A Sustainable Energy Future through Education and Research

Patrik Jansson and Tünde Fülöp

patrikj@chalmers.se, tunde@chalmers.se

Chalmers University of Technology, Göteborg, Sweden

Introduction

Sustainable access to energy for a growing population is a global challenge. Our society is dependent on a stable supply of energy; industry (including agriculture, mining, manufacturing and construction), transport and heating can only work if sufficient energy is available. Over 80% of the current global use of energy is based on fossil fuels: oil, coal and gas. In addition to the potentially devastating climate effects of burning two billion years of stored hydrocarbons within a century, fossil fuels will eventually run out and we will be left with less than one fifth of the current energy supply which will clearly not be enough. Thus the energy system of the world will have to change dramatically to replace the fossil fuels with existing and new sustainable sources. This is a major global challenge for mankind.

But it is not only a technological challenge; there are also important political dimensions: we need international agreements, a stable economy and a long-term view (over several decades). The kind of global restructuring needed requires local as well as international agreements. Already now we are facing tensions due to the uneven distribution of energy *production* (mainly "mining" of oil, coal and gas) and *consumption*. Access to strategically important regions is causing conflicts and as fossil fuels run scarce, increasing prices may lead to increasing tension. Even if we disregard open conflicts, the sheer size of the energy sector makes it a major force in the global economy and with the uneven distribution of producers and consumers this force is destabilizing. The transformation towards sustainable energy solutions will take decades, so a major political challenge is long-term commitment (over several elections). In democracies this requires a voting population which is aware of the energy problem and willing to support the transition. Policymakers around the world, and their voters, need access to comprehensible and trustworthy information about potential energy sources and ways to change our strong dependence on energy.

Energy now and in the future

The current global power production is about 16 terawatts [1], which means that on average a human has 56 kWh / day to live on. But almost nobody is average - the "developed world" uses 100-300 kWh/d/p and the big majority uses significantly less per person. Even with significant energy savings per capita, it is unlikely that a 9-10 billion world population (majority "developed") will use less energy in total than today's 7 billion (majority "developing") [2]. The current energy production in the world is 87% from fossil fuels, 5% nuclear, 6% hydro and only 2% other renewables including wind, solar, geothermal, etc. [1]. Looking at the energy consumption the overall picture is the same but the non-fossil energy is distributed a bit differently [3] due to differences in loss rates and estimation techniques.

Even with a long-term sustainability perspective (switching from fossil fuels to renewables), the fact is that there are fundamental limits to the amount of useful energy we can extract from existing renewable sources [4]. Germany has been very serious about converting to renewable energy production locally (but still imports two thirds) and may serve as an example of the time-scale needed for the first step of the transition: from 2% renewable energy (Germany 1991) to 12% (Germany 2011) took 20 years [5].

The good news is that the massive investments needed for this transition can drive the economy. Simulations of the EU area indicate that Green Growth is a real possibility [6] and that tighter goals for emission could help the economy to transition to lower unemployment at the same time as the energy production becomes more sustainable. An industrial perspective on the sustainable energy challenges and opportunities can be found in the recent Vision 2050 report [7] which describes how a global population of around 9 billion people could live well, within the resource limits of the planet by 2050. The report is written by the World Business Council for Sustainable Development (WBCSD): "*a CEO-led organization of forward-thinking companies that galvanizes the global business community to create a sustainable future for business, society and* *the environment.*" which was founded in 1992. The report describes a number of things that must happen over the coming decade to make a sustainable planetary society possible: "*These include incorporating the costs of externalities, starting with carbon, ecosystem services and water, into the structure of the marketplace; [...] halving carbon emissions worldwide (based on 2005 levels) by 2050 through a shift to low-carbon energy systems and improved demand-side energy efficiency, and providing universal access to low-carbon mobility.*"

The energy system transition also requires a close collaboration between industry, academy and government. Unfortunately many of the energy actors (both in industry and academia) are used to a competitive world and the general view is that a certain technology can outrival another. Governmental and educational actors should therefore communicate to both the general public and the most important energy actors that the development of a wide range of energy sources is essential for several reasons. Clearly, various sources are suited to be used in different circumstances and a smart balance of energy sources can solve part of the intermittency problem that renewable energy sources (wind and solar) suffer from. But more importantly, there is no chance to accelerate the change in energy system by an energy monoculture.

There are limits to the rate at which new energy technologies can be deployed. The reason is that it takes time to build the human and industrial capacity for substantial changes in the energy system. Historical evidence shows that it takes around 30 years for energy technologies that are available in principle to grow exponentially and reach materiality (that is delivering 1% of the world's energy mix) [8]. Designing energy policies to outperform these historical deployment curves is almost impossible due to the global scale and inertia of the energy system. It is therefore important to follow several parallel routes, where each new energy type takes several decades to reach materiality, but the aggregate is faster than that, see e.g. Shell's optimistic projection (Blueprint) of new energy deployment [9]. An important part of this is to continuously build, via education and research, the human potential that is a prerequisite for an acceleration of the first phase, the time before a new energy technology reaches materiality.

Even if the existing renewable technologies may be able to carry us through the next couple of decades, we will still eventually need revolutionary, fundamentally new large-scale carbon-free energy sources. To develop these, we need basic research within the energy area, on a diverse range of subjects from fusion energy via nanotech solar cells to ocean energy, to name just a few.

Energy science

Energy science is truly interdisciplinary. Naturally it relates to physics and mathematics through the fundamental concept of energy and the mathematical methods needed for theoretical modelling, but also to chemistry through the understanding of isotopes, fission, fusion, burning of fossil fuels and production of renewable energy. It relates to computer science via the need for simulations, data analysis, visualisation, control systems, etc. It also relates to geography through the location of energy resources, to economics through energy pricing and policies, to political science for the need of international agreements and to history for understanding the connection to the rise and fall of civilizations. Here we expand on the areas of our expertise (information and communication technology and fusion plasma physics) - we hope to inspire others to think about how their subject is related to sustainable energy so that we can all help.

Information and communication technology (ICT)

ICT can be used in many ways to prepare us for a sustainable energy future. We need

- Computer models, simulations and visualization to better represent and understand the global energy system.
- Decision systems to identify and evaluate different actions in order to capture possibilities and disentangle threats.
- Communication networks and social media to engage stakeholders (both the general public and policy makers) in the energy challenges, both locally and globally.
- Data gathering, curation and analysis to provide an open, shared picture of the "state of the world" in relation to energy and sustainability.
- Educational resources, online courses, and open access to key models and tools, in order to improve our understanding of the energy system and to enable "citizen science".

When existing algorithms, methods, and tools are used for new problems and by new users, this also leads to new feature requests and new research ideas. Thus, even if sustainable energy is the main subject, there will be a need for both IT tool support and original computer science (CS) research. Two particular examples of computer science research with climate impact motivation are described briefly below (more detail in [10-11]).

Computer simulations are essential in virtually every scientific discipline, even more so in those such as economics or climate change where the ability to make laboratory experiments is limited. Therefore, it is important to ensure that the models are implemented correctly, that they can be re-implemented and that the results can be reproduced. Typically, though, the models are described by a mixture of prose and mathematics which is insufficient for these purposes. In recent work [9] we show that using modern computer science techniques (based on constructive type theory) allows one to gradually reduce the gap between the mathematical description and the implementation, and we give examples from economic modelling. We have formalized basic building blocks from economic theory such as Pareto efficiency, Walrasian equilibrium, Nash equilibrium etc. together with the relations between them.

The second paper [10] is inspired by climate impact research and more generally, computational vulnerability assessment: evaluating the vulnerability to climate change of various regions and entities (by large computer simulations). Here, as in the previous example, we focus on correctness rather than speed - there is not much use to get an answer faster it is wrong! The concrete results of this paper are examples where proving correctness (which is usually quite challenging) is actually more efficient than testing (the standard software engineering practice).

Fusion plasma physics

Fusion reactions between light nuclei are the most important energy source in the Universe. All the stars, including our sun, are gigantic fusion reactors. They produce their energy through a succession of reactions beginning with fusion of protons into deuterium. The goal of fusion research is to create controlled fusion energy on Earth, by combining light atomic nuclei into heavier elements. It involves merging (fusing) of light elements, mainly hydrogen isotopes, deuterium and tritium.

Fusion is a form of nuclear energy. The fundamental law of nature that permits energy release by nuclear fusion is Einstein's famous relation between energy and mass $E=mc^2$. The total mass of the reaction products is smaller than the total mass of the fusing elements and the mass difference is released as energy.

To control and extract energy from fusion reactions requires heating the fusion fuel (deuterium and tritium) to temperatures of the order of 100 million degrees, while maintaining a sufficiently high density. At the high temperatures that are necessary for fusion reactions to take place, the fuel becomes fully ionized - it is in plasma state. The plasma has to be confined until the rate of fusion reactions is large enough to generate the necessary power. Magnetic confinement of toroidal plasmas is the most successful confinement concept to date and in the last decades there has been great progress. Megawatts of fusion power have been generated and conditions close to break-even (when the input power is equal to the output power) have been reached. A reactor-scale device (ITER) is under construction in France through an international collaboration. However, there are still some significant scientific and technological challenges to be met to establish the physics and engineering basis for the next generation of fusion experiments. The behavior of the plasma should be understood well enough to be able to operate at optimum performance, and increased understanding of the plasma-boundary region should be gained. It is likely that an economic impact of fusion cannot be realized within the next half century. In spite of this, there are many reasons why a strong effort should continue. If successful, controlled thermonuclear fusion would be a large-scale and environmentally friendly energy option, with many advantages: fusion power stations can be made inherently safe, fusion fuels are virtually inexhaustible and available everywhere, there is no direct contribution to the greenhouse effect and waste from fusion will not be a long-term burden on future generations.

Education and research

Education and research serve an important strategic role. Better energy education on all levels (and in many topics, e.g. physics, economics, chemistry, political science, history), accessible openly and globally, will ease the acceptance of the need for multiple complementing sustainable energy sources and energy-saving measures. Research on both sustainable use of our natural resources and development of alternative energy sources should be given very high priority, not only by governments and universities, but also by the industrial sector. It is important to realize that incremental changes are not enough. In addition to improving existing energy sources, we also need to support new ideas; the full range from curiosity-driven basic research to market-driven innovation.

Colin Harrison (IBM) gave a thought-provoking comparison in a recent presentation about "Information Society & Energy Addiction". He asked "*Is there any historical precedent for developed societies freely choosing to abandon a principal source of economic advantage?*" referring to the fossil fuels addiction. And yes, there is one such example; the abolition of slavery: starting with the British Act of 1834, the developed nations emancipated their slaves. For something similar to happen in the energy sector we need a moral conviction and the necessary technology. It is clear to us that education and research are the key to both parts.

References

[1] BP Statistical Review of World Energy 2012, [With energy statistics up to 2011: Total consumption: 12274.6 Million tonnes oil equivalent (Mtoe): Oil 4059, Coal 3724, Natural gas 2905, Hydro: 791.5, Nuclear 599.3, Other renewable 194.8. Unit conversion: 12275 Mtoe / year / 7 billion = 1.75 toe / y / person = 56 kWh / day / person.]

[2] World Population Prospects, the 2010 Revision, summarized at gapminder.org.

[3] Renewable Energy Policy Network for the 21st century (REN21), Renewables Global Status Report, 2012. [Page 21, figure 1. Note that this report includes "traditional biomass" as 8.5% of the total, while the BP report [1] only includes traded energy. Note also that "Final energy consumption" can differ quite a bit from production due to conversion and transportation losses.]

[4] Sustainable Energy - without the hot air, David J C MacKay, UIT Cambridge, 2008. ISBN 978-0-9544529-3-3. Available free online: www.withouthotair.com.

[5] Development of renewable energy sources in Germany 2011, Based on statistical data from the Working Group on Renewable Energy-Statistics (AGEE-Stat), 2012.

[6] A New Growth Path for Europe - Generating Prosperity and Jobs in the Low-Carbon Economy, Carlo C. Jaeger, Leonidas Paroussos, Diana Mangalagiu, Roland Kupers, Antoine Mandel, Joan David Tàbara, 2011.

[7] "Vision 2050" by the World Business Council for Sustainable Development, 2010.

[8] G J Kramer and M Haigh, "No quick switch to low-carbon energy", *Nature* ***462****, 568-569 (2009).*

[9] Shell energy scenarios to 2050 (from 2008). Available from www.shell.com/scenarios.

[10] Dependently-typed programming in scientific computing, Cezar Ionescu, Patrik Jansson, Accepted for the Post-proceedings of IFL 2012, to appear in LNCS 2013.

[11] Testing versus proving in climate impact research, Cezar Ionescu, Patrik Jansson, in Proceedings of the 18th Workshop Types for Proofs and Programs (TYPES'11), LIPIcs – Leibniz International Proceedings in Informatics, 2013.