The Olympic Game of Eco-Innovation and Technology

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Esteemed Rector Magnificus,
Dear family, friends, colleagues, partners in cooperation, ladies and gentlemen

In the next 45 minutes, I would like to tell you about my vision on eco-innovation of our society and how technology will play a role in that. At the cover of this booklet you can see a modern urban environment, a photograph of parof the city centre of Den Bosch. Considering this beautiful urban design creating a futuristic and inspiring atmosphere, we can philosophize about people living in a modern world.

At a closer look we realize that behind the walls of these buildings, in this mirroring water, and under the surface deep in the ground, complex technology is present. Technology to provide the people that live here with adequate living conditions, supplying them with energy for heating, cooling and cooking and with water for showering, washing and using bathrooms. Presumably these people are modern consumers; they like shopping, buying and using goods and materials, and preparing and enjoying their food and drinks. Many of them are environmentally conscious and separate their solid waste into organic, glass, metal, paper and plastic fractions which are collected every week. Their wastewater is transported through sewers away from their homes, and they trust that it is properly treated and cleaned. Beyond their sight a vast set of technologies is being applied, developed during the last decades, partly through the environmental engineers and scientists trained at Wageningen University. In western countries the local environment is becoming cleaner and cleaner, and also in other parts of the world progressions are made. However, many parts of the world are still deprived from adequate sanitation, water supply, and waste management. A further diffusion of environmental technology and infrastructure through-out the world to achieve cleaner local environments is

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still an important mission to be addressed in future, and Wageningen University will continue to take its part in this.

Recently we have learned that our effort to strive for a clean local environment is only part of the story: we need also to take into account the condition of our planet as a whole. With growing world populations, the human footprint on planet earth is growing to an extent larger than the capacity needed to provide all people with food, water, energy and resources. From global perspective, local actions are needed, but now not only addressing the local clean environment but also reducing global impacts. New scientific and technological approaches are needed to cope with this challenge, and should not always start from current feasible ideas. New ideas and new basic principles are needed which so often are to be found at interfaces between different scientic discplines. This is exemplified by the picture of Plant-Power, integrated into the photograph at the cover of this publication. Growing plants producing electricity, who could have imagined this to be possible? Wageningen University is an excelent place to search and harvest such new concepts at the bordelines between these different disciplines in life sciences.

I invite you to a tour through Eco-Innovation and Technology. I will show you that it is a challenging global game striving for a sustainable future. Here, technology, companies, local communities and local governments play important roles to take front running positions. What I would like you to remember after this talk are the following take-home messages:

- Environmental technologies need to shift from local to global targets but implementation has to be realized at local scale.
- Eco-innovation needs to be accomplished predominantly in the urban environment and direct surroundings since 70% of the world population will be living there in future
- Food, water and environment are no separate issues, and need to be dealt with in their relations to achieve sustainable approaches.
- Companies and governments that will early adopt new sustainable approaches will pave the way of the Eco-Innovation of our societies.

Human impacts on nature

As a first step, I need to explain to you briefly how nature is working, and how human interactions with nature can influence the stability of natural systems. To this end, I made a simplified model. Firstly, I will discuss depleting and accumulating biological systems.

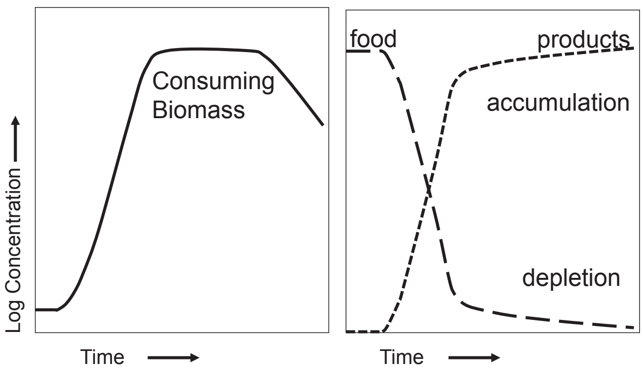

Figure 1: Concentrations with time in a depleting and accumulating biological system which is dominated by consuming biomass.

In Figure 1 a biological system is shown which has an excess amount of food. Food consuming organisms extract materials and energy out of the food for their growth. The organisms start to feed and grow untill the food supply is depleted and the formed products accumulate and become inhibiting.

In Figure 2 such a process is visualised in another way: the biomass consumes the high energy food and converts it into low energy products, using the absorbed energy for growth and other activities. This corresponds to a loss of order in the system and energy dissipation as heat. In physical terms this can be explained in terms of free energy (F) as the sum of energy that can be used for work (often also called enthalpy U) and energy that cannot be used and which is related to the degree of disorder of the system (often also called entropy S) and temperature (T),

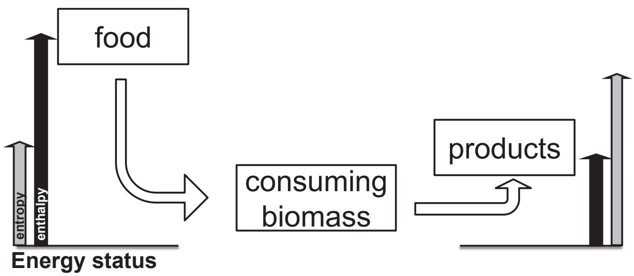

Figure 2: Flow scheme of a depleting and accumulating biological system, and changes in energy (free energy that can be used, black bar; free energy that cannot be used, grey bar).

which yields a well known relation derived from the second law of thermodynamics (Lyklema, 1991):

$$F = U - TS. \qquad \text{(eq. 1)}$$

In the process displayed in Figure 2 the usable free energy part (U, black bar) is partially converted into unusable entropic free energy (-TS, grey bar).

This type of process scheme we encounter frequently in daily practice, for instance in the preparation of biotechnological products like wine and bread. In industrial biotechnology we have made use of these natural depleting and accumulating processes. In these examples mentioned the biomass is formed by microorganisms called yeast, the depleting food is starch and sugars, and the accumulating products are biomass, alcohol (in wine) and carbon dioxide (the gas raising the bread). In nature another type of system is generally present. Natural ecosystems are stabile, they neither deplete nor accumulate because consuming as well as product regenerating (producing) biomass are present and equally active (Figure 3).

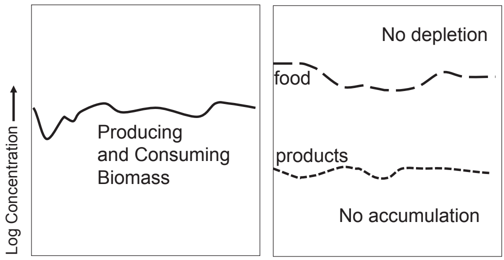

Figure 3: Concentrations with time in a natural biological system with consumption and production of biomass equally active.

To understand how that functions we need to look at Figure 4. We start with the same scheme as before, but we add feedbacks driven by solar energy, converting biodegradation products to new food (higher in usable energy) upwards into the cycle (reducing the entropy). Natural ecosystems are stabile because the cycles are closed; they do not deplete or accumulate and are resilient against changes as a result of foreign material inputs or depleting resources as long as certain critical boundaries are not crossed.

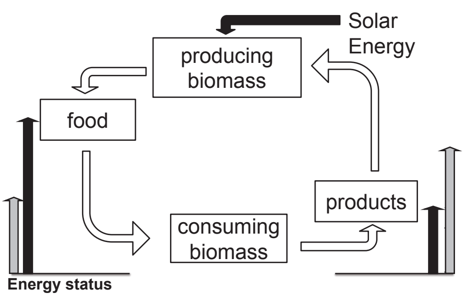

Figure 4: Flow scheme of a stabile biological system, including changes in usable energy and entropy status.

In real ecosystems we encounter a multitude of cycles and networks of interrelations between producing and consuming organisms. These are complex systems and one of our professors Prof. Marten Scheffer is well known for the concept of tipping points demarcating the boundaries beyond which these complex ecosystems become unstabile and shift to other another state of equilibrium (Scheffer et al., 2001; Scheffer et al., 2009). Although the natural system in reality is much more complex, the simple model as I just presented helps to underderstand what happens when human-nature interactions come into play. Upon inputs and extractions by the worlds' human population, global ecosystems are now under pressure. In Figure 5 it is visualised what happens when human impacts become too large for eco-systems to handle. Humans consume food, materials and energy out of produced and fossil resources and the resulting waste is seen as high energy 'food' by the natural ecosystem. Organic and nutrient inputs are fed into the system and accumulate.

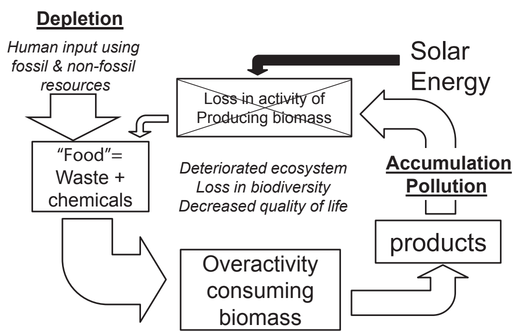

Figure 5: Flow scheme of human impact on an ecological system, perturbing the cycles to such an extent that the system as a whole lapses into uncoupled depletion and accumulation.

In water (rivers, lakes and oceans) this can lead to blooming of algae or toxic cyanobacteria, in which an initially excessive growth is followed by dying of the biomass due to oxygen depletion. Moreover, large loads of synthetic toxic chemicals and metals are entering the ecosystem leading to chemical pollution. As a result the cycle can become perturbed and the ecosystem then falls back to an uncoupled and unbalanced situation characterized by depletion and accumulation, eventually reaching a new equilibrium, generally a deteriorated ecosystem, with a reduced biodiversity. Since our agroproduction and natural resources supply is largely connected to stabile biodivers natural ecosystems, human living conditions may then also become impeded.

From local to global impacts

In the past we have observed such overshoots in rivers, lakes, soil and groundwater, i.e. always considered them as local problems not impacting planet Earth as a whole. Over the last decades, however, indications were found, and evidence is being produced by several research teams, that impact on ecosystems extends to the level of the planet. The most familiar parameter is the increasing CO_2 concentration in the atmosphere as indicator for global warming. Although the discussions on the importance of this parameter are still going on, other planetary parameters are also coming into view, calling for our attention.

Table 1: Planetary Boundaries

Earth Level Process [a)]	Parameter	Unit	Proposed boundary	Current status	% of boundary
Fresh water Cycle	Human consumption	Km^3/yr	4000	2600	65
Phosphorus Cycle	P v	10^6 t flowing into the oceans/yr	11	9	82
Nitrogen Cycle	N_2	10^6 t removed from Atmosphere/yr	35	121	400
Chemical pollution	Chemicals, Plastics,...	ppm, g/l	?	?	?
Organic carbon agricultural soil [b)]	C	Amount C/ha	?	Depleting	?
Climate change	CO_2	(ppm in atmosphere)	350	387	110

a) Selection from: Rockström et al., 2009; b) Extended by author, and taken from Dong et al., 2009.

In Table 1 you can see an overview for a number of crucial earth-scale processes, partially as published by Röckstrom et al. (2009). These researchers propose a set of boundaries for parameters that are essential for stabile global ecosystems and for preserving living conditions for the global human (and cattle) population. I will briefly consider these parameters as mentioned in table 1, starting with phosphorus and ending with fresh water.

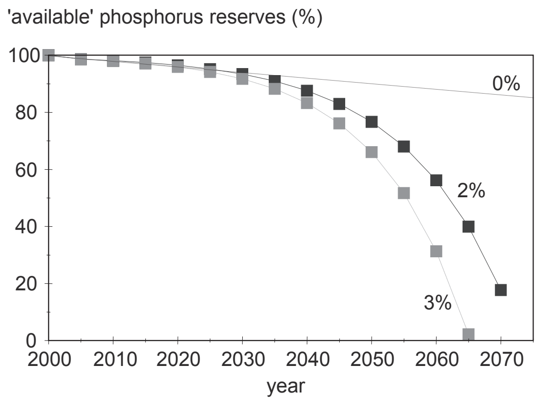

Figure 6: Depletion of phosphorus minerals in currently known mines at different increases in world usage (0, 2 and 3 % per year, according Driver et al. (1999).

Phosphorus is a limited exhaustible fossil resource available in a few places on planet earth (Cordell et al., 2009). This is threatening the long term nutrition of all humans (and plants and animals) in future, since this element is part of life supporting molecules in organisms such as AdenosineTriPhosphate (ATP) essential in all biological energy transfer processes and phospholipids which are the building blocks of biological membranes present in any living cell. Currently we are flushing large quantities of P-resources to soil and water through our sewers and via livestock manure, which eventually end up diffusively spread in the lakes, seas and oceans of the world. Predictions (Figure 6) indicate that depletion of easy

recoverable P-resources will be completed within decades to a century.
The numbers shown in table 1 concern inflow into oceans and seas, and at this moment this level is close to the proposed boundary beyond the value for large scale algae blooms and oxygen depletions in coastal environments to happen. So if we continue using and discharging P at the same level, we will first toxify our lakes and coastal eco systems, and then run into problems with food production because of a global P shortage.

Nitrogen, a basic component of fertilizers is at this moment extracted from air by the Haber Bosch process at the expense of high amounts of fossil energy. Although there is plenty of nitrogen in the atmosphere, depletion is four times greater than the natural recovery rate. This is not (yet) creating problems in form of shortage, the problem is mainly at the other side, accumulation. About 40% of all nitrogen fed into the global cycle of food and feed is not recovered (Liu et al., 2010). After being consumed and transferred to manure and domestic waste waters, this portion is lost to the ecosystem as reactive nitrogen entering water, soils (in the form of nitrate and ammonium), and the atmosphere (in the form of N_2O), the latter being produced by natural processes and causing an enhanced global warming effect. Accumulating reactive nitrogen waste products toxify ecological processes. At the other hand, nitrogen shortages exist in many arable soils in developing countries (Liu et al., 2010) calling for new methods of harvesting and reuse of this portion of nitrogen as fertilizer.

Carbon. The carbon balance is perturbed. *One factor* is depletion of carbon levels in agricultural land due to intensive and increased area of land used for intensive agricultural practises. Lack of carbon in soils results in reduced fertility and soil biodiversity and increased sensitivity to erosion, thus reducing the productivity of agricultural land. Changing land use from agriculture to natural functions, or to less intensively used soils can restore the carbon balance, as has been shown by Kalinina et al., 2009 for northern European soils. Another way of restoration is to increase carbon feed-backs to soil from human waste residues. The other factor is the use of fossil energy resources. Both factors lead to accumulation of carbon in the atmosphere (Rockström et al., 2009). Carbon dioxide in the atmosphere is a strong suspect in contributing to global warming.

Chemical pollution. On local levels, exposure and effects of chemicals on biota has been widely studied, and a good scientific basis on eco-toxicology has been built. The long term effects of persisting poisonous compounds on global ecosystems is largely unknown. Especially hormonal (endocrine disrupting) compounds and chemicals resistant to microbial degradation and featuring bioaccumulation, are of concern. The last years it was shown that vortexing water bodies in the world oceans accumulate plastics and chemicals – so called plastic soups – with unknown effects to these worlds' largest and most productive ecosystems.

Fresh Water will be dealt with in more detail in the following section.

Global fresh water scarcity

The proposed global boundary for fresh water consumption is 10% of the total amount entering the global fresh water and ice reservoirs which is about 40,000 km^3/year. Water resources are currently being consumed at a rate of 2,600 km^3/yr, which is 65% of the proposed boundary (Tables 1 and 2).

Table 2: World regional differences in availability and use of water

	Global	NL	USA	Singapore	Yemen	Jordan
Renewable (km^3/year)	40 000	90	2 478	1	4.1	0.9
Boundary* (km^3/year)	4 000	9	250	0.1	0.4	0.1
Current use (km^3/year)	2 600	8	502	0.5	3.5	0.9
Use as % of Boundary	65	90	200	500	850	900

*) Prelimenary boundary set at 10% of renewable amount, according to Rockström et al. 2009.

The applicability of this boundary to different regions and different climate conditions needs to be further assessed since relationships between amount of available water and ecosystem health are very compex (Arthington et al., 2006; Acreman et al., 2008). The 10% boundary is used here as a first indication. In the Netherlands we consume water at a rate of 90% of the proposed boundary. Climate change may result in more extreme seasons including droughts in spring and summer, and that may impact the ecosystems in the elevated sandy regions in our small country. In other countries more water stress is occurring. In the USA the boundary has exceeded with 200% as an avarage for the whole US. In the western states water stress is much more severe. In other countries like Yemen and Jordan, almost all water from the natural system is extracted and fed back to the environment as used water, in most cases with a reduced chemical and microbiological quality.

In Figure 7a the current global yearly precipitation pattern is presented. Large quantities of rain are falling in the tropical regions, which create local excesses of water. Although water is here readily available, for instance in mid-African countries, it is too often poorly stored. The lack of sanitation and waste water treatment facilities causes extensive health problems by pathogenic bacteria and nutrients entering the water systems. A wide band with very low rainfall is stretching from the West of the USA through Northern Africa and Southern Europe, to Central Asia and the middle and north part of Asia. Also the western parts of South America and Southern Africa have low precipitation. Evaporation rates are generally high, especially in the warmer regions and water used in agriculture is often largely lost to the atmosphere, sometimes also causing salinization of the soil. In many regions seasonal precipitation patterns are changing, affecting water stored in glaciers, lakes and groundwater reservoirs causing enormous impacts on water availability, flood risks and food supply (Immerzeel et al., 2010). Many countries are already confronted with depleting groundwater resources, vanishing lakes and shrinking rivers. I call this zone the global belts of water stress.

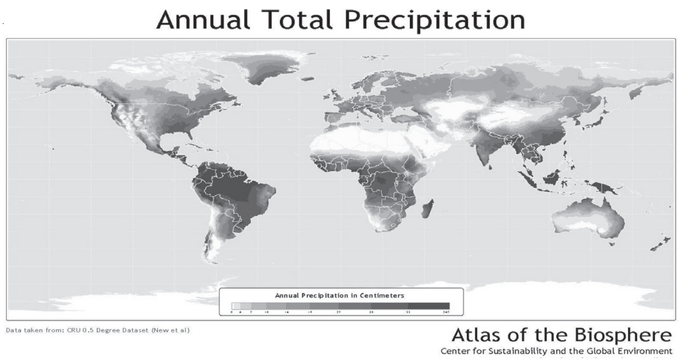

Figure 7 a: World precipetation.

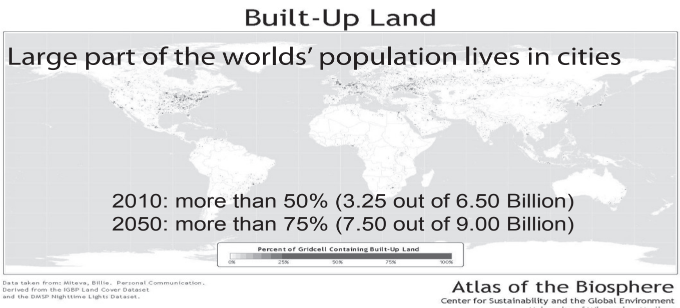

Figure 7 b: World built-up land.

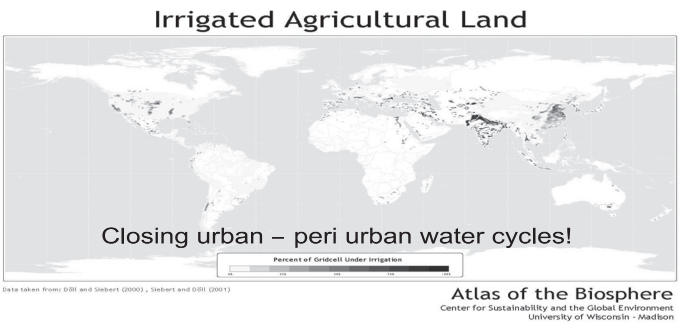

Figure 7 c: World irrigated agricultural land.

In Figure 7b the current surface of built-up land (cities, roads, industry) in the world is shown, indicating where most people are currently living. At this moment people live already for 50% (3.25 billion people) in cities and according to UN predictions this fraction will even further increase to 7.50 billion in 2050, more than twice as much (Lutz W and Samir K., 2010). Many of these people will be living in these water stress belts. This means that fresh water consumption and fresh water depletion will increase two-to threefold if no adequate measures are taken.

Figure 7c visualises how water is currently used in agriculture for irrigation. In the global water stress areas, water is largely used for irrigating agricultural land. Even in the Netherlands – a country apparently rich in water – artificial rain installations are extensively used by farmers in summer. One can predict large increases in water usage for the purpose of increased agricultural activity which is required to grow the food for doubling (urban) populations in these regions. Establishing urban – peri-urban water cycles – in which used water is treated and fed back into the regional hydrocycle thus making it suitable for re-use – will therefore become increasingly essential the coming decades.

Water is not an isolated issue. Water is one of the most important factors in biodiversity. It is the most important medium in shaping and carving the land, driving erosion of land through surface run-off and the action of rivers. Water transports sediments to low lands and delta regions, where newly formed land contains most fertile soils. These soils are essential for agriculture that currently provides most of the food produced at the planet. Erosion and sedimentation are carrying magnesium, calcium, silica and many elements from land to sea which sets conditions for coastal and oceanic life and global biogeochemical CO_2 fixation processes, thus sustaining marine biomass including algae, krill, and fish. Since water is controlling so many local and global processes, feeding high quantities of waste into it in the form of organic materials, excess nutrients, plastics and chemical pollutants, is bound to create problems at all scales.

All of this indicates that we – humans – have to revise our interactions with the planets ecosystems and that we have to organise these in a fundamentally different way. The fixed bio capacity of the world is already at present setting limitations to the growth of the human population and subsequent exploitation of the planet. We need to transform the current linear model which is based on usage and depletion of resources (including fossil energy) and discarding waste. A new model is needed based on recovery and reuse, minimizing the extraction of finite resources, and using solar (renewable) energy: a model which is a look alike of natural ecosystems. New environmental technologies can have a central role in that revision, aiming at environmental targets at local, regional and global scales.

Transitions in Environmental Technologies

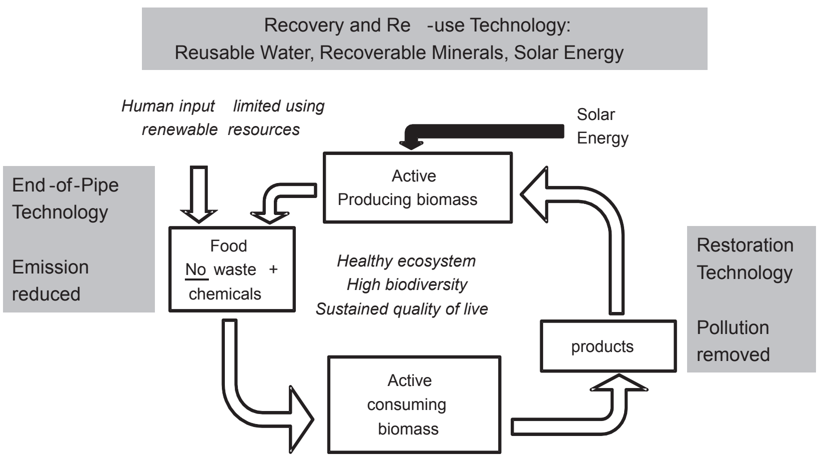

Figure 8: Flow scheme with three types of environmental technologies (grey blocks) and their place of action in helping to reduce the human impact on the environment.

We can discriminate three types of environmental technologies (Figure 8).

1 End of pipe technologies. With these technologies one can stop feeding organic, nutrient and chemical loads into the natural system. A typical example is the

waste water treatment developed and implemented over the last four decades in Western Europe and North America.

2 Restoration technologies: These technologies remove accumulated pollutants and stored nutrients from the natural system. A typical example is the soil and groundwater remediation, developed over the last three decades, and currently implemented in many countries.

3 Recovery and re-use technologies: These are relatively new sets of technologies, through which water, organic material, and minerals are re-used and recycled. The energy needed for this like all future energy requirements – is made available from non – fossil solar based resources.

These three types of technologies are all helpful in abating the consequences of human actions leading to depletion and accumulation. In many parts of the world, type 1 and type 2 technologies urgently need to be implemented. However, addressing global issues, we need to develop and implement recovery and reuse technologies. I will show you two transitions underway:

- From waste water treatment to recovery and reuse of water and nutrients
- From soil and groundwater restoration to sustainable use of the subsurface as an energy storing and water filtering reservoir.

The research of the team I participate in has defined 10 challenges for research and include new and already running projects (Table 3). Many of these projects are carried out in collaboration within partners in WU, Wetsus, Deltares or otherwise.

Table 3: 10 research challenges, active PhD's and Postdoc's, and their supervisors, and projects in preparation: for specific items refer to the website http://www.ete.wur.nl/uk.

Research Challenge		Researchers / Projects	Supervisor(s) WU [a)]	Supervisor(s) / Partners [f)]
1	Anaerobic Digestion	Zang Lei, PhD PhD Vacancy Postdoc Vacancy	Tim Hendrickx Grietje Zeeman Hardy Temmink Grietje Zeeman Caroline Plugge Fons Stams Grietje Zeeman	Tim Hendrickx, Narbin University of technology, China Jules van Lier TUD
2	Bio flocculation and (Bio) Membrane reactors	Lena Faust, PhD Christina Kappel, PhD [e)]	Hardy Temmink Hardy Temmink	Hardy Temmink/Wetsus Hardy Temmink/Wetsus Walter van der Meer, UT/Vitens
3	Novel Sanitation: energy recovery, and reuse of water and nutrients	Davit Castellano, PhD Tania Fernandes, Postdoc In prep. Tailored sanitation for various socio-economic situations in the world; water and nutrient recovery and reuse	Grietje Zeeman Grietje Zeeman René Wijffels	LeAF, Adriaan Mels/Vitens-Evides Bas Ibelings, NIOO Brendo Meulman, Landustrie
4	Carbon and nutrient feed backs to soil (sludge2soil)	In prep. various projects	Cees Buisman & WU soil research groups	
5	Technologies for micro pollutant removal and disinfection	Johannes Kuipers Justina Racyte Andrii Butkovskyi Postdoc Vacancy In prep. Various projects incl. effluent quality related to micro pollutants and pathogens	Harry Bruning Harry Bruning Grietje Zeeman Kasia Kujawa Tinka Murk Hardy Temmink	Simon Bakker, Vitens/Wetsus Simon Bakker, Vitens/Wetsus Lucia Hernandez/Wetsus
6	Desalinisation	Maarten Biesheuvel, Postdoc Ran Zhao, PhD Oane Galema, PhD	Maarten Biesheuvel Bert Hamelers	Bert van der Wal/Voltea Bert van der Wal/Voltea/Wetsus Jan Post [c)], KWR/Wetsus

Research Challenge		Researchers / Projects	Supervisor(s) WU [a)]	Supervisor(s) / Partners [f)]
7	Sediment restoration	Dr. Jasperien de Weert [b)] Magdalena Rakowska, PhD	Tim Grotenhuis Tim Grotenhuis Bart Koelmans	Alette Langenhoff, Deltares
	Groundwater restoration	Sara Picone, PhD	Tim Grotenhuis	Pauline van Gaans, Johan Valstar/Deltares
		Nora Sutton, PhD	Tim Grotenhuis	Pauline van Gaans/Alette Langenhoff/ Deltares
	Thermal energy storage in the subsurface.	Ingo Leusbrock, Postdoc	Tim Grotenhuis	
		Ni Zhoubiao, PhD	Tim Grotenhuis	Niels Hartog, Deltares; Rian Kloosterman/Vitens/Wetsus
		Wijb Sommer, PhD Postdoc vacancy	Tim Grotenhuis Tim Grotenhuis	Pauline van Gaans/Deltares Hans van Duijne/Deltares
8	BioGeoCivil technologies for man made soil and building materials	PhD vacancy	Tim Grotenhuis	Leon van Paassen / Frits van Tol TUD and Deltares
		PhD vacancy	Tim Grotenhuis René Wijffels	Henk Jonkers, TUD
9	Urban Harvest	Claudia Agudelo, PhD Heleen Sombekke, PhD [d)] Marc Spiller, postdoc Ingo Leusbrock, postdoc In prep. Several topics	Karel Keesman Cees Buisman	Adriaan Mels, Vitens-Evides
10	The Biobased Economy	In prep. Sustainable water and nutrient re-use in biomass production		

a) Supervisors are from different parts of ETE and WU to promote interaction. b) Defended PhD Thesis successfully in De-cember 2009. c) VENI NWO-STW Stipendium WU in combination with KWR/Wetsus. d) External PhD Wetsus e) PhD UT, in co-operation with WU and Wetsus. f) Many external supervisors are delegated by co-funding companies and organisations. For Wetsus supporting companies see wetsus.nl.

Transitions in Water Technology

The first one to be discussed is the transition from waste water treatment to reuse of water and recovery of nutrients. The river Rhine was called a dead river and an open sewer 40 years ago (Groot et al., 2006).

> *"By the 1970s, the Rhine had become so polluted that the river was sometimes referred to as 'Europe's sewer.' Businesses and industries along its banks could discharge their waste products into the water with impunity, as Professor Ulli Jessurun d'Oliveira, former chairman of the Reinwater foundation, explains."*

> *"Everything was wrong with it. It was considered a dead river. Nothing could live in it. Enormous industries were all based on the banks of the Rhine because of the possibilities [it offered] for getting rid of waste."*

Nowadays, the water of the river has a strongly upgraded quality and the ecological rebound is making good progress. This was achieved by installing at large scale (end-of-pipe) waste water treatment technologies for cleaning industrial and domestic waste water.

Figure 9: A centralized waste water treatment plant (WWTP) for sewage of 100.000 persons.

In figure 10 the processes are presented that are currently used. Waste water is entering the system and oxygen through airation is fed into the system to help bacteria to convert the waste to carbon dioxide and nitrogen gas and some of it to biomass (sludge). The cleaned water is discharged to open water. From the sludge a relatively small amount of biogas can be made using anaerobic digestion technology.

The current waste water treatment approach called 'activeated sludge technology' consumes energy and valuable nutrient elements such as C, P, K and N are not recovered. Moreover, the sludge becomes contaminated because water from sanitation, washing is being mixed with surface run-off water containing metals that accumulate in the biomaterial of the sludge hindering its reuse in agriculture, leaving incineration as the only option for final treatment of sludge. The produced contaminated ashes are in general discarded or find their way in road construction materials. These ashes also contain valuable elements such as P, K, magnesium, etc., and by mixing them in construction materials these are withdrawn from the food production-consumption cycle. In the light of depleting resources such as phosphorous, this practice cannot be continued in future. To conclude, the current activated sludge waste water treatments costs al lot of energy and do not recover nutrients for reuse. Therefore other approaches are needed.

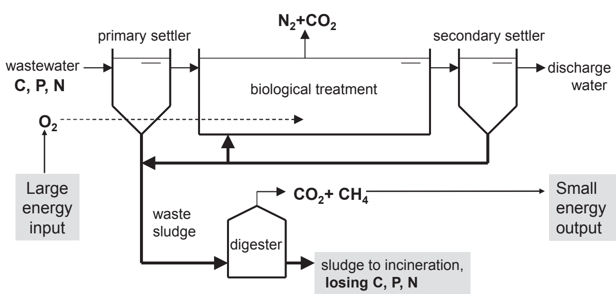

Figure 10: Scheme of a centralized waste water treatment plants (WWTP) oxidizing the bulk of the waste by energy demanding air injection and retrieving only small amounts of energy by the anaerobic digestion of the sludge.

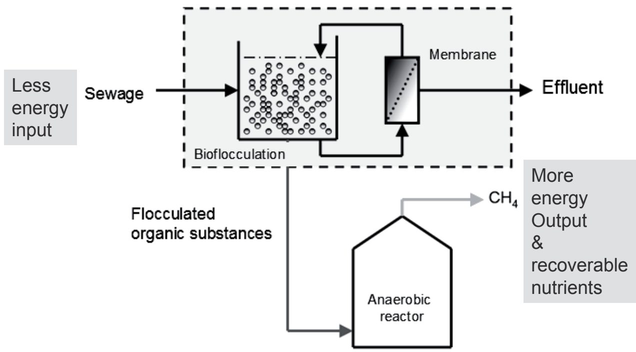

Figure 11: Bioflocculation combined with membrane technology to retrieve organic material from the waste water and direct this flocculated material into the anaerobic treatment.

Anaerobic biotechnologies can offer this other way (Verstraete et al., 2005; Zeeman et al., 2008). Examples are the Upflow Anaerobic Sludge Blanket (UASB) reactors for waste water teatement and digesters for converting sludge ans organic waste into biogas. In these anaerobic systems no air needs to be injected, the bulk of the organics in waste water and sludge is transformed to methane or other energy carriers and nutrients remain present in the effluents. These nutrients can be harvested by new technologies currently under development. Unfortunately, anaerobic waste water treatment processes have also limitations. These processes are too slow at temperatures below 20 °C which gives limitted applicability under moderate and cold climate conditions. Also applications in industrial recycled water streams are hampered by extreme conditions such as high salt concentrations and extreme pH values. Various innovations are underway to overcome these problems. The first *Research Challenge* (Table 3) which I like to bring to your attention is to further optimise the anaerobic waste water treatment and sludge digestion. Reduced local temperature dependency, improved process controll under extreme conditions, and enhanced biodegradability of recalcitrant substrates, will be elements of that research.

An important factor in the renewal of waste water treatment facilities is their life cycle that range between 25-50 years. Renewal investments in waste water treatment and sewer systems are often not paralell which reduces innovation in sanitation largely to newly build urban environments. And even in such situations implementation of high level water and sanitation services needs to be supported by an active innovation policy (Krozer et al., 2010). One way for achieving a faster transition towards recovery and reuse technologies is when technologies are developed that can be integrated in current conventional waste water infrastructure. With limited costs of the upgrading, large steps can still be made. An example is the bioflocculation technology combined with membrane bioreactors as depicted in Figure 11, and which is studied by Lena Faust (Table 3) in cooperation with the Institute for Sustainable Water Technology, Wetsus in Leeuwarden and Wageningen University. The idea is that by directing through bioflocculation more organic material to the anaerobic system, the oxygen (and energy) input can be reduced and the energy output – in form of biogas or other energy carriers can be increased. Research challenge 2 is to understand the biological and physicochemical processes of the bioflocculation in such a way that the system can be engineered and operated towards organic matter accumulation into aggregates that are channeled towards the anaerobic digester. The bioflocculation study comes close to the bioadhesion research I conducted during my own PhD, already quite some time ago.

An important condition to make a real change to recovery and re-use, is the introduction of novel sanitation systems that split black water – which is the toilet water containing urine and faeces – , grey water from bathing and washing, and rain and surface run-off water (Figure 12). New sewer and toilet systems are already available and the rate of implementation into new buildings is increasing. With new vacuum toilets, the toilet water volume fraction can be reduced to 0.5 % of the current mixed sewage flow. In addition to splitting streams, drinking water used for flushing toilets kan be strongly reduced, saving 30% of the domestic water use (Zeeman et al., 2008; de Graaff, 2010).

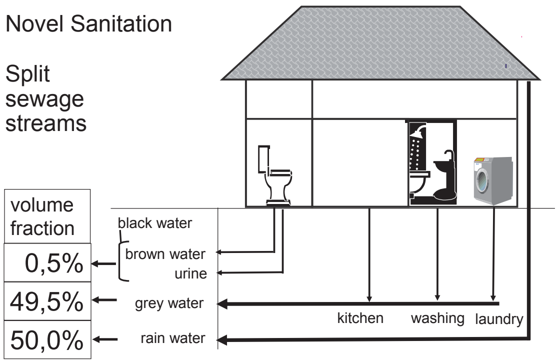

Figure 12: Novel sanitation based on split sewage streams (adopted from Dr. K. Kujawa-Roeleveld and remoduled).

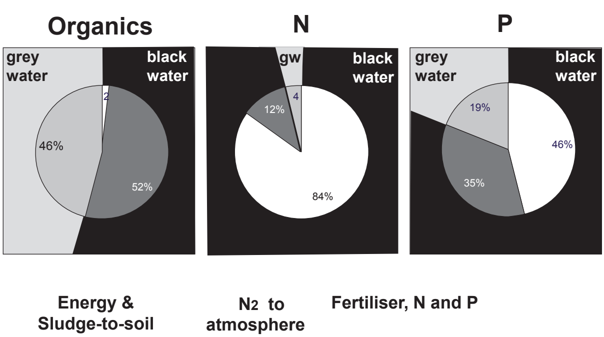

Figure 13: Organic and nutrient distribution over split sewage streams, adopted from de Graaff, 2010. Black water is toilet water containing feaces (dark grey) and urine (white); Grey water (light grey), contains water from shower, washing etc.

Table 4: Metal content in sludge (all values in mg/kg dw); Shade area indicate values to high for reuse at agricultural land according to the so called BOOM criteria (VROM, 2001).

Metal	BOOM Criteria	Conventional Sludge	Split System Sludge
As	15	10	10
Cr	75	42	6
Cd	1.25	1.50	0.70
Hg	0.75	0.90	0.30
Ni	30	32	9
Pb	100	137	<10
Cu	75	407	197
Zn	300	1032	713

In Figure 13 you can see that most of the resources are available in the so called blackwater, namely: Organic Carbon for 55%, Nitrogen for 96% and Phosphorus for 81%. The organics can be converted to biogas and the remaining non-digestable organic residue can be reused for enriching soils with carbon. Nitrogen and phosphorus can be recovered as fertilizer (in this case in the form of the magnesium salt struvite). The remaining nitrogen can be bio converted and fed back to the atmosphere, or used for biomass production using algae (Wijffels et al., 2010).

The past years, a test pilot was run for 32 houses in Sneek, using the splitted sanitation streams, anaerobic treatment of black water, harvesting N and P in the form of struvite, and converting the remaining N to N_2 (de Graaff, 2010). This novel system can be operated in a way that at least as much as energy is being produced in the form of biogas as consumed for operating the system, in the form of energy for heating and electricity for pumping. Nitrogen and phosphorus can be partly recovered. Moreover, the use of drinking water for toilet flushing is strongly reduced. For comparison the conventional systems consume energy and do not recover any minerals.

Research challenge 3 (Table 3) is to further scale up these Novel Sanitation and treatment processes to the level of new large office buildings, neighborhoods and cities changing towards sustainable water and energy infrasctructure. This is the mission of Dr. Grietje Zeeman, one of the senior staff members of the sub-department of Environmental Technology. Another advantage of novel sanitation is the quality of the sludge as shown in table 4, which is of much higher quality then the conventional approach. The metals present in the surface run-off streams do not come into contact with the sludge biomass and cannot accumulate in this material. With some slight valorisation steps, the sludge can was done again be used – as centuries ago – for carbon enriching soils to sustain fertility of land for agriculture.

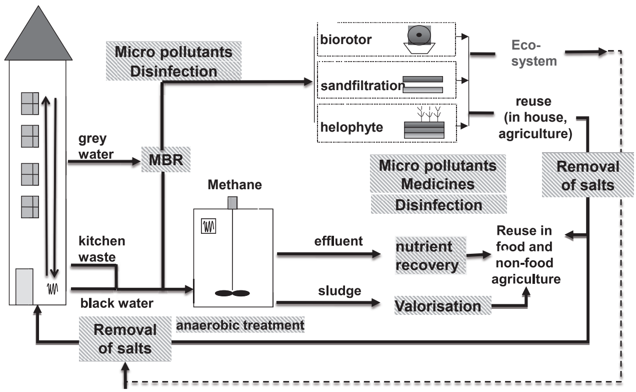

Figure 14: Areas for development of novel technologies (shaded blocks) as placed in water re-use cycles (adopted from Dr. K. Kujawa-Roeleveld and remoduled).

Additionally, nutrients present in the black water effluent can be taken up by algae thus creating nutrient enriched materials to be used as fertilizer in agriculture, and which is currently under investigation at the new NIOO building in Wageningen among other places. Valorisation of sludge and algae biomass and feed-back to soils is research challenge 4 (Table 3), for which good collaborations can be formed with the soil research groups at Wageningen University and the Chairs of Prof. Cees Buisman and Prof. Rene Wijffels.

In figure 14, a scheme of the water cycle in terms of use, treatement and re-use, is presented, and it is indicated where novel technologies are needed. Anaerobic treatment, bioflocculation using membrane bioreactors, nutrient recovery, and sludge valorisation have been addressed in my speech to this point. Now we take a closer look at the water itself. By bringing water into a cycle we need to address a number of new problems, namely the removal of:

- micro pollutants originating from health care products and medicines
- pathogenic microorganisms
- salts since ions do accumulate in recirculated water streams. Moreover, decentralised water production out of brackish groundwater is expected to become an important technology especially in water stressed areas.

In grey water numerous organic compounds are found that are potentially harmfull for ecosystems. Many of these compounds originate form health care products and are poorly degraded by biological systems (Hernandez Leal, 2010).

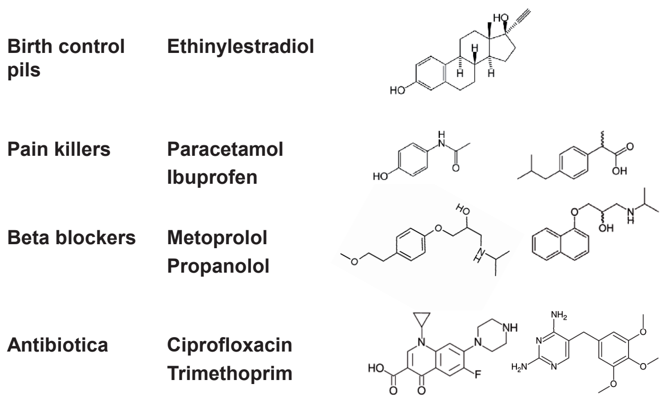

Figure 15: Four Human Medicine classses with some examples and their structure formula.

Human medicines, like hormonic compounds, pain killers, beta blockers and antibiotics (Figure 15) are often moderately to poorly biodegradable and therefore frequently found in the effluents of current aerobic waste water treatment facilities (Berbee and Kalf, 2006; van Beelen SE. 2007; Ter Laak et al., 2010) and of the novel anaerobic blackwater treatment systems (de Mes, 2007; de Graaff, 2010). Since traces of medicines are now also found in sources for drinking water (Versteegh et al., 2007) more attention is give to the prevention of emissions of these type of compounds to water systems. In addition to domestic effluents, waste water of hospitals and elderly homes recieves increasingly more attention with repsect to the removal of medicines and pathogenic bacteria. The new Dutch company Pharmafilter (www.pharmafilter.nl) is currently implementing new treatment and recycling approaches at various hospitals in the Netherlands, aiming at zero emissions of pharmaceutical and microbial pollutants. New projects are starting up such as the SLIK (Sanitaire Lozingen Isalaklinieken) project in Zwolle which is combined with the larger EU collaboration research and application project PILLS – 'Pharmaceutical Input and Elimination from Local Sources'. Further new technological developments are needed to implement and optimise farmaceutical pollutant removal from waste waters of domestic and health care institutions. In addition to medicines in human excretion products, veterinary medicines present in manure applied on agricultureal land form another potential risk to the quality of soil, groundwater and surface water systems (Boxall et al., 2003). Taking antibiotics and the Netherlands as an example, the veterinary sector applied 500 tonnes of antibiotics per year in the years 2008 and 2009, whereas the human consumption amounts 100 tonnes per year (FIDIN, the Netherlands). Potentially, 600 tonnes of antibiotics are being released into the environment of the Netherlands, through animal and human mediated pathways. Researchers found a significant increase in Antibiotic Resistance genes present in the biomaterials in Dutch soils, by studying soil samples from the Netherlands collected and stored in Wageningen over the last 70 years (Knapp et al., 2009). The potential risks for ecosystem or human health are very difficult to assess, but from recent break outs of animal-human transferable diseases we learned that a more precautionary approach in use and emissions of medicines, and especially antibiotics, is needed. All this motivates my *research challenge 5* (Table 3) to investigate combined technologies, physico-chemical and microbiological processes to degrade pharmaceutical and other micro polluting compounds in facilities treating domestic and hospital waste waters and manure. Here we will cooperate with the laboratories of microbiology and environmental toxicology here in Wageningen, Wetsus, KWR among many other partners.

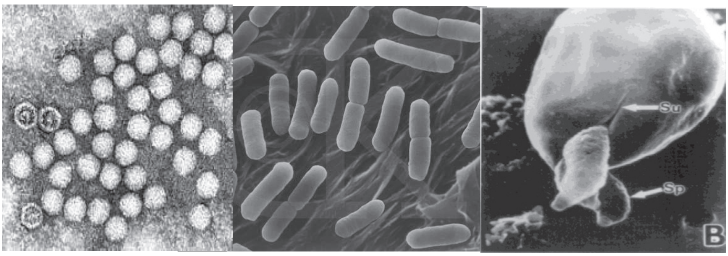

Figure 16: Three types of (pathogenic) microrganisms found in (waste) water.

Microorganisms are one of the most important factors controlling water quality – as I know since I was trained at Wageningen University as an environmental microbiologist. When treated water is re-used (for example in agriculture) it should be free from harmful microorganisms such as viruses, enterobacteria such as E. Coli strains, and protozoa parasites such as cryptosporidium. Technologies should be developed by close cooperation between irrrigation hydrologists, technologist, colloid chemists and microbiologists, and in Wageningen we are lucky to have very good researchers in all these fields. So disinfection of water for re-use is an important part of *research challenge 5* (Table 3). We are currently developing new advanced water technologies for micro pollutant (medicine and greywater compounds) and disinfection. For this, various electrotechnologies are under development in cooperation with WETSUS the Technological Top Institute on sustainable water in Leeuwarden. to attack pollutants or pathogens before waterstreams enter the natural ecosystem or drinking water infrastructure. These technologies include wireless energy transfer to small reactive electrodes or UV LED's as studied by Johannes Kuipers or fluidized bed electrodes under development by Justina Racyte.

Removal of salts is an important factor in industrial water re-use in water scarce regions with intensive water recycling and areas with sea water intrusion *(research challenge 6*, Table 3). A novel technology is under development together with Unilever/Voltea and Wetsus using electricity and double layer mechanisms to remove salts from recirculation domestic and industrial water streams. It may also be used for production of agricultural irrigation or drinking water from brackish groundwater. Salt removal will become more and more essential in re-using water and this new technology is now rapidly developing through the research team funded by Voltea and co-supervised Dr. Ir. Bert van der Wal, and we hope to continue that co-operation in even a more intensive way in future. Studies on other desalinisation strategies are planned in cooperation with KWR.

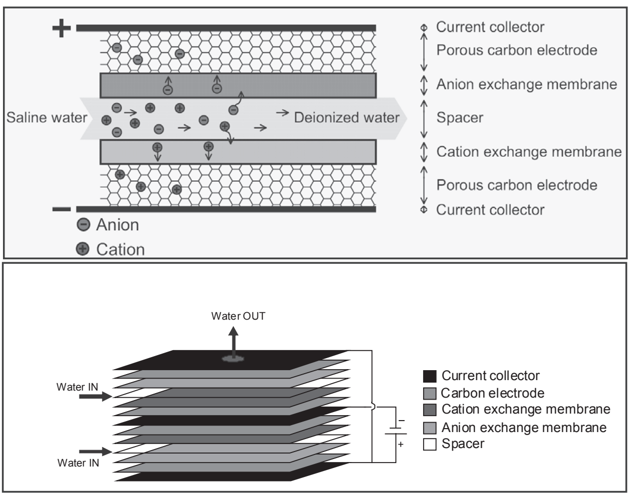

Figure 17: Capacitive De-Ionisation technology for water desalinisation as under development by Voltea, Wetsus and Wageningen University.

Transitions in Subsurface and Groundwater Technology

An interesting case is the history of soil and groundwater restoration in the Netherlands (Grotenhuis and Rijnaarts, 2011). Conventional approaches were replaced by in-situ biotechnologies and monitored natural attenuation (MNA) based on the activities of naturally occuring microorganism in soil and groundwater (Figure 18). In addition to fast clean up, long term local and regional subsurface management are currently being used to resolve residual groundwater pollution.

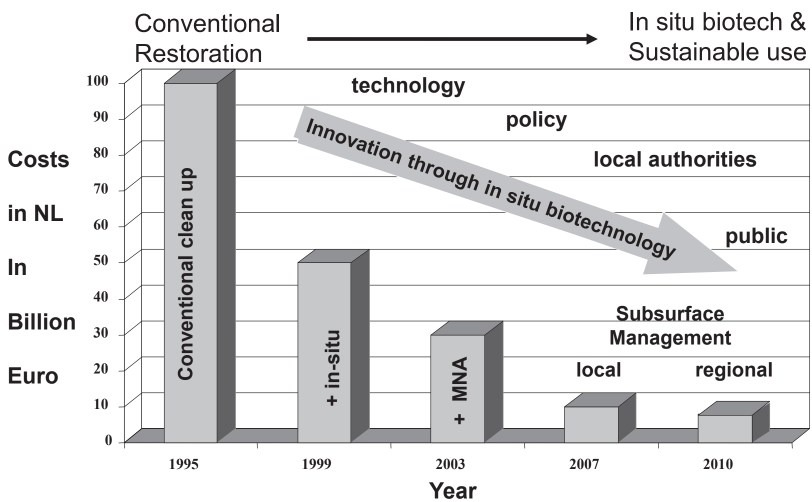

Figure 18: Development in subsurface restoration approaches in the Netherlands showing that costs can be strongly reduced by investments in novel technologies, policies, and communication towards local authorities and the public.

In the period between 1980 and this moment we discovered that about 400.000 sites have become polluted with chemicals, oil, or heavy metals. In 1995 the estimated costs of the problem rose to an extensively high magnitude. With the

only proven technology available at that time – excavation and cleaning by washing or thermal treatment – the costs for total clean up would rise to 100 billion euro. An investment was done of in total several tenths of millions of euros, by governmental funded research programmes such as Speerpuntprogramma bodemonderzoek, NOBIS, TRIAS and SKB. These were integrated collaborations between industry (problem holders and technology suppliers), consultant firms, governmental bodies and Universities. Wageningen University was one of the most important institutions
in training and providing researchers to develop alternative solutions in these programmes. In a period of 15 years a new approach was developed based on the self cleaning capacity of the subsurface, using the natural microorganisms living in soil and groundwater systems. In situ biotechnology became the new approach, a technology that carries to a great extent the know-how of Wageningen University. Costs have dropped with a factor of 10, so the solution became 90 billion euro cheaper than originally assessed. The ratio between research investment and cost reduction is more than a factor of 1000. This shows that long term investments in (environmental) science and technology really pay back. An essential key to success is to combine top science with a high grade of valorisation by the integrated approach of various disciplines and the involvement of companies, governments, research instittutes and Universities. This is an important message to the public and politicians deciding on relevant research investments.

Our current *research challenge* 7 (Table 3) at the sub-department of Environmnetal Technology is partly oriented on degradation, removal and risk reduction of persistant contaminant sources in soil, sediment and groundwater. The groundwater group is supervised by Dr. Ir. Grotenhuis. Combined chemical and biological in situ technologies for groundwater pollution are studied by Nora Sutton, and biological processes that prevent volatile compounds to escape to atmosphere or housing is investigated by Sara Picone. The reduction of emissions of persistant organic pollutants especially nonyl-phenol, from sediments has been studied by Jasperine de Weert (De weert, 2009) who defended her PhD thesis succesfully in December in 2009. Under co-supervision with Prof. Bart Koelmans, Magdalena Rakowska develops in-situ technologies to reduce emission of

PolyAromaticHydrocarbons (PAH) from aquatic sediments by using actived carbon. In adition to groundwater remediation, another aspect of groundwater has become increasingly important, namely the use of groundwater for thermal energy storage.

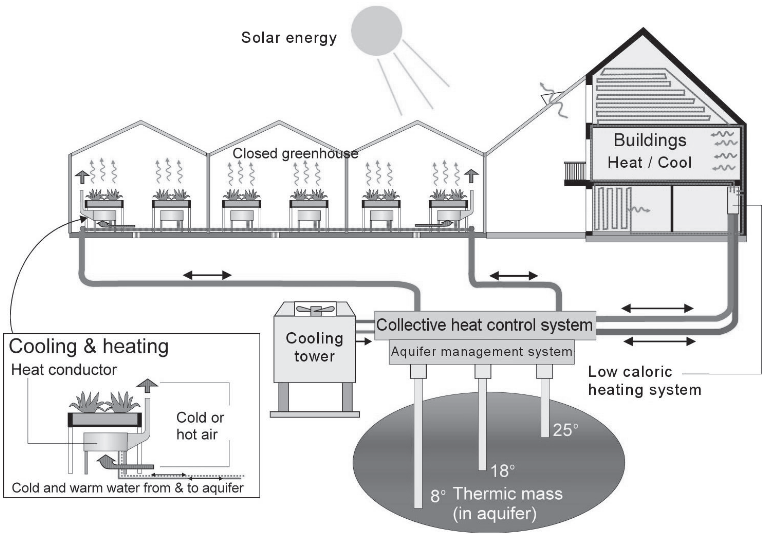

Figure 19: Subsurface Thermal Energy Storage used for cooling and heating buildings and greenhouses.

Figure 19 shows that solar energy (heat) is stored in the subsurface for use in the winter. The same can be done by storing cold in the winter, to be used for cooling in summer. The stored thermal energy can be re-used in the different seasons over and over again, which is an ideal sustainable technology, under the condition that the overall subsurface energy balance can be kept neutral. This is an important question, but difficult to answer and there for part of our current research program.

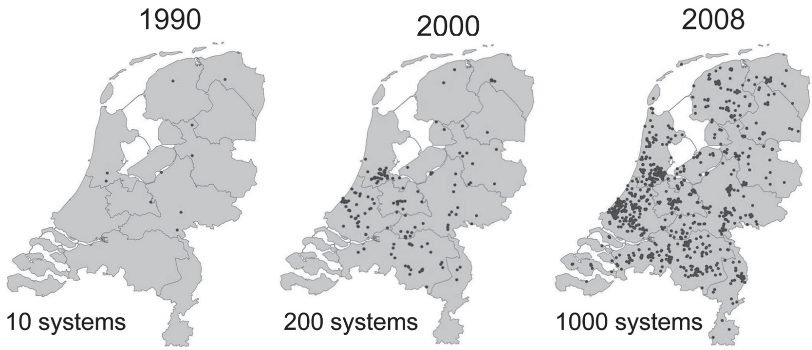

Figure 20: Subsurface Thermal Energy Storage applications in the Netherlands (Figure kindly supplied by If Technology, the Netherlands).

Developments of this technology in the Netherlands show a growth beyond 1000 systems in a short time, and it is prognosed that this can go to 20.000 to 30.000 systems in the near future. Currently, Wageningen University is studying together with IF Technology, Bioclear and Deltares, the sustainability and effectivity of a wide spread application of Subsurface Energy Storage in the Netherlands (www.meermetbodemenergie.nl). The sustainability, the up scaling and possible combinations with cleaning contaminated groundwater is now an important part of *research challenge 7*.

A new direction in research (Challenge 8; Table 3) is to restore past traditional methods to create man made land and building materials from natural solids, organic matter and waste streams. So called 'Es' and 'Enk' soils, and 'toemaakdekken' in the peaty polders in the lower parts of the Netherlands, were formed by man by enriching natural soils with organic matter, sediments and other waste materials. Brazilian Indians apply already for milennia pyrolised organic matter from stoves to their tropical forest soils that are very poor in nutrients thus creating fertile Terra Preta ('black soil'). This was a way to sustain small scale permanent agriculture on open spots in the forest. All traditional methods applied at many regions of the world, were generally done to enlarge the soils' fertility, or to improve water retention or local hydrology for instance lifting up lowlands. Chemical pollution, and our respond to that by environmental regulation, has in fact broken these highly sustainable methods. We would now call these methods, modern or novel up-cycle or Cradle to Cradle approaches, but in fact these were common practise in earlier times in history. Feedback carbon, nutrients and sediments to soils or producing building materials that extract carbon dioxide from off gases or atmosphere are being studied using Biological, Geological and Civil Engineering expertises. This is done in cooperation with partners in Wageningen and with the Technical University of Delft and Deltares. Ofcourse, it is the challenge to develop and apply these methods in such away that the chemical and (micro)biological quality of the soils and materials produced can be guaranteed.

Solar Energy Harvesting Technologies

When we sum up the potential of several water related energy technologies we can conclude that 20% transition to non-fossil fuel related energy sources can be accomplished in the Netherlands by using the combination of these technologies only (Table 5). Domestic water treatment combined with kitchen waste digestion, can give a small but not to be negelected contribution: all bits help. And as you can see, our novel technology plant-power (electricity produced by growing plants) is not yet contributing, but current developments are promising for the future (Timmers et al., 2010).

Table 5: Water related Solar Energy Harvesting Technologies can achieve the 20% renewable energy target as politicians have set for the Netherlands in the year 2020, when their potential is fully used.

Type of Energy	**Current Use, NL (PJ/year)**	**Solar energy technology**	**Potential in 2020 (PJ/year)**	**%**
Thermal	1000	Aquifer Thermal Energy Storage	250 [a)]	25
Electricity	400	Blue Energy	200 [b)]	50
		Wave and Tidal Energy	120 [c)]	30
		Plant-power [d)]	Currently researched	?
Fuel	1900	Aquatic Biomass (f.e. Algea)	190 [c) d)]	10
		Domestic Water + Kitchen Waste	2 [e)]	0.1
Total	3300		762	23

a) www.meermetbodemenergie.nl; b) Post et al., 2008; Post, 2010; c) Bruggers, 2008; d) Timmers et al., 2010; d) Wijffels et al., 2010; e) Zeeman et al., 2008.

Urban Harvest and the Biobased Economy

Developing re-use and recovery technologies is one thing, implementing these in societal structures is another game. We see two important technology integration platforms for the future: the urban environment, and the coupling to global production-consumption networks in the so called 'Biobased Economy'. In the biobased economy food and non-food products are produced on the same basis as natural ecosystems function. With solar powered energy sources, products after use are up-cycled for re-use. The urban environment, the world of the consumers, plays a crucial role in the biobased scheme, for instance by offering feed backs of nutrients to agricultural production.

An important concept is Urban Harvest or Urban Metabolism as developed by our Environmental Technology and Management group. Our current cities, that now only consume, deplete and accumulate, need to designed and transformed into new cities that are based on recovery and re-use of materials, nutrients, and water. The city should not be an energy consumer but should strive to become energy neutral or even an energy producer.

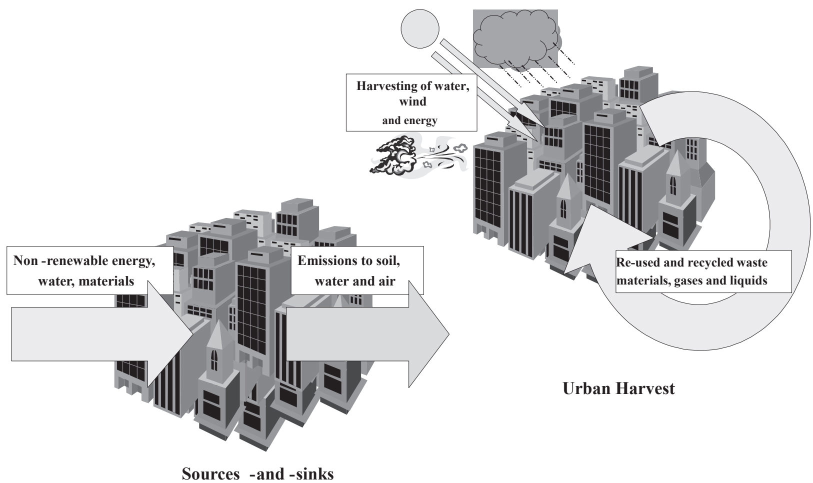

Figure 21: Urban Harvest; changing cities from a linear (depleting and accumulating) model to a circular (recovery and re-use) design.

Cities can function as feed back motors delivering clean water, nutrients and carbon back to the agricultural land for production of food and non-food products. In this way, the depletion of natural resources and pollution of the natural ecosystem can be prevented or at least stay within the global boundary limits. On this integration level we need – and are eager – to co-operate with the social sciences, system analysis and land use planning groups at Wageningen University, which is already taking place in the renewed set up of the Master

Graduation Track of Urban and Environmental Management. This study orientation is currently attracting 60 students a year, with growing numbers. Within the Urban technology and management group, the research is focussed to further develop the theory, strategies and modelling tools of urban harvest to design and plan scenario's for transition to sustainable (cyclic) urban configurations (*Research Challenge 9*, Table 3).

The final *Research Challenge* is a contribution to the sustainable agricultural production of biomass for food fuel and materials, which is an important part in creating a sustainable and biobased global economy (Ridoutt and Pfister, 2010; Yang and Zehnder, 2007; Liu et al., 2009). We plan to start up new research projects in this field the coming years where from the cluster biobased science and technology and in cooperate with other groups in Wageningen to accomplish the required multi-disciplinary integration level, which I believe Wageningen is specialised in.

Teaching and Research

Since my start at Wageningen University, I am strongly involved in teaching and member of the education committee Environmental Sciences, coordinating the BSc and MSc training programmes in this field. Continuous upgrading the technology courses to offer high potential MSc students ample opportunities to step into interesting PhD technology development projects is an important issue. Wageningen University and Wetsus have initiated the so called joined degree on sustainable water technology, together with the Universities of Groningen and Twente. For the Master of Urban Environment Management the ETE group will continue to contribute to upgrade the MSc course program in cooperation with the departments of Environmental Policy and Environmental Sciences. The contribution of the ETE group here is to provide platforms to integrate proven and front running technologies into new and sustainable designs for urban and peri-urban agroproduction regions. An important enforcement in research and teaching is therefore also needed on the topic of the biobased economy. The formation of the Cluster Biobased Science and Technology within the department of Agrotechnology and Food Sciences Group (AFSG) is important step towards the realisation of this enforcement. New initiatives in teaching and research need to be set up in cooperation with international agricultural and food producing organisations and companies to create a new knowledge and technology base for the sustainable biobased world of tomorrow.

Summing up, the world has the challenge to prevent an Environment-Water-Food crisis by taking adequate measures. By developing re-use and recovery technologies, and integrating these into sustainable 'Urban Metabolism' and 'Biobased Economy' concepts we can prevent such a crisis. It is important to address the different parts of the world, with differention in approaches for different socio-economic backgrounds. We believe that innovation needs to be tailor made to regional and cultural context and the environmental infrastructure present. In our western societies we must plan and transform, in the developing countries we must plan and provide, and in the emerging economies we must plan and revitalise. Three times we see the word plan, which expresses our desire to cooperate with research and implementation groups specialised in policy and planning, within and outside Wageningen University.

As a conclusion I would like to recall the 'Take home messages' mentioned at the beginning of this speech:

- Environmental technologies need to shift from local to global targets but implementation has to be realized at local scale.
- Eco-innovation needs to be accomplished predominantly in the urban environment and their direct surroundings, since in future 70% of the world's population will be living there.
- Food, water energy and environment are no separate issues, and need to be dealt with in their relations to achieve sustainable approaches.
- Companies and governments that will early adopt new sustainable approaches will pave the way of the Eco-Innovation of our societies.

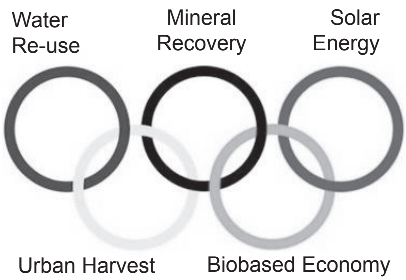

Figure 22: The Olympic Rings of Eco Innovation.

In eco innovating the world we need technologies for water reuse, mineral recovery, and harvesting solar energy, and we need to integrate them in urban environments and a new biobased economy (Figure 22). The ten research challenges I mentioned can be seen as the contribution of our group to this global game, and which will indeed require an Olympic spirit and commitment of all nations around the world. Like us, many parties need to play, cooperate and compete in a global arena to achieve the highest records in sustainability and prosperity, according to fair internationally recognized rules.

Coming to the end of my lecture, I would like to share some words of gratefulness with you. First of all I would like to thank Wageningen University first for offering me the training as a student in which I could follow my own way. The flexibility and tailor made programmes for students is really a trade mark of WU and needs to be cherished. After being graduated at the department of soil science and nutrition, followed by a PhD at the laboratories of Microbiology and Physical and Colloid Chemistry, and now having a position in the Sub department of Environmental Technology as Professor in Environment and Water Technology shows that in Wageningen everything is possible. Mr. Rector Magnificus, thank you for the trust in me and accepting me as new Professor at this wonderful university. Prof. Martien Cohen Stuart and Dr. Arie de Keijzer, I would like to thank for their support during the selection and interviewing process I was submitted to prior to the nomination. All departments and colleagues, since I know already so many of you, their must be great opportunities for cooperation. The ETE group is a wonderful group to work for, and I thank my predecessor Wim Rulkens and new colleagues for the now already pleasant team-work atmosphere. I want to express my appreciation to the staff, postdocs and PhD students that currently form the research and teaching team I am part of.

Special words of gratitude I would like express to Prof. Cees Buisman. Our two research-groups are joined and form together the Sub-department of Environmental technology. By sharing our teams, visions, expertises and networks, and our thrusts in each other, we are committed to give the group a cohesive force, ensuring that the ETE group continues to be successful and internationally leading in environmental technology research and teaching. The co-operation with Wetsus in Leeuwarden will remain an import water-company oriented network for ETE to launch new industrial funded research projects.

My former colleagues at TNO and Deltares, I would like to thank for their support in helping me to stick to research and technology, despite of an increasing pressure to let that go because of management obligations. I hope to continue the co operations with you from here.

A special word is for my parents, and father in law that unfortunately have left this world already. Without their spirit of persistence in striving for goals you believe in, and which they transferred to me, I would never have been able to reach this situation. My three brothers, two sisters, sister and mother in law, and the rest of my family I would like to thank also for sharing this and other precious moments. Finally, I would like to thank my son Timon and my daughter Iris, for the joy they have brought into our life, and I am happy to see that also they have chosen the science path, one in technology and one in food. And of course Nora, my partner: I would never have reached this situation without your love and indispensable support in moments of doubt and glory; thank you.

Cees Buisman and I strongly believe that the new champions of Eco Innovations will be early adopting companies and governments taking first lead in new technologies and new approaches. So, early adopters are also to be likely among you. Therefore, we invite you to join us at Wageningen University and Environmental Technology, and together we go for Gold.

I have said,

Ik heb gezegd.

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