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Table of Contents:

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Interview: "Quarks and Quantum Chromodynamics"

Friedman, Jerome

1. *What is the essence of the contribution for which you received the Nobel Prize?*

We discovered that protons and neutrons, which make up the nuclei of atoms, consist of even smaller particles called quarks. The existence of quarks had been independently proposed a few years earlier by Gell-man and Zweig, but physicists were very dubious about quarks because they were assigned fractional charges and no fractionally charged particles had ever been observed in nature. Also, many searches for quarks had been conducted but none were found, so the physics community in general had discarded the quark model.
Quarks were finally discovered in a series of high energy inelasic electron scattering measurements at the Stanford Linear Accelerator Center by MIT and SLAC physicists. In these measurements, the electron beam and the detecting equipment were the equivalent of a very powerful electron microscope that probed into the interiors of the proton and neutron. Point-like constituents were observed inside. These point-like constituents were later unequivocally identified as quarks after a comparison of electron scattering results with neutrino scattering measurements from CERN demonstrated that these constituents have the fractional charges assigned to quarks.

2. *What are the impacts of this contribution?*

The discovery of quarks changed our view of the basic structure of protons, neutrons and mesons. This discovery also led to the development of Quantum Chromodynamics, the theory of the strong force, which is one of four fundamental forces of nature. The strong force is the force that holds quarks together to form protons and neutrons, and holds neutrons and protons together to form atomic nuclei.
Both quarks and Quantum Chromodynamics were essential components for the development of the Standard Model of particle physics, which successfully represents the sub-atomic world when compared with observations made at existing accelerators. The Large Hadron Collider, the new accelerator at CERN that is expected to start operation in the latter part of 2009, is likely to find extensions beyond the Standard Model but all indications suggest that the framework of quarks and Quantum Chromodynamics will remain intact.

3. *What are the applications of your contribution that may change the everyday life?*

Perhaps it will have applications in the future; but in terms of our current understanding, this research has no applications to everyday life at the present time. However, it informs us about what matter is is made of and how the universe works. It also gives us a better understanding of the evolution of the cosmos, since quarks are some of the earliest particles that emerged in the very early universe. One of the great goals of human intelligence is to understand what we see around us and understand the laws of nature.
But there is another way, that the kind of research I do has contributed to society. Existing instrumentation often has not been adequate to address the challenging problems in particle physics and new types of technology have had to be developed. These new technologies have led to spin-offs, which have broader applications in society. For example, accelerators were invented to study the interactions of sub-atomic particles, and now various types of accelerators are used for such diverse applications as cancer therapy and the fabrication of semiconductors and microchips. Synchrotron light sources developed from electron accelerators are being used to design new drugs, study the structure of viruses and study new types of materials. Nuclear medicine and diagnostic tools such as magnetic resonance imaging, positron emission tomography, and computerized axial tomography also were developed from instruments used in basic research in nuclear and particle physics. The world wide web is an especially interesting example. This technology,

based on the internet, is reshaping the way that we communicate, learn, and engage in commerce. The World Wide Web is a spin-off that was developed at CERN to enable high energy physicists at laboratories across the world to exchange data and programs and work more effectively together. The rapidly developing world wide web is promoting vigorous economic growth in many parts of the world.

4. *Can you shed more light on the last answer?*

5. *We learned a lot from your lectures in Belgrade. Can you tell us, what are the issues that we have to teach our kids, so they become creative when they finish studies?*

We must make sure that children do not lose their natural curiosity. Children are scientists in the way they view the world, because they are continually trying to understand how the world around them works. The educational system should encourage and nurture this curiosity. At all stages of education, students should be given independent projects to do, and questions should be encouraged. Teachers should emphasize ideas and concepts in the classroom rather than the memorization of facts.

6. *What are the major things to keep in mind, when you form a team for a scientific experiment, or similar*

The people in a scientific team should be very capable, compatible with one another and good team players. They also should be open to new ideas, but have a strong sense of skepticism, and be willing to take risks in research.

7. *What are the people to avoid, when trying to generate a break-through achievement?*

People who don't have the above properties should be avoided.

8. What is your opinion about the impact of math?

Math is extremely important. It is the language of physics and engineering and plays an important role a number of other sciences. Students who want to pursue these areas should develop great competence in mathematics.

9. *When targeting a major breakthrough, how sensitive one has to be about the direct interests of tax-payers?*

Since basic research is primarily supported by the taxpayer, the scientist has a great responsibility to the taxpayer. The scientist must do what he/she has been supported to carry out and do the best job possible. The scientist must always keep the public informed about the research being conducted. The scientist also has a responsibility to provide scientific information to the public and political leaders regarding policy issues involving technical - scientific issues. This should be done in a politically neutral manner. Science should never be the captive of politics.

10. *What is the major driving force that motivates a Nobel Laureate to continue to create and generate results after he-she receives the Nobel Prize?*

The major driving force that motivates a Nobel Laureate to continue to create and generate results after he/she receives the Nobel Prize is the same one that operated before the Prize, curiosity and a desire to understand how nature works.

11. *For small nations like Serbian, what is your advice, which road to take, when it comes to science?*

Small nations, like Serbia, should invest in science education and research. If a nation, whether large or small, does not have natural resources, and wants to develop beyond an agricultural economy, it has to develop a knowledge based economy. And this requires developing an excellent educational and science-technology infrastructure. A good example is Singapore, which has a population of 4.6 million people. When it broke away from Malaysia in 1965, it had very little. By investing in education and building its technological base, it has become the 5th richest nation in the world in terms of GDP per capita. Finland is another example of a small nation (population 5.3 million) that has invested in education, science and technology and is doing well. A nation's most important asset is its people; and by providing first rate science education and research opportunities for its people, it will be able to compete in the modern world.

12. *What road to take, when it comes to its general future development plans?*
Invest more in science education and research. Many Serbian students have gone overseas for their graduate education. I have had some outstanding Serbian students in my research group at MIT who have remained in the US. They have done so because they felt that they did not have adequate research opportunities in Serbia. It is important that Serbia provide good research opportunities so that such students are attracted to return home. Serbia should not lose such valuable human capital.

New Views of the Structure of the Universe

Friedman, Jerome

Great progress was made in understanding the structure of the universe in the second half of the 20th Century. This has been driven by research in particle physics, probing the very small, and in astrophysics and cosmology, probing the very large. These two domains are closely related in our current theory of the evolution of the universe.

Particle physics investigates the smallest, most fundamental constituents of matter and the force fields with which they interact.

The tools of particle physics are particle accelerators and particle detectors that are used to conduct scattering experiments. Such experiments are carried out to study particle properties and investigate the fundamental forces. High energy particle beams are also used to produce particles that existed in the early universe. For example, the Fermilab collider reproduces energy densities that existed in the universe only a few trillionths of a second after the Big Bang and produces particles that existed a that time. That is why physicists continually strive to build more and more energetic accelerators. Higher energies enable shorter distances to be investigated, heavier particles to be produced and the universe to be probed at earlier times.

New types of accelerators and particle detectors have made possible extensive experimental results in particle physics, which along with new theoretical developments, have led to the quark model, Quantum Chromodynamics, and Electroweak Unification. These form the basis of a remarkably successful theory of elementary particles, called the Standard Model. Although its predictions have been confirmed with excellent precision at present accelerator energies, this theory is incomplete and has raised a number of deep questions that need to be addressed in the TeV energy region. Some of these have important cosmological implications. Experimental programs to search for answers to these questions have been prepared at the Large Hadron Collider (LHC), a 14 TeV proton-proton collider at CERN, which is scheduled to begin operations for physics in the fall of 2009.

The experiments at the LHC will be carried out with five multisystem particle detectors, the most massive of which are ATLAS and CMS. ATLAS is comparable in size to a seven story building, 130 feet in length and 75 feet in width; and CMS, a somewhat smaller but heavier detector, is more than one and a half times heavier than the Eiffel Tower. Each has about 100 million channels of electronic readout; and with the accelerator, they constitute some of the world's most advanced and sophisticated technology. These detectors are expected detect one billion collisions per second, with each collision producing many hundreds of high energy particles. Only about 100 of the most interesting collisions will be recorded per second and saved for physics analysis. The selection, which is based on topological and energy discrimination, must be made online, requiring enormously fast electronics and massive online computation.

The Standard Model is not complete, as it is based on a mass generating mechanism that has not been verified experimentally. This is the so called Higgs field, which is proposed to fill all space and interact with particles giving them mass. One of the major objectives of the LHC is to confirm the existence of this field or establish a surrogate mass generating mechanism. Theoretical calculations indicate that finding the Higgs Particle, the quantum of the Higgs field, is well within the reach of the LHC. This discovery would shed light on one of the great mysteries of nature - how mass is generated in the universe.

In this new energy range, there will be explorations for new physical principles and symmetries of nature that go beyond the Standard Model. In particular, there will be searches for the signatures of supersymmetry, a symmetry that has received much attention because it appears to be required in quantum theories of gravity and stabilizes the energy scale of the Standard Model against quantum fluctuations. Supersymmetry assigns a mirror set of supersymmetric particles to the known fundamental particles, giving them the same electric charges and interactions but different spins. But supersymmetry has to be a broken symmetry. As supersymmetric particles have not been detected at existing accelerators, it is thought that they must be heavier than their ordinary partners, Theoretical estimates suggest that LHC energies are likely to be high enough to produce the lowest mass supersymmetric particles. As the lowest mass neutral supersymmetric particle is an excellent candidate for the mysterious, exotic dark matter that makes up 23% of the total mass-energy of the universe, the LHC will provide the opportunity to search for it or for other potential candidates.

Clarifying the nature of dark matter would be a major contribution to our understanding of the universe. In addition to dark matter, astrophysical observations have also pointed to the existence of a mysterious form of energy, dubbed dark energy, that pervades all space and makes up 73 % of the mass-energy of the universe. It is somewhat humbling to realize that the matter that we basically understand, the matter consisting of atoms, makes up only about 4 % of the mass-energy of the universe. Dark energy is a complete mystery because attempts to explain it on the basis of particle physics give an answer that is about 120 orders of magnitude too large. Astrophysics experiments are being mounted to further clarify the nature of this energy. As this energy is thought to be associated with a scalar field, a structure similar to that of the Higgs field, the possible discovery of the Higgs particle at the LHC could perhaps shed some light on this mystery.

Another intriguing question to be explored by the LHC is whether extra spatial dimensions exist beyond the ones we know. Speculation about this has been motivated by String Theory and by the observation that this could account for the enormous weakness of gravity as compared to the other fundamental forces of nature. The LHC could detect extra dimensions that extend out to about to about 10^{-18} cm or beyond. There will also be investigations of why the antimatter of the universe disappeared and matter remains. The Standard Model, while predicting some asymmetry in the behavior of matter and antimatter, cannot account for the magnitude of asymmetry present in the universe. Higher energy phenomena that are not included in the Standard Model and could possibly be observed at the LHC must be responsible for this. If this asymmetry were not imbedded in our physical laws, we and the universe as we know it would not exist. There are a host of other profound questions that will be studied; but if history is a guide, the LHC will also turn up complete surprises, phenomena not anticipated in any theoretical speculation. The Large Hadron Collider, the world's largest and most ambitious scientific project, is expected to usher in a new era of discovery and provide a clearer view of the structure of the universe.

Swedish Experiences of Landfill Leachate Treatment Using Sequencing Batch Reactors

Morling, Stig

Abstract - *This paper presents experiences from operation of a SBR unit designed for treating landfill leachate from a mid-sized landfill located in central part of Sweden. A short presentation of landfill treatment options exercised in Sweden is given as an introduction. The SBR plant has been running for six years, and thanks to an ambitious control programme substantial performance data are available, allowing for presentation of both encountered initial problems, process adjustments and a successful operation. The last two years operation has consistently resulted in a complete nitrification and normally more than 90 % total nitrogen removal. The landfill leachate quality after treatment is found more than acceptable with respect to heavy metals and other potentially hazardous compounds - very low concentrations are found. Also the biological sludge has been investigated with respect to heavy metals, PCB and nonylphenol; all these hazardous pollutants are found at low to very low levels in the sludge.*

Keywords - *nitrogen removal, leachate, landfill, SBR, heavy metals*

Introduction

Concerns about the environmental impact caused by landfill leachate rose during the 1970's in Sweden. The initial concerns were focused on the heavy metal content. Traditionally the landfill leachate was either discharged directly to a receiving stream or to a municipal wastewater treatment plant (WWTP).

The formation of leachates is a result of mainly two phenomena: (1) the degradation of waste into liquid and gases, and (2) the percolation of rainwater through the landfill. The first years of landfill leachate management focused on connecting the leachate to a WWP. The alternative option was to strive to find "simple", local treatment solutions. The knowledge of the landfill leachate generation was often limited, as well as clear definitions of its content, and, perhaps most important for the technical development in those years, the absence of general guidelines and effluent standards for landfill leachate disposal. This in turn resulted in a very diverse pattern of optional treatment techniques. It also became more evident that landfill leachate management strategies called for a deeper understanding of the processes within the landfills. Therefore a good understanding of the "inner" environmental processes in a landfill would facilitate the planning of the landfill leachate management. A sanitary landfill passes through three stages with respect to the internal biological process performance as is indicated in Table 1.

Table 1. Simplified characterization of the biological performance in a landfill related to disposal time after Serti (2000).

First phase: Aerobic phase	
Duration	some weeks
Characterization of landfill leachate	pH ~ 8
	High levels of heavy metals
Second phase: Acidic (anaerobic) phase	
Duration	some years
Characterization of landfill leachate	pH ~ 5
	High concentration of VFA
	High levels of BOD
	Ratio COD/BOD is low: 1.3:1 – 2.0:1
	High levels of NH_4-N, organic N and PO_4-P,
	High levels of heavy metals
Third phase: Methane phase (anaerobic)	
Duration	> 100 years
Characterization of landfill leachate	pH ~ 7
	Low concentration of VFA
	Low levels of BOD
	Ratio COD/BOD is high 20:1 – 10:1
	High levels of NH_4-N; Moderate to low levels of organic N
	Very low levels of PO_4-P
	Low to very low levels of heavy metals, apart from Fe and Mn

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The number of phases is sometimes different, but regardless of the numbers, the key-points with respect to the leachate formation are four-fold:

1. The three phases above are the most relevant ones with respect to leachate treatment needs;
2. All phases are distinct with respect to the dominating reactions during the phase and the microbial composition;
3. They are occurring sequentially in time, and
4. They are dependent with one another, in terms of process development.

As found in ***Table 1***, a treatment management must consider the two last phases, as modern landfills are operated with a number of cells, thus producing a leachate of varying age - from less than one year to several decades. The overall picture of the landfill leachate composition is confirmed by an investigation made by Glixelli (2003). In some cases the reported data is divided into the disposal times (phases) as described above. Three major factors emerging in the mid 1980's and early 1990's contributed to the development of landfill leachate treatment methods:

1. A growing concern regarding the landfill leachate composition, inter alia heavy metals content and complex organic compounds, such as dioxins;
2. The insight of the environmental impact from non-oxidised nitrogen (especially ammonia nitrogen) became apparent;
3. The development of nitrogen removal in the Swedish theatre during the second half of the 1980's became an important source of updated knowledge that was found to be very useful when addressing the problems with landfill leachate purification.

The development of landfill leachate treatment technologies in Sweden may, somewhat simplified, be defined by five different main tendencies:

1. A co-treatment with municipal wastewater in a "classic" treatment facility;
2. Different treatment options based on "simple" methods, such as recycling the landfill leachate to the landfill, irrigation of "energy forest" areas, using constructed or natural wetlands or infiltration;
3. Adopted and modified classic biologic treatment methods, to obtain efficient landfill leachate treatment;
4. Chemical physical treatment methods; such as ammonia stripping, chemical precipitation and activated carbon filtration. An example of such a plant is presented below.
5. Use of "advanced" treatment methods, such as reversed osmosis and/or "hyper filtration".

All these methods are currently in use around Sweden. Still there are no general effluent standards established for landfill leachate discharge. Each operator has to apply for and get a "unique" environmental permit for the solid waste operation site, including the landfill leachate treatment. The permits turn out to be very disparate, related to the decision of the local or regional authority.

A number of treatment facilities for landfill leachate have been built in Sweden since the mid 1990's based on the SBR technology. The experiences presented in the US, see Irvine et al. (1982), initiated some early pilot studies in Sweden as well. Morling et al. (1989) reported from a pilot plant study in Varberg, and his work was soon followed by other attempts to operate SBR plants for landfill leachate treatment. As the pilot study at the landfill site in Varberg presented some results that guided the followers during the 1990's it is worth to summarize the findings from this study:

(a) The SBR demonstrated the ability to oxidise almost all nitrogen into nitrate. Once this was established the denitrification was efficient, thanks to the abundance of organic pollution - BOD_7: nitrogen ratio was >12:1. This in turn suggests that the sanitary landfill was in the "acidic stage";

(b) The high content of chlorides did not affect the nitrification; the Cl ranged from 5,000 to 10,000 mg/l;

(c) The water temperature is a dominating factor for the nitrification process. This is of course expected, however the tests showed that it was possible to keep the nitrifyers even at very low temperatures by lowering the load substantially.

The test operation in Varberg was not long enough to reveal some questions regarding the SRT (Solids Residence Time) and sludge quality matters found in the full scale plant in Köping as is discussed below.

Materials and Methods

Plant description

The regional solid waste handling company VMR (Västra Mälardalens Renhållningsbolag) was faced with a demand from the community of Köping to terminate the delivery of landfill leachate to the municipal wastewater treatment plant in 1998, after more than 25 years of operation. The main reasons for this decision were the apprehension that:

(1) The landfill leachate would "pollute" the sludge from the plant with considerable amounts of heavy metals;

(2) The suspicion that the landfill leachate contains high contents of complex, potentially toxic organic matters.

VMR (now VAFAB) started investigations on different options, including jar tests on the landfill leachate using SBR-technology. The tests were performed at a regional laboratory, and demonstrated promising results. Finally the chosen treatment method was based on the SBR-technology, after comparison with other options. Apart from the very encouraging jar test results on the SBR-technology, the location of the sanitary landfill close to the central heat plant for the town, as well as the proximity to the municipal treatment plant offered some opportunities, such as:

1. Heating of landfill leachate would be feasible, as hot water was easily accessible;

2. The proximity to the municipal treatment plant allowed for using some facilities not in use at the plant and also presented an option to use sludge or municipal wastewater to support the biological process in the SBR unit.

The adopted treatment train includes also other facilities, apart from the main SBR unit:

- An equalization basin 3 000 m^3.
- A pumping station feeding the main treatment facility. The flow variation on a daily base has so far been 60 – 160 m^3. This corresponds to hydraulic retention times of 2 to 5 days.
- A heat exchanger providing a lowest temperature on the landfill leachate at 15^{o}C.
- A pumping station for the addition of municipal wastewater from the adjacent Köping town treatment plant. The feed varies on a daily basis from 1 to 5 m^3.
- The SBR facility, with a maximum volume of 300 m^3; and after decant a minimum volume of 250 m^3. It was found suitable and very affordable to use a"surplus" gravity thickener at the municipal plant as the SBR unit. Only minor retrofit actions were necessary to accomplish the needed functions. The aeration is based on a jet aeration system. Decant from the reactor has been arranged by means of an automatic valve. On-line instruments in the reactor included a SS-meter, an oxygen probe and a level probe.
- The treated water passes through two units of slow speed sand filters, each of 100 m^2.
- Addition of chemicals to the SBR-process is arranged for methanol (organic carbon), alkali, anti foam agent and phosphorus.

The adopted sequences for this process are shown in ***Figure*** *1*.

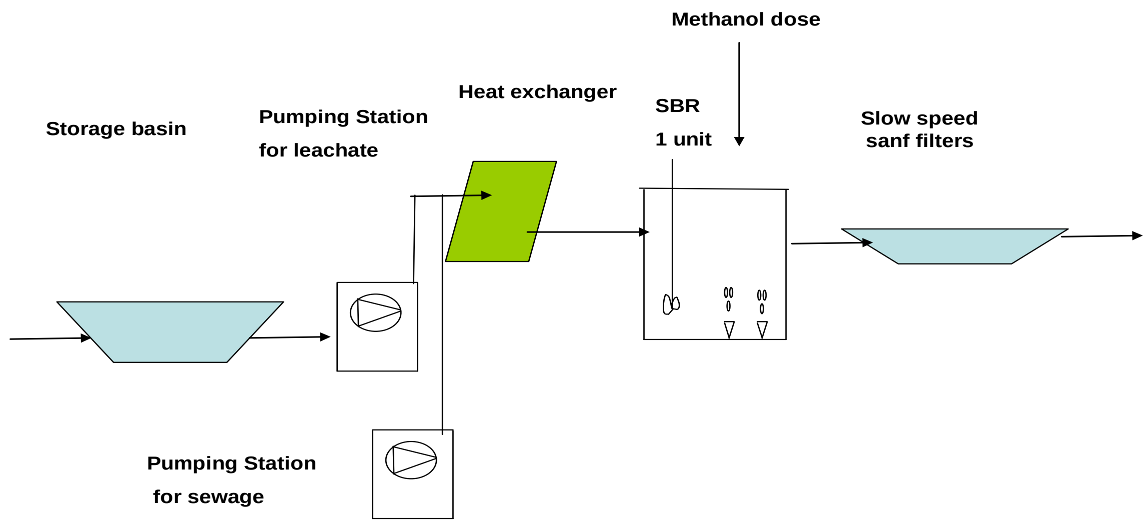

Figure1. **Schematic process train for the treatment of landfill leachate in Köping**

Design data

The local authority decided to put rather stringent effluent standards on the plant, which are summarized in Table 2, together with the adopted design values for the landfill leachate treatment.

Table 2 **Design data for the landfill leachate treatment plant in Köping, Sweden**

Variable	Consent values		Concentration		Amount	
Flow					85	m^3/d
pH			7.5			
Alkalin.			1,000	mg/l		
BOD_7	< 15	mg/l	25	mg/l	2.125	kg/d
COD_{cr}			500	mg/l	42.5	kg/d
Total P	< 0.5	mg/l	1	mg/l	0.085	kg/d
Total N	< 30	mg/l	200	mg/l	17	kg/d
NH_4-N			180	mg/l	15.3	kg/d

Plant Operation

The operation of the plant started in 2000. The SBR-plant was typically operated with an eight, ten or twelve hour cycle as shown in ***Figure 2***.

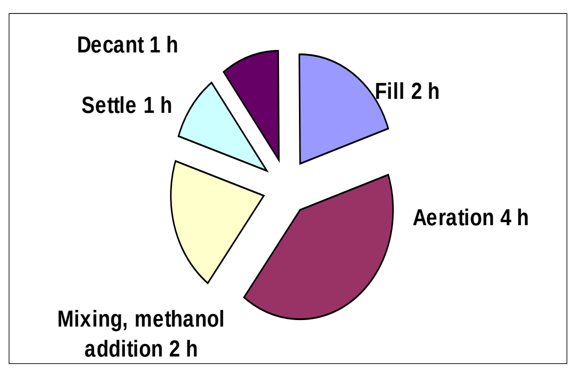

Figure 2 Typical operation cycle for the SBR-plant in Köping (10 hour cycle)

Results and discussion

All analysis results presented in this paper are based on reports from accredited laboratories in Sweden, using the Swedish Standards, which comparable with the relevant EU standards. The plant performance history may be divided into two periods, both providing useful information both with respect to improvements of the plant operation, and guiding operation for design and operation of other plants. The first period covers 2001 through 2003 when the plant was operated in its initial configuration. The second period started early 2004, after a re-arrangement of the final slow speed filter stage. .

First operation period

Although the plant showed very good performance figures during the long periods during the early operation period, some distinct problems were encountered:

1. The fine grade intermittent slow speed sand filters clogged frequently due to discharge of sludge from the SBR-facility. The average SS-content in the decanted water was 86 mg/l, the max value 231 mg/L and the min value 17 mg/l during 2003;

2. As the SRT (Solids Retention Time) was not controlled accurately during this period, sometimes very high SRT occurred, possibly resulting in an excess of pin point sludge, with very poor settling characteristics. Tests with flocculants indicated that a very high dosage was needed to substantially reduce the SS content in the effluent, > 450 mg/l of aluminium sulphate;

3. From time to time the nitrification was affected. The time to overcome this disturbance was sometimes considerable. In Figure 3 is illustrated the nitrogen removal performance. As found from the figure there were two distinct periods with unacceptable nitrogen performance. It was never clearly discovered the true causes for the nitrification inhibition, but for the second period – in fall 2003 – it was suspected that high concentrations of H_2S may have contributed to the situation.

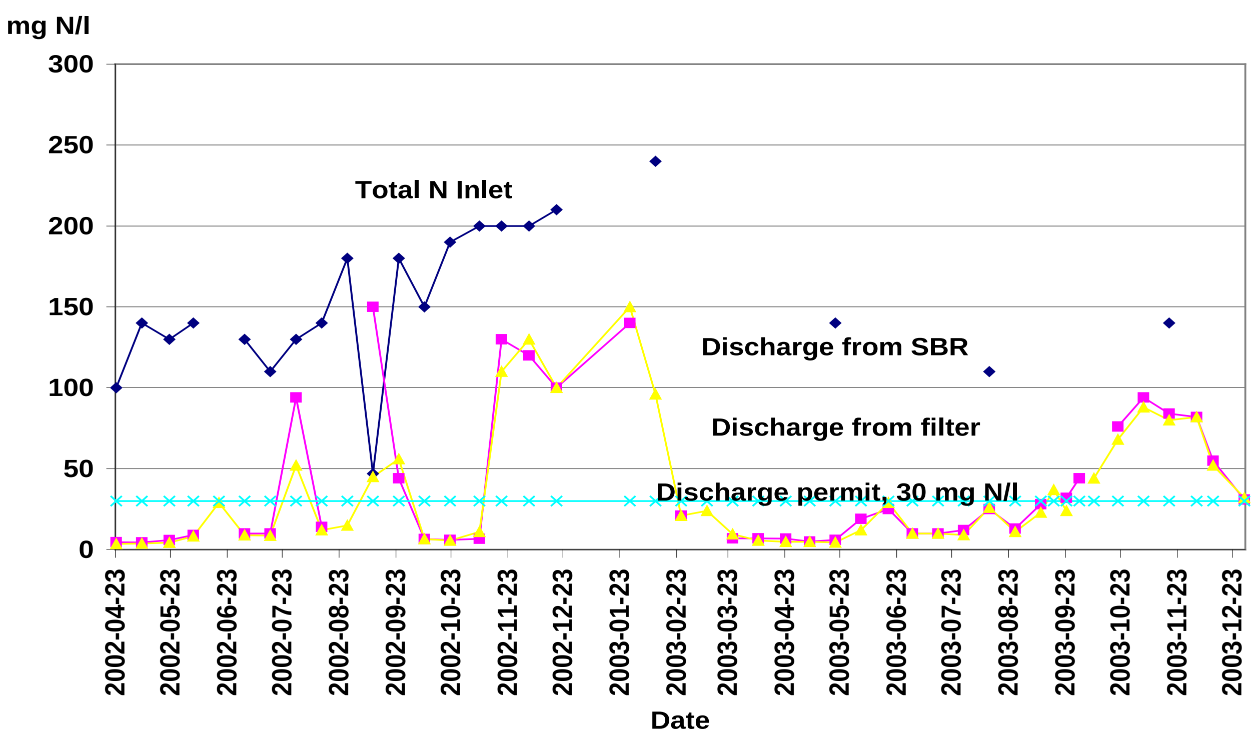

Figure 3 Nitrogen removal performance at Köping leachate treatment, 2002 and 2003

4. The COD-removal was found rather modest, in the range 30 – 45 %. This fact was to a certain extent attributed to the high Cl content, from 2,100 to over 3,000 mg/l. The other consideration in this context was that parts of the COD was “humus”, and thus even relevant to reduce. The actions to overcome these problems concentrated on three issues:

a. To replace the sand in the filters by coarser material;

b. To accurately control the SRT (Solids Retention Time) and operate the plant at an SRT value of 25 to 30 days.

c. Not to use the COD as a consent parameter for the plant.

The control of the leachate temperature showed to be a major factor for the good results. As a comparison the operation of a similar plant in Sala, some 100 km north east to the Köping plant reveals the importance of temperature control; see also Johansson Westholm (2003). The Sala plant is operated without any temperature adjustment, and consequently the nitrification is lost for about three months during winter time.

Apart from these operation problems the plant performed satisfactorily, with good to excellent removal of phosphorus and BOD. Other potential pollutants linked to landfill leachate have been studied at the plant from year 2001. The findings and conclusion regarding these pollutants are found below.

Second operation period

The operation from 2004 has showed very good process stability, with virtually a complete nitrification in the reactor. The only noticeable problem has sometimes been an insufficient dosage of Methanol used as carbon source for denitrification. This in turn resulted in higher than wanted nitrogen discharges. This matter is illustrated in ***Figure 4*** that shows the 1st quarter 2006 performance. A summary of the performance 2004 through 2006, 1st quarter is found in Table 3. The leachate strength with respect to nitrogen is comparatively low, in relation to other reports; see for instance Spagni et al. (2008), who operated a bench scale reactor at ammonia levels of NH_4-N > 1,000 mg/l. Other Swedish plants report levels of 100 – 500 mg NH_4-N/l; see Morling (2007).

Table 3 Nitrogen removal at the Köping SBR landfill leachate treatment 2004 through 2006, 1st quarter

Parameter*[mg/l]*/spec.	Total N, in	Total N, out	NH_4-N, in	NH_4-N, out	NO_3-N, in	NO_3-N, out
Number of obs.	*55*	*54*	*55*	*55*	*54*	*55*
Max value	200	66	180	25	17	56
Mean value	122.1	15.7	105.7	0.8	9.4	9.9
Median value	110	9.9	100	0.033	11	4.8
min value	72	3.2	61	0.005	0.01	0.01
Standard deviation	28.4	13.9	25.2	3.7	5.3	12.1
Standard error	3.83	1.90	3.40	0.50	0.73	1.64
Removal efficiency, % On median values		91		> 99		

The other consent parameters, BOD_7 and total P, have been kept with a good margin throughout this period of more than 2 years. BOD_7 is normally < 6 mg/l and total P < 0.2 mg/l. The SBR-process has been operated with cycle times of 8 to 12 hours, related to the amounts of landfill leachate and pollution loads. The average SS-concentration in the SBR unit during mixing was about 3.0 kg SS/m^3.Needs for chemical addition has been limited to methanol, to provide a sufficient denitrification and anti foam agent.

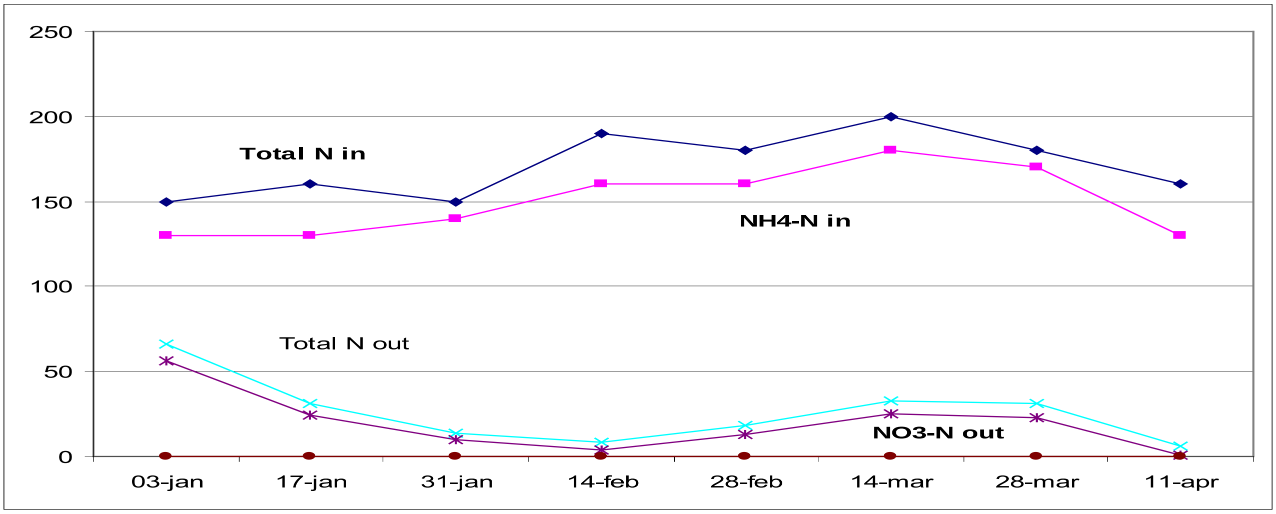

Figure 4 N inlet and outlet from the Köping landfill leachate SBR-plant 1st quarter 2006

The addition of methanol during year 2004 has been 12,000 kg; equivalent to a specific dosage of 2.8 kg methanol/kg total N in the landfill leachate. Addition of anti-foam agent was 240 kg during year 2004.The SS-discharge from the SBR unit has changed significantly: The average SS-content in the decanted water was 18.6 mg/l, the maximum value 44 mg/l and the minimum value 5.6 mg/l from January 2004 through April 2006. Throughout the operation – from the starting year 2001 until Summer 2006 the phosphorus addition from the municipal wastewater contribution has been sufficient for the process, and no further addition of P has been necessary.

Other pollution parameters

As mentioned above the heavy metal content in landfill leachate has been a concern. Thus the content has been analysed at a number of times throughout the operation time. The results of 11 different analyses show the following: Only at very few occasions have heavy metal concentrations been found to exceed the level for potable water in Sweden. A noticeable exception is Mn with concentrations exceeding the consent value for drinking water. Apart from this observation only few analysis are found with values exceeding the potable water quality consent value. This statement may be illustrated for Cd; see Figure 5:

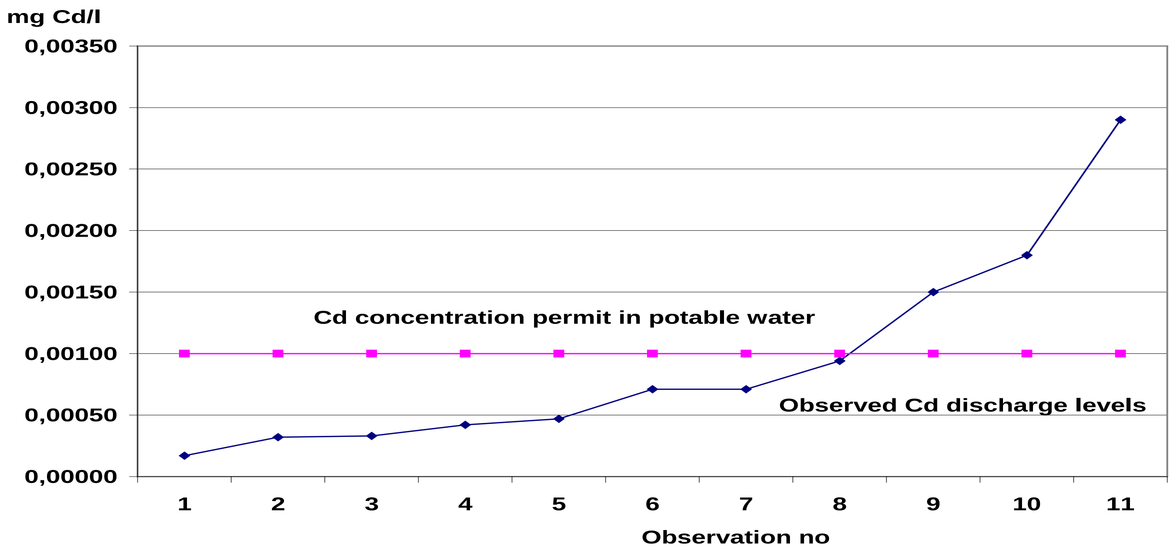

Figure 5 Cd content in treated landfill leachate at Köping SBR plant shown in increasing concentration not by time

The biological sludge in the SBR was investigated with respect to the heavy metal content. Also in this case was found low to very low concentrations of the "most susceptible" metals. In Table 4 the measured concentrations are compared with the Swedish guidelines for sludge quality related to agricultural use:

Table 4. Sludge content of heavy metals compared with reuse requirements for agricultural use

(mg/kg TS)	Sludge from landfill leachate treatment	Swedish EPA guidelikes
Lead	5.1	< 100
Cadmium	1.0	< 2
Copper	99	< 600
Chromium, tot	7.7	< 100
Mercury	0.06	< 2.5
Nickel	7.7	< 100
Zinc	71	< 800

Also complex organics were analysed in the bio sludge, such as PCB and nonylphenol. Seven different PCB-compounds regarded as potentially hazardous – have been analysed at three occasions. The concentrations on these PCB-compounds were found low to very low. The analyses showed that the sum of these seven compounds were < 0.02 mg/kg TS at all three occasions. The Swedish EPA guidelines for agricultural use stipulates PCB < 0.4 mg/kg TS.

The nonylphenol concentration has been measured in the sludge at three occasions. The results found were the following: 12 mg/kg TS (2000-08-16); 3.6 mg/kg TS, (2001-05-04) and 3.1 mg/kg TS, (2002-04-19). Again these levels would be regarded as low, or even very low in comparison with the Swedish EPA criteria for nonylphenol; < 50 mg/kg TS.

Conclusions

Landfill leachate treatment is today applied in most of the Swedish sanitary landfills. This paper presents results from the operation of a rather small facility based on the SBR-technology, in Köping, west of Stockholm. The plant has been operated for six years, and provides comprehensive analysis and results, allowing for some considerations and conclusions regarding biological treatment of landfill leachate. These are:

- The landfill leachate composition was typical for an “old” landfill in the Methane phase;
- The use of small amounts of municipal wastewater possibly saved costs for phosphoric acid addition;
- The causes of initial difficulties on the ammonia oxidation performance were never accurately established. However, seasonal variations of the landfill leachate quality may have contributed to these difficulties. The difficulties were apparent during the late summer and fall periods;
- A seldom systematically investigated perspective may be the “relation man-machine”: The improved knowledge of the plant performance and has enabled the operator to “meet” the variations in due time.
- As expected the water temperature has a paramount influence on the nitrification rate. The rate is found to be at least 52 g NH_4-N_{ox}/kg VSS/d at T = 15 ^oC, however, the maximum rate may be higher, as the nitrification in all cases was complete;
- The SRT was kept in the range 25 – 30 days that resulted in a complete nitrification, to a large extent the same result as presented by Le et al. (1990);
- The results from Köping do not support the indications given by Britain et al. (1999), that the ammonia concentration in untreated landfill leachate is growing with the landfill age;
- The heavy metal content in the treated landfill leachate is found low –to very low, as opposed to the normal assumption that the content is high!
- The sludge quality with respect to polluting agents, both heavy metals and complex organic compounds would be regarded very well.

Acknowledgements

This paper has been made possible mainly thanks to the environmental engineer at VAFAB, Anita Höglund-Eriksson, who provided all operation data. Dr Sami Serti at SWECO VIAK has given the outlines for the characterisation of the biological performance in a landfill. Professor Kenneth M. Persson at LTH, Lund, Sweden has given information on the landfill leachate treatment development in Sweden. Finally, professor Elzbieta Plaza, at KTH, Stockholm, Sweden has given valuable advice on the paper from scientific viewpoints.

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Sustainable Development: A Window on the Future

Cotner, Douglas

Abstract - *Policy makers, governmental officials, scientists, and people in general, have come to recognize that the Earth's biocapacity is being rapidly depleted beyond sustainably renewable levels. As worldwide population continues to grow at an unprecedented rate, and as ever greater of amounts of biophysical goods are appropriated and consumed by the people of the Earth, this recognition has taken on the urgency not felt by previous generations. In this regard, it would be most helpful to have a means by which to see into the future, in general terms. Sustainable Development Science and Human Dimensions Research provide just such a means. Combining these fields of study, allows for the development of what-if-scenarios, and makes available, through observation and analysis of both qualitative and quantitative data, an analytical suite with which to address the problems and challenges associated with achieving sustainability, worldwide. This window represents a reasoning framework, within which to work out the dense and complex problems of sustainable development. At this moment in time, working out these problems is greatly complicated by the diffused state-of-the-science, resulting from fissiparist tendencies, which are now spread across a wide range of fields, exhibiting a profound absence of coherence amongst them, which is to say, a serious absence of interdisciplinary and multi-disciplinary collaboration. This growing tendency inhibits a concentrated focus, which is essential for solving the multi-faceted problems of sustainability.*
Keywords – *biosphere, fissiparism, geosphere, human dimensions, sustainability*

1. Introduction

Many are the things that man seeing must understand. Not seeing, how shall he know what lies in the hand of time to come?

-- Sophocles

The Science of Sustainable Development is a field of inquiry that is principally observationally based. Observations are made, which lead to hypotheses, which are formulated by analyzing past and present field observations in conjunction with the assessment and application of statistical data sets gathered directly through field work or indirectly through data collected and published by others, such as government agencies. Unlike Particle Physics or Molecular Biology, the Science of Sustainable Development is not an experimentally based science. It does, however, have certain quantitative capabilities with which to measure sustainability parameters. Quantification when required is effected by the technique now known as "Ecological Footprint Analysis". Ecological Footprint Analysis allows for quantifiable analysis of the consumption of biophysical goods (Food, Fuel, fiber, et. al.) by a specified population, juxtaposed to the global land equivalents, from whence such biophysical goods are derived.

A Definitional Perspective

The most commonly used definition for Sustainable Development and therefore Sustainability may be stated as follows, according to the Bundtland Commission Report:

> Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concept of "needs", in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and the future needs, (Brundtland Commission, 1987).

This definition has been the mainstay of the worldwide movement for Sustainable Development movement, since 1987. As a point of departure, it is as good away as any to examine the Science of Sustainable Development. It assumes implicitly that Sustainable Development is attainable. Which is to say, if everyone can be brought on-board, and in so doing, create the collective political will to make it so. In this regard, a collective blindness to reality seems to have ensconced itself in intellectual ideology of many who are currently operating in the realm of practice, and scholarship for this science.

Simply stated the Science of Sustainable Development seeks to assess and thereby quantify the total human impact on the biosphere as follows:

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[(Total Human Impact on the Ecosphere) = (Population) x (Per capita Impact)]

We no longer ask whether a specified population of a given region can support sustainability. The inverse is now at the center of the problem. In other words, the question concerning sustainability is now more critically stated as, how much productive land and water area in various ecosystems is required to support a particular population in a specified region, indefinitely at current consumption levels using prevailing technologies.

The Field of Sustainable Development now faces the same problem that the Field of Geography has for the past 50 years, and continues face this problem in terms of *fissiparism*. Geography, in this regard, is a *Mother Discipline*, from which many have appropriated its core tenants. Moreover, after so appropriating, and renaming that which was taken, is propounded as something new and different, thus the term fissiparism is used to characterize such appropriations. Sustainable Development, therefore, now faces the very same dilemma. The same reluctant organizations, that now trade on its importance, refused or seem reluctant in the past, to give the Science an open and fair hearing.

Characterization of the General Problem

With this acknowledgement of the *State-of-the-Science* in mind, how shall we proceed in terms of Sustainable Development, as the window on the future? The Science of Sustainable Development allows for the first time, a window on the future, by assessing not only the consumption of biophysical goods from the ecosphere, but the rate of that consumption as well, utilizing the quantitative technique of Ecological Footprint Analysis. As the drawdown of the Earth's biocapacity accelerates, the world of tomorrow begins to reveal itself. This revelation is consequently perceived, as a poorer material standard of living in the developed world and a catastrophic reduction in the basics for survival in he developing world grows, becoming a persistent reality. This growing reality may be expressed as *Ecological Overshoot*. The phenomenon of *Overshoot* is like ecological overspending. Experience teaches that any business that does not keep financial accounts will ultimately go bankrupt. Therefore, we must keep records that will document whether or not we are living within our ecological means, or whether we are running an ecological debt that will, over time, deplete our renewable assets.

Overshoot

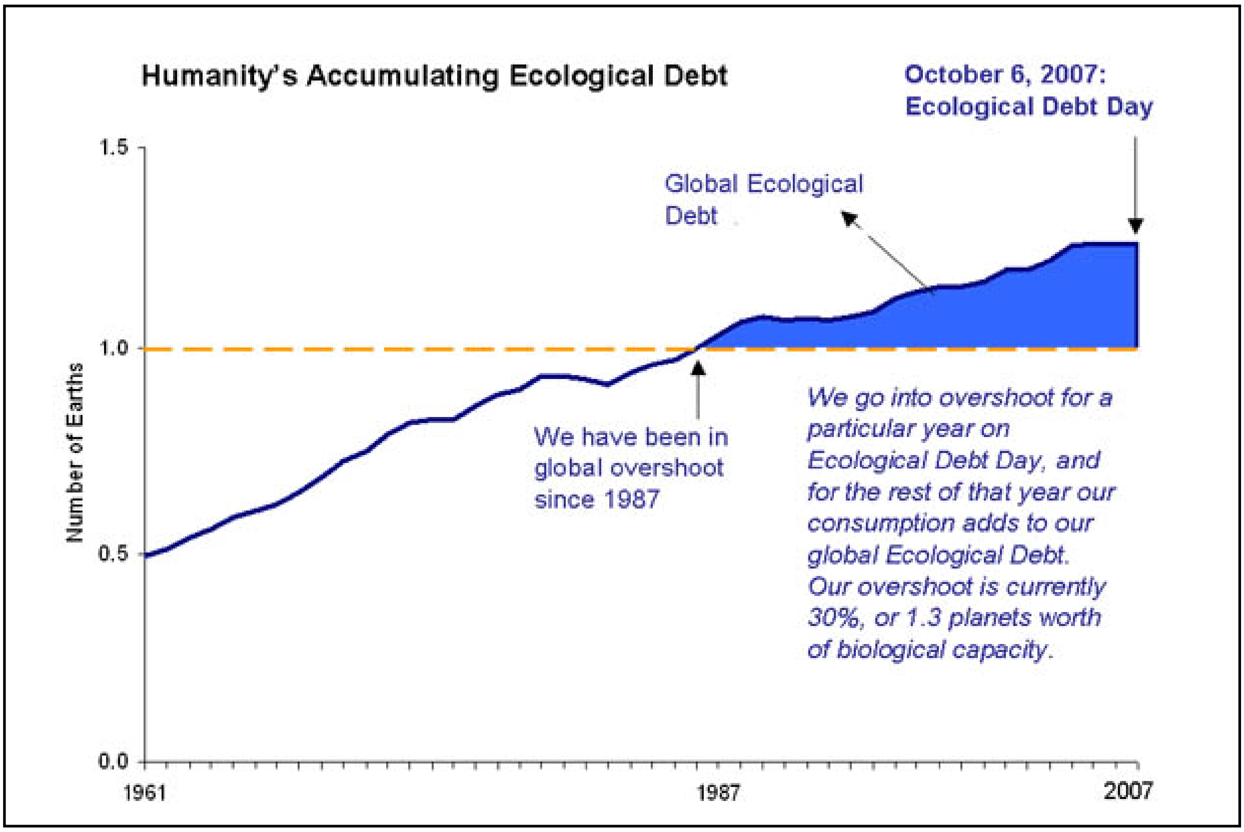

Figure 1: Ecological Debt Day Representation (Courtesy of the Global Footprint Network).

As can be seen in the preceding graph, human populations, as they grow and spread, consume ever-vaster amounts of biophysical goods. In so consuming, we can perceive the Earth of tomorrow in terms of environmental quality, biological diversity, the loss of species, water quality, air quality, and the grim outline of global climate change. Thus, to bring about this ability to see the future as the consequence of Sustainable Development Science is to be able to calculate ecological footprints. Therefore, to compile this kind of information requires extensive time budgets. For example, in a given country or region, there may be well over 3,000 data points required to do the necessary calculations to arrive at the ecological footprints of these types of geopolitical entities. Therefore, the Science of Sustainable Developed may be likened to a lens through which the gross future may be visualized. Therefore, the question that the Science of Sustainable Development asks is, "How can we all, in whatever the country, region, city, town, village, or hamlet enjoy great lives, and achieve this using fewer goods appropriated from our planet's ecosphere"? The lens of Sustainable Development Science, therefore, focuses on this problem.

2. A DISCUSSION AND ANALYSIS OF PROBLEM

In recent years, Sustainable Development has lost traction in its ability to capture the attention of people and sustain it over time. It is being written off and is being appropriated by other disciplines, a seeming contradiction. In the desire to appear as "Green", practitioners of Architecture and Interior designers have professed their belief in Sustainable Development to enhance their bona fides as environmentally friendly and thus *Green*. Other disciples now drawn up under the umbrella of Sustainable Development include the Social Sciences, Political Science, Urban Planning, Environmental Studies, and certain practitioners of the Law.

It is well to remember, that the Science of Sustainable Development was born of a pervasive awareness, that national failures to sustain economic development and manage natural and man-created environments threaten to overwhelm all of our communities. Development cannot subsist on a deteriorating resource base. The resource base cannot be improved or protected when growth leaves out of account the costs of environmental degradation, destruction, and misappropriation. The overarching goal of sustainable development is to maintain our community populations and institutions across future generations without degrading the carrying capacity and utility of our capital stocks, essential infrastructure, and the human living environment. The primary measures of sustainability are *structural and functional integrity, intergenerational capacity, and continuity.* Clearly, the best science based tools to address the problems of sustainability *are Ecological Footprint Analysis, Carbon Footprint Analysis, and Human Dimensions Research*. When applied to the problems of sustainability, both the human and scientific complexities are revealed. Human needs, desires, and consumption continue to drive global resource appropriation, and it is Ecological Footprint Analysis that inventories, calculates, and analyze this consumption.

The ways by which people modify and adapt space in the Built-Environment plays an important and consequent role in resources use and utilization, because these resources (biophysical goods) are appropriated from the Biosphere and Geosphere. Additionally, the Built-Environment, as previously cited, represents a complex whole, comprising myriad, and complexly interrelated groups of spaces, which are modified and adapted on a continuing basis to meet daily human purposes. The Functional-Relational schematic below, attempts to represent, describe, and visualize the elements comprising a model for achieving the goals of Sustainability at various scales of human activity.

A Suggested Sustainable Development Functional-Relational Model for Sustainability

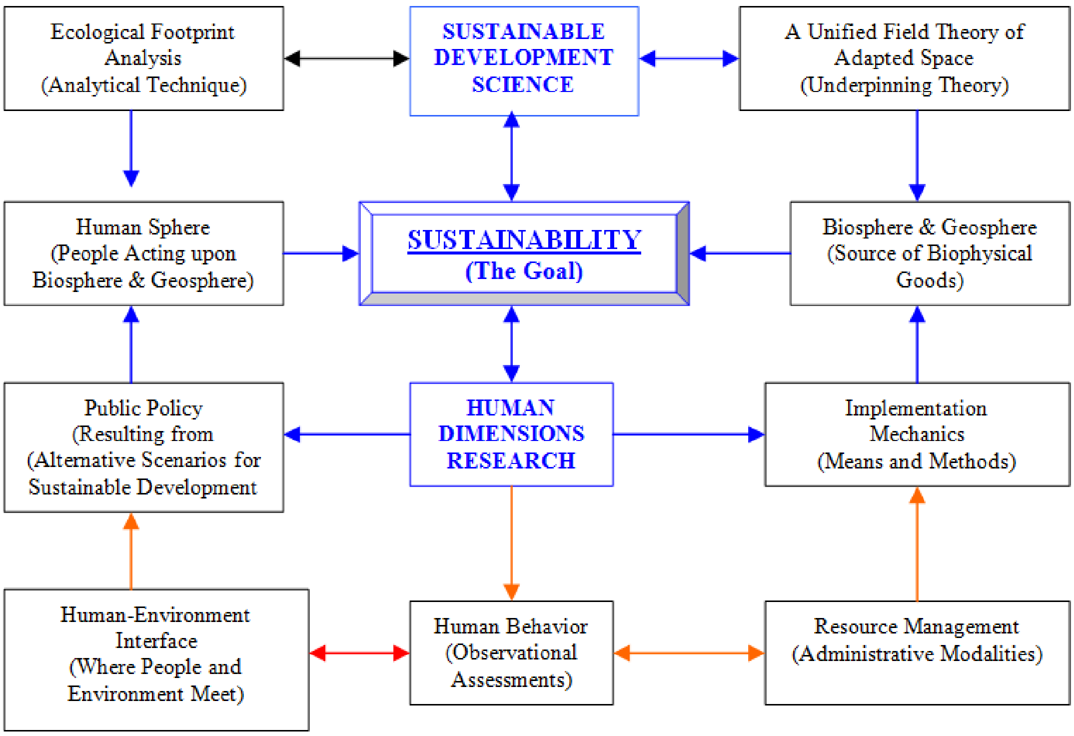

Figure 2: Theory, Mechanics, Applications, and Public Policy for Sustainability.

This schematic attempts to represent, describe, and visualize the elements comprising a model for achieving the goals of Sustainability at various scales of human activity. It is intended to serve as a guide for planners, managers, and administrators. It also bespeaks the fact that sustainability is complex, and highly nuanced. It provides a basis for understanding among all stakeholders, which of necessity, includes scientists, managers, funding agencies, and ordinary people at the local level.
The above schematic (Figure 2) is also designed to state in the strongest terms possible, that sustainability initiatives and projects most be highly concrete, based upon the data and guidelines developed by interdisciplinary scientific teams, and policy makers.

3. Conclusion

It was thus becoming apparent that nature must, in the not far distant future, institute bankruptcy proceedings against industrial civilization, and perhaps against the standing crop of human flesh, just as nature had done many times to other detritus-consuming species following their exuberant expansion in response to the savings deposits their ecosystems had accumulated before they got the opportunity to begin the drawdown…Having become a species of super-detritovores, mankind was destined not merely for succession, but for crash.

-- Overshoot

Catton

Because the Science of Sustainable Development is interdisciplinary, it is naturally allied with *Human Dimensions Research*. As a research suite, they provide both the macro and micro analytical frameworks respectively, with which to address the challenging problems of sustainability. Human Dimensions Analysis addresses that point at which people appropriate biophysical goods at the zone of friction between people and their environment within which they modify space to meet a variety of human needs and living requirements. In Human Dimensions Research, what is sought is a fundamental understanding of the aspects of human behavior as that concerns natural resource management and policy. It therefore applies the findings of its research to concepts, and empirical findings to real world, contemporary problems of management.

Thus, within the theoretical and applied knowledge corpus of Sustainable Development Science and Human Dimensions Research, there is a window on the future. Through this window, one may view the gross outline of tomorrow, which offers a cautionary vision. The view from this window, allows for the luxury of anticipating alternative future scenarios upon which to base and build sustainable natural resource acquisition, distribution, utilization, and consumption. These resources include, Marine Fisheries, Wild Species (including their habitats), Forest, Soil, Grasslands, Water, and Minerals (including Oil, Coal, and Natural Gas). Based on the future view or views possible, public policy options, and management mechanics may be formulated, and consequently agreed upon, by policy makers which will take into account, the full spectrum of stakeholders, in order to assure agreed upon measures for achieving sustainability in both natural and human-made systems. Within this calculus, the Built-Environment must not be excluded from the equation for sustainability.

The ways by which people modify and adapt space in the Built-Environment plays an important and consequent role in resources use and utilization, because these resources (biophysical goods) are appropriated from the Biosphere and Geosphere. Additionally, the Built-Environment, as previously cited, represents a complex whole, comprising myriad, and complexly interrelated groups of spaces, which are modified and adapted on a continuing basis to meet daily human purposes.

In the final analysis, achieving worldwide sustainability so that humans may live upon the Earth in material comfort into the indefinite future must be a bottom-up process. Further, that it must unfold on a community-by-community basis, rooted in tangible and concrete development activities. These activities must be designed and implemented so that they will lead to livable human communities, which will become commonplace in the lives of ordinary people, at whatever the scale of human settlement in which a person lives, works, and plays.

Acknowledgement

I would like to thank the editorial staff of The IPSI BgD Transactions on Advanced Research Journal for committing resources to this special edition, which is devoted to the important subject of Sustainable Development, and for inviting me to contribute to this important edition. Further, that I would like to acknowledge the great helpfulness of Dr. Veljko Milutinovic for his encouragement of my overall research agenda of which this contribution is a part.

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Iteratively Detected Twisted-Pair MIMO-OFDM Transmission with Far-End Crosstalk

Ahrens, Andreas; Lange, Christoph

Abstract— ***Crosstalk between neighbouring wire pairs in multi-pair copper cables has long been seen as an major source of disturbance that essentially limits the transmission quality and the throughput of such cables. However, van Ettens pioneering work has shown that multi-pair copper cables can be treated as MIMO (multiple input multiple output) channels and tremendous performance improvements are possible if appropriate signal processing is applied. For high-rate transmission, often the strong near-end crosstalk (NEXT) disturbance is avoided or suppressed and only the far-end crosstalk (FEXT) remains as crosstalk influence. Therefore in this contribution, the effects of FEXT in iteratively detected and SVD-assisted MIMO-OFDM transmission schemes are studied. Contrary to the cancellation of the crosstalk, which has achieved a level of maturity, the far-end crosstalk paths are viewed as additional transmission paths, which together with the wanted signal path convey the signal from the near to the far cable end. Extrinsic information transfer (EXIT) charts are used for analyzing and optimizing the convergence behaviour of the iterative demapping and decoding.***

Index Terms— ***Twisted-Pair Cable, OFDM, Multiple Input Multiple Output System, Singular Value Decomposition, Iterative Detection, EXIT Chart.***

1. Introduction

Crosstalk as an electromagnetic coupling between adjacent wire pairs has long been seen as one of the limiting disturbances in high-speed local cable networks [2]. Since van Ettens pioneering work in the mid 70's [3] it is well-known that if multi-pair copper cables are treated as MIMO (multiple input multiple output) channels tremendous performance improvements are possible. Therefore appropriate signal processing techniques such as singular value decomposition (SVD) known from wireless MIMO transmission systems have to applied. If multi-channel techniques treat several "traditional" channels as a whole and a "generalized" channel appears, inescapable improvements in the channel capacity can be expected as shown in [4]. Finally, from broadband radio transmission channels, it is well-known that MIMO techniques are able to overcome the limiting factor of multipath propagation known from single-carrier transmission schemes [5], [6]. Often short cables are used in high-speed data rate systems in fi ed access networks, e. g., if optical fibr transmission is used up to a street cabinet or a building and the last drop is bridged by copper cables. Since the near-end crosstalk (NEXT) is a very strong disturbance [2], several techniques have been developed in order to avoid or suppress NEXT [7]. Furthermore, in today's DSL transmission systems (digital subscriber line) often frequency duplex schemes are used. In these cases only the far-end crosstalk (FEXT) remains as a crosstalk influenc . Interestingly, investigations in [8] have shown that the FEXT impact is much stronger in short cables than in longer ones. As shown in [8], FEXT could be a real catalyst for the overall performance at high signal-to-noise ratio (SNR) in uncoded systems if appropriate signal processing is applied. However, coded systems are able to work in a much lower SNR region. Therefore, in this contribution the FEXT impact in an iteratively detected and SVD-assisted MIMO-OFDM transmission scheme is studied [9]. The proposed iterative decoder structures employ symbol-by-symbol soft-output

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decoding based on the Bahl-Cocke-Jelinek-Raviv (BCJR) algorithm and are analyzed under the constraint of a fi ed data rate [10]. Transmitting a multicarrier modulated signal over each wire-pair within a multi-pair copper cable, the influ ence of the crosstalk can be modelled on each subcarrier independently. However, the cancellation of the crosstalk using transmit zero-forcing or Tomlinson-Harashima precoding has achieved a state of maturity. Therein the increase of the transmit power by using transmit zero-forcing can be avoided by using a non-linear modulo operation within the Tomlinson-Harashima precoding [11]–[13]. Finally, postprocessing such as zero-forcing suffers from an increased noise power. Therefore singular value decomposition based signal processing seems to be a real alternative, where neither the transmit power nor the noise power is increased.

The remainder of this paper is organized as follows: Section 2 introduces the cable characteristics and in section 3 the MIMO-OFDM system model is introduced and the performance metrics are given. The channel-encoded MIMO-OFDM system is introduced in section 4, while the associated performance results are presented and interpreted in Section 5. Section 6 provides our concluding remarks.

2. Cable characteristics

The distorting influenc of the cable on the wanted signal is modelled by the transfer function

$$G_{\mathrm{k}}(f) = \mathrm{e}^{-l\sqrt{\mathrm{j}\frac{f}{f_0}}} \quad , \qquad (1)$$

where l denotes the cable length (in km) and f_0 represents the characteristic cable frequency (in $\mathrm{MHz} \cdot \mathrm{km}^2$) [14]. Furthermore, the far-end crosstalk coupling is covered by the transfer function $G_{\mathrm{F}}(f)$ with

$$|G_{\mathrm{F}}(f)|^2 = K_{\mathrm{F}} \cdot l \cdot f^2 \quad , \qquad (2)$$

whereby K_{F} is a FEXT coupling constant, which depends on the cable properties such as the type of insulation, the number of wire pairs and the kind of combination of the wire pairs within the binders [2], [15], [16]. If the far-end crosstalk from several neighbouring wire pairs is considered, with increasing distance of the disturbing wire pair from the considered pair in a cable the impact of far-end crosstalk decreases. Considering n_{F} FEXT-disturbing wire pairs, in conformity with cable measurements, this behaviour can be modelled by [2]

$$K_{\mathrm{F}} = n_{\mathrm{F}}^{0.6} \cdot K_{\mathrm{F1}} \quad , \qquad (3)$$

where K_{F1} is the FEXT coupling constant for one disturbing wire pair. By (3) it is taken into account, that the wire pairs, which are located farther away from the considered wire pair contribute less to the FEXT disturbance than the wire pairs, which are located closer to the considered wire pair [2].

3. MIMO-OFDM System model and quality criteria

Within this contribution a whole cable binder is considered as a transmission channel with multiple inputs and multiple outputs (MIMO). The considered cable binder consists of n wire pairs and therefore a $(n,\ n)$ MIMO transmission system arises. The mapping of the transmit signals $u_{\mathrm{s}\,\mu}(t)$ onto the received signals $u_{\mathrm{k}\,\mu}(t)$ (with $\mu = 1, \ldots, n$) can be described accordingly to Fig. 1. On each wire pair of the cable binder OFDM (or-

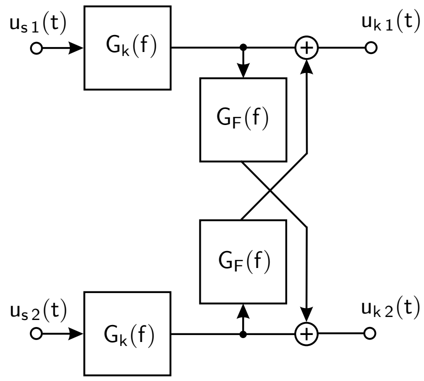

Fig. 1. MIMO cable transmission model system with FEXT ($n = 2$)

thogonal frequency division multiplexing) is used as transmission technique to combat the effects of the frequency-selective channel [17], [18]. In such a (n, n)-MIMO-OFDM system, an N-point IFFT (N subchannels) modulated data signal is transmitted on every wire pair. The system is modelled by

$$\mathbf{u} = \mathbf{R} \cdot \mathbf{c} + \mathbf{w} \quad . \qquad (4)$$

In (4), $\mathbf{c}$ is the $(L \times 1)$ transmitted signal vector containing the $L = N\,n$ complex input symbols transmitted over all n wire pairs. Using OFDM with a sufficien guard interval length, only symbols that are transmitted over the same subcarrier can interfere each other. The data vector $\mathbf{c}$ can be decomposed according to

$$\mathbf{c} = \left(\mathbf{c}_1^{\mathrm{T}}, \ldots, \mathbf{c}_\kappa^{\mathrm{T}}, \ldots, \mathbf{c}_N^{\mathrm{T}}\right)^{\mathrm{T}} \quad , \qquad (5)$$

where the $(n \times 1)$ vector $\mathbf{c}_\kappa$ contains the complex input symbols transmitted over the κth subcarrier on each wire pair. Furthermore $\mathbf{u}$ describes the $(L \times 1)$ received vector and $\mathbf{w}$ is the $(L \times 1)$ vector of the Additive, White Gaussian Noise (AWGN) having a variance of U_{R}^2 for both the real and imaginary parts. Applying OFDM with a sufficien guard interval length, the matrix $\mathbf{R}$ in (4) gets a block diagonal structure according to

$$\mathbf{R} = \begin{bmatrix} \mathbf{R}_1 & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \mathbf{R}_2 & \ddots & \vdots \\ \vdots & \ddots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{R}_N \end{bmatrix} . \quad (6)$$

In (6), zero-matrices are denoted by $\mathbf{0}$ and for the matrices $\mathbf{R}_\kappa$ (with $\kappa = 1, \ldots, N$) the following syntax is used

$$\mathbf{R}_\kappa = \begin{bmatrix} r_{1\,1}^{(\kappa)} & \cdots & r_{1\,n}^{(\kappa)} \\ \vdots & \ddots & \vdots \\ r_{n\,1}^{(\kappa)} & \cdots & r_{n\,n}^{(\kappa)} \end{bmatrix} , \quad (7)$$

with the elements describing the couplings of the data symbols on the subchannel κ as define in [1]. The elements $r_{\nu\,\mu}^{(\kappa)}$ (for $\nu \neq \mu$) are assumed to be identical for each κ, although in practical systems the coupling between the wire pairs is slightly different and it depends on their arrangement in the binder [2]. The subcarrier-specifi interferences introduced by the non-diagonal matrix $\mathbf{R}_\kappa$ require appropriate signal processing strategies. A popular technique is based on the singular value decomposition (SVD) of the matrix $\mathbf{R}_\kappa$, which can be written as $\mathbf{R}_\kappa = \mathbf{S}_\kappa \cdot \mathbf{V}_\kappa \cdot \mathbf{D}_\kappa^{\mathrm{H}}$, where $\mathbf{S}_\kappa$ and $\mathbf{D}_\kappa^{\mathrm{H}}$ are unitary matrices and $\mathbf{V}_\kappa$ is a real-valued diagonal matrix of the positive square roots of the eigenvalues of the matrix $\mathbf{R}_\kappa^{\mathrm{H}}\,\mathbf{R}_\kappa$ sorted in descending order[1]. Using $\mathbf{D}_\kappa$ as preprocessing matrix at the transmitter and $\mathbf{S}_\kappa^{\mathrm{H}}$ as postprocessing matrix at the receiver side, the overall transmission relationship results in

$$\mathbf{y}_\kappa = \mathbf{S}_\kappa^{\mathrm{H}} \left(\mathbf{R}_\kappa \cdot \mathbf{D}_\kappa \cdot \mathbf{c}_\kappa + \mathbf{w}_\kappa \right) = \mathbf{V}_\kappa \cdot \mathbf{c}_\kappa + \tilde{\mathbf{w}}_\kappa \,. \quad (8)$$

Here, the $(n \times n)$ matrix $\mathbf{R}_\kappa$ is transformed into n independent, non-interfering layers having unequal gains. Taking all N matrices $\mathbf{R}_\kappa$ with (with $\kappa = 1, \ldots, N$) into account, the channel matrix $\mathbf{R}$ is decomposed into $L = N\,n$ independent, non-interfering layers having unequal gains.

In general, the quality of data transmission can be informally assessed by using the signal-to-noise ratio (SNR) at the detector's input define by

[1]The transpose and conjugate transpose (Hermitian) of $\mathbf{D}_\kappa$ are denoted by $\mathbf{D}_\kappa^{\mathrm{T}}$ and $\mathbf{D}_\kappa^{\mathrm{H}}$, respectively.

the half vertical eye opening and the noise power per quadrature component according to

$$\varrho = \frac{(\text{Half vertical eye opening})^2}{\text{Noise Power}} = \frac{(U_{\mathrm{A}})^2}{(U_{\mathrm{R}})^2} , \quad (9)$$

which is often used as a quality parameter [19]. The relationship between the signal-to-noise ratio $\varrho = U_{\mathrm{A}}^2 / U_{\mathrm{R}}^2$ and the bit-error probability evaluated for AWGN channels and M-ary Quadrature Amplitude Modulation (QAM) is given by [20]

$$P_{\mathrm{BER}} = \frac{2}{\log_2(M)} \left(1 - \frac{1}{\sqrt{M}}\right) \operatorname{erfc}\left(\sqrt{\frac{\varrho}{2}}\right) . \quad (10)$$

When applying the proposed system structure, the SVD-based equalization leads to different eye openings per layer ℓ according to

$$U_{\mathrm{A}}^{(\ell)} = \sqrt{\xi_\ell} \cdot U_{\mathrm{s}\,\ell} , \quad (11)$$

where $U_{\mathrm{s}\,\ell}$ denotes the half-level transmit amplitude assuming M_ℓ-ary QAM and $\sqrt{\xi_\ell}$ represents the weighting factor (singular value) resulting from the subcarrier-based equalization. Together with the noise power per quadrature component, the SNR per layer becomes

$$\varrho^{(\ell)} = \frac{\left(U_{\mathrm{A}}^{(\ell)}\right)^2}{U_{\mathrm{R}}^2} = \xi_\ell \, \frac{(U_{\mathrm{s}\,\ell})^2}{U_{\mathrm{R}}^2} . \quad (12)$$

The bit-error probability per layer ℓ is given by [19]

$$P_{\mathrm{BER}}^{(\ell)} = \frac{2\left(1 - \frac{1}{\sqrt{M_\ell}}\right)}{\log_2(M_\ell)} \operatorname{erfc}\left(\sqrt{\frac{\xi_\ell}{2}} \cdot \frac{U_{\mathrm{s}\,\ell}}{U_{\mathrm{R}}}\right) . \quad (13)$$

The resulting average bit-error probability assuming different layer-specifi QAM constellation sizes results in

$$P_{\mathrm{BER}} = \frac{1}{\sum_{\nu=1}^{L} \log_2(M_\nu)} \sum_{\ell=1}^{L} \log_2(M_\ell)\, P_{\mathrm{BER}}^{(\ell)} . \quad (14)$$

Therein the number of transmitted bits per data block results in

$$R = \sum_{\ell=1}^{L} \log_2 M_\ell , \quad (15)$$

assuming that all L layers are used for the data transmission. Considering QAM constellations, the average transmit power $P_{\mathrm{s}\,\ell}$ per layer ℓ may be expressed as [21], [22]

$$P_{\mathrm{s}\,\ell} = \frac{2}{3}\, U_{\mathrm{s}\,\ell}^2 \, (M_\ell - 1) . \quad (16)$$

Combining (12) and (16), the layer-specifi SNR results in

$$\varrho^{(\ell)} = \xi_\ell \, \frac{3}{2\,(M_\ell - 1)} \frac{P_{\mathrm{s}\,\ell}}{U_{\mathrm{R}}^2} . \quad (17)$$

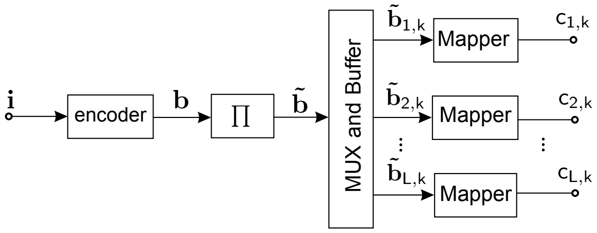

Fig. 2. The channel-encoded MIMO-OFDM transmitter structure

Using a parallel transmission over N subchannels the overall mean transmit power per wire yields to

$$P_{\mathrm{s}} = N \cdot P_{\mathrm{s}\,\ell} = N\,\frac{2}{3}\,U_{\mathrm{s}\,\ell}^2\,(M_\ell - 1)\ , \tag{18}$$

and results in a total transmit power of $n\,P_{\mathrm{s}}$ by taking n wire-pairs into account. Assuming that the transmit power is uniformly distributed over the number of activated layers, i. e., $P_{\mathrm{s}\,\ell} = P_{\mathrm{s}}/N$, the half-level transmit amplitude $U_{\mathrm{s}\,\ell}$ per layer results in

$$U_{\mathrm{s}\,\ell} = \sqrt{\frac{3\,P_{\mathrm{s}}}{2\,N\,(M_\ell - 1)}}\ . \tag{19}$$

4. Coded MIMO-OFDM System

The transmitter structure including channel coding is depicted in Fig. 2. The encoder employs a non-recursive, non-systematic convolutional (NSC) code. The uncoded information is organized in blocks of N_{i} bits, consisting of at least 1000 bits, depending on the specifi transmission mode used. Each data block $\mathbf{i}$ is encoded and results in the block $\mathbf{b}$ consisting of N_{b} encoded bits, including a given number of termination bits. The encoded bits are interleaved using a random interleaver and stored in the vector $\tilde{\mathbf{b}}$. The encoded and interleaved bits are then mapped onto the layers. The task of the multiplexer and buffer block of Fig. 2 is to divide the vector of encoded and interleaved information bits $\tilde{\mathbf{b}}$ into subvectors $(\tilde{\mathbf{b}}_{1,k}, \tilde{\mathbf{b}}_{2,k}, \cdots, \tilde{\mathbf{b}}_{L,k})$, each consisting of R bits according to the chosen throughput. The individual binary data vectors $\tilde{\mathbf{b}}_{\ell,k}$ are then mapped to the QAM symbols $c_{\ell,k}$ according to the specifi mapper used [1].

5. Results

The FEXT impact is in particular strong for short cables [2]. Therefore for numerical analysis an exemplary cable of length $l = 0.4\,\mathrm{km}$ with $n = 10$ wire pairs is chosen. The wire diameter is $0.6\,\mathrm{mm}$ and hence a characteristic cable frequency of $f_0 = 0.178\,\mathrm{MHz}\cdot\mathrm{km}^2$ is assumed. On each of the wire pairs a multicarrier system with $N = 10$ subcarriers was considered. The actual crosstalk circumstances are difficul to acquire and they vary from cable to cable. Therefore exemplary mean FEXT coupling constants of $K_{\mathrm{F}} = 10^{-13}\ldots 10^{-15}\,(\mathrm{Hz}^2\cdot\mathrm{km})^{-1}$ are employed [2], [23]. The average transmit power on each wire pair is supposed to be $P_{\mathrm{s}} = 1\,\mathrm{V}^2$ and as an external disturbance a white Gaussian noise with power spectral density Ψ_0 is assumed. Identical systems on all wire pairs are presumed (multicarrier symbol duration $T_{\mathrm{s}} = 2\,\mu\mathrm{s}$, M-ary QAM and a guard interval length of $T_{\mathrm{g}} = T_{\mathrm{s}}/2$). Furthermore, the baseband channel of the multicarrier system is excluded from the transmission in order to support a parallel analogue telephone service. For a fair comparison the ratio of symbol energy to noise power spectral density at the cable output is define for the MIMO case $(n > 1)$ according to

$$\frac{E_{\mathrm{s}}}{\Psi_0} = (T_{\mathrm{s}} + T_{\mathrm{g}})\,\frac{P_{\mathrm{k}} + (n-1)P_{\mathrm{k\,fn}}}{\Psi_0}\ , \tag{20}$$

with P_{k} as mean power of the signal on the direct paths at the cable output and $P_{\mathrm{k\,fn}}$ as mean FEXT signal power at the cable output [19].

Using the half-rate, constraint-length $K = 3$ NSC code with the generator polynomials of $(7, 5)$ in octal notation, the performance is analyzed for an effective user throughput of 2 bit/s/Hz. Our results, obtained by analyzing the soft-demapper characteristic (Fig. 3) suggest that the performance of the MIMO-OFDM system is strongly effected by the FEXT coupling. Here it turns out that a heavy FEXT coupling is highly beneficia for a fast convergence as it is can be seen in Fig. 4.

A mapping scheme optimized for perfect *a priori* information has usually a poor performance, when there is no *a priori* information. However, when applying iterative demapping and decoding, large gains can be achieved as long as the reliability of the *a priori* information increases upon increasing the number of iterations. The achievable performance of the iterative decoder is substantially affected by the specifi mapping of the bits to both the QAM symbols as well as to the layers. The influenc of different mapping schemes can be quantifie with the aid of the corresponding Mutual Information between the transmitted M-QAM symbol $c^{(\nu)}$ taken from the signal constellation $\mathcal{C}$ and the received AWGN-contaminated channel output

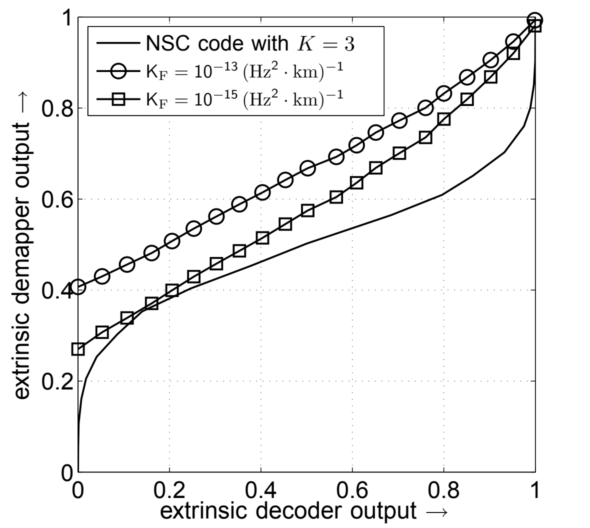

Fig. 3. Exit chart with 16-QAM anti-Gray mapping on all activated layers and the half-rate, constraints length $K = 3$ NSC code with the generator polynomials of $(7, 5)$ in octal notation at $10\,\log_{10}(E_s/\Psi_0) = 20$ dB

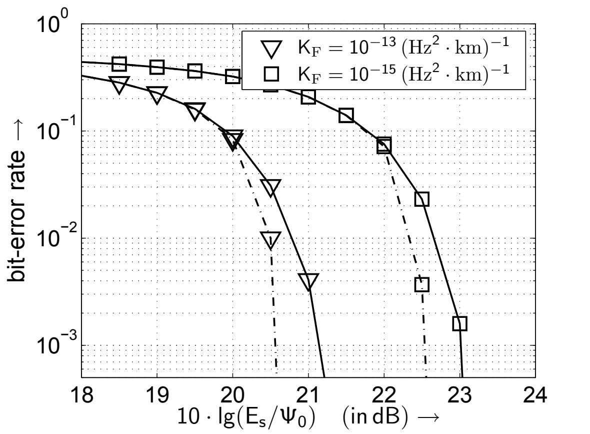

Fig. 4. BER of the iteratively detected channel-encoded MIMO-OFDM system with 16-QAM anti-Gray mapping on all layers (solid line $\triangleq$ 3 iterations, dashed line $\triangleq$ 10 iterations) using the half-rate, constraint-length $K = 3$ NSC code with the generator polynomials of $(7, 5)$ in octal notation

y, which is given by

$$I(c;y) = \frac{1}{M}\sum_{\nu=1}^{M}\int_{-\infty}^{\infty} p(y|c=c^{(\nu)})\log_2\frac{p(y|c=c^{(\nu)})}{p(y)}\mathrm{d}y \ , \tag{21}$$

assuming that all QAM symbols are equiprobable. The conditional Probability Density Function (PDF) $p(y|c=c^{(\nu)})$ is define as follows

$$p(y|c=c^{(\nu)}) = \frac{1}{2\,\pi\,U_R^2}\exp\left(-\frac{|y-c^{(\nu)}|^2}{2\,U_R^2}\right) \ , \tag{22}$$

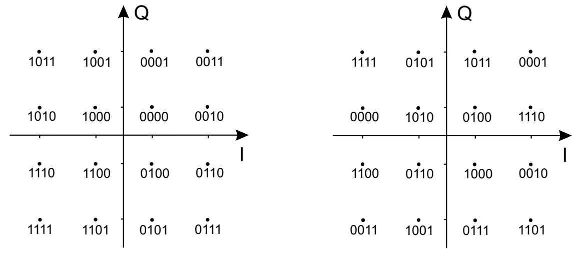

Fig. 5. 16-QAM mapping schemes (left: Gray-coding, right: anti-Gray coding)

with

$$p(y) = \frac{1}{M}\sum_{\nu=1}^{M} p(y|c=c^{(\nu)}) \ . \tag{23}$$

Applying the chain rule, namely that the mutual information between the M-QAM symbol $c^{(\nu)} \in \mathcal{C}$, consisting of the m-bit vector $(\tilde{b}^{(1)}, \cdots, \tilde{b}^{(m)})$, and the received AWGN-contaminated channel output y can be decomposed into a sum of $m = \log_2(M)$ bitwise mutual information terms I_l, provided l out of that m bits are already known to the receiver, leads to

$$I(c;y) = I(\tilde{b}^{(1)}, \cdots, \tilde{b}^{(m)}; y) = \sum_{\ell=0}^{m-1} I_\ell \ . \tag{24}$$

Therein, I_ℓ represents the average of the mutual information, which was averaged over all bits of the mapping. While the employment of the classic Gray-mapping is appropriate in the absence of *a priori* information, the availability of *a priori* information in iteratively detected schemes requires an exhaustive search for findin the best non-Gray – synonymously also referred to as anti-Gray – mapping scheme [24], [25]. Investigations in [26] have shown that the maximum iteration gain can only be guaranteed, if anti-Gray mapping is used on all activated layers. As an example,

TABLE I
CONDITIONAL MUTUAL INFORMATION FOR DIFFERENT 16-QAM MAPPING SCHEMES INTRODUCED IN FIG. 5

	I_0	I_1	I_2	I_3	$I(c;y)$
Gray	0.2117	0.2118	0.2118	0.2118	0.8471
anti-Gray	0.0792	0.1634	0.2768	0.3276	0.8471

Tab. I shows the conditional mutual information at an exemplarily considered noise power per quadrature component of $U_R^2 = 0.05$ for the two 16-QAM mapping schemes shown in Fig. 5, which have been used in assisted iteratively detected bit-interleaved coded modulation schemes [24].

Our BER curves obtained by computer simulations show that the FEXT coupling between neighbouring wire pairs seems to be a real catalyst for the overall performance that is effected by both the cable length as well as the cable properties such as the type of isolation, the number of wire pairs and the kind of combination of the wire pairs within the binders.

6. Conclusion

In this contribution the FEXT impact in iteratively detected MIMO-OFDM transmission schemes has been studied. Our results show that FEXT is not necessarily a limiting factor if appropriate signal processing strategies are used. Our results show that a heavy FEXT impact is overall beneficia for a good convergence behaviour at low SNR.

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Achieving a Comprehensive and Integrated Energy System through Electricity

Pejovic Stanislav, Kennedy Chris, Karney Bryan, Maricic Tihomir[1]

Abstract— *A significant achievement of, and threat to, modern society is abandon with which energy is used for vehicles, electricity, and space heating/cooling. The very scale of these activities is changing the atmosphere, the landscape and even the way we think. Yet energy developments have traditionally been piecemeal within electrical, transportation and space heating/cooling sectors. With illustrations from Ontario, this paper seeks to integrate the electrical system in the context of transportation and heating/cooling demands, thus allowing electricity to facilitate a move to cleaner and greener sources. In this new context, the collective benefits of energy optimization, efficiency and storage become even more crucial.*

Index Terms — *Battery, Canada, Cooling, Electricity, Energy, Environment, Fuel, Heating, Infrastructure, Ontario, Policy, Provinces, Public, Storage, Society, Transportation, Vehicle, World.*

1. INTRODUCTION

Economic history has shown that changes in infrastructure systems have often underlain phases of significant economic growth. Railroads in the 19th century, highway systems of the 1960s, and the internet infrastructure of the late 20th century are prime examples. More generally, changes in infrastructure are recognized to correspond with the 50 to 60 year technology cycles [6]. Transmission lines already realized in some countries could be a great advantage in North America. In terms of energy transmission, there would be a great benefit, in parallel to any other improvements in energy production and storage, to building a high capacity transmission line that connects the various consumers and generators, and provincial grids as well. Such a system could exploit the time differences between provinces to spread peak energy across Canada, thus reducing the reliance of any one region on both peak energy and peak energy prices [35].

This paper considers infrastructure changes, their significance and, in particular, issues related to the electrical system. The comments are of necessity specific to a particular context and jurisdiction, although the underlying causes are common and thus the challenges more general. Thus, this paper focuses on Canada in general and Ontario in particular, and extensions to other contexts are largely left to the reader.

To state the situation starkly, Canadian provincial systems are relatively small, often largely independent, northern distribution systems with moderate north-source connectors but with weak east-west connections of US systems; there are only a few high capacity transmission lines. This can be one reason sometimes contributing to the instability of the provincial grids. For example, the 2003 blackout was imported from the US into Ontario through a north-south transmission line and propagated nearly province-wide through insufficient running reserves with Ontario.

Significantly, Canada once built railways and the St. Lawrence Seaway, understanding that there were ties of national importance that needed to be established. A next step, no doubt expensive but one that would provide crucial benefits and likely inevitable in the long run, would be to create a truly Canadian transmission system with strong interprovincial links.

For the early decades of the 21st century, it seems likely that changes in infrastructure will be driven by stresses related to energy supply [45], [11]. One concern is that extraction of oil from easily accessible reserves may have, or may soon, reach peak capacity, causing energy prices to escalate rapidly. Another issue is the apparent link between global climate change and emissions of greenhouse gases (GHGs), predominantly from the combustion of fossil fuels. As alternative forms of energy supply are sought, a potential outcome may well be a greater integration of energy systems. Energy

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supply systems for transportation, heating and electricity use are largely independent today, but may become more interrelated in the future, e.g., through the large scale adaptation of plug-in electric vehicles or heating by ground source heat pumps. The electrical grid is already crucial, and will likely become even more so with such changes.

Transportation continues to be primarily by automobiles and trucks fuelled by gasoline and diesel, likely (despite the current correction) with increasing prices. Electricity generation by coal has been planned to be phased out locally, and replaced by natural gas, nuclear and renewable generating facilities, plus the contribution from conservation.

Ontario is expected to substantially increase its nuclear power generating capacity, as well as the role of renewable sources. Yet Ontario cities continue to develop with auto-dominated urban form. The influence on air quality with a switch to hybrid or plug-in electric vehicles would be profound.

The focus is on creating infrastructure to achieve quality of place, to attract talented workers. Physical expansion of Ontario cities slows, but the connectivity of the cities increases through construction of a network of high-speed electric trains. New growth occurs through intensification in cities around transit corridors. Use of automobiles (plug-in electric) is balanced by growth in light-rail, streetcar and cycling networks. Activity nodes are greened and pedestrianized [24].

2. Ontario Economy Overview

Ontario's trade is dominated by the auto sector, which accounted for almost $92 billion of exports in 2004. This is counterbalanced by $54 billion of imports in the same sector, leaving a net export of almost $38 billion (Table 1). The next highest sectors in terms of net exports are wholesaling margins; professional and related services; FIRE (finance, insurance, real estate); and the fruit and vegetable sector. It is also pertinent to subsequent discussion to note that Ontario's main net import sector is mineral fuels. The net import of oil, coal, and natural gas cost the province almost $18 billion in 2004.

Sector	Net Exports ($ Billion)
Top Five	
Motor vehicles, other transportation equipment and parts	37.768
Wholesaling margins	12.960
Professional, scientific, technical, computer, administrative, support, and related services	8.021
Finance, insurance and real estate services	5.357
Fruits, vegetables and other food products and feeds	4.347
Bottom Five	
Miscellaneous manufactured products	- 4.140
Hosiery, clothing and accessories	- 4.444
Machinery	- 5.020
Electrical, electronic and communications products	- 6.670
Mineral fuels	- 17.856

Table 1. Ontario's Top and Bottom Five Economic Sectors by Net Exports, 2004 (analysis based on Statistics Canada, CANSIM[1], international and inter-provincial trade data [23]

The province's economy is supported by substantial transportation and energy infrastructure. Ontario has 16,525 kilometers of provincial highway, amongst a 72,350 km network of paved roads. The province's electricity generating capacity was just over 31,000 megawatts (MW), as of August 2007, comprising hydroelectric (7,788 MW), nuclear (11,419 MW), coal (6,434 MW), gas/oil (5,103 MW), wind (395 MW) and biomass (75 MW) generating facilities. The delivery system consists of close to 300 transmission stations and about 30,000 km of transmission circuits.

The province's accounts for 2007 also show that revenues from gasoline and motive fuel taxes ($3.083 billion) and motor vehicle licenses ($1.114 billion) contributed approximately half of the $8.83 billion spent on transportation and communications. The use of gasoline and other fuel taxes to maintain transportation infrastructure may need to be revisited under a changing energy paradigm. The UK, for example, has plans to introduce road tolling for its entire motorway network.

Energy supplied by the combustion of fossil

[2] CANSIM is Statistics Canada's key socioeconomic database. Updated daily, CANSIM provides fast and easy access to a large range of the latest statistics available in Canada. CANSIM brings the power of information directly to you. http://www.statcan.gc.ca/

fuels accounted for 84.6% of the province's 201.6 tonnes of carbon dioxide equivalent (t eCO_2) GHG emissions in 2005. The contributions from electricity generation, natural gas and motor gasoline were relatively similar at 17.6%, 21.2% and 19.2% respectively. Combustion of diesel fuels, largely by trucks, accounted for a further 10.3% of emissions. The GHG emissions, especially from electricity generation, are expected to decrease in the next decade under Ontario's Action Plan on Climate Change. In the long-run, i.e., by 2050, the province aims to reduce GHG emissions to 80% below 1990 levels.

3. Ontario Electricity

One of the greatest achievements of – and also one of the most overwhelming threats to – modern society is certainly the abandon with which we have been able to use energy. Whether for running innumerable electrical devices, cooking food, space warming (or cooling), or running cars, modern society uses a staggering amount of energy, entirely dwarfing any pre-industrial utilization. Moreover, since no source of energy is totally benign environmentally, the accumulations from this scale of activity are changing the atmosphere, excavating mountains, transforming the landscape and changing the way we think about ourselves and our world. One of the premises of this paper is that the magnitude and diversity of these energy challenges represents one of the largest threats – but also greatest opportunities – to Ontario, and indeed the world. The key to appreciate these issues, and particularly the opportunities, is to understand a little more of the trade-off between the infrastructure associated with electricity and vehicular requirements.

At the focal point of these considerations is the potential of a new generation of cars. These new vehicles can supplement, or entirely replace, their use of liquid fuels (gasoline and diesel), with stored electrical energy, usually in the form of rechargeable batteries. Such plug-in hybrid and electrical vehicles currently constitute only a small percentage of sales, but many predict a significant increase in their market penetration over the next 10-15 years. The arguments backing up this prediction are in themselves compelling, but have even broader implications that have not yet been fully appreciated.

The basic facts in favor of a shift from liquid fuel to electricity for transportation are these. First, the purchase price of energy in the form of electricity in jurisdictions like Ontario is usually less than gasoline. For example, if gasoline can be bought for about a dollar a liter and a litter of gasoline has an energy equivalent of just less than 10 kWh, the same amount of electrical energy would cost about 60 to 70 cents. Of even greater significance is the efficiency of use: when gasoline is burned in an internal combustion engine, perhaps 15-20% of this energy (on average) is translated into motion; equivalent values for an electric motor, even allowing for some loss of energy during the process of electrical storage, are more commonly around 80-90%, with further increases expected. Thus, profoundly, a dollar investment to convert electricity into motion would move an equivalent car five to ten times farther than with gasoline.

Considerable attention has been given to questions of moving vehicles by conventional internal combustion engines, versus using some portion of grid-based electrical supply. The sustainability implications of plug-in hybrid electric vehicles [8], energy analysis of both battery electric vehicles and fuel cell electric vehicles [9], and focusing on Canada [44] conduct an analysis to compare different vehicle technologies and the current status of electric vehicles and other alternative fuelled vehicles.

As impressive as such calculations are it would be unfair not to mention some of the challenges. Current storage batteries are expensive, heavy, take considerable energy to manufacture, and yet have limited life. Certainly, with the intensive interest this topic is receiving, considerable gains can be expected in all these measures, but the technical challenges are considerable. Another (often forgotten) factor in this comparison is favoring the tax structure – gasoline taxes are locally much higher (often about 40%) than those electrical rates, with the traditional argument being that this is a logical way of offsetting the considerable cost of the public infrastructure in the form of roadways, interchanges, bridges and related infrastructure. If a considerable shift occurs away from liquid fuels, how will publicly held transportation routes be paid for in as fair a way?

Yet, in as much as there are and will be complications, it is likely that the proportion of the energy required for transportation that is supplied by the electrical system will steadily increase, and by 2021 will begin to be considerable. A consensus for predictions might have plug-in-hybrids representing 10-20% of new sales by 2021. Certainly, if there are technical advances, the growth in market share might be faster.

Yet, here too, we need to be fair and adopt a more holistic view: if transportation energy decreases, along with the desirable consequences of a reduction in air pollution, GHG production, and other related benefits, a considerable extra energy load must be assumed by the electrical system. What is conservative for one system may be challenging to the other. If, for argument's sake, we assume optimistically that a full 25% of personal vehicle energy could be transferred by 2021 to the electrical grid. What would this mean for electrical infrastructure?

Let's assume a "middle-of-the-road" Ontario projection of gasoline usage for 2021 as 18 billion liters. What portion of this can be transferred to the grid? Certainly, estimates vary and many factors will influence the number chosen (see also [40]). If we provisionally assume that 25% or 4.5 billion liters of load is transferred to the grid, this would represent a total yearly demand of roughly 45 billion kWh, which translates into an additional electrical production requirement of 1,700 MW on an average basis, assuming (as is reasonable) about 4 times the effective efficiency from an electrical source. But allowing for line losses, and particularly peak load requirements, as the car might well be charged mostly at night, the installed shift might require about 5,000 MW additional nighttime production capacity, at least half of which might well be obtained by load leveling of other generators (particularly nuclear and any remaining coal fired plants).

The estimated 2,500 MW of extra generating capacity that we would require might cost in the range of $5 to $7.5 billion, assuming a mix of nuclear and wind power. This calculation is based on capital costs for constructing nuclear and wind generating capacity of 2,907 $/kW and 1,938 $/kW from the OPA[2]'s Integrated Power Systems Plan. Spread over a ten year construction period, the capital costs would be between 0.5 and 0.75 $billion/year

Clearly these numbers, though large, are not overwhelming. The increase in production would create further challenges in terms of the grid improvements and investments already mentioned, and in terms of generating capacity. The political leadership, technical and financial planning required to see this through would be, even to understate the obvious, truly impressive. It is interesting to note that for a US study [8] also reported that "A number of studies have shown that the electrical power requirements of PHEV[3]s can be met by the grid for even a very large infiltration of PHEVs."

However, the benefits of the shift are also enormously attractive. Electrical production has many opportunities for GHG mitigation, from clean production to various forms of secondary cycles, or carbon capture technologies. The reduction in air pollution within cities would be noticeable and at times dramatic.

Interesting though, at the moment, Ontario, like so many places, is somewhat mired not in vision but in conventional thinking. The current OPA plan views conservation primarily in the context of saving electrical power with replacement, maintenance and gradual reduction of the electrical system being the operative thinking. The collision course that can be expected is that if, as we suspect here, electrical vehicle energy use will increase significantly, thus dramatically shifting the role, requirement and challenges from petroleum, to improving and investing in the electrical system. However, if the overall goal is the noble one of reducing the overall impact of our energy-related activities – rather than a too narrow and traditional view that considers transportation and electricity as non-overlapping domains – it is time for Ontario, and indeed for many places, to step forward and recognize the benefits available through a more comprehensive vision of infrastructure planning.

4. Managing GENERATION

Since electrical capacity is crucial, it is interesting to note that there is a latent potential in an unexpected source, for it comes not from installing new capacity, but from a better utilization of existing capacity. The economy of

[3] Ontario Power Authority.

[4] Plug-in hybrid electric vehicle

power plant design implies that units' maximum efficiency is at lower outputs then the so-called rated one, which is the maximum output as well. If the system were to be optimized to produce at the lowest price, the difference between the generating power and maximum (rated) power (some generators in addition could be 10% overloaded) of all units in operation will be an essentially free spinning reserve which will stabilize the system (market) and the production costs will not only be reduced, but will be less variable and the system as a whole will be protected from blackouts. The two most important goals achieved are: (i) free spinning reserve, and (ii) the best price of electricity (cheapest electricity production $/kWh) [32], [33], [34], [36]. Such an approach would help the whole economy to flourish. To achieve this goal the Ontario Power Authority, the Ontario Energy Board, Ontario Power Generation, the universities, investors, manufacturers and designers must act together to fully exploit and develop the generation mix, upgrade the transmission and distribution system and reaffirm Ontario's (Canada's) Kyoto commitment. The crippling effect of an undefined market and investment uncertainty must be clarified and solved, or erratic prices will continue and the effective control of the whole system could be forfeited.

A key issue in providing a reliable and affordable electricity system is that of the price of energy consumed and a reasonable variation in this cost. Yet, without explicit consideration of production and spinning reserves in power generation, we contend that stability will be difficult achieve, and any instability will create large economic and social consequences. Although the 2003 blackout was imported from the US, the provincial blackout occurred locally because Ontario had insufficient running power and weak connections with the provinces; thus, overall, the province had insufficient reserve capacity to stabilize the system after a sudden and unexpected loss of imported power.

The demand for power and generation is not uniform in time, and the variable nature in the requirements for energy and its production need to specifically be built into the system if stable and affordable power is to be produced. The minimal spinning reserve and stand-by reserve available must be equal to uncontrolled removal of the biggest generator or biggest power plant, or the power transmitted by an uncertain transmission line, whichever is greater. This operational principle is often called the "n-1" criterion within US energy planning; it is an approach based on the premise that no single event (such as the loss of a line or a generator or an electric plant) should lead to the cascading uncontrolled failure of a large portion of the system.

Storage and reversible pump-turbine storage plants are often an excellent solution for peak power generation, providing "spinning no load" reserve, stand-by reserve, and achieving a low price per unit produced (kWh) and per unit installed (kW capacity) [21], [35]. Droughts do not endanger supply as pumped-turbine storage electric plants do not suffer this limitation and thus overcome this shortage. Despite the long-term promise of other technologies, pumped storage systems remain the key economical way of storing large amounts of clean electricity. When combined with production from thermal pollutant and nuclear power plants, pumped storage plants can reduce contamination from power production by up to 50%, while at the same time minimizing power production costs (dollars per kWh). New variable speed hydraulic machines continually operates at its best efficiency and also greatly reduces vibrations, thus decreasing operating and maintenance cost by up to 50% or more if appropriately managed; total efficacy off the plant is increased up to 85%; in other words electrical energy pumped into the storage at off peak hours generates into the grid up to 85% as expensive peak energy.

Finally, the only generators which could deliver electric energy at the price below 5 cents per kWh are nuclear, hydro and coal fired power plants, but really only if combined with pumped-storage plants and high capacity long distance transition lines connecting provinces into a strong overall system. Variable speed pump-turbines are the best units to deliver spinning and speed no load reserve, optimize energy generation and minimize operating and maintenance cost of big nuclear and thermal generators.

3.3 Coal Fired Generation

Although authorities would not imperil the electricity supply by shutting down coal-fired plants before replacement capacity is available, depletion of fossil fuels will do that soon enough.

Until such time, a reasonable approach would be to upgrade the environmental emission controls by installing the appropriate air pollution control devices, and run these plants to the end of their life. At 36% thermal efficiency for these plants, conversion to natural gas would be uneconomical. The money would be better spent on hydroelectric, pumped storage, gas-fired "peakers" (i.e., plants specifically designed to meet peak load requirements) and transmission lines to connect the Ontario grid not only to the US but to neighboring provinces as well. At the same time, pumped storage plants reduce the maintenance costs of thermal plants.

3.4 Gas Fired Generation

With natural gas prices tripling over the past years, its use as a fuel for power generation has to be carefully scrutinized. Peakers may be attractive for dealing with daily load conditions, especially during the summer. They would only have to run for approximately 1000 to 2000 hours per year. Commercial combined cycle plants with no local steam market may be difficult to develop. It is unlikely developers would carry the fuel risk for such a project.

3.5 Hydroelectric

Surprisingly, hydroelectric power has significant untapped potential in Ontario (and in many other places). Yet if this potential is to be properly and fully realized, one of the most pressing requirements is again to establish a reasonable and stable economic climate that will effectively reward and encourage suitable energy investments. This problem is itself challenging, but is a prerequisite to all other development [46].

5.4 Nuclear, battery, hydrogen, hydro future

Advanced nuclear reactors ought to be capable of producing electricity for about 4 cents per kWh. The best operational model could be mixed use sending electricity to the grid during peak hour, charging electrical vehicles batteries, but at other times making hydrogen and pumping into storage. The proper mix of storage and pumped storage to electricity production would be market and cost dependent. Hydrogen might conceivably replace gasoline; hydroelectric and storage plant will be spinning reserve to cover peaks and protect system from blackouts. Advanced design, hydrogen as a fuel and storage cycles provide an economical, secure and safe energy future. The combination is an extraordinary green idea. Moreover a robust nuclear-hydro-battery-(hydrogen} structure can provide a framework for incorporating energy from wind, solar and other diffuse energy sources, which could become more important as their technology improves.

2.2 Renewable – Solar, Biomass and Wind

The greatest difficulty in implementing such systems in Southern Ontario was that we do not have enough sunny days. In remote areas in Northern Ontario, solar power has somewhat limited potential. Therefore, its impact has been negligible on the overall power generating capacity of Ontario.

Significant amounts of wood waste are available throughout Ontario, mostly from sawmills. A few of the larger sources have already been developed for power generation and are financially viable, provided the discarded wood is available at no cost. The biggest problem with wood waste plants is that plant capital costs become excessive below an output capacity of around 10 MW (due to economics of scale) and transporting wood waste for more than 150 km is usually too costly and becomes energy intensive in its own right. Having said this, there are several wood waste projects under consideration and this energy source can provide several hundred MW of relatively "green power."

Another good source of energy is biogas from sewage treatment plants and landfill sites. Biogas can be used to fuel reciprocating engines down to several hundred kW in size and are relatively simple and inexpensive to build, particularly since they are dealing with a waste and producing a useful product.

Wind power is probably the best-known renewable energy source under consideration. Although the technology to build windmills has evolved significantly, wind power plants are still relatively costly, though this cost has been decreasing. Also, since power is variable, win plants are not firm and must be backed up by conventional generation plants; they are often best viewed as a fuel saving opportunity for fossil fuel plants. Having said this, wind power is capable of providing over 1000 MW of electrical power here in Ontario, and it thus can play a role in achieving an overall solution. More importantly, wind's effectiveness increases greatly when used in conjunction with pumped storage, batteries, and hydrogen production; in this case, power can be produced whenever wind is available, and the energy consumed whenever the energy is required, and not simply when the wind blows. All investments should be balanced, or at least carefully re-evaluated, and the money saved put into basic and peak generators.

2.3 Small Power Plants

The biggest problem with small generators is that plant capital costs become excessive below an output capacity of around 10 MW due to economies of scale. There is considerable opportunity to develop new power plants, particularly of small to medium size, without significant environmental or economic problems. These are particularly attractive in sites where most of the other power production infrastructure is already in place. Yet it is probably unrealistically to think that small power plants can by themselves meet all of Ontario's energy challenges.

2.4 Deep Lake Water Cooling Project cools Toronto

Toronto has developed an alternative cooling system, which uses the cool energy in cold water (4^0C) to air condition high-rise buildings in downtown Toronto. This innovative system has great environmental benefits as it reduces energy consumption, and so reduces carbon dioxide emissions.

2.5 Geothermal

Geothermal systems are offering relief for many homes and businesses and could reduce total energy demand. A geothermal, heat pump is a mechanical appliance that transfers heat from one source to another pulling heat from the earth and transfer it to homes or buildings. Heat pumps can provide both heating and cooling using 30%-70% less electricity than conventional electric heating and cooling systems.

5. Public Policy

Perhaps nowhere in recent experience have engineering insights and public policy development interacted more strongly than in the intersection of energy, environmental and the economic issues. Take, for example, the seemingly straightforward question of what light bulb to choose and whether to replace inefficient refrigerator.

Significant attention related to environmental-energy policy has been focused on the question of which are better, fluorescent or incandescent light bulbs?

The question seems at first glance clear, yet the answer, which is critical to good policy, is not. Conventional wisdom suggests that fluorescent bulbs are preferred because they consume less energy in the form of "wasted" heat. Yet, in a cold Canadian home during winter, is the heat emitted by such a bulb really wasted?

If lights do indeed provide a kind of electrical subsidy to fossil fuel heating, than should the policy choice take into account the electrical and heating technology mix? And when does the symbolic power of a simple action get lost in the complexity of real world evaluation? These are not easy questions [12].

In a similar way, due to the balance of heating and cooling in a house, the replacement of old refrigerators in cold countries generates significantly less energy and cost savings than expected. Furthermore, the provincial electricity mix and the use of different energy sources to meet heating and cooling requirements lead to a smaller decrease in GHG emissions than expected, and in some provinces, actually increase GHG emissions.

As expected, detailed analysis shows that there is an overall household reduction in energy use for each province when replacing the old refrigerator by an efficient one; however, these energy savings are less than what we would expect when looking at the energy consumption of refrigerators alone. Actually, effective energy savings are only between 10 and 50% of expected energy savings based on consideration of refrigerators efficiency alone (see Figure 1). This is because of the increase of space heating energy requirements caused by the replacement of the refrigerator.

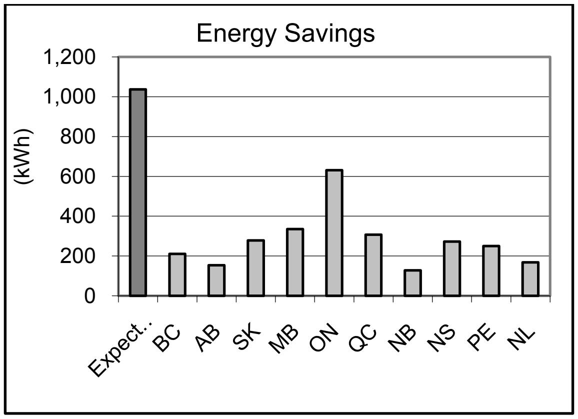

Figure 1: Energy savings expected and estimated in this study for Canadian provinces: British Columbia (BC), Alberta (AB), Saskatchewan (SK), Manitoba (MB), Ontario (ON), Quebec (QC), New Brunswick (NB), Nova Scotia (NS), Prince Edward Island (PE), and Newfoundland and Labrador (NL).

On the other hand, the replacement of an old refrigerator in provinces such as British Columbia, Manitoba, Quebec, and Newfoundland and Labrador causes an increase of GHG emissions. This striking consequence can be explained by the energy sources used to meet heating requirements and used for electricity generation. In these provinces, hydroelectricity produces little GHG. A part of the households are heated with electricity. For these households, the replacement of the old refrigerator doesn't have any consequence on GHG emissions. But other households are heated with oil or natural gas, which are GHG emitting technologies; in such households, the replacement of the refrigerator causes an increase of GHG emissions. The percentage change of GHG emissions is least for Newfoundland and Labrador where it represents an increase of 2% of residential GHG emissions in 2002 and greatest for British Columbia where it represents an increase of 5% of residential GHG emissions (see Figure 2)

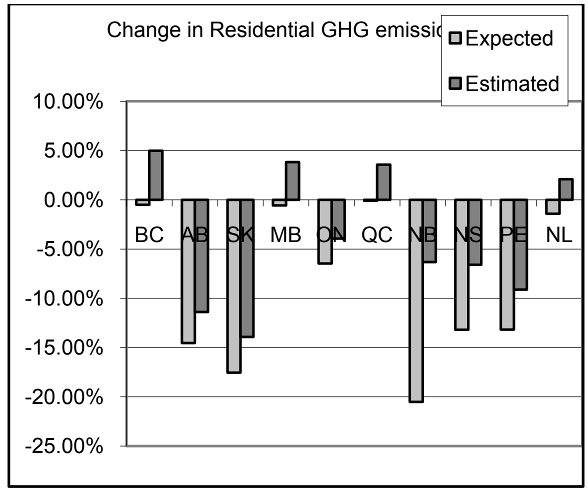

Figure 2. Changes expected and estimated in this study in residential GHG emissions in Canadian provinces

6. Conclusion

We have summarized a new vision for Ontario's future energy infrastructure, with comparison to current plans, which may be necessary responses to stresses over energy supply. Two investments – using plug-in hybrid electric vehicles to begin to displace the conventional automobiles fuelled by gasoline along with an improved electrical grid supplemented by strategic investments in electrical production – may well be required to reduce Ontario's dependence on fossil fuels.

Under current provincial plans to rejuvenate the electricity grid, phasing out coal, and to provide an extensive new transportation system for the GTHA[4], Ontario is expected to spend on average about $5 billion per year. To put the main infrastructure components in place for the new scenarios will likely require up to another $2 billion per year. This rough estimate does not include increases to transmission capacity or purchasing of land [25].

Electricity has great potential as a future energy source for transportation. If generated from sources other than fossil fuels, then electricity provides a low polluting means of propelling transportation vehicles. Moreover, with advances in plug-in hybrid electric vehicle

[4] Greater Toronto and Hamilton Area

technology, there is potential to exploit the greater efficiency of electric motors over conventional internal combustion engines. In order for electric vehicles to replace fossil fuel vehicles, however, it is necessary to provide more power generation capacity. Electricity has to be provided in excess of current demands thereby enabling other energy sectors to shrink.

A future in which current levels of automobile use are simply replicated by electric vehicles is, however, undesirable on economic grounds. Current levels of automobile use in Ontario are excessive. Levels of congestion are so high, e.g., currently costing the GTHA economy $2.7 billion per year [26], [27], that the Province plans substantial new investment in public transportation systems. The economic effects of designing highly automobile dependent cities is decreasing productivity and worrying decreases in household savings rates due to over consumption.

In order for Ontario to meet its long-term GHG reduction target (80% below 1990 levels by 2050) it will need to take an even more integrated view of energy use in the province.

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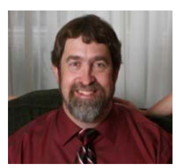
Tihomir Maricic graduated in Mechanical Engineering from University of Nis, Yugoslavia, in 1981. After the graduation he joined the crew of the builders of Iron Gates 2 Hydroelectric Development Project. For more than 10 years, through the variety of positions he has gained substantial and wide experience in hydro equipment design, manufacturing and installation. After moving to Canada, he has used this experience in international and domestic hydro projects as a design engineer, consultant and project engineer for service and rehabilitation. 2006 Tim has joined Ontario Power Generation as a Senior Plant Engineer with Asset Management Department of Niagara Plant Group. Tihomir (Tim) Maricic is a licensed Professional Engineer in the Province of Ontario.



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