Design of sustainable energy systems : a new challenge for Engineering Education

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***Abstract* –This paper presents the main features of the master-level programme in "EcoEnergy" offered as a full-time one year course at "Institut National Polytechnique of Toulouse" in order to provide engineers with a state-of-the-art education in the area of advanced energy technologies and systems. It is based on an original and equilibrated combination of process systems engineering and electrical engineering disciplines, with an interdisciplinary problem-solving approach necessary for identifying sustainable solutions in the energy sector. More precisely, the students learn how to design, develop and implement energy systems and technologies in various industrial sectors for which efficient management of energy issues is vital to remain competitive.**

Keywords: Education, Sustainable development, Energy, Process Systems Engineering, Electrical Engineering

I. INTRODUCTION AND MOTIVATION

The energy sector represents up to 50% of the whole ecological footprint of humanity. The main Development of sustainable energy system solutions constitutes a real challenge as a result of the global warming problem together with depletion of fossil fuel resources. This constitutes an important technical challenge to the engineering community. In that context, there is a clear need to educate engineers who can respond to these challenges by considering factors beyond the traditional process, product, or enterprise.

Electrical engineering, along with other disciplines, needs to focus on the sustainability of its activities. Indeed, electricity production is the first factor of artificial carbon dioxide emission by mankind on Earth. On another hand, electricity exhibits a lot of assets for an improved penetration of energy sectors, due to its low direct emissions, high efficiency and flexibility and also as a favoured vector for renewable and nuclear sources. So it is necessary to manage new processes of electricity production and treatment with low emissions from renewable energy sources but also from fossil and nuclear as well. Moreover electrical engineering have the advantage of a great ability in holistic or systems approach; it has developed many types of energetic models which is very useful for understanding complex systems.

Chemical engineering is also implied by such a goal, particularly processes which are inherently involved in mass and energy transformations, in energy production and storage and for the treatment of fossil or renewable fuels. Moreover, among all the specialities of chemical engineering, process systems engineering (PSE) is perhaps best positioned to address the challenges of sustainability, since PSE also adopts a holistic or systems view, which is essential for understanding and modelling the complex interactions between industry, society and ecosystems. Such methods will become increasingly important for both new and existing technologies at all stages of their research, development, and use.

It must be emphasized that traditional course programmes (MSc or Engineer level) are generally based on either environmental engineering for quantifying environmental impacts, or on energetic topics involving mainly thermal energetic processes, or on electrical engineering with electricity-oriented energetic processes, or on chemical and process engineering focused on mass and energy transformation.

All these factors participate to a situation which presents unprecedented challenges and exciting opportunities for both Electrical Engineering and PSE to play a crucial role in the quest for sustainable energy systems.

In that context, the aim of the master-level programme in "EcoEnergy" offered as a full-time one year course at "Institut National Polytechnique of Toulouse" is to provide engineers with a state-of-the-art education in the area of advanced energy technologies and systems. The key feature of the programme is based on an original and equilibrated combination of *process systems engineering* and *electrical engineering* disciplines, based on an interdisciplinary problem-solving approach necessary for identifying sustainable solutions in the energy sector. As shown on "Fig. 1" for example, the fuel cell inherently illustrates the motivation to use and combine concepts of both disciplines to cover the chain of electricity production (mainly electrical engineering oriented) from a portfolio of various sustainable process alternatives (mainly process systems engineering oriented).

More generally, the students learn how to design, develop and implement energy systems and technologies in various industrial sectors for which efficient management of energy issues is vital to remain competitive. The assessment of both current and potential future energy systems is covered and includes topics on resources, extraction, conversion, and end-use, with emphasis on energy needs in the 21st century in a sustainable manner. Different renewable and conventional energy technologies are presented and their attributes described within a framework that aids in evaluation and analysis of energy technology systems.

The remaining sections of this paper present the learning objectives, the teaching strategy, the state of development and career opportunities induced by the the "EcoEnergy" programme [1].

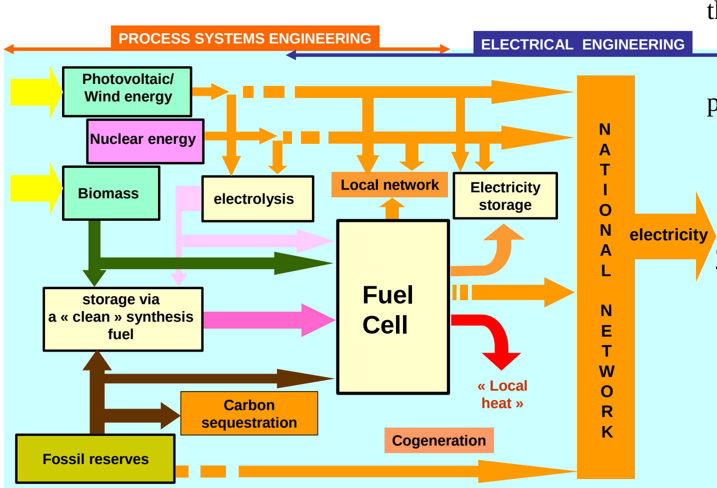

Fig. 1. The fuel cell example: the core of a future energy portfolio mixing electrical engineering and process systems engineering disciplines.

II. LEARNING OBJECTIVES

A first motivation of the "EcoEnergy" programme was to practice an interdisciplinary approach between two engineering disciplines, namely Process Systems Engineering and Electrical Engineering to tackle the sustainable energy issue, "Fig. 2".

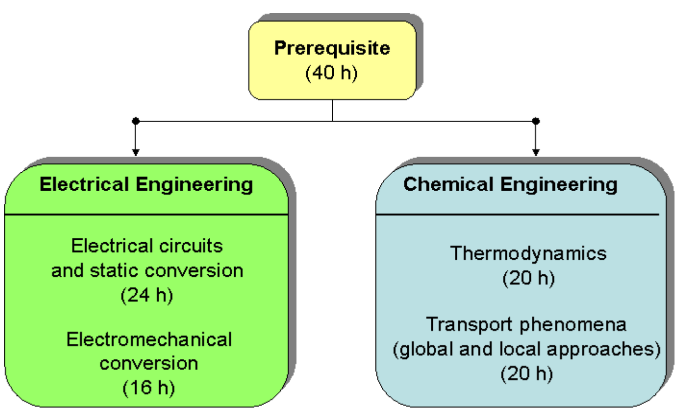

Fig. 2. Prerequisite for the Ecoenergy programme.

For this purpose, a prerequisite was to provide the students with the key subjects of both disciplines that are typically relevant with the specific energy subjects that will be the core of the programme. Of course, the chemical process engineering students will not become specialists of electrical engineering and conversely. The integrated prerequisite subjects are presented in Fig. 2. Let us mention that this period is strongly interconnected to the other common courses so that the students can be mixed as earlier as possible to favour interdisciplinary dialogue. Since this programme may be accessible from students of other disciplines (e.g. fluid mechanics or biochemical engineering), the courses are not arranged in parallel.

The programme is then based on a 3 components-based platform shown on "fig 4":

1. <u>general scientific disciplines</u> to give a global overview on energy electrical networks and converters, electrochemistry, electrical interfaces, electrocatalysis;
2. <u>a methodology framework</u> which highlights systemic approach on energy conversion : analysis and design of complex processes (e.g. process simulation, pinch technology), criteria for assessing the sustainability of energy technologies, integrated processes, Bond Graph modelling, electrochemistry modelling, hybrid architectures, energy storage, optimization tools for decision-making (mutiobjective optimization based on stochastic algorithms, e.g. Multiobjetcive Genetic Algorithms), ecodesign based on e.g. Life Cycle Assessment, and carbon balance, optimal control;
3. <u>specific energy technologies</u> from components to systems: overview of energy supply portfolio, fossil fuels and fossil energy, hydropower energy, nuclear energy, wind power, solar photovoltaic energy, fuel cell and distributed energy, electrochemical components, advanced heat exchanger technologies, solar thermal energy, bioenergy, hydrogen energy, greenhouse effect and CO_2 treatment processes and sequestration….

These underlying objectives can be revisited to give an energy-centred organization: the program builds upon 7 compulsory core courses "Table 3" (27 ECTS credit units in all). The other ECTS credit units (18) are assigned to English and industrial training periods.

Course package	Module	ECTS	Evaluation mode
Industrial period (4-6 months)		31	
English		2	Report, oral examination
Thematical seminars on energy	Fossil fuels and fossil energy,		
	Natural gas transport, Biomass energy		
	Solar energy, Wind energy, Hydrogen		
	Nuclear energy,		
	Industrial and residential buildings, CO2	3	Report
Systemic design	Process analysis and design	2	CSP
	Bond Graph systemic modelling	2	CSP
	Optimal control		
	Optimal design	2	CSP
Ecodesign	Life Cycle Assessment	1	CSP
	CO2, greenhouse effect, sequestration	1	CSP
Electrochemical components	Electrochemical components	3	CSP
	Fuel cells		
	Electrochemistry		
	Electrified interfaces, electrocatalysis		
Electrical networks and hybridation	Electrical networks, static conversion	3	CSP
	Distributed and embedded networks		
	System energetic hybridation		
	Hybrid vehicle SABER		
Renewable energy	Photovoltaic energy	2	CSP
	Wind energy		
	Bioenergy	2	CSP
Project	Case study	6	Report, oral examination
TOTAL ECTS		60	

Table. 3. Course organization in Ecoenergy program
This table is also in full size at the end of the paper

III. TEACHING/LEARNING STRATEGY

One of the drivers of the programme was to develop teaching/learning methods and strategies closely mixing academic/industry professionals combining lectures, seminars, computer-based work, practical experimental work and projects….

A lot of courses are computer-intensive (hybrid systems studied with Bond Graph simulator or SABER, heat integration scenarios performed with ProSim simulator).

A practical case study concerns the fuel cell application: two complementary methodologies of experimental characterization are carried out, dynamic plot of fuel cell voltage as a function of current density and impedance spectroscopy [2]. This experimental part then leads to the parameter identification of a PEM fuel cell. The behaviour of the PEM fuel cell performance is then studied as a function of disturbance generated by connected static converters.

The validation of the course module is carried out by case study projects referred as CSP performed by multidisciplinary student teams (3 or 4). Their detailed presentation can be found at http://www.ensiacet.fr [1].

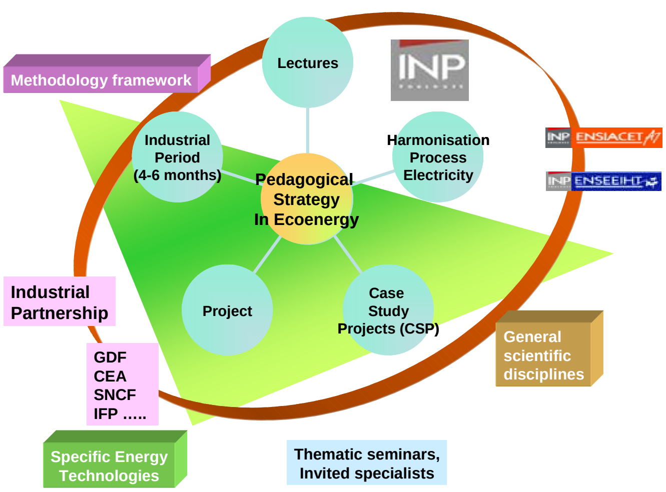

Fig. 4. Pedagogical strategy in the EcoEnergy programme

Thematic seminars on energy are organized one day a week to favour industrial involvement in the programme. Let us mention that an industrial partnership was initiated at the preliminary design phase of the programme (CEA, IFP, GDF …). Although these seminars are devoted to the presentation of specific topics on energy such as CO_2 process treatments and sequestration (IFP), hydrogen as a future energy vector (CEA), nuclear energy (CEA), gas networks (GDF), wind energy (EdF Energies Nouvelles) and so on…, a large place is given to debate in order to strengthen students' oral communication skills on the given topic. Groups of students have to write alternately a report on these seminars in English and diffuse it rapidly both to the class and to the pedagogical team.

A more general case study project (approximately up to 100 h) is also proposed to multidisciplinary student teams. The project subject is submitted in the second month of the programme to facilitate literature analysis (4h every two weeks) and a progressive knowledge of the subject. Then, an intensive period is scheduled over all the last month so that they can concentrate their attention to the technical choices and design phase. Industrial partners are involved in the definition of the subjects.

For the sake of illustration, let us mention some projects treated by student teams in 2006-07 and 2007-2008:

- Design of the electrolysis zone in a hydrogen production plant using High Temperature steam Electrolysis coupled with a Very High Temperature nuclear Reactor (with CEA, Commissariat à l'Energie Atomique, Cadarache);
- Investigation on the electrical system of a Shell eco-marathon fuel cell vehicle (with INSA, Institut National des Sciences Appliquées, Toulouse), [3].
- Production of biogas fuel for Toulouse buses.
- Solar generator for the future laboratory building in ENSEEIHT

The industrial period (4-6 months) is the opportunity for students to apply and further develop the skills acquired in the technology of their programme during a placement in an energy company or a research centre. A tutor from the host company supervises and guides the student during project work, while a second supervisor from the university will supervise the evolution of this industrial period.

Typical industrial projects carried out in 2006-07 are following:

- Contribution to the development of a wind project (EdF energies nouvelles);
- Geothermal energy valorisation in Alsace (in an electric company);
- Membrane-based process for hydrogen production and purification from oil-based fuels (ARC Centre for Functional Nanomaterials, The University of Queensland St Lucia, Australia);
- Improvement of the energetic and environmental performance of Midi-Pyrénées secondary schools.

IV. STATE OF DEVELOPMENT

The EcoEnergy programme opened in 2006-07 with 15 students (11 students from electrical engineering, ENSEEIHT, INPT, 4 from ENSIACET INPT). In 2007-08, 22 students attend this programme (8 students from electrical engineering, ENSEEIHT, INPT, 13 from ENSIACET INPT (mainly from process systems engineering department), 1 ERASMUS student from Germany. In parallel, a New Energy Technology Mastere (from "Conférence des Grandes Ecoles" was created in 2007 with the same pedagogical objectives (even if the form may be a little different) and 3 engineers from industry joined this programme.

V. CAREER OPPORTUNITIES

The EcoEnergy programme is designed to deliver qualified engineers equipped with the latest skills and the right experience for a successful career in the energy industry.

Of course, many traditional energy industry sectors are likely to recruit students graduating from this programme: this is all the more important as companies have to integrate sustainable considerations in their activities. It must be pointed out that the issues surrounding the role of energy extend far beyond the energy sector, since energy use is integral to many chemical and process activities. The concepts developed find here a logical application.

Yet not surprisingly, the renewable energy industry seems very attractive to offer motivating career opportunities. As reported by EUREC, the European renewable energy (RE) industry is today one of the fastest growing industry sectors in the EU. The renewable energy industry, because it is labour-intensive, creates employment at much higher rates than many other energy technologies. New research, industrial and craft jobs appear directly in R&D, production, installation and maintenance of renewable energy systems. Backward linkages to other sectors triggering demand for technical RE expertise exist for consultancies (local, departmental or regional communities in France, for instance).

According to estimations of the European Renewable Energy Council (www.erec-renewables.org) [4], over 1 million jobs for the Renewable Energy sector are likely to be created by 2010, a number that is to double for the new Renewable Energy sector target of 20% by 2020. Even if it is only a small proportion of these employees who require education at graduate level, it is clear that the demand for technical renewable expertise is growing. We hope optimally prepares graduating engineers for jobs in the energy industry.

Moreover, the students show a true strong motivation to join such scientific curriculum which clearly deals with environmental concerns and sustainable development.

VI. REFERENCES

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[4] European Renewable Energy Council EREC: "Renewable Energy Target for Europe", January 2004, Brussels. See www.erec-renewables.org for details

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