IL NUOVO CIMENTO Vol. 33 C, N. 5 Settembre-Ottobre 2010
DOI 10.1393/ncc/i2011-10729-9

Colloquia: LaThuile10

The Global Energy Observatory: A one-stop site for information on global energy systems

R. Gupta

Theoretical Division, Los Alamos National Laboratory - Los Alamos, New Mexico, USA

(ricevuto il 14 Settembre 2010; pubblicato online il 12 Gennaio 2011)

Summary. — This paper reviews the energy-development-environment-climate challenge that the world faces and makes a case for why we need to act with urgency and collectively to address it. It introduces an open web-based tool called the Global Energy Observatory (GEO) that is being developed as a moderated wiki to serve as a one-stop site for information on energy systems. GEO's purpose is to help experts and the public understand the dynamics of change in the highly complex network of energy systems and to help accelerate the transition to carbon-neutral and sustainable systems.

PACS 88.05.-b – Energy analysis.
PACS 88.05.Bc – Energy efficiency; definitions and standards.
PACS 88.05.Np – Environmental aspects.
PACS 88.05.Jk – Policy issues; resource assessment.

1. – The Energy-Development-Environment-Climate (EDEC) challenge

The second half of the twentieth century was phenomenally successful in raising the living standards of over two billion people to unprecedented levels. The scientific and technological innovations, advances in all branches of arts and sciences, and maturation of institutions (social, economic, political) that facilitated this rapid transition are too numerous to recount. The issue I will focus on is energy: a key enabler of this development. During the 20th century the ability to harness the chemical energy stored in fossil fuels (oil, natural gas and coal) and convert it to electric energy and transportation fuels was exploited at gigaton scale. Today the world has over $40 trillion invested in fossil-fuel based energy infrastructure that continues to provide electric power and transportation at relatively low cost. In spite of the environmental consequences, this growth is hard to argue against since, by the year 2000, about 2.2 billion people (the entire population of the world in 1950) became empowered to live the modern dream: they and their children have the opportunities and support systems to realize their full potential. The energy-development-environment-climate (EDEC) challenge for the 21st century can be summarized by the following three questions:

– Is the fossil-fuel driven path to development and maintaining the standard of living enjoyed by 2.2 billion people sustainable in terms of availability of resources and the impacts of the use of fossil fuels on the environment and the climate?

– Can this standard of life be made available to the current world population of about 6.8 billion and by 2060 to the anticipated 10–11 billion people?

– If the historic fossil-fuel driven growth is not sustainable and reducing CO_2 emissions becomes a global imperative, then what are the carbon-neutral and cost-effective alternatives, R&D and investments needed, and window of time available?

I will attempt to address these questions broadly and, with apologies to many, not delve into details and many important issues. Let me start by first briefly addressing the phenomena of peak oil. I give four reasons for why discussions centered around "peaking" are not compelling motivators for change:

– It is amply demonstrated that any non-renewable reservoir (mine, field, region) exhibits a peak in the rate of extraction. Viewed from this perspective "peaking" is a feature of extraction valid for all non-renewable finite resources of any size.

– The timing, shape and magnitude of this peak depends on many factors such as the technology available, the cost of extraction and delivery, the demand, regulatory environment, and social and political pressures. It is the reduction of this multitude of factors into a phenomenological model that leads to predictions such as Hubbert's curve for peak oil. These projections are *real and very important* but can be changed if there is social and political will. For example, Saudi Arabian government has the reserves, control, and financial resources to double its oil production. Whether or not it chooses to make the investments to do so depends on the above factors.

– Fossil fuels are fungible but not equivalent in value, the pollution they cause, and emissions. Ordered by their overall value today they are oil, heavy oil, natural gas, tar sands, coal, shale, peat, clathrates, etc. The global sum of their known resources could guarantee the world a few hundred years energy supply. Thus, scientifically, the question one can ask is how much oil would be produced from all possible resources if there was a guaranteed floor price of say $60 per barrel. The problem we are grappling with is how to include into the calculation all the direct and indirect costs including impacts on the environment and the climate.

– The geographic distribution of fossil fuels is very uneven with three regions (North America, Persian Gulf, and Russia) holding about 70% of the reserves. Thus, for many, it is a problem of distribution and not scarcity. Wind and solar resources too are uneven and not located close to demand centers. This uneven distribution raises the more serious and immediate concerns of economic and national security.

Given these facts many people feel there is no energy crunch—to them it is simply a matter of opening new areas to harvest plentiful resources especially in North America, Russia and the Persian Gulf and letting prosperity drive innovation so that technological solutions emerge in time before these resources run out. The EDEC challenge then is: can such accelerated exploitation of resources be extended to all resources needed to maintain affluent lifestyles including natural (fossil fuels, ores, important trace minerals), water, environmental, and biosphere resources and sustained for at least the next 50 years?

The second knotty issue whose discussion I will also short-change is that of the scale and timing of the impacts of anthropogenic emissions of greenhouse gases (GHGs)—the climate change challenge. Said differently, even if there was unlimited supply of fossil fuels, do/will we have the time and resources to arrest and mitigate the impacts of pollution and climate change. Again, I briefly summarize my understanding of the subject and provide the basic arguments for why I am convinced that we have to start addressing and implementing climate change mitigation and adaptation strategies *now*.

– A number of gases such as CO_2, CH_4, O_3, N_2O, are emitted when fossil fuels are extracted and combusted and these contribute to the greenhouse effect. While their quantities, lifetimes in the atmosphere and magnitude of effect differ by orders of magnitude, they all provide a positive radiative forcing that heats the Earth.

– CO_2 is of most serious concern because i) the scale of emissions is enormous, currently about 30 gigatons per year; ii) it is the highest oxidized form of carbon and nature processes CO_2 slowly, mainly through photosynthesis, mineralization and absorption by water in oceans. These processes cycle only about 16 gigatons per year. iii) The remainder, about 14 gigatons of CO_2 per year, gives rise to increase in concentration in the atmosphere by about 1.8–2.0 ppm per year since 2000 (the Keeling curve). Thus nature is able to recycle only about half the current emissions. iv) At this accumulation rate deep oceanic water is the primary remaining reservoir but its time scale to cycle CO_2 is thousands of years. Thus, to first approximation, half of all CO_2 emissions will continue to accumulate, and this fraction may increase due to non-linear feedbacks. v) There are no easy or cost-effective technologies available to remove CO_2 from the atmosphere at this scale. Carbon Capture and Sequestration (CCS) from point sources such as power plants is still a field in its infancy and CCS will add significant cost. Thus, any CCS mitigation strategy, if feasible at gigatons scale, will have to be developed over many decades. vi) There are other contributors, both positive and negative, to radiative forcing including aerosols and black carbon. Their emission rate can be changed dramatically over a ten-year period through regulations mandating scrubbers since relatively cost-effective technologies are available and have been demonstrated at scale by many developed countries. There is concern that their combined impact may be to mask the full radiative forcing of CO_2, in which case the predicted warming could be much worse once the desired-for regulations restricting their emissions are enforced globally. For these reasons climate change mitigation strategies focus on CO_2.

– Our current understanding is that every 100 ppm increase in atmospheric concentration of CO_2 will lead to 0.8–1.0 °C rise in temperature; and a further 2 °C rise in average surface temperature could be disastrous for many parts of the (highly populated) world. It is this part of the argument that has attracted the largest debate because untangling the various radiative forcings and converting radiative forcing into consequences (temperature rise, changes in weather and biosphere) has been hard and with large uncertainties due to the complexities of the various factors and their interactions and feedbacks. I am convinced by the growing body of scientific evidence of the connection between use of fossil fuels, increase in GHGs and temperature rise. I, therefore, advocate action to reduce emissions of GHGs.

– Many of these natural phenomena have multiple feedback loops that we do not fully understand, and worse we have almost no knowledge of when non-linearities in them will start to grow significantly. Thus, we have little or no knowledge of the onset of runaway solutions, *i.e.* points in time (or CO_2 concentration), when we will not have the technical or the financial resources to put into place mitigation and adaptation strategies even if social and political will to take action could be generated globally. This very high impact possibility calls for *urgency in action*.

With this current understanding of the EDEC challenge, and the need to share development (rather than condemn 50% of world population to poverty), the question is: what should our strategy be to simultaneously address development, environmental stewardship and mitigation/adaptation to climate change? Before discussing options it is useful to discuss the scale of change required to appreciate the magnitude of the challenge.

2. – What constitutes a part of the solution?

History demonstrates clearly that while people will transition rapidly to non-polluting forms of energy given a chance, in need they will also use any and all fuels available. The problem with fossil fuels is that they are amazing! They are unsurpassed in terms of their energy density (both gravimetric and volumetric), portability, safety and ease of use, and power density (rate of heat delivery). While many innovative and entrepreneurial people will continue to invent novel ways to exploit alternate resources and develop niche markets, in the long run they have to address the comparative issues of scale, density, intermittency and life-cycle cost. The question is not if a given technology will sell and be profitable, but whether it is sustainable and can cost-effectively scale up to global needs. The two scales that, to my mind, constitute a part of the "solution" are:

– *1 terawatt for electric power:* To provide 21st century opportunities to 10 billion people will require about 7–10 terawatts of electric generation capacity; the range reflecting uncertainty in how much more energy efficient industrial processes, gadgets and lifestyles become. This is 2.5-3.5 times the current capacity. To meet this demand and reach my criteria of a "solution", *i.e.* 1 TW, nuclear power (current fleet of 438 reactors with 372 Gigawatts capacity) would have to grow by a factor of 2.7! Hydroelectric installed capacity is about 800 GW globally and unlikely to even double as the most productive sites have already been exploited. Today, only fossil fuel based generation, with about 2 terawatts installed capacity, qualifies. Geothermal heat pumps for home airconditioning are cost-effective, as is utility scale wind where the intermittency and transmission issues have been addressed.

– *10 million barrels a day (Mbd) for liquid fuels:* The second leading source of liquid fuels after oil are biomass derivatives (ethanol, biodiesel and green diesel) at about 1.5 Mbd. They contribute about 2% of the 85 Mbd used globally. Even if we are able to improve liquid fuel efficiency in the transport sector by a factor of three globally, the demand will not decrease significantly if 10 billion people use some form of personal liquid fuel driven transport. Thus, 85 Mbd is a reasonable target for meeting global demand and a 10 Mbd wedge a part of the "solution" if transportation continues to be driven by internal combustion engines albeit far more efficient. If fully electric cars become the norm, then the total demand for oil could reduce very significantly to about 20 Mbd, but the above projections for electric power generation capacity may need to be doubled to 14–20 terawatts.

3. – Evolutionary transformation of the current energy systems

The existing infrastructure is too large to change overnight, nevertheless it is in the midst of very significant transformation in both the developing and the developed world. In the developed world the first generation power plants (those installed before 1970) will mostly be replaced by 2020. The developing world is installing its capacity for the first time. Some specific examples of the ongoing changes are:

- *Fuel substitution:* In almost all countries thermal generation based on fuel oil is being rapidly replaced by natural gas and combined cycle gas turbines (CCGT). Examples include Mexico, Persian Gulf countries, Egypt and Israel. The main challenges are replacing coal for base load power generation and oil for transport.

- *Fuel mix:* The Asian Tigers (Japan, South Korea, Taiwan) are evolving to a roughly 40-30-30 mix, *i.e.* 40% nuclear, 30% fossil (coal and natural gas), and 30% renewables. Coal and nuclear plants provide base load. Gas turbines and hydro (conventional reservoir based, run-of-river, and pumped storage) are used to address peak demand and integrate intermittent resources such as wind and solar into the grid.

- *Efficiency:* There is growing emphasis on improving the efficiency of all coal and gas plants by transitioning to Cogen (ultra) super-critical coal and CCGT gas plants. Similarly, fuel efficiency of cars is improving and by 2020 significant penetration of the market by fully electric vehicles is considered realistic. Home appliances are increasingly more energy efficient but each home now has more gadgets.

- *Pollution control:* In this aspect the record is mixed. The developed world is installing low NO_x burners and desulphurizing units on both new and retrofit power plants, while in the developing world there is lack of consensus on their necessity, so regulations are inadequate and adoption is on case by case basis driven by cost.

These changes are all clearly in the right direction of increasing energy efficiency and decreasing carbon intensity, but their combined impact has been overshadowed by the growth in demand, consequently global emissions of CO_2 are still increasing at about 3% annually. This growth reflects the first priority of a large part of the world—to continue to address the development challenge and the needs of 4.6 billion under-served people. To simultaneously mitigate climate change will need a paradigm shift. Whether this shift is brought about by technological innovations alone or whether it also requires a change in our expectations, living standards and use of energy is a much debated question.

4. – Seven scientific grand challenges that can provide a paradigm shift

A radical change from the above market-driven incremental evolution of energy systems, *i.e.* the business-as-usual scenario, to meet climate change mitigation goals requires one or more of the following innovations to take place if technology is to provide "solutions". In the US, competitive edge *versus* coal for any renewable power generation occurs when tariff is below \$0.10 (\$0.05) per kilowatt hour if CO_2 is (not) priced.

- *Carbon Capture and Sequestration (CCS):* For continued development based on fossil fuels, CCS is a must. Today, the cost of CO_2 separation from even point sources such as power plants is high, and enough sequestration sites with adequate capacity have not been adequately characterized nor long-term risks fully quantified.

- *Solar at \$1 per firm Watt:* Solar (both PV and thermal) technology is evolving fast, however, without any subsidies the cost of installed PV today is \$5–7 per peak Watt (or \$20–30 per realizable Watt or \$0.25–0.3 per kwh) and \$5 per Watt for thermal with 8 hours of heat storage. Furthermore, integration of large scale solar (and wind) into the grid requires overcoming the intermittency of generation issue.

- *Storage and transmission:* Wind and solar, the two cleanest resources, are intermittent and cannot provide guaranteed supply as they depend on the sun shining and the wind blowing. Two cost-effective backup systems are pumped storage hydroelectric and gas turbines, but these cannot be counted on to provide firm capacity for days as is often the case, otherwise there is no real replacement of fossil-fuel fired capacity by renewables. Current battery technology has provided a good backup solution for essential home needs, but battery packs are inadequate for say home air-conditioners. It is unlikely that conventional batteries with significantly higher charge density can be realized (they are close to explosive limits already), so one needs new concepts for energy storage. One option is storage in chemical bonds, *i.e.* mimicking photosynthesis, as discussed in the next item. To use geographical distribution of solar and wind resource to balance demand and supply over continental distances requires transporting electric energy long-distance in very large quantities. Rough estimates indicate US needing a hundred times larger long-distance transmission grid—something that is impractical using "copper" wire technology. An attractive option is superconducting technology if it can be made cost-effective and easy to deploy and maintain at the required scales.

- *H_2 and liquid fuels from photochemical or thermal splitting of water:* The cleanest chemical storage medium that can be scaled up, and comes close to fossil fuels in gravimetric energy density is hydrogen, especially if it is converted to hydrocarbons for easier storage and use. The challenge is to produce hydrogen without using fossil fuels as feed-stock. Options are photochemical splitting of water using cells with cheap, efficient and corrosion resistant electrodes (mimicking photosynthesis) or thermal splitting using high temperature gas cooled nuclear reactors.

- *Closed nuclear fuel cycle:* To deploy nuclear power at Terawatt scale, and in many more countries than the present 29, will require higher guarantees of safety at every stage of the fuel cycle and the nuclear complex, security of nuclear materials, and waste management. A closed nuclear fuel cycle is one option, but it carries the concern that any country with this technology is, *de facto*, a nuclear weapon state albeit virtual. Furthermore, cost-effective fuel processing, and an international framework for issues such as assured supply and take-back need to be worked out.

- *Tailored biomass:* The hope is biomass cultivation will not displace food (take over agricultural land) but use large tracts of marginal lands, and without further stressing water resources or significantly increasing the use of fertilizers and pesticides. Thus, biomass for fuel needs to be pest resistant, low water- and fertilizer-consuming, and easily degradable. This is a challenge for the bio-chemical industry.

- *Fusion:* The principles of fusion are known, however, in spite of very significant progress over the last 50 years, creating and maintaining extreme conditions of temperature and radiation in test and eventually commercial reactors remains a challenge for our colleagues in plasma physics, chemistry and material sciences.

A huge effort is being made globally to achieve these scientific/technological breakthroughs. The drivers are obvious—there is an enormous pot of gold at the end of this rainbow and fame for addressing the challenge of the 21st century. My belief is that there will not be *one* solution but, as history shows, a combination of *all* depending on cost and relative measure of "cleanliness" based on a life-cycle analysis. Also, many options will be profitable in niche markets (representing billions of dollars) but will not grow to the terawatt scale. My bet is that solutions to the EDEC challenge this time around, that provide ever more freedom, choice and productive lifestyles to 10–11 billion people, will not be simply technological. Society will need to redefine its priorities, needs, and measures of well-being and happiness.

Given the enormous complexity and magnitude of the EDEC challenge, what extra contribution can a high energy physicist make to help facilitate the transition? My answer has been to create a web-based tool called the Global Energy Observatory to help the public understand the development needs of countries, existing networks of energy systems and their emissions, and the dynamics of change in them, so that there is better analysis, planning, policy and execution.

5. – The Global Energy Observatory (http://globalenergyobservatory.org)

GEO is a web-based collaborative tool (a moderated Wiki with built in real-time analysis tools) that aims to provide a one-stop site for detailed unit-by-unit information on 29 different types of infrastructures that constitute a very large fraction of global energy systems. The relational database (MySQL) is organized into four categories:

- *Power plants:* Coal, gas, geothermal, hydro, nuclear, oil, solar PV, solar thermal, waste and wind electric generation plants.

- *Fuels and resources:* Oil and gas fields; coal and uranium mines; crude oil refineries; solar and wind potential; biomass and water resources; CO_2 sequestration.

- *Energy transmission infrastructure:* Oil and gas pipelines; coal, LNG, oil ports; rail and road and shipping links; electric power grid.

- *Consumers:* This database (under construction) will quantify demand and track consumption/demand by the industrial, commercial and residential sectors.

All infrastructure and consumption data are geospatially and time referenced. The goal is to integrate them with real-time analysis tools to understand global energy networks, emissions and the impacts on the environment, and the dynamics of change in them.

GEO is a framework for collecting data by i) harvesting open "official" databases and ii) facilitating the public to volunteer information. Data for a given infrastructure unit is entered/accessed as a web-editable page. Large structured databases are input directly using scripts. Some of the challenges of traditional wikis we are addressing are:

- Open "official" databases exist in many different formats (HTML, excel, pdf) and are often highly fragmented. GEO brings them together in one integrated system and in a structured format for archiving, databrowsing and multi-level analyses.

- Facilitate multi-level and multi-sector analysis by a comprehensive collection of data and linking associated infrastructures in the database.

– "Official" data are not complete, and updates lag by 2-5 years. To facilitate completion, the GEO framework accepts edits and volunteered information from users.

– "Official" data compilations miss the opportunity to capture a large body of high-quality data. For example, published and unpublished data collected and analyzed by academic departments, journalists, advocacy and environmental groups. Our aim is to provide these organizations with an easy to use and download compilation which, in turn, serves as sufficient motivation for them to partner in building GEO and validating the framework and databases further.

– GEO includes a framework for continuous moderation and validation of data that is analogous to peer reviewed referee system followed by scientific journals.

– We have found that both kinds of data, "official" and volunteered by the users, requires validation and verification but at different levels. We are therefore building algorithms that will run in the background to flag possible inconsistencies.

We are currently focusing on building analysis tools and collecting and analyzing data. I look forward to many of you exercising the system and providing us feedback.

6. – Things we can do today to address the EDEC challenge

In addition to educating ourselves and helping others adopt the many energy saving and less carbon intensive technologies, there are two areas that need far more public engagement and action:

– A dramatic shift from dependence on private cars to public transport, and all countries facilitating this by planning and timely implementation of efficient public transport systems. Public transport is especially important to implement in the developing world while it urbanizes to prevent unwieldy congested cities. In addition, there need to be global agreements on very aggressive fuel efficiency standards, for example, a car and small truck fleet average of 25 km per liter by 2030.

– *Population stabilization:* There remains a lack of convincing analyses that the Earth can sustain 10–11 billion people and provide all with 21st century opportunities. We must, therefore, confront the social, political and religious sensitivities and start serious discussion on whether population stabilization through education and voluntary adoption of birth control methods should be a global goal. Also, to implement current efforts in the developing world there is need for a global fund to provide all people of reproductive age free, uninterrupted and easy access to high-quality methods. Such a global fund will require about $10 billion per year.

In my view overcoming the EDEC challenge will require assuming collective responsibility and making it a global priority. This has not yet happened. Until technological solutions emerge, countries and individuals will have to rethink the balance between profit, competitive edge and cooperation and what each of these means and what responsibility each requires. To summarize, the question we face today is age old—how many people will share the opportunities and the wealth of this planet and be its stewards? Will the answer in the 21st century be the 20th century one, about 30%, or the Utopian one, 100% of the global population?

Further reading: The online wikipedia is a good and easy to access starting point for information on fossil-fuels, Hubbert's curve and "peaking", Keeling curve, climate change, greenhouse gases, radiative forcings, energy density of fuels, solar and wind technology, energy storage and transmission technology, CCS, biomass and biofuels, nuclear fuel cycle, and fusion. Population data are available at `http://prb.org/`. A good databrowser for viewing 2009 BP statistical data is `http://mazamascience.com/`.

* * *

This work has been supported by the New Mexico Consortium and Regional Climate Initiative at Los Alamos. I would like to thank G. Isidori and M. Greco for inviting me to share my understanding of this highly complex and urgent issue.