# *Proposal of an Online Master of Science in - Exergy & Sustainable Development*

## *Program aim*

The aim of the program is to prepare students for a professional career in the design of technical systems that meet the need for environmental, social and economic sustainability. In addition to in-depth knowledge of technical processes and systems, students will be trained to understand the basic challenges of sustainable development, with specific focus on the challenges that face the energy system. Training is provided in the use of exergy based optimization and modeling tools for systems analysis, design and planning at the technical plant level as well as at regional and global levels. In order to provide in-depth knowledge, the program is focused primarily on energy conversion systems including the distribution and use of electricity, heat and cooling, and the transportation system. The program is unique in that it deals with these issues on overall perspective systems levels and that the courses are integrated so as to train students to approach problem solving in an interdisciplinary way.

## *Introduction*

Sustainable development has become a central concept in politics as well as in education in most of the world and the UN has declared 2004–2014 the *Decade of Education for Sustainable Development*. In 2002, i.e., ten years after the World Summit in Rio de Janeiro the Swedish government agreed on a National Strategy for Sustainable Development *Sweden's National Strategy for Sustainable Development 2002*[1], that was further elaborated in a new declaration in 2004 *A Swedish Strategy for Sustainable Development – Economic, Social and Environmental*[2], that in turn was updated in 2006 *Strategic Challenges – A Further Elaboration of the Swedish Strategy for Sustainable Development*.[3] In all these declarations education is stated of main importance: *Education and research in combination with skills training that reflects sustainability concerns is one key to sustainable social development in Sweden and around the world. …A sustainable development perspective must permeate all education and learning. While such an approach should convey a message, its most important objective is to provoke active participation and critical thinking about building a sustainable society*[4]. This brings expectations to be met by the educational systems in all programs at all levels and in particular at graduate level.

Sustainable development is mostly an educational task. Recent warnings from the IPCC (Intergovernmental Panel on Climate Change) all but confirm an ever increasing climate crisis[5]

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[1] Government Communication 2001/02:172, Sweden's National Strategy for Sustainable Development 2002, http://www.sweden.gov.se.

[2] Government Communication 2003/04:129, A Swedish Strategy for Sustainable Development – Economic, Social and Environmental, Swedish Ministry of the Environment, EO Print AB, June 2004, http://www.sweden.gov.se.

[3] Government Communication 2005/06:126, Strategic Challenges – A Further Elaboration of the Swedish Strategy for Sustainable Development, http://www.sweden.gov.se.

[4] Ibid, p. 70.

[5] IPCC 2007, Intergovernmental Panel on Climate Change, *Climate Change 2007*, http://ipcc-wg1.ucar.edu.

due to human activities, e.g. the release of carbon dioxide into the atmosphere from the use of fossil fuels. The increasing lack of understanding and action reveals a need for knowledge with more of a holistic view of the situation. All related and relevant areas from both natural and social sciences must be treated simultaneously together with a focus on sustainable development issues to gain understanding of the problems. Interdisciplinary studies and activities are a natural ingredient together with problem oriented approaches and a focus on moral issues are also to be encouraged. This in turn implies educational and pedagogical challenges in order to create prosperous knowledge and understanding for the development towards a sustainable or rather vital society. The UNESCO project *Encyclopedia of Life Support Systems*[6] is but one project that offers essential knowledge to such activities.

Exergy is a suitable scientific concept in the work towards sustainable development. Exergy accounting of the use of energy and material resources provides important knowledge on how effective and balanced a society is in the matter of conserving nature's capital. This knowledge can identify areas in which technical and other improvements should be undertaken, and indicate the priorities, which should be assigned to conservation measures. Thus, exergy concept and tools are essential to the creation of a new engineering paradigm towards sustainable development.

*Exergy and Sustainable Development* is closely related to *Industrial Ecology* and *Sustainable Engineering* that are relatively new areas of education and research that are rapidly emerging on a global scale. Exergy and Sustainable Development has its roots in the field of exergy and its applications towards sustainable development and is the least developed field amongst these. Exergy and Sustainable Development aims at a sustainable co-existence between engineering and the environment and the analogy between natural and technical systems and processes is a core concept. Processes in nature, where cycles are closed and waste from one process is input for another, are models for socio-technological processes. Exergy and Sustainable Development is in particular focused on the bases of engineering and engineering design with regard to sustainable development concepts and conditions.

The concept of exergy dates back the origin of thermodynamics and the work of Carnot in 1824. In 1977 the concept was first introduced by Wall[7] as a useful concept within resource budgeting in order to improve resource use and decrease environmental impact. Since then the exergy concept has turned out be one of the most promising concept to meet the need for an industrial development towards harmony with the natural environment. A number of international publications do recognize exergy as Energy, the International Journal (since 1976 published by Elsevier, http://www.elsevier.com) that in 2002 incorporated Exergy, An International Journal. The interrelated field of Industrial Ecology was introduced by describing the analogy to nature. This field has grown fast with a number of education programs and with the Journal of Industrial Ecology (since 1997, published by MIT Press, http://mitpress.mit.edu/JIE) and the International Society for Industrial Ecology (since 2001, http://www.yale.edu/is4ie). The interrelated field of Sustainable Engineering is the youngest of these areas, however, with a very strong potential to grow with the Centre for Sustainable Engineering (http://www.csengin.org). Carnegie Mellon University, the University of Texas at Austin, and Arizona State University established the Center for Sustainable Engineering in 2005, supported by the National Science Foundation and the Environmental Protection Agency. Sustainable Engineering may be defined as engineering

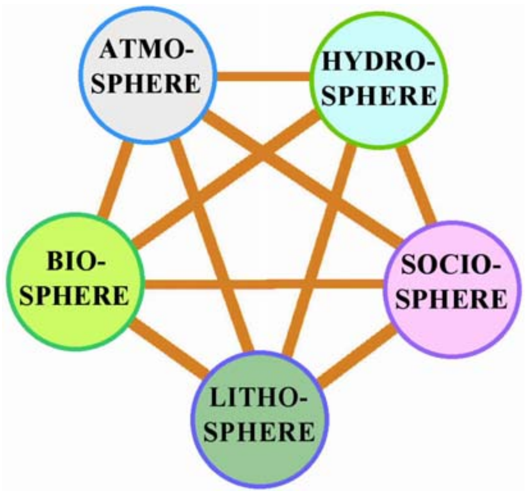
[6] EOLSS, Encyclopedia of Life Support Systems, www.eolss.net

[7] 1977 G. Wall, "Exergy a Useful Concept within Resource Accounting," Report No. 77-42, 58 p., Institute of Theoretical Physics and Mechanics, Chalmers University of Technology, Göteborg, Sweden, http://www.exergy.se/ftp/ex77c.pdf.

for human development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Bruntland Commission, 1987).

## *The Biosphere and the Human Society*

On the surface of the Earth, at many different levels of size and of time-scale, systems operate by involving many kinds of matter in a complex pattern. Energy and matter permanently flow through different systems on the Earth's surface. Many branches of science, e.g. hydrology, climatology, oceanography, and ecology, study this. It is impossible to fully understand how all these systems and flows of energy and matter cooperate. The Figure below offers a model for all the systems of the Earth's surface simplified by a network of 5 spheres; atmosphere, hydrosphere, lithosphere, biosphere and sociosphere or technosphere, i.e., the human society with all its industrial systems.




*The Earth as five spheres in mutual interaction*

The industrial system includes both the industrial complexes or industrial process systems and all kinds of technological systems used in the exploration-production-consumption chain. The following consideration are important steps in an exergy and sustainable development approach:

- In the biosphere, evolution has resulted in efficient use of materials and energy in systems to build and break down functional materials into increasing deposits of exergy capitals that are of essential important to life, if we consider planet earth as one system.
- In the sociosphere, deposits of exergy capitals are exploited and harmful waste streams to soil, water, and air are produced. The exergy capital of the earth is depleted and an unsustainable situation occurs.
- By learning from the biosphere, society may design and manage its socio-technological processes in a more sustainable manner, resulting in speeding up technological evolution towards a sustainable development and increasing of the exergy capital of the earth.

## *Program idea*

The focus of the program is on the sustainable development of the industrial society, through the interaction of various scientific fields like science, engineering, environmental sciences, economics, policy sciences, and technology. In practice this is an interdisciplinary activity, where engineers, natural scientists, and social scientists cooperate together in defining the situation, finding solutions for environmental problems and shaping sustainable development.

Since sustainability has become a global issue of high statues, there also has been a call to include it in education programs at both undergraduate and graduate levels. In learning a profession or being schooled in a science, it is no longer possible to ignore sustainability aspects. The general view is that the place of the profession in the wider context of society, the consequences of actions for the environment or global equity etc. should be a part of the education program. This could be seen as a modern version of the science and society courses of earlier days, wherein also the need for the broader societal context was translated into education programs. In many universities, it is now possible to follow courses on sustainability issues related to one's own profession.

The main focus of this education program is on the scientific analysis, design, and implementation of technological activities in analogy to the ecological system and in such a way that the environmental impact is minimized in order to establish sustainable development.

However, if sustainability is indeed a societal important issue; it should not only be a side issue in curricula of all sorts. There must also be a source of new ideas on how to think about sustainability and how to make it a natural part of engineering and technical design. It requires the development of concepts, theories, tools and methods, which can be used by engineers. Therefore, it requires people who occupy themselves with sustainability as a profession. These people then can feed the sustainability courses in other curricula.

Designing a curriculum to teach students to think about sustainability in a coherent manner is not easy. As in the early days of *Environmental Science*, there is the danger of overloading the program with cases-in-point, while the theoretical background and the development of concepts and methods lag behind. It would therefore be easier if there were a science or research field already out there, around which a curriculum can be shaped. Therefore, *Exergy and Sustainable Development* is a good candidate for an education program to train students in thinking about sustainability, for the following reasons:

- *Exergy and Sustainable Development* is a specific scientific field with a clear focus on sustainability and sustainable development.
- The object of investigation, the physical economy, so far offers the only real integrative view on society and environment.
- *Exergy and Sustainable Development* is styled as an interdisciplinary research field, because engineers, natural scientists, and social scientists cooperate together in this field. An interdisciplinary attitude is a requirement in order to do justice to all three aspects (societal, environmental, and economic) of sustainability.
- The organization of the physical economy in analogy to the natural ecosystems, is a real object of investigation that allows coherence that may be lacking in other interdisciplinary fields. *Exergy and Sustainable Development* has developed and will develop theories and methods of its own for studying this object.

The compulsory part of the program is broad enough for a useful interdisciplinary teaching and the elective part of the program gives the student enough specialization.

## *Learning outcomes and career opportunities*

The main idea of the program is to give students in-depth knowledge of how physical resources are used in the society and how this use can be made sustainable. Of special importance is to provide tools for the description and design of the energy supply from the level of local components up to the global level. The program combines the analysis of both the present resource use with its environmental impact and the limitations and possibilities of future technologies. Supply and demand of physical resources are examined.

Graduates have a thorough insight into the possibilities and limitations of technical systems in relation to exergy and sustainable development, including economic aspects. More specifically, graduates will be able to:

- Demonstrate knowledge of the technical characteristics of exergy-efficient conversion and end-use technologies
- Understand the physical opportunities and constraints associated with the use of different physical resources, conversion and end-use technologies, as well as the major challenges facing these systems from a local and global sustainable development perspective
- Design and evaluate the supply and conversion solutions for utilities, buildings, energy-intensive processes, etc with regard to exergy and sustainable development
- Model, simulate, predict and evaluate processes and systems, also with limited or incomplete information. In particular, students will be able to apply different tools for systems analysis such as exergy analysis, life cycle analysis, systems modeling and exergy economic accounting and optimization tools
- Contribute to strategic planning of energy systems and technologies based upon a working understanding of the principles of exergy and sustainable development

Graduates will be well prepared for tasks such as design, development and implementation of sustainable systems and technologies and to work out policies for initiating such tasks. Examples of career opportunities after graduation from the program include the utility and process industry, the energy supply sector, larger municipalities, consulting companies, energy equipment manufacturers, research institutes and government agencies.

## *Program outline*

The Exergy and Sustainable Development program has a global perspective and the common language is English in order to attract students from all over the world, and in particular from less developed countries. The program is available online and the literature will be available free of charge from the Internet. Only the final MSc thesis must be presented in person. However, if this is not economically feasible then measures will be taken to assist this. The study program consists of a two year curriculum. The first year focuses on the core concepts of Exergy and Sustainable Development and the second year on applications of these concepts to real or realistic systems. Subjects are practice-focused and education is managed by quality principles, i.e., taught and examined by means of activity in forums, hand in of assignments and project reports, together with evaluations and actions taken. The program provides eventual possibilities for exchange with foreign universities and companies. The program is finalized with an individual research trajectory culminating in an MSc thesis that will be presented in person at a yearly conference like event. Multidisciplinary activities will be encouraged in order to learn to analyze a problem from different points of view and to discover the added value of working in multidisciplinary environments.

The study load is given in European Credits (EC). A full year of study is 60 EC study time, according to the European Credits Transfer System (ECTS). 1 EC is 28 hours of study and 60 EC is about 1700 hours.

| Master Program on Exergy and Sustainable Development | | | |
|---|---|---|---|
| **1st year** | | | |
| **Period 1** | **Period 2** | **Period 3** | **Period 4** |
| **Sustainable Development - Introduction 15 EC** | | **Exergy Analysis 7.5 EC** | **Environmental Management Systems 7.5 EC** |
| **Quality Management 7.5 EC** | **Exergy 7.5 EC** | **Sustainable Energy Systems 15 EC** | |
| **2nd year** | | | |
| **Period 1** | **Period 2** | **Period 3** | **Period 4** |
| **Sustainable Development - Analysis 15 EC** | | **Master Thesis 30 EC** | |
| **Exergy Economics 7.5 EC** | **Life Cycle Exergy Analysis 7.5 EC** | | |

## Sustainable Development - Introduction (15 EC)

The natural ecological system and the evolution of life. Introduction to activities linked to resource depletion and environmental destruction. Principal mechanisms operating in nature and in the society. Restrictions and opportunities that follow from the need to transform society to conform to sustainable development.

The industrial society, its history and present state, peak oil. State and Trends of the Environment, Atmosphere, Land, Water and Biodiversity. Global environmental situation, global warming and regional perspectives. Human Dimensions of Environmental Change. The near future situation. Basic concepts of SD. Indigenous knowledge, so called primitive cultures and permaculture or development of agricultural ecological systems as to be capable of being sustained and independent. Physical, Ecological and Social principles of SD. Status and trends of SD worldwide regarding biological diversity, climate changes, material flows, food production, health, water purification and sustainable energy systems. Furthermore, issues of human and industrial ecology are treated, together with economical and political strategies in order to meet the need for SD.

Study visits in order to expose the lack of SD in the society and to come up with proposals to meet this. Suitable targets are for example waste handling, sewage treatment, food production, local means of transportation, indoor climate systems, water facilities, energy supply systems or impact on the living environment from pollutions or toxics.

## Quality Management (7.5 EC)

History of industrial management. The concept of the continuous improvement or Shewhart cycle (Plan Do Check Act), Statistical method from the viewpoint of quality control. The Deming 14 points: create constancy of purpose, adopt the new philosophy, cease dependence on mass inspection, constantly and forever improve the system, remove barriers, drive out fear, break down barriers between departments, eliminate numerical goals, eliminate work standards, institute modern methods of supervision, institute modern methods of training, institute a program of education and retraining, end the practice of awarding business on price tag, put everybody to work to accomplish the transformation. Variation and the control of processes. Joy in learning. Cooperation. Profound knowledge. Learning organizations. This course offers you a number of suitable tools in quality management, e.g., Kaizen, Ishikawa diagrams, ISO 9000, etc.

### Exergy (7.5 EC)

Exergy is a fundamental and general concept to measure physical value of systems and resources of energy, matter and information. Exergy is of utmost importance in the physical understanding and analysis of real systems and plays an important role in order to meet the need towards sustainable development. This course offers you the knowledge to apply exergy to real systems or within other fields of study. In a project work you are given the opportunity to apply exergy to an area of your interest.

### Exergy Analysis (7.5 EC)

Assessment tools include energy models, cost-efficiency analysis, and investment analysis. Exergy Analysis may increase the efficiency of systems and processes that convert resources of energy, matter and information. Exergy analysis is applied to real systems or within other fields of study. In a project work you are given the opportunity to apply exergy analysis to an area of your interest.

### Sustainable Energy Systems (15 EC)

A system perspective on the industrial society with emphasis on the use of energy and material resources. Development of future energy systems adopting a wide systems perspective. Assessment of new energy technologies and systems that can be used to mitigate negative environmental impacts, with respect to costs and technical potential. Knowledge of the present energy and resource use situation, alternative resource use and other measures as conservation and planning to find better solutions for future resource use in the society. Training in writing, presenting and reviewing a technical report.

### Environmental Management Systems (7.5 EC)

Present global environmental crisis requires among other things a careful management strategy. In addition the increasing market globalization implies further improvements to meet a stronger economic competition, a lack of non renewable resources and an even more critical environmental situation. This course offers you a number of suitable tools in this regard, e.g., ISO 14000, EMAS, and many others. In a project assignment the student is given the opportunity to apply these to real cases of your interest.

### Sustainable Development - Analysis (15 EC)

Introduction to issues linked to sustainable development. Global material flows. Systems perspective on industrial society, with emphasis on the restrictions and opportunities that follow from the need to transform society to conform to sustainable development. Focus on the activities in society that cause environmental and resource problems, and on strategies (including analytical tools) to address the problems. Sustainable development is introduced as a concept within an organizational and management theory perspective that is essential to the reduction of resource depletion and environmental destruction. Presentation of realistic and effective actions towards sustainable development by means of individual projects.

### Exergy Economics (7.5 EC)

Application of cost-benefit analysis, including taxes, subsidies and other governmental means to technical applications and industrial processes. Cost functions for important unitary processes. Exergy economic accounting and optimization, with Lagrange multipliers and relation to direct prices, shadow prices and marginal prices. Different methods of optimization and their applications. Methods to optimize the design of heat exchanger networks and systems that also contains other energy conversions, e.g., Pinch Technology and Energy Utility Diagram.

### Life Cycle Exergy Analysis (7.5 EC)

Study of analytic tools such as Life Cycle Assessment, Material Flow Accounting, Substance Flow Analysis and Life Cycle Exergy Analysis, and of the application of such tools to relevant sustainability issues. Sustainable engineering as engineering and sustainable design as design that increases the exergy capital of the earth. Life Cycle Exergy Analysis of a suitable process or system of choice.

### Master's thesis (30 EC)

Each student is assigned an individual thesis project of 5-6 months of work (30 EC). The project may be carried out in an academic environment (university, research institute, or equivalent), in an industry, at a consulting agency, or similar. It is also possible to do the thesis with supervision from a teacher of the Exergy and Sustainable Development program.

## *Application and admission*

### Admission requirements

General admission requirements are together with a Bachelor of Science (180 EC).

### Selection Process

The selection process is based on a total evaluation of the following selection criteria: university, GPA, course work related to the program, thesis proposal, relevant working experiences and references.

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