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ENERGETIC LIMITS TO GROWTH

by Jay Hanson – www.dieoff.com

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By definition, energy "sources" must generate more energy than they consume; otherwise, they are "sinks".

In 1972, the Club of Rome (COR) shocked the world with a study titled *The Limits To Growth*. Two main conclusions were reached by this study. The first suggests that if economic-development-as-we-know-it continues, society will run out of nonrenewable resources before the year 2072 with the most probable result being "a rather sudden and uncontrollable decline in both population and industrial capacity." [1] The second conclusion of the study is that piecemeal approaches to solving individual problems will not be successful. For example, the COR authors arbitrarily double their estimates of the resource base and allow their model to project a new scenario based on this new higher level of resources. Collapse occurs in the new scenario because of pollution instead of resource depletion. The bottom line is traditional forms of economic development will end in less than 100 years – one way or another. The COR study has been much belittled but proof of the COR's thesis can readily be found in the real-world concept of "net energy" and that is the focus of this article.

Net Energy

Net-energy analysis became a public controversy in 1974 when two stories made the news. In the first, *Business Week* reported that Howard Odum had developed a "New Math for Figuring Energy Costs." Among other results, this new math indicated that stripper oil well operations were energy sinks rather than energy sources. According to this analysis, these operations could be profitable only when cheap, regulated oil was used to produce deregulated oil. The other net-energy story of 1974 was the study of Chapman and Mortimer asserting that a rapidly growing nuclear program would lead to an increased use of oil rather than to the desired substitution (see *Net-Energy Analysis* by Daniel T. Spreng, Oak Ridge Assoc. Univ. & Praeger, 1988).

As we know from physics, to accomplish a certain amount of work requires a minimum energy input. For example, lifting 15 kg of rock 5 meters out of the ground requires 735 joules of energy just to overcome gravity – *and the higher the lift, the greater the minimum energy requirements.* [2] Combustion engines that actually do work – so-called "heat engines" – also consume a great deal of energy. [3] The efficiency of heat engines is *limited* by thermodynamic principles discovered over 150 years ago by N. L. S. Carnot. [4] Thus, a typical auto, bulldozer, truck, or power plant *wastes more than 50 percent of the energy contained in its fuel.*

One seldom thinks about the energy that is utilized in systems that supply energy – such as oil-fired power plants. But energy is also utilized when exploring for fuel, building the machinery to mine the fuel, mining the fuel, building and operating the power plants, building power lines to transmit the energy, decommissioning the plants, and so on. The difference between the total energy input (i.e., the energy value of the sought after energy) minus all of the energy utilized to run an energy supply system equals the "net energy" (in other words, the net amount of energy actually available to society to do useful work).

We mine our minerals and fossil fuels from the Earth's crust. *The deeper we dig, the greater the minimum energy requirements.* Of course, the most concentrated and most accessible fuels and minerals are mined first; thereafter, more and more energy is required to mine and refine poorer and poorer quality resources. New technologies can, on a short-term basis, decrease energy costs, but neither technology nor “prices” can repeal the laws of thermodynamics:

** The hematite ore of the Mesabi Range in Minnesota contained 60 percent iron. But now it is depleted and society must use lower-quality taconite ore that has an iron content of about 25 percent. [5]
** The average energy content of a pound of coal dug in the US has dropped 14 percent since 1955. [6]
** In the 1950s, oil producers discovered about fifty barrels of oil for every barrel invested in drilling and pumping. Today, the figure is only about five for one. Sometime around 2005, that figure will become *one for one.* Under that latter scenario, even if the price of oil reaches $500 a barrel, it wouldn't be logical to look for new oil in the US because it would consume more energy than it would recover. [7]

Decreasing net energy sets up a positive feedback loop: since oil is used directly or indirectly in everything, as the energy costs of oil increase, the energy costs of everything else increase too – including other forms of energy. For example, oil provides about 50% of the fuel used in coal extraction. [8]

Oil

One of the most important characteristics of energy is its “quality”. Fuels come in varying qualities. For example, coal contains more energy per pound than wood, which makes coal more efficient to store and transport than wood. Oil has a higher energy content per unit weight and burns at a higher temperature than coal; it is easier to transport, and can be used in internal combustion engines. A diesel locomotive wastes only one-fifth the energy of a coal-powered steam engine to pull the same train. Oil’s many advantages provide 1.3 to 2.45 times more economic value per kilocalorie than coal. [9]

Oil is the highest quality energy we use, making up about 38 percent of the world energy supply. No other energy source equals oil’s intrinsic qualities of relative ease of extraction, transportability, versatility and cost. The qualities that enabled oil to take over from coal as the front-line energy source in the industrialized world in the middle of this century are as relevant today as they were then.

Unfortunately, forecasts about the abundance of oil are warped by inconsistent definitions of “reserves”. In truth, every year for the past two decades the industry has pumped more oil than it has discovered, and production will soon be unable to keep up with rising demand. Almost 50 years ago, the geologist M. King Hubbert developed a method for projecting future oil production. Hubbert found that when approximately one half the Estimated Ultimately Recoverable (EUR) oil had been produced in an oil basin, production "peaks" and then declines towards zero. He calculated that oil production in the lower-48 states would peak about 1970. His prediction has proved to be remarkably accurate. Both total and peak yields have risen slightly compared to Hubbert's original estimate, but the timing of the peak and the generally declining production trend are correct.

For the last 50 years, many geologists and oil companies have published estimates of the total amount of crude oil that will ultimately be recovered from the Earth over all time. Remarkably, these assessments of EUR oil have varied little over the past half century 10 and global oil production is now expected to peak around 2005. [11]

The End of the Consumer Economy

Although economists are trained to treat energy just like any other resource when it comes to "supply and demand", it is manifestly *not* like any other resource. *Net energy is the pre-condition for all other resources.* The coming peak in global oil production signals the end of the consumer economy because *nothing can replace conventional oil.*

Economists frequently cite Canada's Athabasca oil sands as a handy replacement for conventional oil. [12] But oil sands and tar shale are very energy-intensive, environmentally destructive, and not all that large anyway. For example, back-of-the-envelope calculations show that the Athabasca oil sands could supply less than three years' worth of oil for the global economy. Three hundred billion barrels of oil (AEUB) gushing out of a pipe would only last 12 years at present World consumption of 70 million barrels a day. Oil sands would last just three years if we super-optimistically assume 25 percent net energy for the digging, etc. over the entire resource. "The mining operation involves stripping off the overburden; separating the bitumen with steam, hot water and caustic soda, and then diluting it with naphtha. After centrifuging, liquid bitumen at 80°C is produced, which is then upgraded in a coking process and subjected to other treatments, eventually yielding a light gravity, low sulphur, synthetic oil." (*The Coming Oil Crisis,* p. 121, Campbell, 1997)

How about natural gas? Unlike oil, natural gas can not easily be shipped by sea. It must be liquefied prior to shipment, then shipped in specially designed refrigerated ships destined for specially equipped ports, and then regasified for distribution – at an estimated 15 to 30 percent energy loss. [13] Moreover, natural gas cannot be easily stored like oil or coal. Global natural gas production is expected to "peak" sometime between 2010 [14] and 2020. [15] Hopes of exploiting the ice-like methane hydrates from the ocean floor also appear doomed because the solid is unable to migrate and accumulate in commercial volumes. [16] Today's euphoria over methane hydrates reminds me of that which surrounded oil shale and tar sands a couple of decades ago. With regard to coal, U.S. coal production rose to a record high of 1,118 million short tons in 1998. U.S. coal, however, is expected to become an energy "sink" – not worth digging out of the ground – by 2040. [17]

What about nuclear energy? The fraction of energy produced by conventional nuclear plants can not be significantly increased because of a shortage of fuel. [18] Moreover, all but one of the new "fast breeder" reactors have been abandoned because they are "too costly and of doubtful value". [19]

The expansion of solar energy systems is limited by the availability of land. Estimates are that about 20 percent of U.S. land area (about 450 million acres) would be required to support a solar energy system that would supply less than one-half (37 quads) of our current energy consumption (80 quads). [20]

Fuel Cells to the Rescue?

The automobile industry is planning to put fuel-cell-powered automobiles on the road by 2004. But the new cars won't be on the road for long because these fuel cells use hydrogen via methanol that is made from fossil fuel. [21] Hydrogen is not a "source" of energy – it's an energy "carrier" (like electricity). About 95 percent of the hydrogen used in the U.S. market is produced by a chemical process known as "steam methane reforming". [22] A carbon-based feedstock (usually natural gas or coal) is combined with steam under high pressure and temperature to produce hydrogen at about a 35 percent energy loss. Methanol is usually produced from natural gas or coal at a 32 to 44 percent net energy loss. [23] In the U.S., oil production "peaked" in 1970 and is declining towards zero. Scenarios for widespread use of hydrogen are therefore likely to include steam reforming of gasified coal or biomass. *But the coal will be gone in 40 years and there just isn't enough land for biomass!*

Money Is Not Energy

Energy companies are in business to make money – not energy. For example, economic subsidies allow ethanol companies to waste energy while making a profit. Specifically, about 71% more energy is used to produce a gallon of ethanol than the energy contained in a gallon of ethanol. [24] Obviously, alternative energy technologies that require energy subsidies are only viable as long as we don't need them!

From the standpoint of achieving society's goal of a long-term solution to our energy problems, profit is simply the wrong objective for energy companies. Even without direct and indirect subsidies of $650 billion a year [25] it's conceivable that energy companies could make money – but lose energy – by burning one $10-barrel of oil today in order to pump *one-half* of a $50-barrel tomorrow. The price of oil is expected to rise sharply – and permanently – when global oil production peaks in less than ten years.

Economists Can't See It Coming

"Energy" is defined as the capacity of a physical system to do work. Over a hundred years ago, scientists pointed out that energy – not money – is the true source of the capitalist's wealth:

> It is, in fact, the fate of all kinds of energy of position to be ultimately converted into energy of motion. The former may be compared to money in a bank, or capital, the latter to money which we are in the act of spending ... If we pursue the analogy a step further, we shall see that the great capitalist is respected because he has the disposal of a great quantity of energy; and that whether he be nobleman or sovereign, or a general in command, he is powerful only from having something which enables him to make use of the services of others. When a man of wealth pays a labouring man to work for him, he is in truth converting so much of his energy of position into actual energy...The world of mechanism is not a manufactory, in

> which energy is created, but rather a mart, into which we may bring energy of one kind and change or barter it for an equivalent of another kind, that suits us better - but if we come with nothing in hand, with nothing we will most assuredly return. [Balfour Stewart, 1883] [26]

But economists still do not study energy [27] – they study money and prices. Physics incorporated thermodynamics – moved from "production" to "circulation" – over 100 years ago. But modern economic texts, such as McConnell & Brue, 1999, and Samuelson & Nordhaus, 1998, still do not discuss thermodynamics or entropy! Money isn't a measure of anything "real", like joules or kilograms. Money is merely social power because it "empowers" people to buy and do the things they want – including buying and "doing" other people.

Economists frequently point to "prices" and make claims about the real world. This or that is "better off" they say, and go on their way. *But the price of a thing does not reveal its quantity or its quality, particularly in the energy business.* At best, the relationship between prices and natural resources is nonlinear. A good analogy for the oil market is the float in a carburetor: as the engine demands more gas, the float falls and allows more gas to flow in from the tank. But the float has no information concerning the amount of gas left in the tank until the fuel line is unable to keep up with demand. So it is with the market. As the demand for oil increases, the increase in price signals oil companies to pump more oil out of the ground – which lowers prices again. *But the oil market has no information about the amount of oil left in the ground until production is unable to keep up with demand*. In October 1980, Julian Simon challenged Paul Ehrlich and colleagues to a $1,000 bet that in ten years the price of any raw material they selected would fall (measured in constant 1980 dollars). In October 1991, Ehrlich paid up. The prices of the five minerals chosen (copper, chrome, nickel, tin and tungsten) had dropped substantially. [28] Obviously, though, prices did not reflect the fact that ten years' worth of minerals had been taken out of the ground! *One concludes that prices give no warning of approaching resource exhaustion.*

How much is $10 worth of oil? It depends upon when and where you bought it. What's the net energy of $10 worth of oil? If oil costs $10 a barrel, how much is left in the ground? Who knows? Prices simply measure states of mind. This means that economists issue opinions on opinions. In short, economists are pollsters with an attitude. Based on the best information we have at hand today, sometime during the coming century the global economy will "run out of gas", as fossil energy sources become sinks. One can argue about the exact date this will occur, but the end of fossil energy – and the dependent global economy – is inevitable.

Conclusion

Imagine having a motor scooter with a five-gallon tank, but the nearest gas station is six gallons away. You can not fill your tank with trips to the gas station because you burn more than you can bring back – it's impossible for you to cover your overhead (the size of your bankroll and the price of the gas are irrelevant). You might as well put your scooter up on blocks because you are "out of gas" – forever. It's the same with the American economy: if we must spend more-than-one unit of energy to produce enough goods and services to buy one unit of energy, it will be impossible for us to cover our overhead. At that point, America's economic machine is "out of gas" – forever.

I'll conclude with an observation of Cosmologist Fred Hoyle who stated, "It has been often said that, if the human species fails to make a go of it here on Earth, some other species will take over the running. In the sense of developing intelligence this is not correct. We have, or soon will have, exhausted the necessary physical prerequisites so far as this planet is concerned. With coal gone, oil gone, high-grade metallic ore gone, no species however competent can make the long climb from primitive conditions to high-level technology. This is a one-shot affair. If we fail, this planetary system fails so far as intelligence is concerned. The same will be true of other planetary systems. On each of them there will be one chance, and one chance only."

Jay Hanson has been a member of his local utility's Integrated Resource Planning advisory committee. He owns a computer business that designs and manufactures software and hardware and also runs the Internet Website: www.dieoff.org.

Jay Hanson
78-7230 Puupele Road
Kailua-Kona, HI 96740
Tel: 808/324-6645

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1 p. 23, **THE LIMITS TO GROWTH**, Meadows et al.; Universe, 1972. Anecdotes about the Club of Rome have become "urban legends". An urban legend is a good story that appears mysteriously and spreads spontaneously in varying forms, contains elements of humor or horror (the horror often "punishes" someone who flouts society's conventions), and is usually false. Even authors of peer-review scientific articles [e.g., Cook and Sheath in **NATURE & RESOURCES,** 33(1): 29 (1997)] have been seduced by these good stories. If one actually reads the material, & finds that *none* of the COR's so-called "predictions" have failed. See: http://dieoff.org/page169.htm

2 For a vertical lift: joules = meters X kg X 9.8

3 Internal combustion, steam, or gas turbines are called heat engines because they convert fuel into heat, then into mechanical motion.

4 A typical gasoline engine with a compression ratio of 8:1 cannot exceed a theoretical 45 percent efficiency, in practice might be about 35 percent; for a diesel with 20:1 it's 55 percent, 45 percent; for a turbine with 30:1 it's 60 percent, 50 percent.

5 p. 11, **BEYOND OIL,** by John Gever et al., Univ. Pr. Colorado, 1991.

6 p. 12, Gever.

7 p. xlv, Gever.

8 p. 314, **GETTING DOWN TO EARTH,** by Robert Costanza et al., Eds.; Island Press, 1996

9 p. 87, Gever

10 p. 7, **OIL AS A FINITE RESOURCE,** by James J. MacKenzie; WRI, 1996; Online version: http://www.wri.org/wri/climate/finitoil/eur-oil.html

11 **THE END OF CHEAP OIL,** by Colin J. Campbell & Jean H. Laherrère; *Scientific American,* March 1998; http://dieoff.org/page140.htm

12 **MODELS OF DOOM,** Editorial; *The Economist,* Dec 1997; http://www.economist.com/editorial/freeforall/20-12-97/xm0002.html

13 Natural gas loss estimated by Walter Youngquist Ph.D. & Chair Emeritus, Dept. Geology, Univ. Oregon (personal correspondence).

14 Franco Bernabé, chief executive of the Italian oil company ENI SpA cited in **CHEAP OIL,** by Howard Banks; *Forbes Magazine,* June 1998; http://www.forbes.com/forbes/98/0615/6112084a.htm

15 p. 119, **THE COMING OIL CRISIS,** by Colin J. Campbell; Multi-Science Publishing Company & Petroconsultants, 1997.

16 p. 120, Campbell, 1997.

17 p. 67, Gever.

18 p. 90, **ENERGY FOR TOMORROW'S WORLD**; by the WEC; St. Martin's Pr., 1993.

19 **JAPAN PUTS REACTOR PROGRAM ON THE BACK BURNER;** Nando Times, Oct. 1, 1997; http://dieoff.org/page155.htm

20 **FOOD, LAND, POPULATION AND THE U.S. ECONOMY,** by David Pimentel & Mario Giampietro; CCN, 1994; http://dieoff.org/page40.htm

21 **FUEL CELLS 2000;** http://www.fuelcells.org/fuel/fct/goingon.shtml

22 **HYDROGEN,** by Daniel Morgan & Fred Sissine; CNIE, 1995; http://www.cnie.org/nle/eng-4.html

23 **DEVELOPMENT PATTERNS FOR LNG SUPPLY AND DEMAND,** by Arthur T. Andersen et al; EIA, 1997; http://www.eia.doe.gov/oiaf/issues97/lng.html (See ref. # 46)

24 **ENERGY AND DOLLAR COSTS OF ETHANOL PRODUCTION WITH CORN,** by David Pimentel; Hubbert Center Newsletter # 98/2, 1998; http://hubbert.mines.edu/news/v98n2/mkh-new7.html

25 Worldwide, subsidies worth at least $650 billion – the equivalent of 9 percent of government revenue – specifically support natural-resource-intensive industries and activities, including mining, oil drilling, energy use and driving. p. 35, **THE NATURAL WEALTH OF NATIONS,** by David Malin Roodman; Worldwatch & Norton, 1998.

26 p. 132, **MORE HEAT THAN LIGHT**, Philip Mirowski; Cambridge, 1989.

27 Physics incorporated thermodynamics – moved from "production" to "circulation" – over 100 years ago. But modern economic texts such as McConnell & Brue, 1999, and Samuelson & Nordhaus, 1998 still do not discuss thermodynamics or entropy!

28 p. 330, **ECONOMICS,** Samuelson & Nordhaus; McGraw-Hill, 1998.