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Towards global sustainability: Education on environmentally clean energy technologies

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ABSTRACT

The recent climate change agreement in Paris highlights the imperative to aggressively decarbonize the energy economy and develop new technologies, especially for the generation of electrical energy that are environmentally clean. This challenge can only be addressed by a multi-pronged approach to research and education of the next generation of scientists and engineers as well as informed public discourse. Consequently this requires the introduction of new and comprehensive education programs on sustainable energy technologies for universities and, possibly, high schools. Among others, the new programs should provide in-depth knowledge in the development of new materials for more efficient energy conversion systems and devices. The enhanced level of education is also needed for properly assessing the competing technologies in terms of their economic and social benefits. The increasing recognition of the significance of clean and efficient energy conversion indicates the need for a comprehensive education program to be developed. The purpose of the present work is to consider the structure of both an education program and the related textbook where the energy-related fundamental and applied subjects are presented in a concentrated and uniform manner. Such a textbook could be an education aid for students of energy-related courses as well as the teachers involved in the formulation of the education programs. The textbook, which should be dedicated mainly for students at the undergraduate levels at universities, and possibly high schools, should include in-depth interdisciplinary sections dedicated to energy experts and graduate students. This paper considers the present international efforts in reducing the impact of climate change and the need to develop new technologies for clean energy generation. It is argued that progress in this area requires recognition of hydrogen as the main energy carrier of the future. This work also delineates the goals of the Sustainable Energy Network, SEN, involved in the UN program of Future Earth.

1. Introduction

There is growing awareness that climate changes and the associated global environmental consequences may soon cross a critical point that could be catastrophic for humans. Therefore, there is an increasingly urgent need to take radical steps to transition to global environmental sustainability in order to secure on going global prosperity. Failure to act now will have undesired consequences for future generations who require non-contaminated water to drink, and clean air to breathe. Assuring a sustainable future requires full understanding, and appreciation, of the strong interplay and overlaps among energy, environment, food, water, and climate as schematically depicted in Fig. 1.

The recent historic Paris agreement among 195 countries on adopting a legally binding accord on climate change aims at limiting global warming to 1.5 °C to fulfil the long term goal of keeping the global average increase to less than 2 °C above its pre-industrial level. The agreement signals a global determination to reduce, and ultimately eliminate, the use of fossil fuels in energy generation and to develop alternate technologies. The enthusiastic global reaction to this agreement is reflective of community concerns of the detrimental environ-

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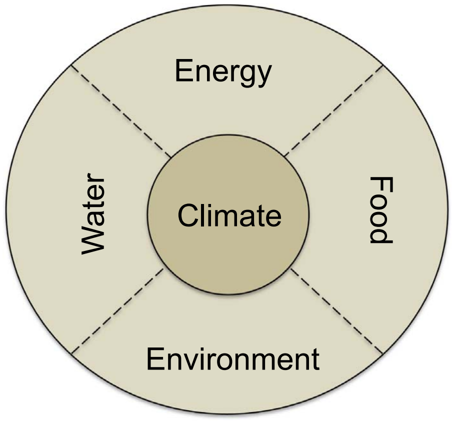

Fig. 1. The great nexus of sustainability.

mental effects of climate change, such as melting of the polar ice, rise in sea levels and increasing frequency of extreme weather conditions leading to more frequent droughts and floods as well as human health concerns. The demand for programs to address climate change will require the training of technical and managerial staff that will be required to implement new energy technologies such as nuclear energy, hydrogen energy and renewable energy.

The United Nations has established the Future Earth program that aims to understand the causes and consequences of global environmental changes, annunciate the goals for Sustainable Development and to advise the international community on the knowledge that is needed for its implementation [1]. The Future Earth program has commenced its visionary process that aims to inform the community on how to avoid detrimental environmental changes. According to the Future Earth 2025 Vision there is the need to develop a new approach that links diverse disciplines and leads to establishment of an agile global innovation system. The success of the Future Earth program requires that the community is actively involved in, supports, and ultimately takes advantage of it.

Energy generation has a major impact on climate change. Therefore, there is an increasingly urgent need to include the energy-related topics in contemporary education programs. The objective of this work is to consider the related interdisciplinary aspects.

The current key goal of the international community is reduction of adverse impact of climate change. A related key goal is to address the question on how the energy can be generated in an environmentally sustainable manner. Therefore, the primary goal of SEN is to establish the framework of a program for universities, and possibly high schools, on Sustainable Energy. The first step towards this goal will be the production of a multidisciplinary Textbook on Sustainable Energy. The textbook is expected to be developed into a dynamic global knowledge system successively adopting new discoveries in energy generation and new educational approaches providing successive generations of students with the skills that are needed for the transformation towards global sustainability. It is expected that energy generation will have a crucial role in the transformation. This work briefly considers the international efforts on reduction of climate change and the critical points of the Future Earth program.

The recent agreement on climate change in Paris (December 2015) indicates growing awareness about the imperative to address the catastrophic deterioration of the environment. The present work considers the related objectives of the UN program of Future Earth and the associated Sustainable Energy Network, SEN.

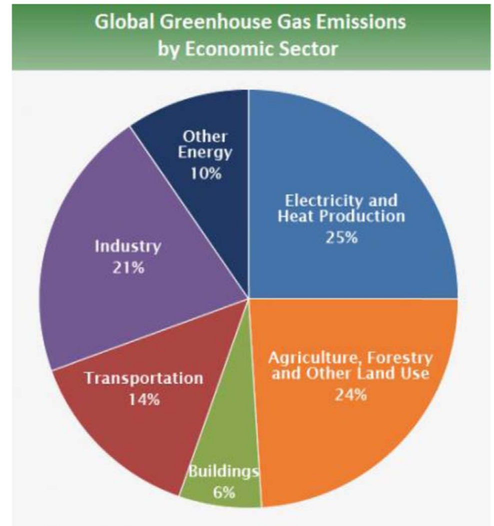

Fig. 2. Sources of global green house gas emissions in 2010 [2].

2. Energy and the environment

The process of photosynthesis, leading to the removal of carbon dioxide from the atmosphere, resulted in the formation of carbon rich fossil deposits over some hundreds of millions of years. Large scale combustion of these deposits is resulting in an unsustainable release of CO_2 to the atmosphere, leading to an enhanced greenhouse effect and consequent climate change, with the potential for catastrophic changes to the environments of the planet.

The main environmental danger is that, owing to human activity, water, air and soil become polluted and contaminated. If this happens, access to clean water, air and food is at risk. It is becoming increasingly clear that a reduction of human induced climate change is required to protect the environment. The UN has organised a range of international gatherings to send strong signals to the global community about the impact of climate change on the environment and the urgent need to address this.

Climate variability is altered by the increased emission of greenhouse gases into the atmosphere. Since the atmosphere does not recognise national boundaries, any tangible strategy to reduce the climate change requires coordinated international agreements on reduction or containment of the emissions.

The largest source of greenhouse gas emissions is from burning carbon, stored as fossil fuels, during energy generation. The main sources of the emission are represented in Fig. 2. Fossil fuels are still predominantly used in the generation of electricity in power plants, in transportation (cars and buses) and for heating. While their reduction is imperative for reducing the impact of climate change, the costs of the mitigation of the greenhouse gas emission are substantial for many economies, especially emerging economies with high population densities. The costs of any mitigation strategy must be managed at a global scale, and with fairness to all.

The growing awareness of the impact of climate on the environment sees a call from the community to develop environmentally friendly systems, such as low ecological footprint buildings, photovoltaic farms and, most recently, hydrogen-fueled cars, buses and other transport machinery. Renewable energy offers immense opportunities in this regard. According to Bloomberg New Energy Finance, global investments in clean energy technologies have grown more than 5-fold from $62 B in 2004 to $329 B in 2015. In fact, deployment of solar- and wind-based power sources has seen dramatic expansion in the last decade, and constituted 3.2% of the total electricity generated around the world, and 4.2% in the U.S.A. Fig. 3 shows the share of solar and wind power in the global electricity production in 2013 [3].

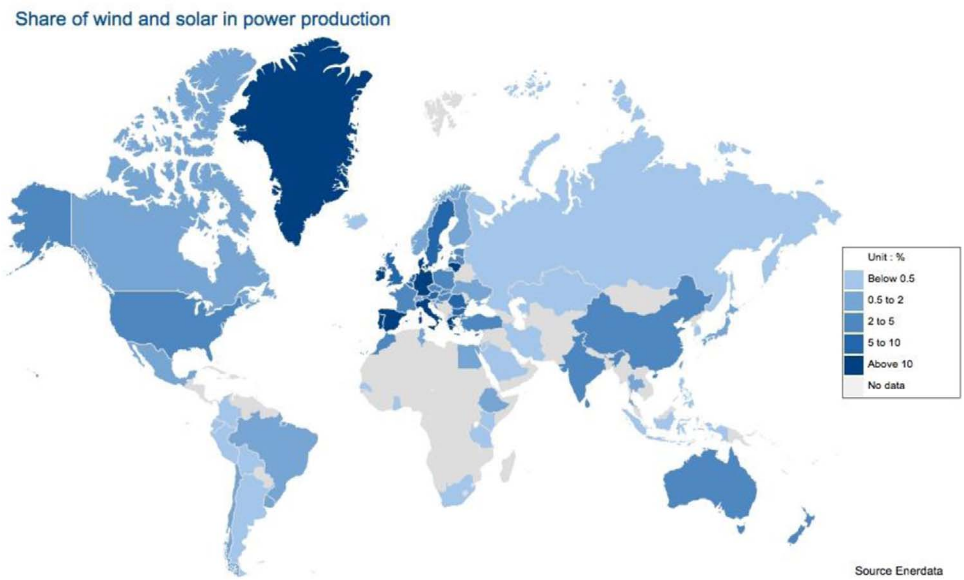

Fig. 3. Deployment and share of solar and wind in the global electricity production in 2013 [3].

The global installed solar-based electricity generation capacity exceeded 227 GW at the end of 2015, and produced nearly 1% of the global electricity. During the same year, wind-based power generation capacity reached 435 GW and was responsible for 7% of the global electricity production [4].

Despite impressive rates of market penetration and cost reduction, a major shortcoming of renewable energy technologies such as wind and solar have been their inherent intermittency. The deployment of these clean technologies relies heavily on the availability of large-scale utility-paired energy storage systems that can provide a buffer against the generation of energy by solar and wind technologies. In this regard, the development and rapid deployment, of hydrogen energy as well as photoelectrochemical and electrochemical technologies provide attractive opportunities for large-scale energy storage. The importance of educating and training students in these scientific and technological areas cannot be understated, and hence, are included as part of the proposed curriculum.

The hydrogen economy is an attractive way to address this. Such an economy uses hydrogen as the global energy carrier, along with electricity. At the same time there is an increasingly urgent need to replace the current technology of hydrogen generation that uses natural gas as the feed-stock by technologies based on renewable energy sources.

While substantial efforts have been made in the generation of energy through renewable sources, the current pace of reduction of greenhouse gas emission is inadequate if global temperature rises are to be contained to manageable levels, i.e., below 2 °C. The present strategy to reduce carbon emissions involves modification of existing technologies as an interim until, long term, more effective solutions are developed. For example, huge energy savings could be achieved by replacing low efficiency combustion engines by more efficient fuel cells in transportation. Therefore, there is a race to develop low cost hydrogen fuel cells suitable for transportation purposes. This race also involves the development of electric cars. Since batteries simply store energy there is a need to ensure that car batteries are charged using renewable energy sources.

A game changing approach to the elimination of fossil fuels would be the introduction of hydrogen as the main energy carrier. The wide scale adoption of hydrogen as the fuel of choice in transportation should be independent of the supply of oil that is most commonly sourced from politically sensitive domains. Moreover, the direct combustion of hydrogen fuel results in the formation of water, which can be managed in ecologically sensitive ways.

Cars and buses powered by hydrogen do not lead to air pollution in urban areas. However, the introduction of the new hydrogen economy in an environmentally sensitive manner requires that the hydrogen fuel is generated using renewable energy rather than steam reforming of methane, SRM, as this is typically the case at present. The main disadvantage of SRM is that carbon dioxide is a major by-product. As an environmentally benign energy carrier, hydrogen provides large-scale storage capacity. It can also be efficiently converted to electricity in fuel cells for load levelling purposes.

A world-wide introduction of hydrogen as the dominant fuel for transportation and energy storage applications requires the development of new technologies and advanced materials for the storage, transportation, distribution and, almost critical, the generation of hydrogen in an environmentally friendly manner. One possible approach for the latter is the use of nuclear energy for splitting water into its elemental components, although this has obvious environmental and political implications. Another approach is to use solar energy to split water into hydrogen and oxygen, but this presents its own challenges.

In summary, introduction of a sustainable hydrogen based energy economy requires the development of entirely new technologies. This consequently requires developing new skills and industries. In order to achieve this there is an urgent need to develop and introduce new curricula into educational programs. As a consequence of the complex nature of energy technologies, these programs, by necessity interdisciplinary, cover a variety of science and technology fields as well as economics and politics [1]. In order to confront these challenges, the Future Earth program has proposed to establish the Sustainable Energy Network, SEN. The objective of this paper is to outline its mission and related goals.

Human activity has resulted in climate changes that are already apparent. The associated damage of the environment, leading to pollution of air, water and soil, is potentially catastrophic for the planet Earth. The development of sustainable energy sources is essential for reducing, and ultimately eliminating the detrimental changes. This imposes the need for the next generation of students to access educational programs offering the skills required to develop of clean energy conversion systems. The goal of the Sustainable Energy Network is to develop such education programs and to produce the related educational resource materials.

3. International efforts to reduce carbon emissions

It is now widely recognised that the hazards and risks related climate changes can only be practically addressed through international cooperation, and by acknowledging the dangers of an ever increasing amount of greenhouse enhancing gases being emitted to the atmosphere from emerging economies. This awareness, which led to a consensus for international action to reduce the emission of greenhouse gases, resulted in the United Nations initiatives to set emission targets and to introduce emission trading. The most important UN-led climate conventions include the UN Framework Convention on Climate in Kyoto, December 1–10, 1997; the UN Conference on Sustainable Developments in Rio; June 20–22, 2012; and the Paris Climate Conference, November 30-December 11, 2015.

The Kyoto Convention on Climate aimed at devising an effective policy response to the emissions of greenhouse gases and consequent global warming. The Convention resulted in a protocol, adopted on December 11, 1997, committing its parties by setting internationally binding emission reduction targets [5]. The subsequent conference in The Hague, 2000, established that the emission targets set in Kyoto are difficult to realise without comprehensive emission trading and adequate monitoring of the emission levels. According to Victor [6], one attractive alternative to the emission target levels would be an agreement on set emission prices in terms of a carbon tax. The related amendments of the Kyoto Protocol were adopted at the UN Climate Change Conference in Doha, Qatar, 2012.

The aim of the UN Conference on Sustainable Development in Rio, 2012, was to secure the political commitments for sustainable development and, most importantly, the declaration on the Higher Education Sustainability Initiative, HESI [7]. Academic organisations in 47 countries agreed to the following:

- Introduce education programs on sustainable development concepts
- Encourage research on sustainable development issues
- Promote the introduction of green campuses
- Support sustainability issues
- Engage with, and share results on, sustainability through international frameworks

The HESI document delivers a strong message about the crucial role of the academic community in addressing human induced climate change through the introduction of new education programs. The HESI document indicates the need to introduce education programs on new technologies for the sustainable generation of clean energy, and the conversion and storage of energy, in an environmentally friendly manner.

The 2015 UN Climate Conference in Paris has adopted an international agreement aimed at transforming the world's fossil fuel-driven economy and slowing the pace of global warming to stabilise this to below 2 °C above pre-industrial revolution levels. The Paris conference has proposed a system for ensuring that emissions are reduced and has provided financial incentives for poor countries to cope with the transition to a low carbon economy.

Recently, the UN has established the Future Earth program that aims at curating the knowledge that is required for the transition to global sustainability. From an energy perspective, the transition should be considered in terms of global efforts towards changing to a hydrogen, rather than carbon, based energy economy.

Deterioration of the environment promoted the UN to initiate actions aimed at reducing climate change in order to protect the planet Earth from irreversible environmental damage. The Higher Education Sustainable Initiative (Rio 2012) invited actions from educational institutions to promote sustainable solutions through research and education.

4. Hydrogen economy

The goals and mission of the hydrogen economy have already been considered at the Hydrogen Economy Miami Energy Conference (March 18–20, 1974). Hydrogen has been formally proposed by President George W. Bush in 2003 as the fuel of the future. This proposal was followed by the formation of the International Partnership for Hydrogen Economy, IPHE, by the US Department of Energy and US Department of Transportation in 2003.

The identification of a hydrogen economy, where hydrogen is the main energy carrier along with electricity, was a substantial step towards reducing the use of gasoline for transportation. Transportation accounts for over 20% of the energy used by advanced economies, and this is invariably obtained from fossil fuels. However, the wide scale implementation of hydrogen as the energy source for transportation requires the development of a range of hydrogen specific technologies, including hydrogen generation, storage, transportation, distribution and safety [8,9].

Nearly 75% of the industrial production of hydrogen involves steam reforming of methane (SRM). The by-product of this technology is carbon dioxide:

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2$$

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

Consequently, although the combustion of hydrogen is clean, as its oxidation product is water, its generation currently is not. Therefore, there is an urgent need to develop environmentally friendly methods to produce hydrogen. This may be achieved by new technologies that employ renewables, such as solar [10], wind and tide energy [11] or non-CO_2 generation sources such as nuclear energy [12].

The decision to introduce hydrogen energy is one of the most significant initiatives of the international community that aims at both global energy security and the protection of the environment. Implementation of the hydrogen economy will be profoundly influenced by introduction of appropriate education programs that will train the technical staff who will develop new hydrogen-related technologies, as well as service all aspects of the hydrogen economy.

The international initiative to introduce hydrogen as the key energy carrier along with electricity is a substantial step towards the reduction of climate change and energy security. Successful implementation of a hydrogen economy requires introduction of education programs.

5. Dramatic consequences of climate changes are already apparent

Access to clean air and drinking water is the basic human right. However, the development of industry and the associated use of fossil fuels for energy generation has resulted in, an increasingly apparent, pollution of air and water. The deterioration of the environment is most noticeable in developing countries and has already had dramatic consequences.

In many parts of the globe air pollution has crossed the levels that are safe for human health. According to the Journal of the American Medical Association, exposure to air pollution leads to increasing cardiopulmonary mortality due to lung cancer [13–15]. There is attested evidence for the relation between air pollution and lung disease and this link needs to be highlighted in medical textbooks. As reported by the European Environmental Agency, EEA, air pollution is responsible for an increase in asthmatic and alternative pulmonary diseases [16]. According to the World Health Organisation, WHO, air pollution results in an increase in the risk of stroke, heart diseases, acute respiratory diseases as well as lung cancer [17]. In 2013 the related costs escalated to $2200 billion [16].

The deterioration of the environment results in an increasing level of contaminations in water, such as bacteria and toxic organic compounds [18]. According to the UN, 1.1 billion people lack access to clean drinking water [19] and some 2 million, mainly children, are killed annually by waterborne diseases [20]. Clean drinking water is not available for large populations in parts of Asia and Africa. In Bangladesh around 40 million people only have access to drinking water, which according to the WHO, is unsafe to drink because of high contents of arsenic and bacteria [21].

The increasing intensity of alarming consequences of environmental degradation prompted the UN to undertake a radical global action aiming at addressing the problem and to establish the Future Earth program.

Awareness is growing that rising air and water pollution is affecting human health. Air pollution is responsible for an increase in lung cancer and asthma. The contamination of water results in waterborne diseases that kill some 2 million, mainly children. According to the World Health Organisation 1.1 billion people lack access to clean drinking water.

6. The future earth program

The Future Earth program of the UN is a platform for the research projects that are required for the transformation towards global sustainability [1]. The platform, which includes a range of specialized networks and partnerships with policy-makers and other stakeholders across the areas that have an impact on the Future Earth mission, aims at building the knowledge base required to provide sustainability options and solutions.

The Future Earth program, which is scheduled to run for 10 years (2016-25), will engage with the range of sciences that address and have an impact on sustainability-related challenges, such as delivery of water, energy and food, as well as to increase the social resilience to future threats through developing early detection systems [1]. The Future Earth program aims at delivering the products and services that are needed to mitigate or overcome these challenges. It will develop the knowledge base that is needed for global sustainable development. Finally, Future Earth will spread this knowledge across cultural and social barriers in order to form a homogeneous system to carry forward the Future Earth vision. It is expected that the work of the Future Earth program will deliver the interdisciplinary knowledge necessary to implement the transformations that are required for global sustainability. The aim of the Sustainable Energy Network, SEN, is to contribute to the objectives of the Future Earth program in terms of energy generation that is consistent with its key goal: the development of clean energy technologies that are needed for the transition to a sustainable future. According to Rockström [22], the Future Earth program has the potential to become the largest and the most ambitious international scientific initiative ever undertaken.

The Future Earth program is the global research platform that will identify the opportunities for the transformation towards global sustainability. This requires the development of a multidisciplinary knowledge base linking a range of disciplines and forming a global network. The mission of the Sustainable Energy Network targets the objectives of the Future Earth program namely the generation of clean energy.

7. Energy-related education programs

7.1. Energy systems

The concept of the education programs on energy proposed in this work is expected to be the starting point of a dynamic platform that is continuously developed as progress of the related disciplines occurs. This section considers the basic energy systems and outlines a strategy to progress towards an environmentally sustainable energy future.

7.1.1. Electrochemical energy

Electrochemical energy involves a range of processes including energy conversion systems, such as fuel cells, electrolysis devices, batteries, chemical gas sensors as well as electrochemical pumps and separators. Batteries, for example, allow efficient interconversion of renewable electric energy into chemical energy and vice versa. Their performance involves the processes of charging (enforced by an external voltage) and discharging. The latter is a spontaneous process related to a decrease in the Gibb's free energy. The battery-based conversion systems may be used for storage of solar or wind energy. The present strategy focuses on the development of new materials with enhanced ionic conduction and charge capacity.

Fuel cells allow efficient conversion of the chemical energy of fuels into electrical energy. The driving force of the conversion is the decrease of the Gibb's free energy of the related redox reactions that take place at the anode (oxidation) and cathode (reduction). The useful energy is related to the flow of electrons in the external circuit that is enforced by blocking the transport of electrons through the solid electrolyte. A solid oxide fuel cell (SOFC), which utilizes an yttria-doped zirconia ionic conductor as electrolyte, is represented schematically in Fig. 4.

A major limitation of SOFC is their requirement to operate at high temperatures. Lowering the operating temperature requires the development of solid electrolytes with enhanced ionic conduction at low temperatures whilst maintain low electronic conduction. A possible strategy to address this would be the development of the low-dimensional interface structures, LDISs, which are critical for the progress of the electrode reactions [23,24].

The electrochemical devices, which play a substantial role in contemporary technologies, require specialized materials that serve specific tasks including excellent catalytic activity to the electrode reactions, as well as high electrical conductivity via either ionic or electronic charge carriers in a controlled manner. Immediate challenges include the development of novel materials with optimized properties to enhance the performance, durability, cost and/or lower operating temperatures.

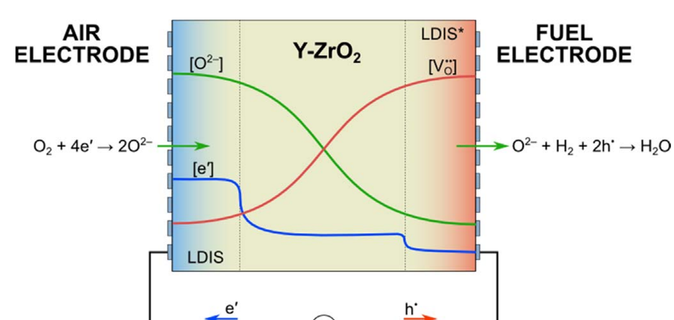

Fig. 4. Schematic representation of yttria-doped zirconia solid oxide fuel cell and the concentration gradients of ionic and electronic charge carriers within the solid electrolyte (LDIS and LDIS* denote the low dimensional interface structures at the air and fuel electrodes, respectively).

7.1.2. Photoelectrochemical energy

The most commonly reported photoelectrochemical energy conversion system consists of light-induced water oxidation, including total oxidation leading to the generation of hydrogen by water splitting [10] and partial oxidation leading to removal of organic compounds [18]. The process is based on oxide semiconductors, which are corrosion resistant when immersed in water. The process of light-induced water splitting (total oxidation) results in the formation of oxygen at anodic sites and hydrogen gas at the cathode.

The hydrogen produced in a photoelectrochemical system may be used to store solar energy. The commonly applied research strategy in the development of oxide semiconductors, such as TiO_2, is to enhance light absorption through the modification of the electronic structure. Recent reports indicate that the performance of photoelectrochemical systems is determined by the local properties of the interface layer and the associated functional properties, such as the gradient of defects concentration within this layer, the electric fields that are required for charge separation, and the concentration of surface active sites. The progress requires the development of surface engineering leading to the formation of the interface layer with enhanced performance. This entails better understanding of the effect of the interface properties on the charge transfer associated with water oxidation. Intensive efforts are aimed at the development of the new generation of solar materials, based on oxide and oxy-nitride semiconductors, that may be used to convert solar energy into fuels such as hydrogen [8,10,25,26].

The wide-scale introduction of hydrogen-fueled vehicles would be a significant step towards the reduction of CO_2 emissions. Their development, however, requires progress in a range of hydrogen-related technologies, including (i) hydrogen solar cells, (ii) hydrogen fuel cells, and (iii) electric motors. These technologies would be coupled within a single energy conversion system that is represented schematically in Fig. 5.

7.1.3. Solar energy

The most common use of solar energy is in solar heating. Alternatively, the solar photons can be used to generate charge carriers at semiconductor junctions and either generate electricity directly, or accomplish photochemical or photoelectrochemical production of hydrogen by splitting water molecules (as outlined above). The most widely used solar cells, that convert solar energy to electricity, are based on silicon. Substantial progress in the development of silicon-based solar cells has resulted in lowering the costs of photovoltaic power and these are competitive with the cost of power produced by the combustion of fossil fuels.

7.1.4. Alternative renewable energy

There is an increasing interest in the use of wind, tide and geothermal energy, which are under intense development. There is an increasing need to increase the use of wave and tide energy. Of these of geothermal energy is suitable for base-load electricity generation. Another underexplored concept is to utilise the chemical concentration gradients, where fresh river water merges into oceans, to generate electricity, utilising the Nernst equation. Specifically, the concentration gradients of salt in water may be converted into electricity using membrane technologies [27].

7.1.5. Hydrogen energy

The implementation of a hydrogen-based economy imposes the need to develop a range of new technologies associated [8]. The most spectacular impact of a hydrogen economy on our environment will be in transportation when car makers develop affordable hydrogen-powered vehicles. However, to be sustainable it is critical that the hydrogen is generated using technologies that are environmentally clean and employ carbon free renewable energy, fission energy or, ultimately, nuclear fusion.

7.1.6. Nuclear energy

The application of nuclear energy for power generation is based at present on nuclear fission. Nuclear fission involves the splitting of selected heavy atomic nuclei into lighter ones with the release of energy. Awareness is growing that nuclear fission, although resulting in the formation of long lasting and harmful radioactive wastes, is an alternative to fossil fuels the short term. The progress in this area requires enhancement of nuclear power reactors and development of the technology to manage radioactive wastes. After the Fukushima Daiichi Nuclear Power Station accident, enormous efforts have been made to improve the safety of nuclear power stations. These improvements have led to design of modern fission reactors, which include in-build fail-safe systems. Independently, the management of nuclear waste aims to use transmutation reactions, where the long life radioactive wastes are converted into stable elements that are harmless to the environment. The new technologies of transmuting high level radioactive waste to short-lived nuclides, and ultimately stable elements, are under development. Efforts are also being directed towards the development of intrinsically-safe nuclear reactors.

Great hope is associated with nuclear fusion that is expected to be the ultimate environmentally friendly solution to sustainable electricity production and the elimination of the emission of greenhouse gases [28]. While the technology of nuclear fusion is still not mature, its development would lead to the generation of large amounts of

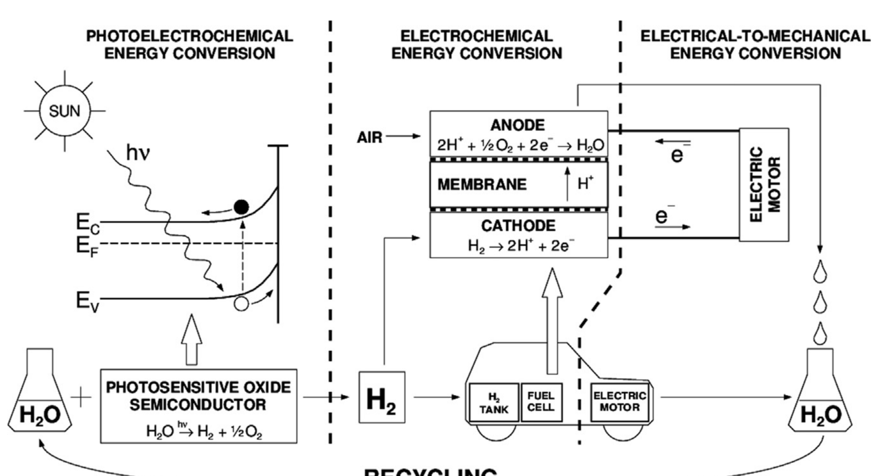

Fig. 5. Schematic representation of a range of energy conversion systems, involving the solar-to-chemical energy conversion by photoelectrochemical cell, the chemical-to-electrical energy conversion using fuel cell and the electrical-to-mechanical energy conversion by electric motor.

environmentally clean energy. Nuclear fusion is based on the synthesis of heavier elements from light atomic nuclei. The associated difference of mass results in the release of huge amounts of energy according to the Einstein formula:

$$E = mc^2 \tag{1}$$

where E is energy, m is mass and c is the speed of light. Initiation of the fusion reaction requires high densities of plasma and temperatures of the order of hundreds of millions of Kelvin. The Lawson criterion [21] defines the set of conditions necessary to ignite and sustain a thermonuclear synthesis leading to the fusion of deuterium and tritium:

$$^{3}_{1}H + ^{2}_{1}H \rightarrow ^{4}_{2}He + n + 14.7MJ \tag{2}$$

Progress in nuclear fusion requires overcoming the numerous technological hurdles, including the development of advanced tritium breeders that are stable at high temperatures [28]. Lithium metatitanate (Li_2TiO_3) is one of the candidate materials under study.

Approaches to the demonstration of nuclear fusion reactors are being implemented by Japan and the EU [29]. The development of nuclear fusion reactors is coordinated, internationally, by the International Thermonuclear Experimental Reactor (ITER) program [30]. At completion, in 15–20 years, the ITER is expected to deliver 500 MW of power.

7.1.7. Smart coal energy

While the world is, albeit slowly, heading towards sustainable energy, several economies will remain reliant on fossil fuels, such as coal, for some time. It is essential, however, that during the transition to a global carbon neutral environment, the fossil fuels be used in an environmentally friendly manner. This can be achieved by enhancing the energy conversion efficiency, ECE, to a maximum level.

Energy generation based on the combustion of fossil fuels is generally associated with very low ECE, typically in the range of 25–35%. This ECE may be increased nearly 2-fold when the conversion process to produce electricity involves high temperature fuel cells [31], instead of direct combustion. Alternate technologies for using coal for energy generation involve a range of environmentally benign approaches, such as coal gasification, oxy-combustion, chemical looping combustion, solar reduction of CO_2, molten carbonate or solid oxide fuel cells and CO_2 sequestration. These approaches, which allow significant enhancement in ECE and complete capture of CO_2 have a substantial impact on the amount of greenhouse gases released to the atmosphere. Consequently, the related impact on climate change is reduced markedly.

7.2. Challenges

The transition from fossil fuels to a hydrogen economy imposes the need for entirely new skills for the development and implementation of new energy-related technologies. This in turn requires new education programs in universities and related institutions to train the technicians and engineers who will be responsible for the practical implementation of the new technologies, as well as the researchers who will develop these. Developing sustainable energy sources alone will be insufficient given the enormous infrastructure changes required for the wide scale adoption of new technologies [8]. Consequently, there is an imperative to address the social, economic and political changes that will accompany the technological change. In order to achieve this, the general public needs to be engaged with the process so to ensure that the changes are politically feasible.

The demand, and interest, of students for energy-related programs is at all-time high and is increasing. Therefore, the targeted educational courses are expected to attract talented students eager to make their career in energy-related areas and the transition to global sustainability. Preparation and implementation of such courses is difficult, since the energy-related topics are interdisciplinary, involving diverse scientific disciplines as well as non-scientific areas. The courses presently offered frequently require the students to learn discipline-specific technical languages across several disciplines. An additional difficulty in introducing the training programs in energy is a lack of adequate textbooks that bring these interdisciplinary topics together within a single volume.

There is clearly a demand for education in sustainability and sustainable energy. Indeed a number of universities are already offering programs, and even degree-oriented courses, in specialised areas. The number of new programs being introduced by universities reflects of the growing awareness within society that universities need to address the increasing demand for technicians and engineers trained to work in emerging areas such as sustainable energy. However, the courses on offer differ widely in their content. A comprehensive textbook will help students to appreciate the breadth of the topic and to select those that best match their interest. The universities that introduce energy-related teaching programs will attract both high quality students and industry support.

There is an increasing demand for education programs in new energy technologies in general and sustainable energy in particular. The main hurdle to the introduction of such programs is their interdisciplinary character. The aim of the Sustainable Energy Network is to develop multidisciplinary education programs on energy that are free of interdisciplinary boundaries.

8. Background sciences

A range of relevant sciences is required as background to fully understand energy conversion and the identification of functional materials that are necessary to achieve optimal performance of the corresponding system. As an example, developing a new solar cell requires expertise in electrochemistry, surface chemistry, catalysis, solid state science and materials science. Paradoxically, the enormous growth in energy and related technologies that have occurred over the past 60 years has led to the formation of more specialized areas, such as solid state chemistry, solid state electrochemistry, the science of materials interfaces and nanotechnology. The distance between these fields, in terms of basic concepts and the related theoretical background, is substantial. What is now required is the formation of an encompassing homogeneous program, supported by teaching materials including textbooks, where the barriers between the different disciplines have been minimized through appropriate definition of terms and the introduction of a homogeneous notation. A possible approach in the basic energy systems and the associated disciplines that are essential for the introduction of such an education program is shown in Fig. 6.

The proposed program is necessarily multidisciplinary in nature. It is preferable, however, that the individual courses are presented in an interdisciplinary fashion to the students that allow proper and seamless interweaving of the fundamental concepts from each discipline. The courses are preferably taught by a team of faculty, who complement each other's expertise to make the whole bigger than its parts. Active team-teaching broadens students' perspectives, and helps them gain better appreciation of the complexity of energy sciences and how they impact on other areas, such as water, food, environment and climate.

The selection of disciplines to be included in specific courses depends on the precise university program. The expected programs should include the commonly available topics of materials science and engineering, electrochemistry, solid state science and surface chemistry. However, and as described below, programs in sustainable energy technologies should also include newly emerging disciplines, such as the science and engineering of materials interfaces, solid state electrochemistry, nanotechnology and sustainability.

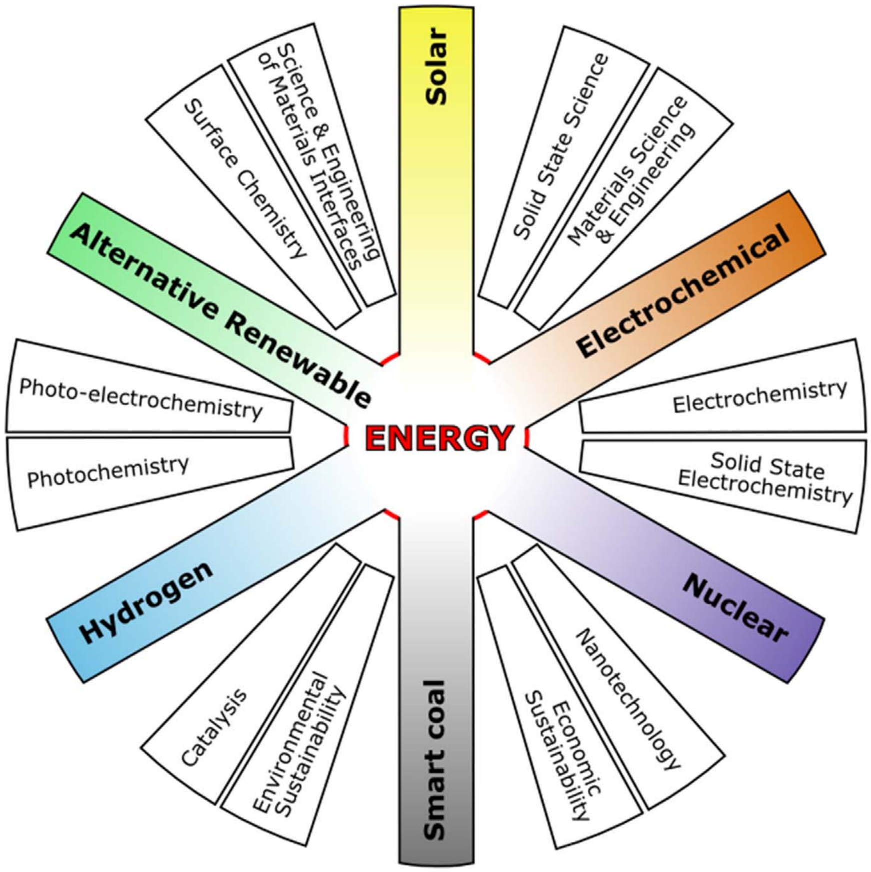

Fig. 6. Schematic representation of the multidisciplinary education program on basic energy systems and the related scientific disciplines.

8.1. Science and engineering of materials interfaces

Charge and mass transfer across the interfaces is critical for efficient performance of energy conversion devices, such as solar, photocatalytic, electrochemical and photoelectrochemical energy conversion. Knowledge of the local properties of the low-dimensional interface layer is crucial for proper understanding of the mechanism and the kinetics of charge transfer in order to engineer the interfaces with optimized performance. Since the local properties of the interface layer (e.g., electrode-electrolyte) are often entirely different from the bulk phase, and can be extremely complex, efforts in understanding its properties have resulted in the formation of a new scientific discipline.

8.2. Solid state electrochemistry

The development of modern electrochemical devices requires better understanding of the effect of structural imperfections (point defects) on the charge transport via solid conductors, involving electronic, ionic and mixed conduction. The concept of solid state electrochemistry is similar to the concepts of traditional electrochemistry [32], however, the difference between the two areas is substantial. In the latter case the electrochemical reactions take place at elevated temperatures.

8.2.1. Nanotechnology

Awareness is growing that nano size low-dimensional systems exhibit outstanding properties that are entirely different than the bulk phase [33]. Design and processing of nano-size materials, with desired properties for specific applications, requires better understanding of their local properties. This consequently requires completely new experimental and theoretical approaches. This is especially the case for nanostructured electrode surfaces used for splitting water by sunlight [34].

8.2.2. Sustainability

There are three basic pillars of sustainability, namely social, economic and environmental sustainability. Understanding the complex interdependence of these is important and may be critical in the wide scale uptake of new technologies. This is evident in the way that institutions have developed nanotechnology centres that invariably couple scientific capabilities with outreach programs and partnerships.

There is an increasing demand from the community to develop new renewable energy conversion systems that are environmentally friendly [35]. At the same time there is an increasing need to engage experts in energy-related areas. This imposes a need on universities to educate scientists, including social scientists, and engineers who will be able to work at the front line in the development and maintenance of new energy systems.

A single textbook that could coherently integrate several multidisciplinary topics, would help drive new teaching initiatives. The main component of such a textbook should be related to tutorials in order to help the teachers in selecting specific topics that are most appropriate for the profile of the course. The textbook should also include theoretical and laboratory exercises as alternative teaching modes. The aim of these exercises is to convert the passive knowledge students obtain through lectures and tutorials into an active knowledge on the application of the theoretical models for the determination of specific energy-related quantities associated with energy-related materials and devices.

The laboratory program should give the students opportunities in the experimental determination of the energy-related properties for standard materials and cultivate skills in the development of new materials with enhanced performance. The laboratory activities should also include setting-up models of specific energy conversion devices and verification of their performance. It is expected that the laboratory experience will give the students an opportunity for making future discoveries and their experimental verification. The proposed textbooks should essentially help students, who have an aspiration to become the experts in specific areas of energy, and work at the front line of new technologies. Such technologies must be developed in order to facilitate efficient transfer towards global sustainability.

The related educational courses are expected to attract talented students seeking a career in energy-related areas. This has been seen previously during the pioneering days of nuclear energy and in some regions rich in fossil fuels. The challenge is to devise a program that focuses on sustainable energy matters, such as solar hydrogen, which is interdisciplinary and involves all the basic concepts. The program should also provide a suitable platform, such as a textbook, designed to meet its aims.

The pre-requisite of the education program in sustainable energy is a strong background in mathematics, physics and chemistry. Several systems require basic knowledge of biological sciences as well.

8.2.3. Textbooks

The preliminary concept of the textbook suitable for an interdisciplinary sustainable energy program is represented in Fig. 7. It is proposed that such a program would involve three core teaching modules, including the basic sciences module, the applied sciences module and the module related to energy conversion systems. Selection of the specific units, in addition to elective units offered by other courses, depends to the specific degree-oriented program. The textbook is expected to be part of a dynamic platform aimed at the development of future education programs.

While the proposed education program on sustainable energy should include all types of energy systems, individual universities may elect to focus on energy systems that are associated with their research expertise, such as photovoltaics, and the local energy environment [36].

It is important to note that the textbook should be considered as a starting point of a dynamic knowledge system involving progress of all the scientific and social disciplines involved. The most difficult aspect is the need to integrate different disciplines, which are remote in terms of conceptual backgrounds. This can only be achieved if traditional boundaries are overcome. It is expected that the textbook will be exposed to the entire academic community through the UN program of Future Earth program.

The energy education program involves a range of disciplines, which are remote in concepts and theoretical background. Therefore, the main challenge in the development of energy programs is the need to overcome the traditional conceptual boundaries in order to form a homogeneous education platform.

9. Strategy of integration of different disciplines

Energy is a vast field comprising many disciplines with different conceptual backgrounds

and overlaps widely with climate change, pollution, water utilisation and management as well as population placement and growth. Therefore, the interdisciplinary approach in energy-related topics is needed in the development of the related education programs. It will be a challenge to develop the new teaching paradigm to achieve the synergies required at undergraduate level.

The increasing interest of students in energy-related science and engineering topics has already resulted in the introduction of energy programs by many universities. However, the programs offered so far are diverse in terms of the size, content, level of theoretical background and specialisation profiles. The diversity is reflective of the available resources. Consequently courses with the same title, offered by different universities, are frequently distinctively different. The extent of the diversity is so huge that students willing to study specific energy-related areas have problems in selecting the right place to study. The reason of the diversity is related to lack of interdisciplinary textbooks that could serve as a competent cross-section of the energy-related topics. The textbooks are also need as a guide to the program for teachers.

The education program and the related textbook will capture the imagination of the larger scientific community, around the globe, only when the related documents are homogeneous and useful for the communities across many disciplines. Therefore, the first approach is to develop a multidisciplinary textbook for undergraduate and possibly senior high school students. The most important hurdle that should be expediently overcome is the need to produce a program that transcends disciplinary boundaries. The essential approach to the integration of different disciplines is the definition of terms and notations that should be consistently and uniformly applied in all chapters as well as application of a common language. Such a book should identify the knowledge gaps and potential opportunities for the development of advanced technologies that can meet sustainability goals. The proposed textbooks are expected to be a reference document helping students to choose the right energy-related program offered by universities.

An alternative, or parallel, approach would be to edit a volume on sustainability that is geared more towards the specialists in different energy areas as well as climatologists, socio-economists, combustion scientists and nuclear engineers.

The energy-related education program must integrate expertise in a range of natural science and engineering areas as well as environmental, social and economic sciences. This can be achieved through consistent definition of the related terms and the use of common language.

10. Strategy of the sustainable energy network

The mission of the Sustainable Energy Network is to develop an education program in energy-related areas. Such program is expected to address the increasing demand of students willing to increase their knowledge in energy-related areas in order to get actively involved in the development of new energy technologies that are environmentally clean. Such a program is also addressing the key need of the community to reduce climate changes through the reduction of the emissions of greenhouse gases and the imposition of sustainable development.

The development of the energy-related education program should start with production of the interdisciplinary textbooks edited by experts in specific disciplines. The textbook is expected to be a platform of a dynamic process leading to the development of future textbooks and energy programs. Therefore, the primary textbook is expected to cover the most important energy areas, including renewables as well as alternate energy systems. In the latter case, the textbooks should consider strategies to address the sustainability requirements through enhanced energy conversion efficiency. Since the development of new energy technologies requires new materials with specific properties, the textbook is expected to include sections on materials science and engineering as well as solid state science. The development of new functional materials is crucial to the development of new energy conversion systems.

It is expected that the need to establish new energy courses will be accompanied by establishment of the related research programs. Scientists actively involved research will have a considerable advantage in attracting talented students to work with them.

The development of new renewable and sustainable energy sources is substantial [37], however, the current progress towards the wide-scale implementation of these is not adequate to the meet the urgent

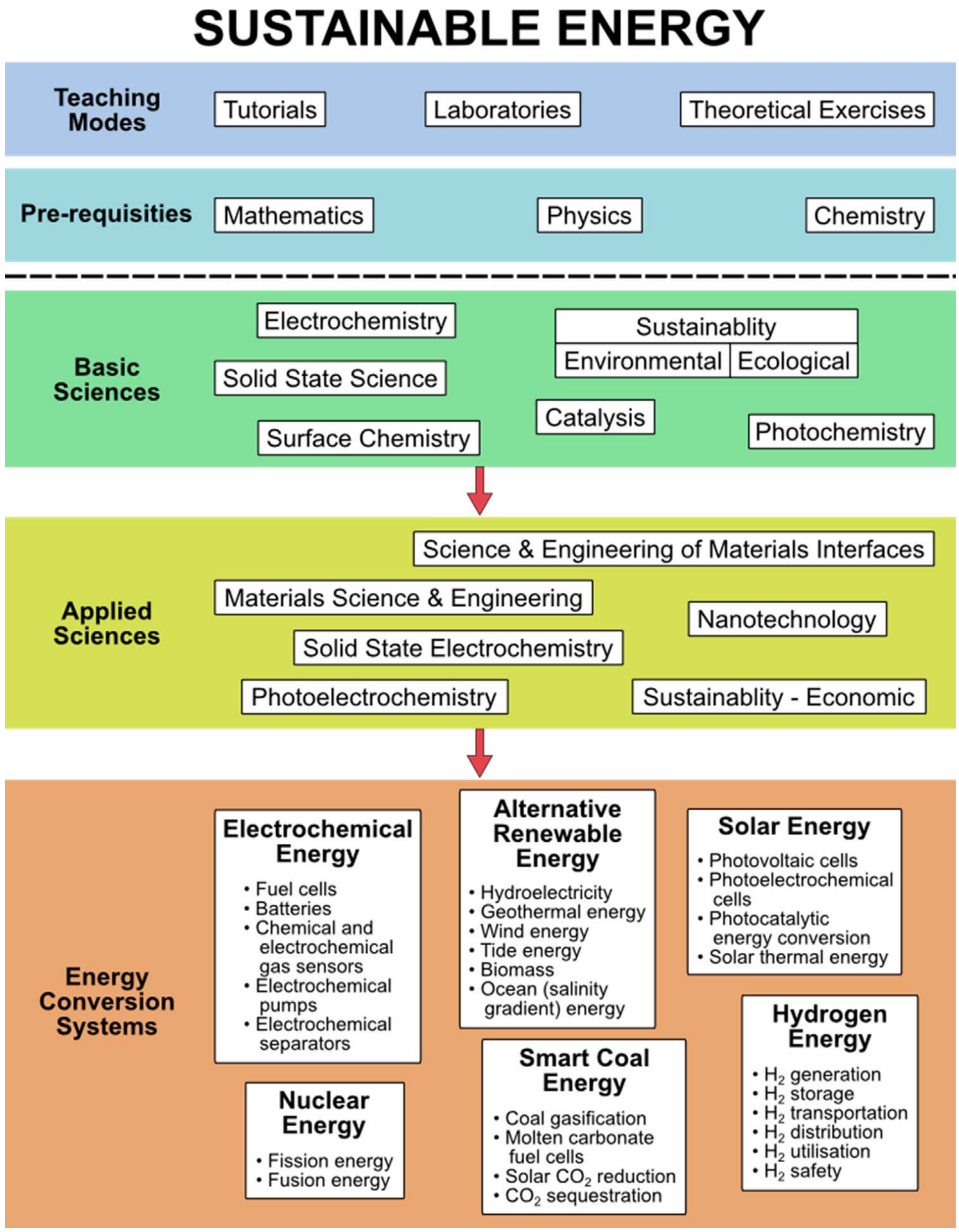

Fig. 7. Preliminary curriculum of the education program on sustainable energy systems.

need to reduce emissions of greenhouse gases essential to limit the adverse effects of climate change. While the need to reduce reliance on fossil fuels is clear, these fuels are still in use in many economies. In the short term sustainability requires that the energy conversion efficiency associated with the use of fossil fuels is increased and the energy losses are minimized. Therefore, there is a need for the energy-related education programs to include emerging technologies of the optimal use of fossil fuels [38,39] with enhanced energy conversion and reduced emissions of greenhouse gases.

The SEN activity at this stage aims at editing scientific reports in selected energy areas of importance for sustainability [24–26,28].

The mission of SEN is to address the key needs of the community, may be accomplished only with the support of the community.

11. Conclusions

Over millions of years deposits rich in carbon have been formed as a result of the light-induced process of photosynthesis converting carbon dioxide and water into organic compounds and oxygen. As a result of human activity these deposits have been exploited as a source of energy by combusting the carbon rich products. This has resulted in the emission of greenhouse enhancing gases, especially CO_2 into atmosphere. The related thermodynamic effect of these has resulted in global warming of oceans, cryosphere and the atmosphere. The impact of this pervades most of Earth's systems. As a result climate change is taking place at faster rates than evident from anywhere in the geological record. It has been noted that five Solomon islands have been already covered by water [40]. The UN has stressed the need to undertake radical steps to protect the environment for future generations.

It becomes increasingly clear that an approach that weans humankind from carbon-based fuels and the development of new energy technologies that are environmentally clean is needed as soon as possible. In order to address this need, the UN Future Earth program has recently established the Sustainable Energy Network, SEN, to introduce a framework of an education program on Sustainable Energy. This program will guide the development of innovative teaching programs for universities and possibly also senior high schools. A key part of the program will be an interdisciplinary textbook on Sustainable Energy involving the key disciplines, presented in a homogeneous manner. The key challenge of the SEN is the need for such a textbook to transcend traditional discipline boundaries. The program and the textbook should provide a platform for the education of the next generation of people in the science, social science and engineering space to grow the social, economic and environmental benefits.

So far there is a range of programs, such as *Sustainable Energy* or *Energy,* that differ substantially in their contents. It is expected that the textbook combining the related sub-disciplines in a homogeneous and contiguous manner, and edited by key experts in specific areas, will help the students to cross the interdisciplinary boundaries and select the topical programs of their interest.

The authors welcome the comments of readers on any aspects of the paper and especially on the proposed education program, its scope and framework. The comments of students and educators will help us in addressing the interest of the academic community.

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