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Speculations on global energy demand and supply going forward

Jeffrey J Siirola[1,2]

Global energy demand is a function of population and standard of living growth, both of which are expected to stabilize, enabling future annual demand to be projected from historical patterns and predicted improvements in efficiency. Factors which could significantly alter the demand projection, however, include new energy requirements for water pretreatment and for carbon management. About 80% of current energy demand is met by fossil fuels and projected fossil reserves are plentiful. Concern over possible climate change may lead to the adoption of carbon management technologies in the short term and greater exploitation of non-carbon energy sources in the longer term including solar, nuclear, and geothermal, although biomass may not be a major medium for exploiting solar energy.

Addresses
[1] Purdue University, West Lafayette, IN 47907, United States
[2] Carnegie Mellon University, Pittsburgh, PA 15213, United States

Corresponding author: Siirola, Jeffrey J (jjsiirola@gmail.com)

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Introduction

Energy is widely recognized to be a critical enabler of modern society. The public is quite aware of its role in providing transportation and a comfortable living environment but possibly less conscious of its direct correlation with economic output and standard of living. The availability of various forms of energy is taken for granted, although it is understood that some have had to be imported with attendant political implications. More recently, concerns have been raised over the potential global environmental consequences of certain energy conversion processes and in particular the combustion of carbonaceous, especially fossil, fuels. This article addresses future trends in the global demand for energy, factors that may impact and possibly significantly modify those trends, the ways in which the resulting demands for energy are most likely to be met, and some of the challenges that must be overcome to meet those demands in a sustainable manner.

Energy demand growth

In 2011, the global demand for energy in all forms was on the order of 550 exajoules [1]. This demand was met from a variety of primary sources including approximately 31.5% from oil, 28.8% from coal, 21.3% from natural gas, 10.0% from biomass, 5.1% from nuclear fission, 2.3% from hydroelectric, and 1.0% from all other miscellaneous sources including wind, solar photovoltaic, solar thermal, geothermal, etc. Important questions include how will this demand will likely change going forward, how the demand will likely be met, and what might be some of the challenges and consequences in meeting that demand.

Aggregate global energy demand depends on many factors most importantly including population, the standard of living of that population (closely related to the gross domestic product), and the energy intensity associated with that gross domestic product and that population, which varies across different regions of the world.

Current global population is 7.1 billion people [2]. The current global population growth rate is 1.1% and is decreasing. Most estimates are that global population will likely exceed 9 billion before 2050, but if present trends continue, may never reach 10 billion. Birthrates do vary among different cultures and sociological groups and trends do change over time. The current lowered birthrates have been attributed to a variety of factors including increased education levels, availability of contraception, governmental policies, etc. While there is no guarantee that current trends will continue indefinitely, there are other compensating political and social forces that are likely to come into play if growth rates become negative and populations actually begin to decline. As a result, global population is expected to stabilize.

Even as population stabilizes, gross domestic product of each region of the world will continue to grow (in constant dollars). Estimates of this growth vary widely by region and existing GDP level but generally are generally sigmoidal accelerating as basic needs are better met then decreasing as higher GDP levels are reached. The 2012 world GDP (purchasing power parity basis) was about 85 trillion dollars and is likely to grow to 250 to 300 trillion (constant) dollars by 2050 [3].

Current energy consumption per GDP also varies widely by region [4]. The world average is about 6.5 MJ/$GDP(PPP). The US is a bit below average at 5.0 MJ/$GDP while Europe is lower (3.5 MJ/$GDP) with parts of Scandinavia much lower (2.0 MJ/$GDP). On the other hand, both China at about 17 MJ/$GDP and the Mideast at 13 MJ/GDP are much above average. It is also true that historically, energy use grows at a slower rate than GDP growth in part because of continuous improvements in energy efficiency and also because at higher GDP per capita levels more of the economy is service and knowledge intensive rather than manufacturing, transportation, and energy intensive. However, even if most of the world follows Scandinavia and aggressively adopts already demonstrated energy efficiency improvements related to lighting, window, building and refrigeration insulation, electric motor and compressor efficiency, vehicle mileage standards and hybrid technologies, and lifestyle choices related to integrated urban housing, shorter or eliminated commutes, and increased use of mass transport especially rail, population and standard of living trends imply total global energy demand may still nearly triple to on the order of 1500 exajoules by midway through the present century. It could be even greater.

Water desalination could significantly increase energy demand projection

The above projection was based on extrapolation of regional population trends and standard of living trends, observed energy consumption patterns as standards of living have risen historically, and expected rates of adoption of energy efficiency improvements. There are two issues that could increase energy demand by midcentury significantly more than this projection.

Making water potable and suitable for human consumption and treating wastewater for return to the environment are both somewhat energy intensive, but both are included in the energy costs associated with rising standard of living considered above. Water is also required for crop and animal food production but at the present time is generally not pretreated. However, fresh water availability is becoming a regional issue, as currently more than a third of the world's population find access to acceptable water limited for at least part of the year, and annual withdrawal from subsurface aquifers at rates faster than the recharge rate is clearly unsustainable [5].

Present methods of water pretreatment for human consumption involve suspended solids removal followed by disinfection. While not widely practiced now, removal of soluble salts may also become necessary for both potable and agricultural water if demand requires the use of more brackish sources or the reuse of sources contaminated by urban, industrial, and agricultural runoff containing increased concentrations of dissolved salts. Soluble salt removal is especially energy intensive. It is, of course, already practiced in regions that obtain potable water via seawater desalination, and is the reason while Persian Gulf states have some of the highest energy consumption rates per capita and per GDP. Whether by reverse osmosis, forward osmosis, multiple effect thermal evaporation, or some other yet to be developed technology, making these sources of water suitable for use could add a large energy requirement increment. On the basis of existing experience in regions which desalinate seawater, total energy demand could significantly increase depending on what fraction of all water must be desalinated before use (to approximately a factor of two if all of it has to be) [4].

Carbon management could also significantly increase energy demand

Carbon dioxide emissions, mostly from carbonaceous fossil fuel combustion for energy production, are another growing concern. As an interim carbon management measure until carbon-free energy sources are widely adopted, it is likely that carbon dioxide will be captured from combustion systems and then stored somewhere. A number of carbon capture systems are being developed (from the fuel before it is combusted or from the combustion flue gases after combustion) which typically involve several separation operations and high pressure injection into some suitably deep, stable, and secure subterranean formation. Although many technologies are being considered, early results with systems of two separations and higher pressure ratio compression in the case of coal-fired electricity generation imply a parasitic energy requirement of on the order of one-third [6]. This is probably an upper bound, but it would require a 50% increase in new power plant energy capacity just to facilitate carbon capture and sequestration (in the case of coal-produced electricity). If it were desired to capture and reduce levels of carbon dioxide already in the atmosphere by engineering means, associated energy requirements would be significantly greater [7].

However, there are alternative carbon management strategies that may reduce this increase in energy demand. Examples include the substitution of non-carbon energy sources (solar, nuclear, geothermal, etc.) for fossil fuels, and as a bridging strategy the substitution of more energetic fossil fuels (e.g. natural gas) for less energetic ones such as coal (now encouraged by the recent development of inexpensive extraction technologies for large shale gas reserves). This substitution could actually result in primary source reductions, especially if coupled with more thermodynamically efficient conversion systems possible with gaseous fuels (e.g. combined very high temperature Brayton-Rankine cycles), particularly if environmental impacts, for example NOx, resulting from ever higher operating temperatures are also mitigated.

Other carbon management strategies targeted at dispersed energy consuming systems with little prospect