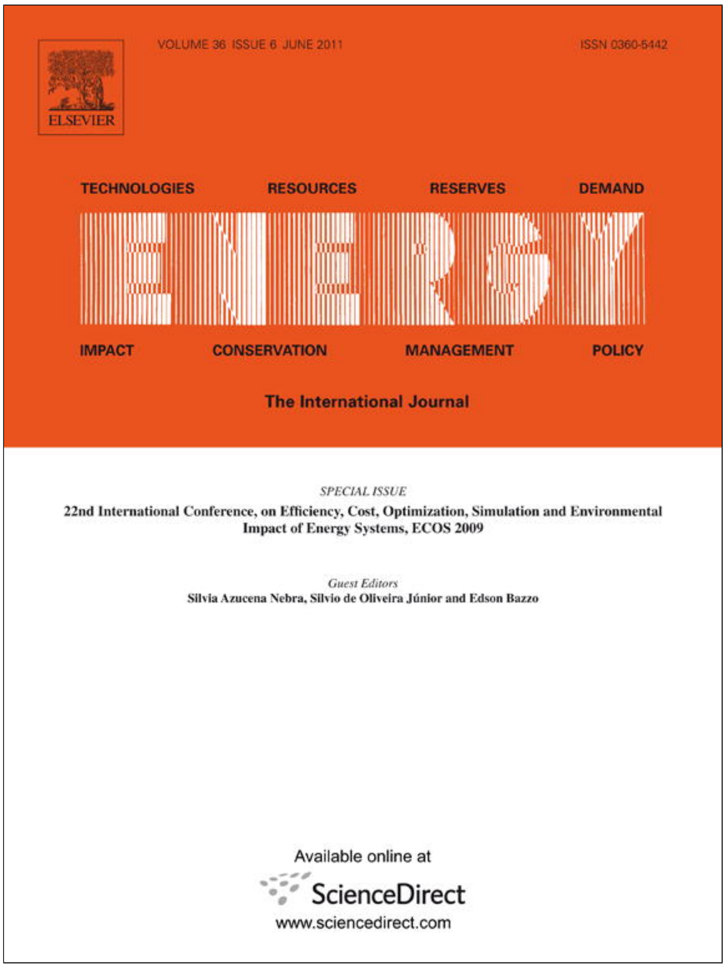
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The ECOS 2009 World Energy Panel: An introduction to the Panel and to the present (2009) situation in sustainable energy development

Noam Lior

University of Pennsylvania, Department of Mechanical Engineering and Applied Mechanics, Philadelphia, PA 19104 6315, USA

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ABSTRACT

This paper introduces the ECOS 2009 conference World Energy Panel, and presents the opening talk that briefly surveys the present (2009) situation in sustainable energy development. Recent (2008) estimates and forecasts of the oil, gas, coal resources and their reserve/production ratio, nuclear and renewable energy potential, and energy uses are surveyed. A brief discussion of the status, sustainability (economic, environmental and social impact), and prospects of fossil, nuclear and renewable energy use, and of power generation (including hydrogen, fuel cells, micro-power systems, and the futuristic concept of generating power in space for terrestrial use), is presented. Comments about energy use in general, with more detailed focus on insufficiently considered areas of transportation and buildings are brought up. Ways to resolve the problem of the availability, cost, and sustainability of energy resources alongside the rapidly rising demand are discussed. The author's view of the promising energy R&D areas, their potential, foreseen improvements and their time scale, and last year's trends in government funding are presented.

The ECOS 2009 Conference World Energy Panel

One of the key scientific events of the 22nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems – ECOS 2009 was the World Energy Panel composed of international energy experts that discussed, with good audience participation, the world situation of energy and its various impacts, and sustainable paths to the future. The panelists briefly presented the situation in the major energy hubs of the world: China, India, Japan, the European Union, Latin America, and the United States of America.

The panelists and their presentation titles were:

Professor *Noam Lior*, University of Pennsylvania, USA, *Panel Coordinator*: "Sustainable energy development: A brief introduction to the present (2009) situation",

Dr. *Amilcar Guerreiro*, Director of Economic-Energetic and Environmental Studies of the Energy Research Company – EPE – "Empresa de Pesquisa Energética", Brazil: "Brazilian renewable energy outlook",

Professor *Na Zhang*, Chinese Academy of Sciences, China: "Energy situation and future development strategy in China",

Professor *Kirit S. Parikh*, Former Member, Planning Commission, Government of India, Chairman, Integrated Research and Action for Development, India, "India's energy needs, CO_2 emissions and low carbon options",

Professor *Antonio Valero*, Member of the FP7 Energy Committee of EU, Director of the Centre for Research into Energy Resources and Consumption, CIRCE. University of Zaragoza, Spain: "The Energy Research Policy of the European Union",

Professor *Toshihiko Fujita*, University of Marine Science and Technology Japan: "Overview of Japan's energy situation and energy conservation measures",

Professor *Claudia Sheinbaum*, former Minister of Environment of Mexico City, member of the Mexican Academy of Sciences and Contributing Author for the Fourth Assessment Report. Group 3. Chapter 7: Industry. Intergovernmental Panel on Climate Change, honored with the 2007 Nobel Peace Prize, UNAM, México: "Energy reforms and sustainable energy policies in Latin America: overview of past decades".

The reviewed and accepted full papers by the panelists who chose to submit them for publication consideration are included in this special issue of Energy. The introductory paper, "Sustainable energy development: A brief introduction to the present (2009) situation" by Noam Lior, follows.

1. Introduction

This paper is intended to provide a brief background description to my introductory presentation for the World Energy Panel,

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summarizing key highlights of the global status in 2008 of energy resources and use, related environmental effects, an unofficial review of directions that the new U.S. administration led by President Obama plans to take as reflected by its U.S. Department of Energy proposed fiscal year 2010 budget, and description of some possibly sustainable paths to the future. In accord with the panel presentations format, the included highlights are not elaborated upon, but the main references are cited in the "References" list following the text, and a broad list of useful references is given in the "Further Readings" list at the very end.

2. The current energy resources and consumption situation has not changed much relative to last year

- A major concern (or opportunity?) is, however: the price of oil was lately growing very rapidly, from $28/barrel in 2003 to $38 in 2005 and occasionally to above $80 in 2006 and peaking at $147 in 2008, but then precipitously dropping to $40 by the end of 2008 [1].
- The peak price is one to two orders of magnitude higher than the cost of extraction, possibly meaning that financial speculation is overwhelming supply and demand, and all technical improvements.
- As shown in Fig. 1, in 2008 world primary energy use rose by 1.4%, with the increase *rate* dropping, due to rising prices, the recent economic downturn, and increases in energy efficiency, but is likely to rise again soon with the economy, as the large developing countries in Asia keep improving their standard of living, China's rose by 7.2% (lowest since 2002), India's by 5.6%, and some significant drops are those of the EU −0.56%, Japan −1.9%, US −2.8%, and led by Australia −4.2% [1,5].
- The reserves-to-production ratio (R/P) remains rather constant: ∼40 for oil, ∼60 for gas, and 120+ for coal, and mostly rising (Figs. 2–4)! There probably exists sufficient oil and gas for this century and coal for 2 or more [1].
- Tar sands and oil shales are becoming more attractive and available in quantities probably exceeding those of oil and gas.
- Nuclear power produces ∼14% of world electricity; the number of reactors is increasing very slightly [4]; public perception is improving, new government initiatives started, but the same problems remain (cf. [17,22]). Recent stoppage of the development of the U.S. Yucca Mountain long-term nuclear waste storage facility [41,42] is temporarily a serious setback to nuclear power development.
- Renewable energy can satisfy at least two orders of magnitude more than the world energy demand (cf. 19,20,27,33–37), but negative impacts aren't inconsequential (cf. [53]).
  - Wind and solar photovoltaics (PV) are experiencing an exponential growth as costs decrease and with the support from government incentives (cf. [1,3,5,19,27–30,45].)
  - Interest is renewed in solar thermal power (cf. [23–26]).
  - Biomass energy has an important role but questions about its sustainable use are increasing (cf. [31–33])
  - Geothermal energy deserves more attention (cf. [35–37]).
- Strong subsidies for converting food to fuel are increasingly proven to be a mistake, helping triple the price of foods and reducing their availability, and raising water consumption, all as predicted by some ahead of time (cf. [47,48]).
- While hydrogen, and fuel cells, continue to be valuable in the energy portfolio, they have not met the expectations expressed by the huge R&D investments made by many governments. This could have been foreseen by more careful early analysis, and some of the moneys and valuable scientists' time could have been spent better.
- The plug-in electric or hybrid car seems to be the preferred route to private transportation. Improvement of traffic management, roads, and public transit are at least as important but don't receive adequate attention.
- The new U.S. administration's requested annual energy budget [41,42]:

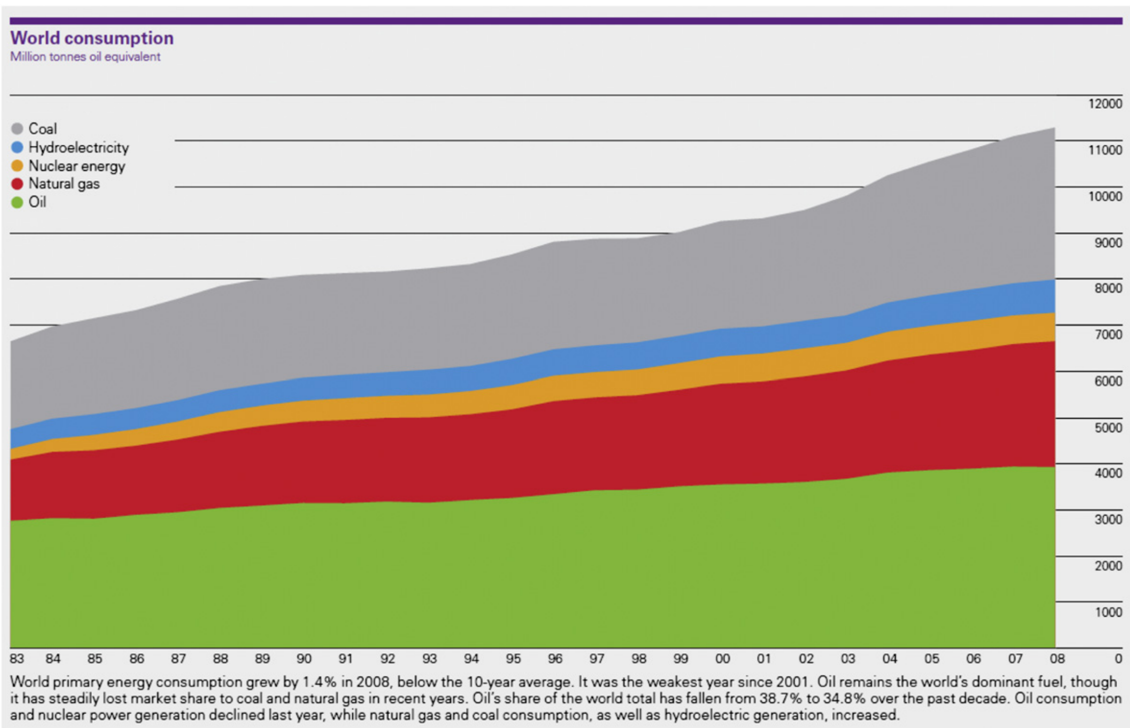

Fig. 1. World primary energy consumption 1983–2008 [1].

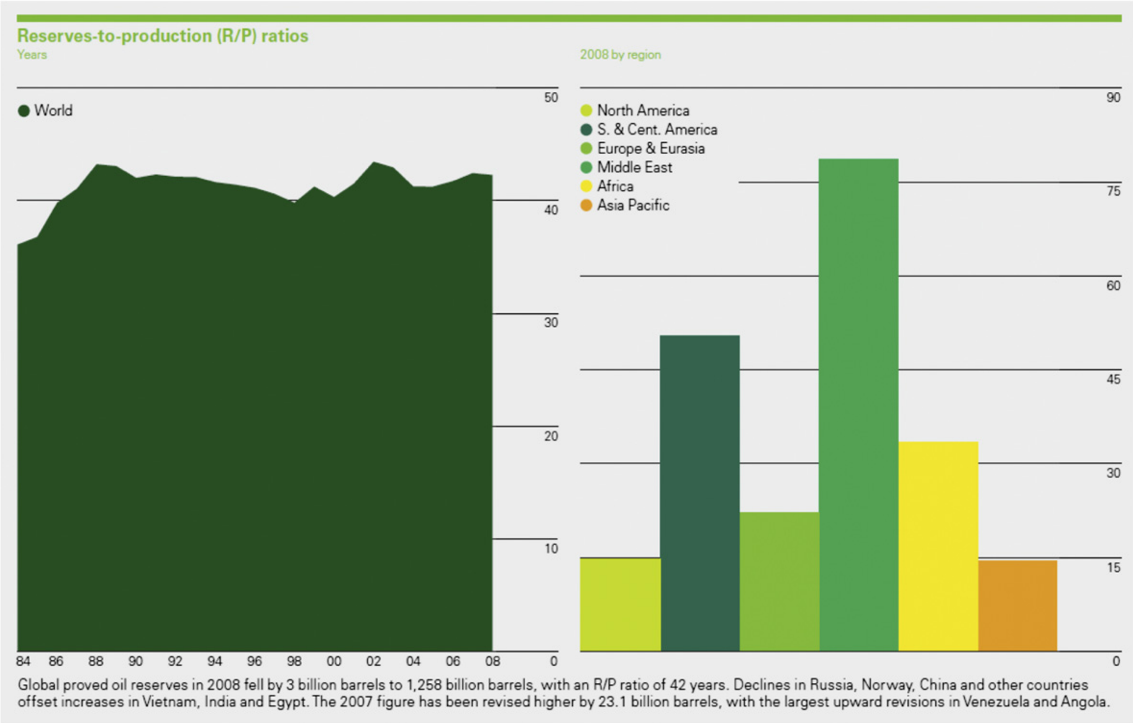

Fig. 2. The oil (proved reserves)-to-production ratio (R/P), 1983–2008 [1].

- Somewhat favours renewable energy development and global warming control
- Is slightly lower than last year's
- But received a one-time order of magnitude increase through the economic stimulus program intended to ease the unexpected economy turndown.
- Globally, costing of energy resources remains inequitable, as it doesn't include subsidies, environmental impact, and other consequences
- Development of renewable energy, and of all energy systems for that matter, is dominated by the highly controlled, cost-

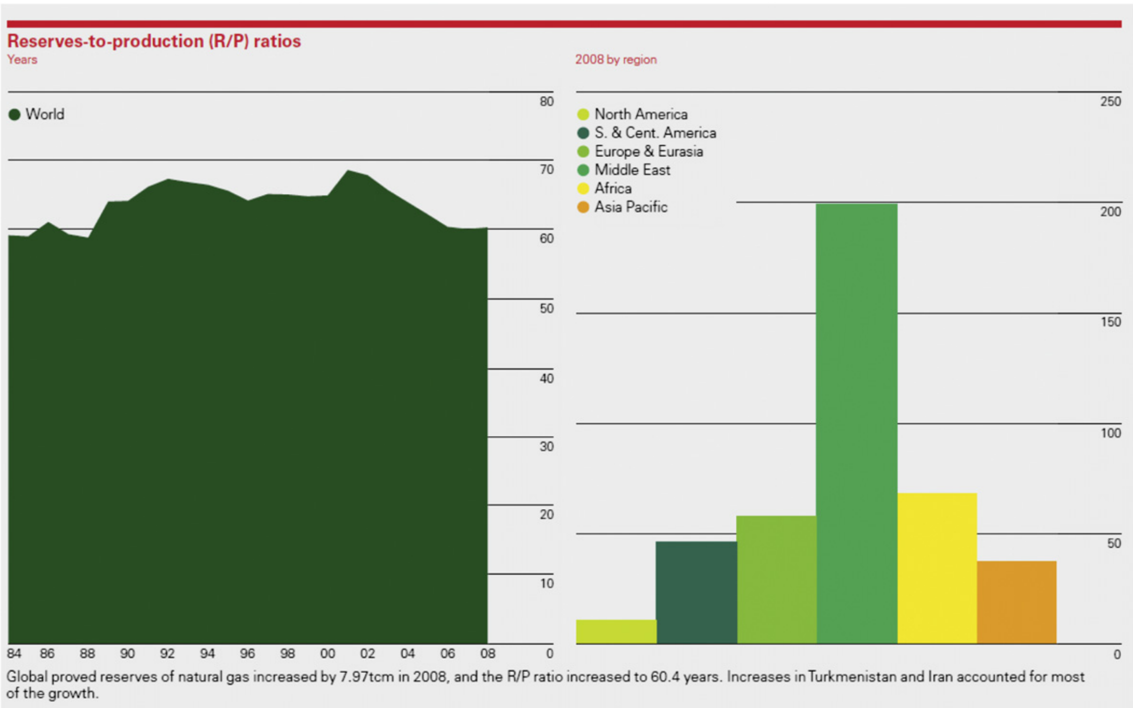

Fig. 3. The gas (proved reserves)-to-production ratio (R/P), 1983–2008 [1].

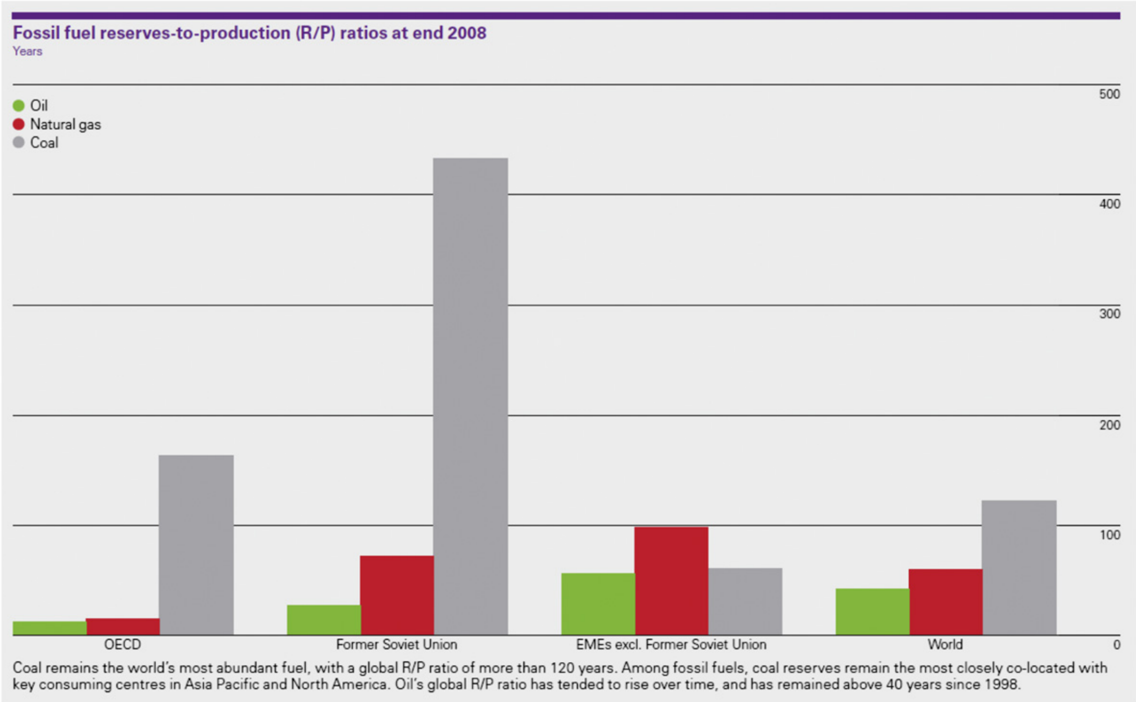

Fig. 4. Fossil fuels (proved reserves)-to-production ratio (R/P), 1983–2008 [1].

unrelated, highly-fluctuating and unpredictable conventional energy prices
- Fuel and energy consumption in general must be significantly constrained, with due attention to prevention of the rebound effects; pursuit of higher efficiency without care of the rebound effect is counterproductive (cf. [43–45]).
- The "Living Planet Index" is estimated to have declined since 1970 by about 30%, and the "Ecological Footprint" increased by 70% in the same period: we seem to be *running out of environment much faster than out of resources*[1].
- It is highly inadvisable, and unlikely, that energy resourcing, conversion and consumption continue to be developed unsustainably.
- Sustainability is only emerging as a science, and must be developed and applied urgently (cf. [11]).

3. Future power generation

- The most imminent challenge is that expected demand for electricity would require during the coming two decades the installation of as much power generation capacity as was installed in the entire 20th century (cf. [1,2,5,12,14,38]).
  - One 1000 MW plant every 3½ days
  - E.g., China is adding already one coal-fired 1000 MW plant each week [13,39].
- The global electric energy generated growth in 2008 was 1.3%, to 20,202 Terawatt-hours = 73.2 EJ [1,2,5].
  - Notably, the global growth was more than 3-fold *lower* than in preceding years
  - It dropped in the U.S. by 1.3%, and in EU by 0.1%; rose in India by 2.9%, China 4.5%.
- While the plug-in hybrid electric car, and electric-driven public transportation, seem to be the most promising ways towards energy-efficient transportation, this would further raise the demand for electricity in a most significant way, perhaps increasing it by about 30%.[2]
- To mitigate associated negative effects of such massive increase, it would increasingly have to be done sustainably.
- Because of its abundance and relatively low cost in the most energy consuming countries such as China, the USA, parts of Europe, India, and Australia, coal is likely to be increasingly the main basic fuel for these plants [5,14,39], partially after conversion to gaseous or even liquid fuels, with the reduced emissions IGCC (Integrated gasification combined cycle) plant receiving major attention (cf. [49–52]).
- The combined cycle power generation plants are the most desirable, having efficiencies of up to about 60% even at present, less emission than other plants when using natural gas, and reasonable cost that would keep decreasing as the technology advances further.
- The technology for CO_2 capture in fossil fuel power generation is within reach, but sequestration of the CO_2 is not yet (cf. [6,16,40])
- Despite the unresolved problems of waste storage, proliferation risk, and to some extent safety, nuclear power plants are likely to be constructed at least for special needs, such as countries that have much better access to uranium than to

[1] Evidence about longer term availability of fuel resources, for this century and beyond, can be found in references [1,5,20,21,46]; evidence about the rapid drop in the "*Living Planet Index*" and rapid rise in the "Ecological Footprint" can be found in [10]. While there may be some disagreements about the accuracy of these environmental indices, the trends are correct.

[2] There are about 650 million cars in the world. If each becomes electric and uses 20 kWh electricity/day (average world value), we would need an annual electricity amount of (4.745) 10^{15} Wh/year. Assuming about 10% transmission losses and 20% battery charging losses, this needs generation of (6.263) 10^{15} Wh/year. This would increase the current total global electricity production demand of 20.2 PWh/year, by 31%.

fossil fuels, and if carbon emissions become costly. The amount of uranium-235 in the world is considered by many to be insufficient for massive long-term deployment of nuclear power generation, which can change if breeder reactors are used, but that technology isn't safe and mature enough and is not likely to be in the next couple of decades [4,18–21].

- Wind power generation will be deployed rapidly and massively, but will be limited to regions where wind is economically available, and will be limited by the extent and quality of the electricity distribution grid [27–30].
- Photovoltaic power generation will continue increasing in efficiency and decreasing in price, and being employed in many niche applications, but being three to five times more expensive now than other power generation methods, and also limited by the extent and quality of the electricity distribution grid, and even by availability of materials, it may not reach parity in the coming decade [3,5,20,27,45].
- Geothermal energy potential is orders of magnitude higher than the total world energy demand, it is "renewable", and it supplies heat at a steady rate. R&D for deeper drilling and for geothermal power generation deserves much more attention [19,20,27,35,37].
- Improvements and technological advances in the distribution and storage of electric power will continue and should be advanced much faster (cf. [15]).
- The investments in energy R&D appear to be much too low, less than half a percent of the monetary value of the energy use, to meet the future needs [32].

Some of the related key global data are shown in Table 1.

4. An unofficial review of the new U.S. Administration's Energy R&D budgets and trends [41,42]

The year 2009 is an important year for energy in the U.S. because the voters turned the 8-year leadership by a Republican Party government and president into the Democrat Party hands, alongside with the historically significant election of President Barack Obama. The new administration, following basically its campaign promises and also faced with the immediate worst economic downturn since the great depression, started making significant changes in many directions, including in the energy and environment areas. This section briefly summarize the U.S. Department of Energy (DOE) fiscal year 2010 budget request that pertains to the energy and environment area and discuss changes relative to past years under the previous administration. Some of the statements are taken verbatim from the DOE budget documents, but the commentary is entirely the author's and does not represent, nor is sanctioned by, government.

The requested budget is stated to support the President's commitment to the challenges of economic uncertainty, U.S. dependence on oil, and the threat of a changing climate (reducing U.S. carbon emissions) by transforming the way the U.S. produces and consumes energy. Most impressively in purpose and magnitude, an additional one-time allocation of $38.7 billion from the American Recovery and Reinvestment Act of 2009, is to be added to the 2010 year DOE budget and used (typically starting in 2009 with a duration of about 3 years) to accelerate investments in energy conservation and renewable energy sources ($16.8 billion), environmental management ($6 billion), loan guarantees for renewable energy and electric power transmission projects ($6 billion), grid modernization ($4.5 billion), carbon capture and sequestration ($3.4 billion), basic science research ($1.6 billion), and the establishment of the Advanced Research Projects Agency ($0.4 billion), all "to help jumpstart the economy and save and create jobs at the same time". To characterize the enormity of this expenditure, the $38.7 billion from the American Recovery and Reinvestment Act is more than 6-fold higher than the DOE Annual Energy R&D and Science budget and about 16-fold higher than the annual amount that the EU 7th platform allocated for R&D in roughly the same areas.

The budget emphasizes (a) clean, renewable energy generation, (b) energy efficiency and conservation, (c) electric grid modernization, (d) other low emission energy technologies focused on low-emissions transportation, safe and reliable nuclear energy, and cleaner coal, and (e) improved energy information data and analysis.

Proposing to use a cap-and-trade process, the current U.S. administration plans to reduce the U.S. greenhouse gas emissions by 14% under the 2005 baseline by 2020, and by 83% below the 2005 baseline by 2050 (similar to the IPCC (Intergovernmental Panel on Climate Change) proposal).

It includes $1.2 billion for three new approaches to augmenting research and development efforts:

- Energy innovation hubs

Establish eight multi-disciplinary energy innovation hubs at a total of $280 million to address basic science, technology, and economic and policy issues hindering the nation's ability to become energy secure and economically strong while reducing greenhouse gas (GHG) emissions. This initial set of research hubs will explore solar electricity; fuels from sunlight; batteries and energy storage; carbon capture and storage; grid materials, devices, and systems; energy efficient building systems design; extreme materials; and modeling and simulation (the latter two for nuclear energy).

- Energy frontier research centers

The existing 16 Energy Frontier Research Centers (EFRC) will continue to be supported.

These centers, involving almost 1800 researchers and students from universities, national labs, industry, and non-profit organizations address the "full range" of energy research challenges in renewable and low-carbon energy, energy efficiency, energy storage, and cross-cutting science.

Table 1
Some key data during the period 2006–2008.

Item	Global amount
Total primary energy use	473 EJ[a] [1]
Industry	19% [5]
Transportation	19% [5]
Residential, services, agriculture	24% [5]
Electricity	38% [5]
Electric power installed	4.4 TWe [5]
Electricity generated per year	20.2 PWh = 73.2 EJ[b] [2,5]
People without electricity	1.9 billion
Global temperature rise in industrial period	0.76 °C, exponential rise[c] [5,6]
Water shortages	900 Million people lack safe drinking water, 2.5 billion people have inadequate access to water for sanitation and waste disposal, ground water depletion harms agriculture [7,8]
Food shortages	1.02 Billion undernourished people (1 in 6) [9]

[a] Four percent lower than the IEA value in [5].
[b] Indicates a 53% power plant capacity factor.
[c] The temperature increase per decade is more than twice as fast as that observed over the preceding hundred years.

- Advanced Research Projects Agency-Energy (ARPA-E)

ARPA-E with $410 million funding, is a new DOE organization to advance high-risk, high-reward energy research projects that can yield revolutionary changes in how we produce, distribute, and use energy.

The remaining information presented here about the budgets must be prefaced with a statement that examination of governmental and institutional aims and budgets is very difficult, in part because of duplication and overlap of programs, and frequent changes across them, and all the numbers given here are thus not always precise.

Outside of the huge injection of the funds from the American Recovery and Reinvestment Act of 2009, the USDOE budget dedicated specifically to energy R&D was requested to be reduced in the 2010 budget by about 11% from the 2009 (past administration's) amount, to about $4.2 billion. It additionally includes perhaps about $2 billion in basic energy sciences (out of the $4.9 billion USDOE Office of Science budget after its 3.9% increase, that funds also several other areas which are not directly related to energy). Thus the approximate total requested R&D and basic sciences budget for energy is about $6.2 billion.

Out of the USDOE energy R&D part, the programs of energy efficiency and renewable energy continues to increase its dominance to 58% (from 53% in 2009 and 48% in 2008) relative to those of fossil energy and civilian nuclear energy[3], basically at the expense of the latter that dropped to 19% (from shares of 20% in 2009 and 27% in 2008).

In more detail, the most important budget changes include:

- A 3.9% increase ($263 million, after the 19% increase in 2009) in the DOE's *Science* programs (nuclear physics including major facilities, materials, nanoscience, hydrogen, advanced computing).
- A 6.9% increase (vs. the 27% decrease in 2009) in the *Energy Conservation and Renewable Energy* program, with major gains in solar (+89%, following a +37% increase in 2009), wind (+36%), geothermal (+14%), vehicle technologies (+22%) to increase efficiency (focus on the plug-in hybrid electric vehicle, PHEV, to support the Presidential goal of deploying 1 million PHEVs by 2015 that can get up to 150 miles per gallon, 64 km/l) and enable operation on non-petroleum fuels, and buildings technologies (+70%); drop of 60% (after the 31% drop in 2009) in hydrogen and fuel cells and drop of 25% in water power. DOE's efforts on biofuels would focus exclusively on developing non-food/feed based cellulosic feedstocks, and ethanol production technologies.
- A 21% decrease (compared with the 23% increase in 2009) in the *Fossil Energy* program to $882 million, includes $404 million for clean coal technology, and $25 million for gas hydrates ("ultra-deepwater natural gas"). Very noteworthy is that here the Recovery Act is to provide *$3.4 billion* additionally for carbon capture and storage (CCS) and for the Clean Coal Power Initiative (CCPI), and more than offsets the $229 million decrease in the DOE's annual Fossil Energy budget.
- No capacity expansion for the 727 million barrels Strategic Petroleum Reserve (planned earlier to be expanded to 1 billion barrels beginning in FY 2008 and later to 1.5 billion barrels). The rapid increase in oil prices was one of the important reasons for that decision.
- Investment tax credits (typ. 30%) of $3.15 billion were allocated in 2005 and 2008 for accelerating commercial deployment of technologies central to carbon capture and storage, plus an additional $2.3 billion allocated this year from the American Recovery and Reinvestment Act of 2009 for manufacturing facilities that produce specified advanced energy products such as renewable energy power systems, automotive storage systems, energy conservation, carbon dioxide capture and storage (CCS) technologies and other systems designed to reduce greenhouse gas emissions.
- A 4% reduction in the fission nuclear energy program, to $761 million, aggravated by the fact that its R&D portion is reduced by 22%. The program continues to be aimed to develop advanced nuclear power for meeting energy and climate goals, to develop advanced, proliferation-resistant nuclear fuel cycle technologies and to maintain the national nuclear technology infrastructure. The highlights are:
  - Work will continue on nuclear waste storage and disposal options, and "Generation IV (Gen IV)" advanced nuclear reactors, including the sodium-cooled fast reactor, molten salt reactor, supercritical-water-cooled reactor, lead-cooled fast reactor, very high temperature reactor, and the gas-cooled fast reactor.
  - Seemingly termination of the $302 million Global Nuclear Energy Partnership (GNEP), launched in 2006 "to promote nuclear power in the United States and around the world and promote nuclear non-proliferation while developing new types of spent fuel reprocessing plants and fast-neutron reactors", with a main focus to speed the deployment of a commercial-scale nuclear fuel reprocessing plant in the United States.
  - All funding for development of the Yucca Mountain facility for permanent geologic storage site for spent nuclear fuel and high-level radioactive waste nuclear waste has been eliminated. The Administration intends to evaluate alternative approaches for meeting the federal responsibility to manage and ultimately dispose of spent nuclear fuel and high-level radioactive waste from both commercial and defense activities. This is a remarkable reversal of past year's decision to invest an additional $495 million for that facility (after spending about $13.5 billion (2007 value) over the past 26 years), touted all along as the main U.S. solution to its nuclear waste disposal.
- A $4.6% increase (to $421 million) in the fusion program, including continuation of the contribution to the multinational ITER program;
- A 52% increase (to $208 million) in the electricity delivery and energy reliability program. A long overdue attention to this historically underfunded but critical program, that addresses clean energy transmission and reliability, smart grid R&D, energy storage, cyber security of the electric distribution system, permitting, siting, and analysis (that uses education, outreach, and analysis to help states, regional electric grid operators, and federal agencies develop and improve electricity policies, market mechanisms, state laws, and programs to assist in modernizing the electric grid and the development of new electric infrastructure needed to bring clean energy projects to market), and infrastructure security and energy restoration.
- A 20% (vs. 5% in 2009) increase for the Energy Information Administration to improve energy data and analysis programs.

These numbers are rough, because there are research areas in the basic sciences that apply across energy source categories, and there are separately very large budgets that are dedicated to high energy physics and to the maintenance of large experimental facilities in the national laboratories.

[3] Excluding consideration of the GNEP program, described below.

Table 2
A qualitative assessment of promising research directions and their U.S. government funding trend (proposed 2010 annual budget, not including the one-time proposed funding from the American Recovery and Reinvestment Act of 2009).

Direction	Potential	Foreseen improvement	Time scale, years	2010 Government funding trend
Conservation	☆☆☆+	50% of use	Ongoing	☺
Transportation	☆☆☆+	50% of use;120 g CO_2/km by 2012	3–20	☺☺
Hydro power	☆	Reduction of environmental harm	Ongoing	☹☹
Biomass	☆☆+	30% U.S. energy	4–40	☹
Wind	☆☆☆	2.5 c/kWh, 15%	1–10	☺☺
Solar PV	☆☆☆+	Competitive price	6+	☺☺
Solar thermal	☆☆	Competitive price	5+	☺
Geothermal (deep)	☆☆	Competitiveness	20	☺
Hydrogen	☆☆	Affordable transport fuel	15	☹☹
Fossil fuel power	☆☆	67–75% efficiency, ~0 emission	6–15	☺
Oil and gas	☆+	Exploration, recovery, transportation	3–15	☹☹☹
Coal	☆+	Exploration, recovery, transportation, conversion	7	☺
Energy storage	☆☆☆+	Cost, weight and volume reduction	5–12	☺
Electricity transmission	☆☆☆	Grid expansion, smart grid, loss reduction	10	☺☺
Global warming	☆☆	0 CO_2	10–15	☺☺
Fuel cells	☆+	60% + efficiency; order of magnitude price reduction	9	☹
Micropower	☆☆☆	Cost, market penetration	7+	☺
Superconductivity	☆☆☆	Order of magnitude	30+	☹☹
Nuclear fission	☆	Manageable wastes, no proliferation	9	☹
Nuclear fusion	☆☆☆	Feasibility	35+	☺
Space power	☆☆☆+?	Competitiveness	50+	☹☹

☺: increased; ☹: decreased.

Based in large part on the USDOE budget trends, Table 2 very qualitatively summarizes the author's view of the promise and potential of the major energy R&D areas, foreseen improvements and their time scale, and trends in the U.S. Government funding, for 2009.

An educational endnote to the U.S. energy budget discussion is that *environmentally* unsustainable 50 years of nuclear weapons production and government-sponsored nuclear energy research results now in annual management and remediation ("cleanup of the environmental legacy") expenditure that is larger than the entire annual energy R&D budget. It consummately demonstrates how past unsustainable activities penalize progress to the future.

5. Possibly sustainable paths to the future

The first step in any path to the future is wiser use of the energy resources, also referred-to as conservation. This would include elimination of obvious waste, higher energy conversion efficiency, substitution for lower energy intensity products and processes, recycling, and more energy-modest lifestyles. Conservation must be implemented in a way that does not deprive people from the basic necessities and comforts of life, nor has a very negative impact on productivity.

It is impossible to find and implement effective ways for curbing energy demand and related emissions, and for supplying the needed energy if the wide fluctuations in oil and gas prices, like those experienced in the course of the past year, are not curbed. These fluctuations are a major impediment to sustainable development. This could be accomplished by a combination of technical measures and fiscal regulation, and should be implemented rapidly.

Much more effective involvement of, and cooperation among, the countries of the world in reducing GHG emissions and other negative environmental consequence of energy use must be rapidly put into action. Since large scale carbon sequestration is still impractical, major research, development and testing must be performed in that area.

The pursuit of more efficient and less polluting transportation must include not only vehicular improvements (with preference for the plug-in electric or hybrid car) but also traffic management, significant development of efficient public transit, and redesign of cities.

Buildings are the biggest single contributor to world greenhouse gas emissions. At the same time, improvements are stymied mostly by the fact that energy costs of a building are a very small faction of the resident's/owner's income, who thus have little incentive to implement them. Legislation that assigns real costs to building energy use and emissions, accompanied by financing practices that monetize long-term energy costs in near-term investment decisions can make a major contribution to this effort. Developing economical "Eco-efficient" or "Living" buildings that not only reduce their negative environmental impact but also help heal and improve the environment is highly encouraged. A broader method is to design residential communities in a way that reduces both indirect use of energy and emissions by reducing the need for transportation and resources by the residents.

At least for this century, more efficient and less polluting use of fossil fuels, as well as better and cleaner exploration and extraction of such fuels, is to continue to be pursued. Since coal is and will remain in the foreseeable future to be the major fuel for electricity generation, development of clean use of coal should be accelerated. Important steps must also be taken to prevent energy efficiency "rebound", the frequent outcome in which higher efficiency and lower costs lead to increased consumption and other problems (cf. [43,44]).

It appears that massive use of nuclear fission power would be stymied unless permanent and economical solutions to the nuclear waste, such as element transmutation, would be attained. This year's decision by the U.S. administration to stop funding for the development of the Yucca Mountain long-term radioactive waste depository is a setback to nuclear power development. Nuclear fusion power could produce a very satisfactory long term solution, but is still rather far from being achieved.

R&D and implementation of renewable energy must continue vigorously, with the most promising technologies currently being wind, solar photovoltaics and solar thermal power, and to some extent biomass. Extra careful sustainability analysis must be applied to the use of biomass for energy, to avert damage to land, water and agriculture and to avoid undue competition with food production. Economical very deep drilling technologies for reaching the enormous renewable geothermal heat resources should be pursued.

R&D to develop commercial superconductors would reduce energy losses significantly, but will take some decades at least. Space power generation for terrestrial use must be explored as a long term solution.

The inequitable costing of energy resources and their conversion must stop, by governments and industry assigning a true value based on all short and long term externalities. In-depth scenario studies are necessary for quantitative forecasting of the best ways to spend government research moneys, but qualitatively, and based on the current knowledge and situation, they should be enabled to develop effective commercial ways for attaining the sustainable development objectives.

It is not conceivable that sustainable development can take place without applying reasonable measures for population control.

Sustainability is only emerging as a science, and must be developed and applied urgently to provide analysis and evaluation tools. It is of immediate importance because energy conversion and use are associated with major environmental, economical and social impacts, and all large energy projects should, therefore, be designed and implemented sustainably.

The critical problems that energy development poses and the possible paths to the future create at the same time great opportunities for respected solutions by the engineering/scientific community that promote new and expanded creativity, higher employment, and higher job satisfaction. It also offers special prospects for small enterprises and nations that are not hampered by the inertia inherent in larger organizations.

A frequent major obstacle is the political system needed to support rapid and effective movement along the new paths, and to plan beyond its tenure, and that often prefers solutions that are primarily supportive of its own survival: popular support for sensible paths should be sought/educated to diminish this obstacle.

Many of the innovative solutions require very long periods of time. It is of vital importance to start intensively now, so we wouldn't be too late.

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