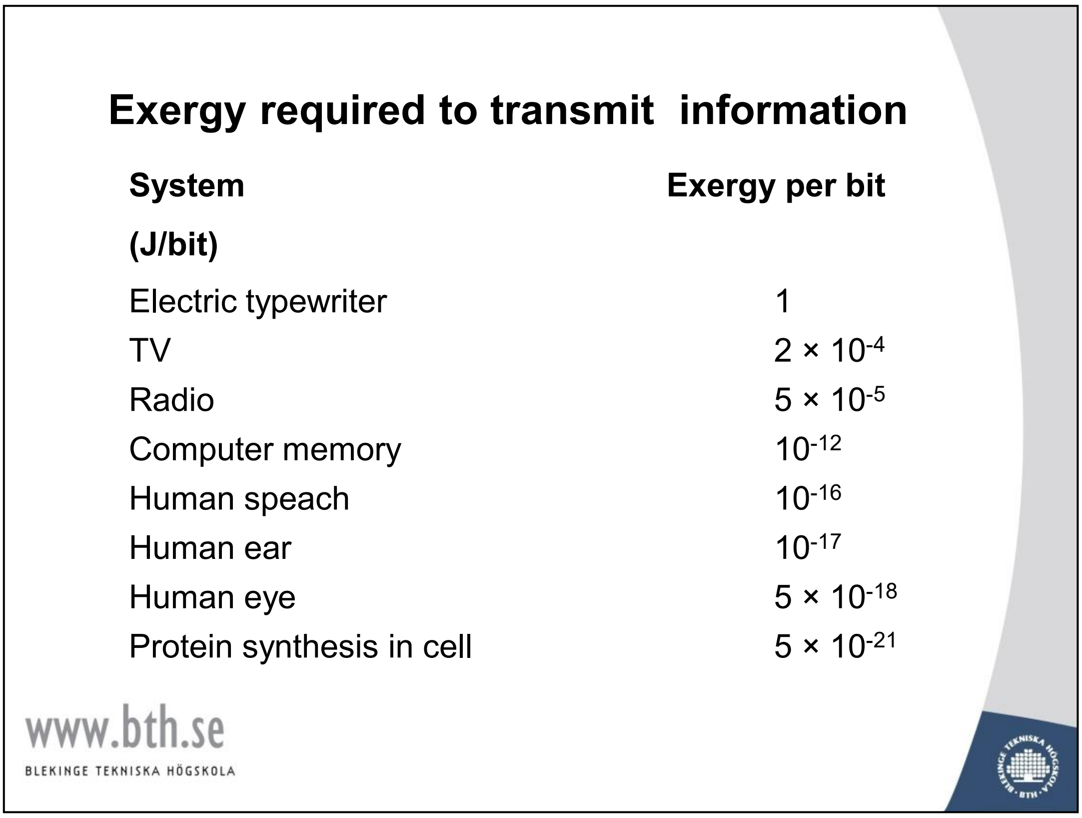
And again, the basis of it all – nature. The most fantastic, wonderful, chemical battery we can think of.



Exergy required to transmit information

System (J/bit)	Exergy per bit
Electric typewriter	1
TV	2×10^{-4}
Radio	5×10^{-5}
Computer memory	10^{-12}
Human speach	10^{-16}
Human ear	10^{-17}
Human eye	5×10^{-18}
Protein synthesis in cell	5×10^{-21}

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A few final comments. When nature ”communicates” between its life forms, e.g. animals and plants communicating within and between species, or cells within a body communicating within and between cells, this generally occurs by very sophisticated and effective means. Humans have not even come close to this level of sophistication, when it comes to our production in various technical systems.

Every letter we write with an old type of electric type-writer consumes around one joule for every bit of transferred information. To type ”a” instead of ”b” provides, in this table, one bit of information. In this way, we can calculate how much exergy is needed to transfer various amounts of information in different communication systems.

A TV is providing its pictures by bits of information, each bit being a little square composed of a specific color. Put together, they give us the image. In an old-type TV we get 20.000 times more bits of information per joule of exergy than in an old-time electric type-writer. But look at the efficiency of a computer memory, a few steps below in the table. It gives us one thousand billion times more bits of information per joule, than the electric type-writer. Which leads us to one major principled interpretation of the table. There is almost no limit to how much workable energy we can save, i.e. exergy, by design of more sophsticated technical systems at all scales – from components in products, to how societies work with all technologies put together into systems.

Everything, in the end, is about communications in different systems. From how our brains compute the senses that enters it, through information transfer in various IT systems, to the communications at large in our societies. Think of, for instance, beers of various tastes. They may transfer information through our senses to our bräins in the form of pleasures, and the pleasures may increase if we, for instance, have certain memories attached to a certain place we have visited and where a certain beer is produced. This may serve as an example to understand trade related to beers. At a societal level, we can chose an information system to bring about those pleasures by bottling of beers with different tastes and shipping them around every day by huge numbers of long-distance trucks. An alternative communication strategy could be for the breweries to exchange recepies *once* and then doing well with local transports.

In this way, only our fantasies provide the limit to how much resources society could save by swopping clumsy and resource-consuming processes for information transfer, at all scales, for more sophisticated ones, to bring about high life-qualities to people and all life forms.

But there is another rational for showing this table as well, its final part of biological information systems, see next slide.

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In the previous slide, look at the sophistication level of the communication processes taking place in life, e.g. in protein synthesis. It makes computer memories, where we humans perform technically at our best, appear clumsy in comparison. Why does nature work at such levels of *extreme* sophistication? This is because the amounts of information that is transferred per second in each cell, to keep it alive and to repair it when damaged and to function in harmony with other cells, is HUGE. If our bodies would operate at the same levels as our computer memories, we would need something like a nuclear power plant to run each of our fingers. Nature NEEDS to operate at those levels, to make it all come together. And THAT system, nature, our habitat on this planet, is the one we pollute. We allow it to be exposed to ever increasing levels of metals and compounds that shouldnt be there, causing mutations. Or endocrine disruption, when biological systems react to certain substances that mimic hormones. We dont put coffee in our computers, but we put chemicals foreign to nature out there.

To understand natural sciences at this level, may help our natural and intuitive senses in one fundamental aspect: caution with the basic system evertything else depends on, our home in the universe.