3 A Sustainable Technological World

The major properties and behaviour of a Sustainable Technological World (STW) are presented. The Brundtland definition of sustainable development is adopted and the period between human generations is fixed to 25 years and placed in the perspective of the future. It is argued that a STW exchanges oxygen with the atmosphere and should be powered by water formation. The mass and energy of a STW is calculated from the water exchange between hydrosphere and atmosphere and from the width of the human class in the biosphere assuming equal flows in each class. The air and water flow of a STW is calculated by allowing for a STW the same air and water intake as a human body. The behaviour of a STW with respect to the other world spheres is treated highlighting filling, emptying and emissions. The 6 underlying assumptions are discussed and the chapter ends with 3 major conclusions, regarding properties, emissions and human stakes in a STW.

3.1 Introduction

In this chapter a Sustainable Technological World (STW) will be explored in a quantitative manner in balance with geosphere and biosphere and the position of mankind in the biosphere.

It is not *the* STW but *a* STW because - for one reason - the aim is to describe the largest STW in balance with Nature not the smallest. The smallest will be a STW coinciding with the noosphere, literally the sphere of mind or intellect [1]. This is in line with the thoughts of Teilhard de Chardin [2] seeing the noosphere as an ultimate and inevitable sphere of evolution.

The point of departure regarding sustainable development is the Brundtland description [3]. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Brundtland recognizes in it two key concepts. The concept of ‘needs’ in particular the essential needs of the world poor, to which overriding priority should be given. And secondly: The idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs [3].

3.2 Time and Generations

The Brundtland idea that a generation has responsibility for the next generations is neither new nor exclusively human. It is rooted in evolution and can be experienced in the biosphere everywhere. The difference is that mankind has awareness of the future and has the possibility to create better or worse conditions for human life to come.

In a STW the clock set by the Brundtland definition is the time interval between adjacent generations. So 12 clock hours is set equal to 25 years. In a STW this gets a special meaning. All goods are offered to the next generation and it is decided whether to return it to Nature or to keep it in a STW. So the characteristic time of renewal of the material content of a STW is 25 years.

The period of 25 years is a human average. Young women are fertile half this age and older women may still give birth at 50 years. Both situations extremes are facts of life in today's world [4].

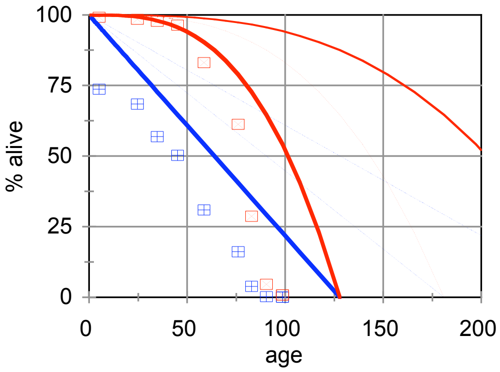

Figure 3.1: Extending the lifespan [5]. Points: England and Wales in the 1880's and 1990's [4], Lines: future lifespans.

In the near future medical science will progress challenging the average of 25 years. Current medical research allows children to have mothers more than two generations older. There are indications that medical research will allow people a much longer life than the 130 years barrier and in 23rd century people may enjoy a lifespan of 969 years like Methuselah. Figure 3.1 gives an indication of how extending lifespans will change the relationships between the generations. The current average lifespan of 3 generations will increase or the time for one generation will increase. There is also the SF-notion that creation of children will become independent of relationship between the 2 genders.

It can be concluded that 25 years is a current average and that there are pressures to extent that period in the future.

3.3 Mass and Energy

Brundtland idea of limitations and environmental ability are translated in a STW with an upper limit for its mass and its energy consumption.

There are no *a priori* restrictions on the composition of a STW. The only condition being it is confined in a STW. But there will be restriction on use release and manufacture of products. See Section 3.5.

Energy consumption is equivalent with energy degradation. Thus an upper limit means an upper limit to primary energy. Again there is no constraint regarding the composition: the source can come from planet Earth, star Sun or something else. Again, see Section 3.5, there will be restriction on use, release and manufacture of energy carriers.

What matters further is how much mass is needed to convert primary energy. Theoretically it is quite possible that a STW has an allowed upper mass and energy, but that all the mass is consumed in the construction of energy plants. See also Section 4.3. Good quality primary energy releases mass in a STW for other purposes.

For the same reason energy storage is a major issue. It is allowed to store energy in mass of a STW but the penalty is the same: it occupies STW mass. Good storage is storage in Nature.

Mass and energy in a STW are thus not independent phenomena. In this Section upper limits will be given for both. This is arranged in terms of 3 statements at the end of 3 headings. The first is qualitative and deals with exchange molecule of a STW and atmosphere and the energy associated with it. The second relates mass with molar exchange with the atmosphere and the third gives the allowed exchange flow of a STW.

In the 4th and final heading the mass and energy of a STW are calculated and benchmark values are given for specific energy, power and production.

Of course in the end this comes down to 2 assumptions: one for the kilograms (mass STW) and one for the Joules (energy STW). However both quantities should be maximal and in balance with Nature and man’s position in Nature. After all, the reasoning should be applicable to all creatures. A STW is not necessarily human or restricted to humans.

A qualitative picture of a STW

The atmosphere is the smallest subsphere of the geosphere. It is in balance with the hydrosphere exchanging water. For million of years it is also in steady state with the biosphere exchanging carbon dioxide. The biosphere is lighter than the hydrosphere, so a qualitative picture is easily painted, see Figure 3.2.

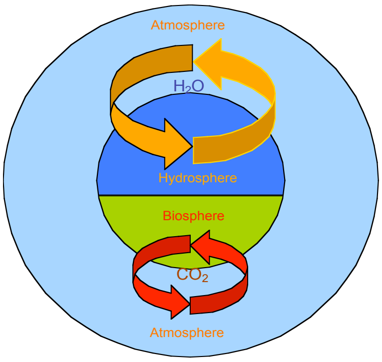

Figure 3.2: 2 grant World cycles.

A STW has to have also stable relationships with the atmosphere. It is a STW for humans. Humans need oxygen so the molecule to exchange between STW and atmosphere is oxygen too. Gravity pushes light compounds outwards and therefore the outskirts of the Earth are populated by the lighter elements. The geosphere and biosphere are both oxidic and a STW can reduce and oxidize these compounds and store the oxygen in the atmosphere.

A body fits in if its mass is less than it surroundings. The biosphere fits in the geosphere as subspheres have a lower mass. For the same reason the mass of a STW can not exceed that of the biosphere and a qualitative picture is again drawn in Figure 3.3.

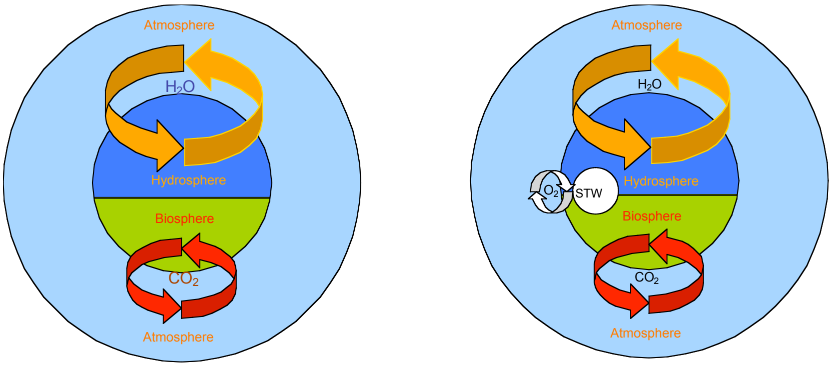

Figure 3.3: From 2 to 3 grant world cycles.

In Chapter 2 is shown that the energy of the hydrosphere and biosphere is coupled to molar exchange with the atmosphere. The hydrosphere is driven by physical energy. The biosphere keeps reduced forms of CO_2 (carbohydrates) internally while storing the other molecules in the geosphere.

A STW is driven by the heat of reaction of water formation and dissociation coupled to the oxygen exchange to the atmosphere. The water, the oxidized form can be stored in the geosphere, the reduced form, hydrogen, has to be kept in a STW. In this way the chemical energy associated with molar exchange is maximised and the mass of the reduced form to be stored in a STW is minimal. Which primary energy sources are used in a STW is left open: the molar exchange of oxygen puts simply an upper limit on the energy of a STW. In the same way it is also left open what happens with the waste energy: which portion of the primary energy should be actually used for the benefit of mankind can not and will not be answered *a priori*.

Statement 1:
A STW exchanges oxygen with the atmosphere and the associated energy is obtained from water formation and dissociation.

Molar atmospheric flow and mass hydrosphere and biosphere
To relate molecular exchange and mass engineers [6] start writing down Fick's law having Figure 3.4 in mind,

$$J = k_{oy} \cdot \Delta y_{mol} \cdot \rho_{y,mol} \cdot A \tag{1}$$

with J the molar flow, k_{oy} an overall mass transfer coefficient, $\rho_{y,mol}$ the difference in molar fraction of the molecule going from phase x (hydrosphere, biosphere, a STW) to phase y (atmosphere), $\rho_{y,mol}$ the molar density of the y-phase and A the interface between the two phases.

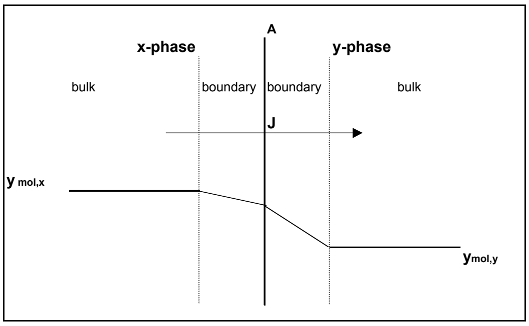

Figure 3.4: Mass transfer from x-phase towards the y-phase.

Scientists worry about Fick's law because the mass transfer coefficient depends on concentrations and the interface A is unknown in general requiring detailed knowledge of the size-shape distribution of the x-phase.

With the help of the Sauter characteristic size d_S,

$$d_S = \frac{6 \cdot V}{A} \tag{2}$$

the unknown surface can be transformed into the better known volume V at the price of the unknown number N_s of Sauter particles which comes in the equation due to the unknown shape of the x-phase,

$$J = k_{oy} \cdot \Delta y_{mol} \cdot \rho_{y,mol} \cdot 6 \cdot [N_S]^{1/3} \cdot V^{2/3} \tag{3}$$

assuming that the Sauter size is the edge of a cube. (The standard approach is to consider the Sauter size as a diameter of sphere, gives a similar but slightly more complex expression.)

The mass M of the x-phase is known not the volume, so with the x-phase density ρ_x (kg/m^3),

$$J \;= k_{oy} \cdot \Delta y_{mol} \cdot \rho_{y,mol} \cdot 6 \cdot [\frac{N_S}{\rho_x^2}]^{1/3} \cdot M^{2/3} \tag{4}$$

To apply it to world spheres it is reduced to its basic form,

$$J = k \cdot M^{2/3} \tag{5}$$

where should be kept in mind that k also includes a time average term k_t as J is a year-averaged molar flow,

$$k = k_t \cdot k_m \;= k_t \cdot k_{oy} \cdot \Delta y_{mol} \cdot \rho_{y,mol} \cdot 6 \cdot [\frac{N_S}{\rho_x^2}]^{1/3} \tag{6}$$

Equation (5) relates mass and molar flow and connects mass and energy because molar flow is coupled to energy. Equation (5) is exact for a given case (hydrosphere, biosphere), becomes semi-empirical in demanding the same k for both cases (hydrosphere and biosphere) but leads to a balanced outcome for the third case (a STW). In Table 3.1 (data extracted from Table 2.8 and Table 2.10) the vale of k is calculated for the systems hydrosphere/ atmosphere and biosphere/atmosphere.

Table 3.1 Value of k (mol/s.kg$^{2/3}$) for systems hydrosphere/atmosphere and system biosphere/atmosphere.

system	Mass Gton	Flow Gton/year	Molecule	Molar mass kg/mol	Mass transfer coefficient mol/s.kg$^{2/3}$
hydrosphere / atmosphere	1.66E+09	5.40E+05	H_2O	1.80E-02	6.8E-03
biosphere / atmosphere	3.15E+03	4.47E+02	CO_2	4.40E-02	1.5E-02

With an air density of 41 kmol/m^3, a water density of 1000 kg/m^3 and putting $k_t = \rho_{y,mol} = N_S = 1$ one calculates for the system atmosphere/hydrosphere k_{oy} 2.7E-3 m/s, quite a normal value for a gas phase controlled mass transfer. The value for the biosphere differs by a factor 2.2. This is small considering the impossible to estimate values of k_t and N_S which both might substantially different from 1.

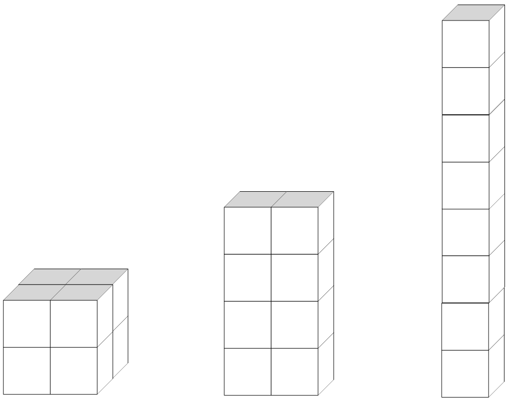

Figure 3.5: 8 cubes packed in 3D (N_S = 1), 2D (N_S = 1.6) and 1D (N_S = 2.8).

Figure 3.5 illustrates how shape changes N_S. As the world spheres are thin shells a 2D-value approaches reality the best. But on the other hand the spread in shape of the biosphere is substantial.

Statement 2:
Molar flow and mass of biosphere and a STW are coupled by the k-value of the hydrosphere/atmosphere.

Position Mankind in the biosphere
To frame particles in a distribution filtration engineers [7] use the logarithmic distribution. The framework consists of a selected size [8], a fixed class width and the upper and lower limit of the particles.

In [9] the length is chosen to describe the largest and smallest creatures living in the biosphere. It starts with 100 m tall trees and ends with 1 µm bacteria.

The length of humans varies typically from 0.5 m for a baby up to 2 m for a male adult. This gives a class width length of 4. Combining limits and class width gives a framework of 14 classes between the limits of 128 m and 0.48 µm.

In Table 3.2 selected examples are given for the 3 major domains of living organisms: Archea, Bacteria and Eukarya [10]. The Eukarya cover 13 classes starting with the tallest tree, the Coast Redwood, down the unicellular yeast cell belonging to kingdom fungi.

. The tallest and smallest of the mammals, reptiles and insects are given. The list includes the smallest animal with a bone structure, a fish, and algae are present in the form of diatomites (Chrysophyta class of eukaryotic microorganisms). Diatomites are important feed for whales and their skeletons are still in use in body-aid and precoat filtration.

The Archea living exotic lives under extreme conditions and the Bacteria have limited length potential but do add one class.

Table 3.2: Length of Archea, Bacteria and Eukarya. Data class 1-8 and class 10 Eukarya: different standard sources. Data microorganisms selected from: [10].

class	size range m		Archea	Bacteria	Eukarya	
	max	min				
1	1.28E+02	3.20E+01			Sequoia sempervirens	plants
2	3.20E+01	8.00E+00			Balaenoptera musculus	mammals
3	8.00E+00	2.00E+00			Python reticulatus	reptiles
4	2.00E+00	5.00E-01			Homo sapiens	mammals
5	5.00E-01	1.25E-01			Pharnacia kirbyi	insects
6	1.25E-01	3.13E-02			Suncus etruscus	mammals
7	3.13E-02	7.81E-03			Sphaerodactylus ariasae	reptiles
8	7.81E-03	1.95E-03			Paedocypris progenitica	fish
9	1.95E-03	4.88E-04		Epulopiscium fishelsoni	Amoeba proteus	protozoa
10	4.88E-04	1.22E-04		Spirochaeta plicatilis	Megaphragma caribea	insects
11	1.22E-04	3.05E-05	Thermofilum librum	Oscillatoria	Chrysophyta	algae
12	3.05E-05	7.63E-06	Methanopyrus kandleri	Prochloron	Trypanosoma gambiense	protozoa
13	7.63E-06	1.91E-06	Halobacterium salinarum	Escheria coli	Saccharomyces cerevisiae	fungi
14	1.91E-06	4.77E-07	Archeoglobus lithotrophicus	Clamydia psittaci		

To fill the classes filtration engineers idealize the logarithmic distribution assuming that the contents of adjacent classes are related,

$$\sum N_i \cdot d_i^m = \sum N_{i+1} \cdot d_{i+1}^m \tag{7}$$

with N the number of particles, d the size of the particles and m the order. For $m = 0$, 1, 2 and 3 each class contains respectively equal numbers, equal particle length, equal particle surface and equal particle volume. But in practice any m-value $m \geq 0$ is allowed. The number of particles in the coarse classes decreases with increasing *m*, because more particles are needed in the fine classes. For a given mass this process results in a maximal value for *m*; above this *m*-value the coarsest class contains less than 1 particle.

In the case of the biosphere there is an important piece of additional information. The minimal number of living organisms in class 4 is at least equal to the number of people on Earth: 6.445 billion [11].

The distribution over the classes is also sensitive to shape. Besides the standard shape the cube (in most textbooks sphere) there is the human shape to consider.

In [12] it is stated that an adult with a healthy weight has a Quetelet-index (= mass/length^2) between 20 and 25 kg/m^2. For younger humans this is not valid in accordance with the impression of the age-dependent shape noticeable in daily life and the baby show-up in Figure 3.6.

Figure 3.6: A five month old baby and an adult comparing shape at the same length [8].

A 3 kg baby with length 0.5 m has a Quetelet-index of 12. The reference human shape was calculated from these 2 extremes for a 1 m child weighing 16 kg giving $N_S = 3.4$ at $d_S = 0.17$ m. The mass range within the human class was set at a factor 32 varying from a just born at 2.8 kg at 0.5 m to a male adult of 2 m with mass 90.5 kg. This mass ratio was kept the same for all classes and the volume was kept the same by giving a factor 4 to the length and a factor $\sqrt{8}$ to the other two dimensions. Due to this uneven distribution along the axes the value of Ns will vary from class to class.

In Figure 3.7 the number and mass of class 4 are shown as a function of the order *m* of the distribution for the cubic and human shape. The constraint of at least one organism in class 1 limits *m* to 3.88 (cubic shape). Adopting the human shape shifts this maximum to 4.49. The condition of minimal 6.45 billion of cubic shape limits m to the range 3.34 > *m* > 1.55 and changing to the human shape doubles the region: 3.85 > *m* > 0.01.

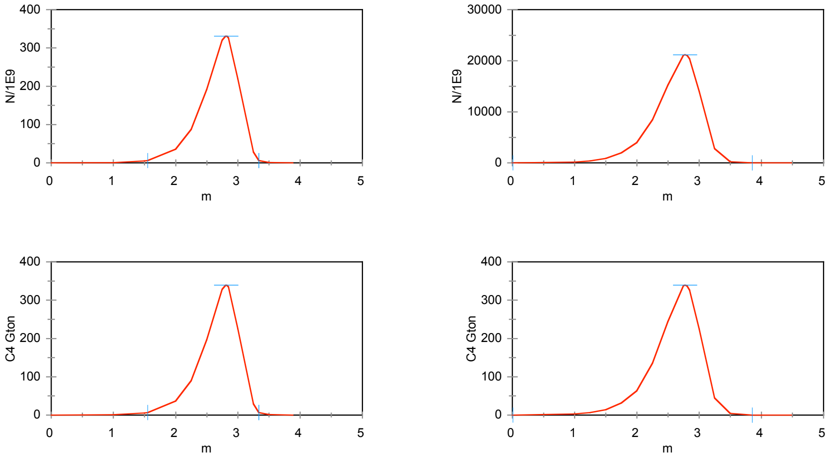

Figure 3.7: Number (top) and mass (bottom) of class 4 assuming cubic shape (left) and human shape (right).

The maximal number of organisms living with human together in class 4 depends not so much on the order but on shape. Cubic shape dictates a maximum of 3.3E11 inhabitants at *m* = 2.81, human shape allows at a slightly lower m-value more species: 2.1E13.

Shape has no effect on the maximum mass in class 4: 340 Gton but it influences the minimum. Cubic shape allows the humans to share 6.6 Gton or 1024 kg/ capita while human shape leads to 16 kg/capita as expected.

From this class 4 analysis it can be concluded that the human shape gives more reasonable outcomes. This means also that the Sauter size d_S and N_S values of the human shape should be preferred (Figure 3.8 right). But it implies also that the number of living organism is maximal 1.4 E29 (Figure 3.9 right) rather than 1.5 E30 (cubic shape).

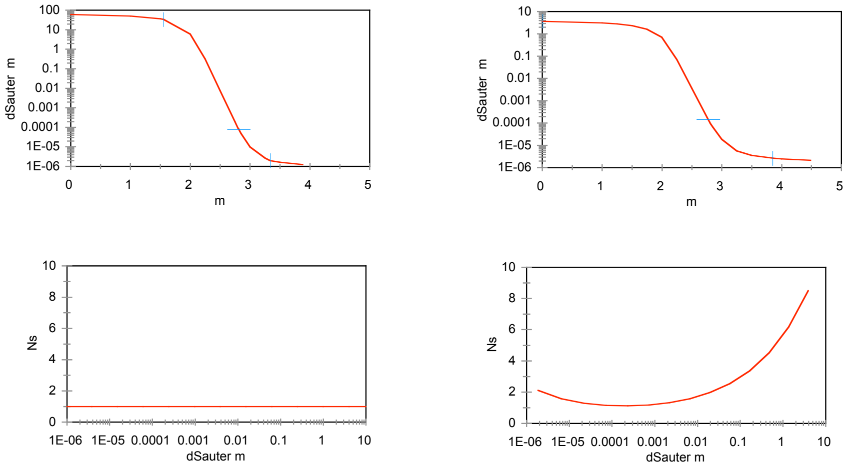

Figure 3.8: Top: Sauter cubic edge of biosphere as function of *m*. Bottom: number of cubes necessary to describe the shape in each class of the Biosphere represented by its Sauter cubic edge. Left: cubic shape; Right: human shape

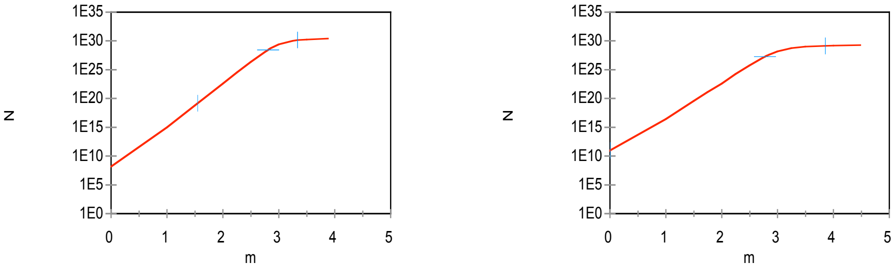

Figure 3.9: Effect of shape on the number of living organisms in the biosphere. Right cubic shape; left: human shape.

An estimate of the number of living organisms is an important spin-off, but it must be emphasized it is an estimate of the assuming constant *m*.

In practice *m* varies as shown in Figure 3.10 for 4 different Arizona red sand test dusts used in for example testing nonwoven filter media.

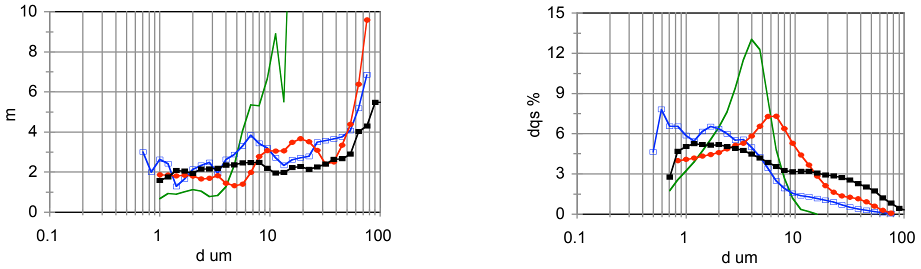

Figure 3.10: Order m (left) and differential surface distribution in % (right) as a function of spherical diameter [13], showing: ○ Ultra Fine Test Dust (UFTD) with d_S = 3.6 µm (), □ Fine Test Dust (FTD) with d_S = 4.0 µm (FTD), ● Medium Test Dust (MTD) with d_S = 7.7 µm and ■ Coarse Test Dust (CTD) with d_S = 11.3 µm.

These test dusts cover typically as many as size classes as one species (mammals for example) and therefore the maximal *m*-value is larger than for the biosphere. At the Sauter diameter the m-value averages at about 2, but increases sharply at the coarse side and losing value at the fine side also because in general small particles are more difficult to count. This behaviour of dead material in only a few classes would support the estimate that 1.4 E29 is a maximum. As the biosphere can be seen of a series of overlapping species, inserting *m* = 2 for the biosphere would predict a much more modest value of about 3.8E22.

Included is also the surface distribution (Figure 3.10 right) which shows for instance that the largest and smallest particle can not change the picture. So it is irrelevant whether or not there are some eukarya taller than 128 m and some archea/bacteria less than 0.477 µm in length. For the framework it is relevant that class 1 and class 14 are filled adequately by substantial numbers of average sized species.

Statement 3:

The molar flow of a STW is equal to the quotient of the molar flow of the biosphere and the number of biosphere classes.

Mass and energy of a STW

First the mass and molar flow to and from the atmosphere are calculated. See Table 3.3. The maximal flow is calculated from the biosphere flow of 1.02E7 Gmol/yr (see Table 2.10) using *Statement 3* and *Statement 2* to convert flow to mass. The minimal mass is obtained from the biosphere mass of 3.15E3 Gton using *Statement 3* and *Statement 2 to calculate the flow*. The average value of mass and flow is put equal to the harmonic mean of the minimal and maximal values.

Table 3.3: Mass and molar flow of a STW.

		Biosphere		a STW		
		average	k	max	min	average
mass	Gton	3.15E+03	1.04E+04	1.98E+02	6.01E+01	1.1E+02
flux	Gmol/yr	1.02E+07	4.59E+06	7.26E+05	3.28E+05	4.9E+05

Statement 1 identifies oxygen as the molecule to exchange between a STW and the atmosphere. The associated reaction is the formation of liquid water from gaseous oxygen and hydrogen according to the reaction,

$$O_2 + 2\ H_2 \rightarrow 2\ H_2O$$

With a standard enthalpy of reaction of heat of 571.7 kJ/mol O_2 [14] the energy of a STW can be calculated.

The results are given in Table 3.4 also presenting benchmarks for annual production, specific energy and specific power.

Table 3.4: Basic properties and benchmarks of a STW.

Basic properties		
Mass STW	110	Gton
Power STW	8800	GW
Life-span artifacts, average	25	yr
Benchmarks		
Annual production of artifacts	4.4	Gton/yr
Specific energy consumption producing artifacts	64	MJ/kg
Specific power consumption STW	80	mW/kg

The annual production of artifacts is a maximum as new generations may decide to keep things rather than reprocess them. The specific energy consumption is the ratio of power and annual production. It must be considered as a maximum for benchmarking production as it assumes that in the state of use no energy is necessary. This benchmark will be used in Chapter 4. The specific power consumption is a maximum for energy consumption in state of use disregarding production. It will be appear in Chapter 5.

3.4 Air and Water

Processes require more process compounds than necessary from a bookkeeping point of view. They are not 100% efficient. For compounds other than water and oxygen storage in a STW is the first alternative. However the energy coupled water and oxygen streams are simply too large to be stored. Some allowance has to be made for inefficiencies regarding usage and production of oxygen and water.

A STW is a human thing and consequently the reference case is the human system.

The human system

Humans breath, drink and eat and in that order the exchange flow decreases. In Table 3.5 the information is collected on the major flows on a daily basis.

The air exchange is entirely an affair of the lungs, but the water exchange is more complicated. The input water stream comes mainly (72.2%) by drinks and food makes it up to 100%. Water leaves the human body for more than half via the kidneys (51.2%), the skin and the lungs take care of less than a quarter each (respectively 24.5% and 20.4%) and via the intestines the remaining water (3.9%) is removed.

Table 3.5: Average major human body flows as estimated from various data on human adults found in [12] and [15]. Carbohydrate = dry food.

compound	input		production		output	
	kg/day	Gmol/day	kg/day	gmol/day	kg/day	gmol/day
nitrogen	11.95	427			11.95	427
oxygen	3.68	115	-0.68	-21	3.00	94
water	2.11	117	0.38	21	2.49	138
carbohydrate	0.73	24	-0.64	-21	0.09	3
carbon dioxide			0.94	21	0.94	21
total	18.46	683			18.46	683

The combustion reaction of dry food (carbohydrate) is,

$$O_2 + CH_2O \rightarrow CO_2 + H_2O$$

It is clear from the data in Table 3.5 that much more exchange occurs than required by the reaction itself. It is remarkable that for oxygen as well as for water the molar input is a larger by a factor 5.45 than what is involved in the reaction. The molar input air flow is a factor 25.7 higher than what is actually converted.

Air and water of a STW

In a STW the same factor for air and water are allowed as for humans. With the known molar masses of air and water and water formation reaction, the air and water flows in a STW are calculated. In Table 3.6 the results of the calculations are presented.

Table 3.6: Basic properties, benchmarks and air and water flows of a STW.

Basic properties		
Mass STW	110	Gton
Power STW	8800	GW
Life-span artifacts, average	25	yr
Benchmarks		
Annual production of artifacts	4.4	Gton/yr
Specific energy consumption producing artifacts	64	MJ/kg
Specific power consumption STW	80	mW/kg
Air and water flows		
Air	375	Gton/yr
Water	100	Gton/yr

The air and water flow are derived from combustion reactions, but as a STW is not necessarily (only) indirectly powered by water formation this water and air can be used for any chemical process. (The oxygen released by the roasting of iron ore can enter a STW again for oxidation of methane.) It is not to be confused with cooling water which is like taking a shower.

3.5 Exchange with Nature

A STW will have a composition changing with time because its contents (artifacts) are born out of necessity for people who continually change their mind and not only from generation to generation. The collection of artifacts has a gross composition and this will change. The direction of change (lighter and more functionality) is not the topic of this Section but the problem how a STW communicates and exchanges its material content disregarding its energy molecules (air, hydrogen, water).

In the first heading the exchange with biosphere and geosphere is treated. This so-called replacement allows a STW to change its composition on a regular basis. The question is not so much what a STW wants from Nature but if Nature can cope with (preferably to Nature‘s benefit) the products it gets back from a STW.

Emissions occur in Nature. Volcanoes release the pressure in the Earth’s mantle by sending huge quantities of volatiles and particles into the atmosphere and creatures like plants, insects, carnivores and humans use aromatic substances to attract, identify, and keep distance. Emissions are thus sometimes functional and the question is what a STW is allowed to emit. This is theme of the second heading.

In both headings a distinction is made between synthetic and natural compounds.

Replacement

Filling a STW with material is the first step. The lightest constructive element in the periodic system is carbon, as hydrogen and helium are gases and lithium, beryllium and boron are well hidden in the lithosphere and far too reactive and toxic. A STW with a mass of 110 Gton [Table 3.6] can thus contain maximal 9.2E6 Gmol carbon and with a filling rate of 3.7E5 Gmol/yr it takes 25 years to fill a STW. The carbon source would be coal stored by the biosphere in the lithosphere. And in Figure 3.11 (left) this transfer of carbon to a STW is depicted.

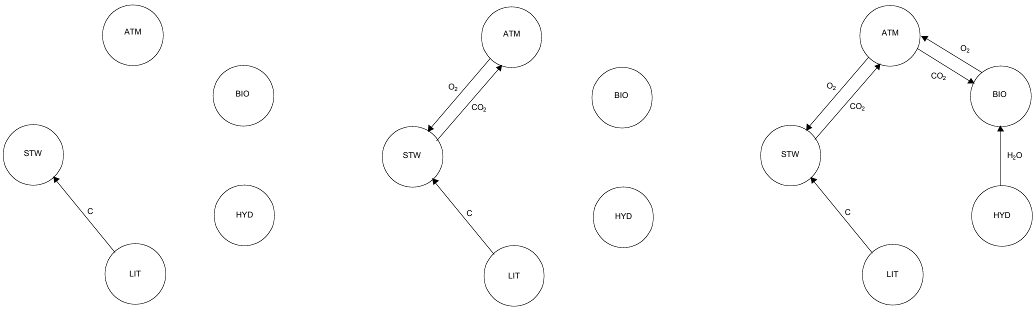

Figure 3.11: A carbon STW in imbalance and balance.

During the filling a STW is not in balance with the feeding sphere (in this case the lithosphere).

The second step is to empty a STW of old stuff. Once the filling process is over it is decided to burn the carbon and to import carbon from the lithosphere. See Figure 3.11 (middle). Available on an annual basis is 5E5 Gmol/yr oxygen [Table 3.3] leaving 33% for inefficiencies and other activities, like for example central heating, manufacturing (graphite fibres, nanotubes) or transportation. In this second period of 25 years the imbalance is shifted to the atmosphere and lithosphere, with the carbon STW acting as chemical reactor converting lithospheric carbon into atmospheric carbon dioxide at the expense of the oxygen in the atmosphere. A STW can thus be in dynamic equilibrium with two other spheres but the overall balance is absent and therefore not sustainable.

The biosphere helps in Figure 3.11 (right). Or more precisely it helps the atmosphere. It removes carbon dioxide from the atmosphere, stops the decrease in oxygen and fixes the carbon as carbohydrate, but it needs water from the Hydrosphere to do so. 75 years later the atmosphere and the carbon

STW are in equilibrium, and the imbalance has shifted to a growing biosphere and shrinking hydrosphere and lithosphere. Apparently intermediate spheres can be dynamic balance but not the (compositional) ends.

To close the pentagon the biosphere has to give back its carbohydrate. The carbon part is pushed in the lithosphere and the water part flows back in the hydrosphere as shown in Figure 3.12 (left). But it cannot be closed.

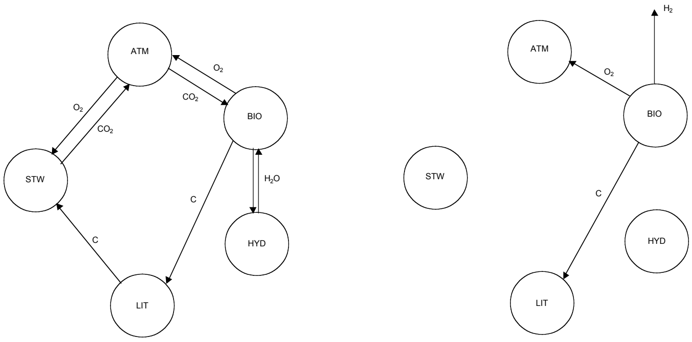

Figure 3.12: Closed and open carbohydrate cycles.

The closure is however at the very best the outcome of a very complicated reduction process as carbohydrates do not split up in carbon and water just like that. The question is clearly how the coal was formed in the past and if it was formed like in Figure 3.12 (right) than the closure can not be achieved at all. The hydrogen will escape to the universe leaving the deuterium behind. And even if not so, it should be realized that the biosphere has an appetite for lighter isotopes too, a phenomenon resulting in isotopic fractioning.

Circumstantial pathways - riding along the pentagon edges – involving as much partners does not lead to sustainable solutions. Humans may opt for global solutions but trees have other interest.

The sustainable solution is to give back what is obtained, as shown in Figure 3.13 (left). The carbon example shows clearly that the wrong decision is to burn the carbon. The carbon should be given back to the lithosphere under the appropriate reductive conditions, ensuring no oxidation. The form of the carbon (diamond, graphite, nanotubes, soot, etc) is then of no consequence in this bilateral exchange between the lithosphere and a STW.

Extracting salts can cause severe storage problems. PVC production requires for example carbohydrate from the biosphere and rock-salt from the lithosphere, but the sodium should stay as long in a STW as the chlorine in the PVC. PVC is a synthetic and like all other synthetic it should be broken down into its natural components before it can return to Nature. So all that time the sodium has to find a use in a STW too. And if not, it has to be stored in some form excluding dissolution and chemical reaction.

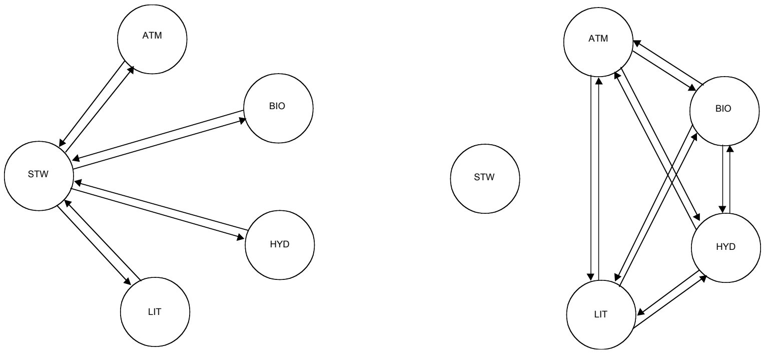

Figure 3.13: Relations for a STW and those between natural spheres.

Another fundamental source for a STW is material flowing between natural spheres. See Figure 3.13 (right). The water cycle between hydrosphere and atmosphere gives fresh water from salt water. Where they meet again energy can be obtained. This salinity power is explored in Chapter 4. Biomass no longer in use decays to carbon dioxide and in this process at the interface of atmosphere and biosphere a STW may have a stake as also demonstrated in Chapter 4. The ongoing formation of manganese nodules on the ocean floors is a flow between hydrosphere and lithosphere a third well-known example. And there are many more. The advantage of these sources for a STW is that the input may differ from the output stream and a STW has only a downstream obligation (salt water, carbon dioxide, dissolved metals salts) and can take full advantage from its upstream resources (carbohydrate, fresh water, manganese nodules). But again no synthetic chemicals can be dumped in Nature by a STW.

Emissions

A STW may emit natural compounds in relation to its mass. The governing equation is derived from equation (5),

$$J_{STW} = J_s \cdot \left[\frac{M_{STW}}{M_s} \right]^{2/3} \tag{8}$$

with J the flow of a natural compound, M the mass and the subscript s stands for (sub)sphere. A natural compound in this approach is thus any compound with a natural average flow. If more (sub)spheres emit the same compound, the highest one allowed is valid for a STW.

Table 3.7.lists the methane emissions from different sources. A farmer produces food so that part of his activities is in the biosphere.

Table 3.7: Categorizing methane emission data (Mton/yr) from [16].

sources	min	average	max
wetlands	55	115	150
termites	10	20	50
ocean	5	10	5
subtotal biosphere except agriculture	70	145	205
enteric fermentation	65	85	100
rice paddles	20	60	100
animal wastes	20	25	70
subtotal biosphere	175	315	475
coal mining, natural gas, petroleum industry	70	100	120
biomass burning	20	40	80
landfills	20	40	70
domestic sewage treatment	15	25	80
subtotal TW	125	205	350
natural other	10	15	40
total	310	535	865

The biosphere with an average emission of 315 Mton/yr allows a STW methane emission of maximally 34 Mton/yr or 0.4 mol% of the permitted oxygen flow. The allowed STW methane flow is thus 6 times smaller than current practice in the Technological World (= TW).

Oxygen, carbon dioxide and water are natural compounds but have a special role in the energy supply of respectively a STW, biosphere and hydrosphere.

The carbon dioxide emission of a STW can thus not be calculated from equation (8). It will be estimated in the next Section.

Compounds not emitted by the subspheres should also have zero emissions in a STW. These synthetic and natural compounds may still have a function to alert, identify and to stay out. The amount necessary should be minimal but measurable or detectable. That is determined by the state of the art of detection instruments or the (human) nose, as is practised in the addition of aromatic substances to natural gas to warn of leakage or spillage. But in any case, the limited amount of air and water available in a STW guarantees minimal emissions, if measurements are made at the right spot.

3.6 Distribution and Sharing

The content and activities of a STW are shared by people living on Earth.

Budgets per capita can be calculated for a given world population and this is done for the emission of methane. For carbon dioxide the emission per capita can be estimated allowing the calculation of the carbon dioxide of a STW as promised in the previous Section.

In the second heading air budgets are treated. The theme is air pollution assuming stagnant air above people sharing the air above them. This is translated into a stagnant air residence time, being more important for urban societies than speculating about the effects of all the chemicals produced in oxidation [17] and reduction processes using air.

The third heading is about societies (companies) emitting chemicals. They confiscate the budgets of their employees and if they emit more than they have stakeholders unaware of their stake.

Emission budgets of methane and carbon dioxide

With fixed limited properties of a STW the budget for every human soul is simply the amount divided by the number of people

With 6.45 billion people [11] the methane emission budget per capita is 5.2 kg/yr equivalent to 0.9 mol/day. (Compare with Table 3.5 data.).

This works also the other way around. A STW takes over the hard labour of man. The difference in energy consumption between an office worker and a blue collar worker is about 60% [12]. The allowed carbon dioxide emission per capita in a STW is then about 6.3 gmol/day (See Table 3.5) or 100 kg/yr. With 6.45 billion people a STW is allowed to emit 0.65 Gton/yr carbon dioxide.

Air sharing and stagnant air residence time

The 375 Gton of air (Table 3.6) is shared by the 6.45 billion people living on Earth, resulting in an annual flow per capita q_c of 58 ton/yr. This annual flow plays a role in the equation for stagnant air residence time [18],

$$\tau = G \cdot \frac{a_c}{q_c} \tag{9}$$

with a_c the land surface available per capita and G, the grammage, the mass of air per unit Earth surface available. The value of the grammage is equal to 10 ton/m^2 as calculated from the mass atmosphere 5.14 E6 Gton (Table 2.4), and Earth surface 5.10 E14 m^2 [19]. With a population of 6.45 billion and a land area of 1.32E14 m2 [11] the stagnant air residence time of air is 3600 years for a STW. But this assumes that dispersion of people across the land surface is uniform. In practice people cluster in societies in small areas so that eventually the stagnant air residence time becomes less than a life time. See Chapter 6.

Stakeholders

Societies may need more than the budget of their members. These members have – mostly unaware - a stake in these societal activities. Societies are in a STW if the claim is less than the budgets of their members and the members agree upon that and if not the society is out of a STW.

The number of stakeholders is easily calculated from the actual flow and the permitted flow per capita. If the stakeholders supersede the society members in number, than the society is not fitting into a STW. The only thing to do for the society is reduce emissions, as stagnancy of air leaves no other option.

Companies not embedded in society (an emitting plant with zero or only foreign employees) are thus *a priori* not fitting in a STW.

3.7 Discussion

In this chapter the major properties of a STW are presented using the minimum number of assumptions (statements).

The 1st assumption fixes the time period between adjacent human generations. The 2nd and 3rd assumptions state that a STW exchanges oxygen with the atmosphere and the associated energy is obtained from water formation and dissociation. The 4th assumption selects the relation between mass of the hydrosphere and the exchange flow of water between hydrosphere and atmosphere. The 5th assumption prescribes that the molar flow of a STW is equal to the quotient of the molar flow of the biosphere and the number of biosphere classes. The 6th assumption allows a STW to be as efficient with air and water as a human body.

A discussion about reducing the 6 assumptions does not make much sense: the 6 are necessary. The only type of discussion is whether or not one or more could be replaced by another one. Without much difficulty one could replace assumption 4 by the assumption that the mass of a STW should be equal to the mass of the human class in the biosphere. It would give similar figures and errors in the average mass. The practical reason in favour of assumption 4 is that is also used in emissions, so the type of equation is necessary anyway.

So it is important that the assumptions are chosen in such way that they can be used in more than one sense. One way to look at a STW is that a man-made sphere full of artifacts and any other creature may have one. Indeed the same framework may be used to construct a STW for any other air breathing creature. Characteristic differences will be introduced by assumption 1, 5 and 6, because respectively the time between generations differs, the length ratio differs and therefore the number of classes and the air and water intake differ.

So the assumptions 1, 5 and 6 are human-specific and the assumptions 2, 3 and 4 are generic for any air breathing animal.

Another point of discussion is whether or not more than 6 assumptions are necessary to describe all major macroscopic properties of a STW. It will depend on what is meant by the word major. For certain, the 6 assumptions allow any chemical composition within the framework of replacement and emissions. There an infinite number of STWs possible in a compositional sense. An infinite number of STWs is a precondition, because any evolutionary path should be possible. STW composition is therefore not a major property of a STW but only important for a given STW. For the time being it can be concluded that the 6 assumptions are enough to describe a STW on Earth.

3.8 Conclusions

1. The first major conclusion is simply a copy of Table 3.6, summarizing the major properties of a STW.

Basic properties		
Mass STW	110	Gton
Power STW	8800	GW
Life-span artifacts, average	25	yr
Benchmarks		
Annual production of artifacts	4.4	Gton/yr
Specific energy consumption producing artifacts	64	MJ/kg
Specific power consumption STW	80	mW/kg
Air and water flows		
Air	375	Gton/yr
Water	100	Gton/yr

2. The second major conclusion is that natural STW emissions can be calculated or estimated (CO_2) and that for synthetic compounds the upper limit is given by detection.

3. The third major conclusion is that all people on Earth have a STW stake and that societies should be aware of these stakeholders.

3.9 Literature

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