From the Writer

I initially became interested in the issue of peak oil after reading a magazine article on the topic several years ago. The evidence for an imminent oil peak seemed quite convincing, and the projected consequences both realistic and dire. In the face of this, I recall being shocked that it is not an issue to which more attention is given, particularly in a social climate where energy use relative to global warming is seemingly of paramount concern. I decided to explore peak oil in more depth in a research paper, hoping to shed light on the importance of considering the problem of peak oil in constructing a plan for future energy-use models.

I began my research by reading *Beyond Oil: The View from Hubbert's Peak* by Kenneth S. Deffeys, which provided a useful overview of the science behind oil exploration and development, as well as further evidence that current production models will soon be insufficient to meet oil demand. Armed with more knowledge in the area, I continued research in both academic and popular publications. I constructed a draft, which, with input from my writing professor, I molded through several revisions into the final paper. I am pleased with the result, although because of the limitations of scope I am afraid it may seem overly pessimistic, presenting problems without complete solutions. Given the opportunity, I would like to complete a complementary paper in which I discuss possible solutions to the energy crisis.

— Gordon Towne

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Prize Essay Winner

Peak Oil: Priorities in Alternative Energy Development

If Americans, as it is popular to suggest, are "addicted to oil," it would appear that they are increasingly in danger of overdosing on the hydrocarbon drug. America's reliance on oil is staggering. In 2006, the United States consumed 20.6 million barrels of petroleum per day,[1] two thirds of which went to fuel the transportation sector.[2] This figure accounts for a total of 97.8 percent of the fuel used for transportation in the United States,[3] making the contribution of all other alternatives appear essentially negligible. However, the U.S. is not alone in its addiction, as similarly astronomical statistics exist for much of the developed world, and these figures are projected to rise. Industrialization of developing nations, and particularly China and India, is driving world oil demand ever higher. Current projections forecast a 50 percent increase in worldwide oil demand within the next decade.[4] It is universally recognized that petroleum is a finite resource, and this reliance cannot continue indefinitely. However, the largest concern is not depleting the oil supply entirely, but having demand outstrip the maximum quantity of oil that is economically feasible to produce. This watershed is likely to occur at the global oil peak, the point at which diminishing reserves cause year-over-year production to reach a maximum and decline thereafter, an event projected to occur in the near future.[5] The impending arrival of the global peak in world oil production represents the most pressing threat to the current energy model. The feasibility of alternative fuels should be evaluated primarily based on their ability to adhere to the time frame and challenges presented by limited oil supply, and greater awareness of peak oil must be promoted to speed the diffusion of petroleum replacements.

The existence of a peak in oil production follows from patterns of oil extraction. Petroleum geologists recognize that levels of production necessarily follow a logistic, or bell-shaped, curve (see Figure 1). That is, over time, oil production increases until it levels off at a maximum, and then decreases symmetrically. Regional production has been observed to follow

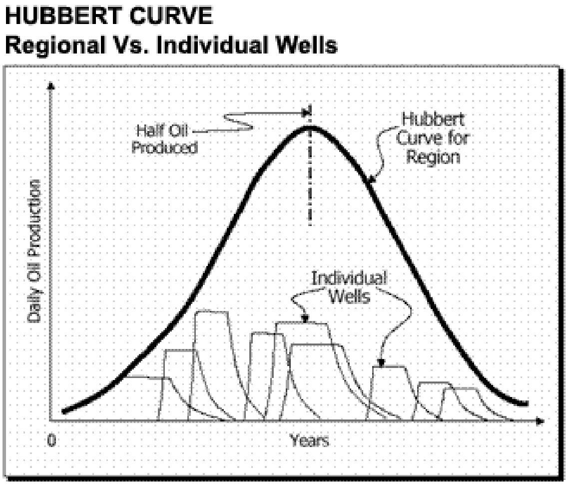

Figure 1. Source: Energy Bulletin, "Peak Oil Primer," http://energybulletin.net/primer, accessed April 2009.

this logistic curve in a number of instances, including total United States domestic output. This model extends from the pattern of lifetime output from any one oil well, as oil production for any region can be seen as the aggregate of all of the wells therein.[6] Conventional petroleum extraction techniques follow a fairly set method. Primary extraction begins when an oil well is first tapped. At this point, underground pressure causes oil to flow freely to the surface. As this pressure is normalized, pumpjacks are used to extract oil from the ground until this process becomes more costly to maintain than the value of oil that it produces.[7] Thereafter, secondary extraction begins, typically with a process known as a "waterflood."[8] A number of wells in an oil field are sacrificed and used to pump water into the ground, increasing the underground pressure so that oil can be more readily maintained from the remaining pumpjacks.[9] As a consequence of this process, over the life of a well, it becomes increasingly more costly to produce decreasing quantities of oil. Production continues until returns diminish to the point where it becomes economically infeasible to extract the remaining reserves. On average, even after secondary extraction, half of the original supply of oil remains in the ground "in isolated droplets in the reservoir rock" that are impossible to extract efficiently.[10]

As more oil is extracted from existing wells, it also becomes more difficult to locate the remaining oil deposits. Newly discovered oil fields generally contain significantly lower quantities of oil than past discoveries, based on the principle that the bigger deposits are easiest to find, and thus were found and harvested first. Thus, the problem of diminishing oil production from a single field over time is compounded by the fact that it becomes increasingly costly to locate progressively smaller oil deposits. Modern oil exploration is conducted using seismic detectors aboard large trucks or ocean-going ships.[11] These oil-prospecting vehicles have high operating costs per unit area explored, so as oil becomes more scarce, the overhead cost for locating any one deposit increases. When oil becomes sufficiently scarce and expensive to locate and extract, the amount that can be produced will begin to decline year over year. The point of transition from increasing to decreasing production is known as the oil peak.

The economic, political, and sociocultural implications of peak oil, when it occurs, will be dramatic and pervasive. At the peak and immediately thereafter, burgeoning world oil demand will surpass the quantity that can possibly be supplied. This discrepancy will cause the cost of oil to skyrocket, which will be readily visible in the price at the pump. Because transportation is embedded in the cost of nearly all goods and services, rising fuel costs will place direct pressure on a broad range of businesses. This effect will manifest itself in increasing unemployment, along with rising consumer costs in everything from food to clothing and electronics. Domestically, the resulting ripple effect will be sufficient to set the economy on a cycle of stagflation, that is, simultaneous economic recession and monetary inflation. On its surface, this is not dissimilar from the effects of previous oil shortages, most notably that resulting from the OPEC embargo of the early 1970s.[12][13] In this instance, a temporary, artificial supply shortage was sufficient on its own to catalyze a cycle of stagflation, sending the U.S. economy into recession. In the case of peak oil, however, once this cycle begins, oil production will only continue a downward trend. In an unmitigated situation, this will cause the supply-and-demand discrepancy to grow ever wider. Where previous fluctuations in oil supply have triggered cyclic rises and falls in domestic economic health, problems spawned by falling oil supply will only worsen as production continues to decrease.

Beyond the strict economics, peaking of world oil will necessarily cause sweeping changes in the American way of life and that of most other developed countries. As production falls sufficiently on the back side of the peak, fuel shortages will become an unavoidable reality. Here, again, we can look to the oil crisis of the early 1970s as a model. Under pressure of diminished oil supply, the United States government passed mandatory petroleum rationing legislation, including enactment of a national 55 mile-per-hour speed limit to conserve fuel.[14] In the case of peak oil, consumers would likely be forced to face similar conservation measures. Again, however, it is important to note that unlike previous energy crises these measures could not be enacted on a temporary basis. Indeed, conservation efforts would have to escalate over time proportional to the decrease in world oil supply if oil were to remain a primary fuel source. The American car culture would need to reconcile itself with the new realities of petroleum scarcity, and consumers would need to sacrifice much of the mobility to which they have become accustomed.

On a global scale, an increased potential for violence and conflict will also emerge on the back side of the peak. As economist Daniel Yergin notes, the inherent nature of oil's distribution leads it to be "intimately intertwined with nationalism and national power, and subject to political and military struggles for its control."[15] Nowhere is this as prevalent as the oil producing regions of the Middle East. The Organization of the Petroleum Exporting Countries (OPEC), led by its principal member, Saudi Arabia, represents the single largest petroleum exporting conglomerate in the world.[16] Exports by Saudi Aramco, Saudi Arabia's nationalized oil producing company, contribute 90 percent to the country's total earnings.[17] An upset to such a heavily rooted industry would likely dislodge the balance of power and interfere with the livelihoods of a large proportion of the population. The resulting political and economic instability will offer terrorist organizations an opportunity to seize greater control and gain favor with the disenfranchised citizenry. These developments will only increase the turmoil in an already precarious environment.

Because of these worrisome consequences of an unmitigated peak in oil production, an accurate forecast of when the peak is likely to occur is crucial. Research in this area was pioneered in the mid twentieth century by oil industry geologist M. King Hubbert. In 1956 Hubbert predicted through mathematical analysis that domestic U.S. oil production would peak in the early 1970s. Hubbert's analysis was based on the assertion that the overwhelming factor determining the quantity of oil that can be produced is the quantity remaining in the ground. Fellow geologist Kenneth Deffeys clarifies this notion by analogizing that "the ease of catching fish depends mostly on how many fish remain in the pond."[18] Hubbert leveraged data on yearly U.S. oil production and accurate estimates of total U.S. petroleum reserves to predict that production would reach its zenith when half of the total quantity of oil available had been extracted.[19][20] History shows Hubbert's analysis to be surprisingly accurate, as domestic oil production did in fact peak in 1970, and continued down the logistic curve thereafter.[21]

Hubbert's methods for predicting the U.S. peak can be extrapolated upon to forecast the world peak. Doing so, however, involves difficulties related to uncertain world oil supply data. Hubbert benefitted from a standard set by the U.S. Securities and Exchange Commission on how reserve data are calculated, but there is no such international standard.[22] There are also short term economic benefits for international oil producers in artificially inflating the reserve numbers, promoting confidence in oil as a sustainable investment. Deffeys suggests that OPEC has been releasing these inflated numbers for years.[23] In practice, this means that there is a certain amount of conjecture required to synthesize international reserve data to get a clear picture of how much oil is left in the ground. Also, due to the interconnectedness of oil production to the larger geopolitical sphere, local peaks and valleys in the production data are inevitable and can disguise the apex of the smooth logistic peak. Thus the idealized point of maximum output may not be evident until after it has occurred.[24] As a result, there is some variation in projections of the world oil peak. Despite this, many experts forecast a world peak sometime before 2010,[25] while some suggest that production has already peaked.[26]

In addition to Hubbert's method of leveraging production data, patterns of changes in oil prices can also be used to forecast the arrival of the oil peak. Indeed, some experts choose to ignore production data entirely. Economist Stephen P. Holland published a paper in 2008 in which he concluded that "prices are a better indicator of impending oil scarcity than are peaks in production" and "focusing attention on peak production is misguided since focusing attention on price would give an earlier predictor of impending resources scarcity."[27] Price-based analyses are likely to result in similarly dire conclusions, however, as current fluctuations in oil price are indicative of instability likely to occur around the global peak. This price volatility is especially apparent in OPEC exports. From 1983 through 2002, OPEC was able to regulate the price of oil between $22 and $28 per barrel, varying rates of supply accordingly to maintain this level. In fact, price stabilization was a primary impetus for formation of the cartel in the first place. However, in recent years OPEC has been unable to control prices, operating at maximum production levels while prices skyrocketed past $100 per barrel.[28] This pervasive price instability indicates that oil peaking may be occurring now or will occur in the immediate future.

There is also additional anecdotal evidence that the world peak is imminent. For example, the government of Saudi Arabia, responsible for the largest proven quantity of reserve oil remaining on the planet,[29] announced in 2003 that their "production had maxed out at 9.2 or 9.5 million barrels per day."[30] Such apparent admissions of defeat by oil producers have become increasingly prevalent in recent years. Even the most conservative estimates by western oil companies forecast a peak within the next two decades.[31] Shell Oil, for instance, has published data that show a world oil peak in 2025 or immediately thereafter. Adding more credence to these figures is the 2006 admission of John Hofmeister, president of Shell Oil, that "the easy stuff is running out."[32] The fact that even those within the oil industry are breaking the traditional silence and beginning to publicly recognize that the current energy model is unsustainable is indicative of the fast-approaching peak.

Many factors, including the threat of peak oil, price increases and volatility, geopolitical concerns, and consideration of the environment and climate change, have resulted in a recent popular recognition of the need to restructure the prevalent energy-use model. It is natural to seek an "ideal" fuel source, which simultaneously meets current demands for environmentalism, sustainability, and economic feasibility. In 1994, economist Richard England wrote on the need for alternative energies to be developed expediently so that when the crucial moment came when society would have to choose a new fuel source, we would have several fully developed, feasible options. Unfortunately, the evidence suggests that we have missed the vital window to develop such an ideal source, as implementation of a replacement fuel will prove time-consuming. A 2005 study commissioned by the Department of Energy on the topic[33] concludes that, because large development projects typically progress slowly through the bureaucratic governmental approval process, it will likely take over ten years for a viable infrastructure to be established around an alternative fuel.[34] Absent special government intervention, it is unlikely that alternative fuel processing plants and distribution facilities would be operational anytime within the next decade. However, development of this infrastructure poses only the first step in the transition process. Currently, the average automobile on American roadways is nine years old.[35] At current rates of turnover, it would take an additional decade after alternative fuels become broadly viable for just half of the American automobiles to transition from traditional petroleum. This time frame extends reliance on petroleum as a majority fuel source for another twenty years to come, well past even conservative estimates for a world oil peak.

If significant measures are not taken immediately to expedite a transition to a non-petroleum-based transportation model, the drastic consequences of a world peak in oil production may be unavoidable. The slower this transition, the longer the period during which we must rely on dwindling oil supply, and the more drastic the economic and sociopolitical consequences. Based on these concerns, it becomes clear that speed of potential deployment is a primary concern when evaluating the effectiveness of petroleum alternatives. We must limit our discussion of alternative fuels, for the time being, to those which are currently operational, and could be deployed on a national and international scale with minimal additional effort.

Speeding the rate of adoption of alternative-fueled vehicles represents a canonical innovation diffusion problem. Research on innovation diffusion presented by Everett M. Rogers suggests that this process must begin with the common recognition of a problem or need.[36] Unfortunately, in today's climate, there is little consensus as to the primary problems alternative fuels should address. Due to lack of knowledge or secondary concern over the dwindling oil supply, many choose to evaluate alternative fuels with an eye toward climate change and environmentalism. In order for any alternative fuel to be adopted efficiently by the national and global market, there must be a consensus on the problems the technology is meant to address. Because alternative fuels can be seen as a preventative innovation, in that adoption is intended to mitigate the negative consequences of oil peaking, their diffusion is likely to be slow unless consumers are able to see a short term individual advantage in addition to the long term collective benefits.[37] The consequences of oil peaking will likely help in this regard, as rising oil prices are likely to drive consumers to look toward more economical alternatives. However, waiting for rising oil prices to drive consumers away from petroleum will only exacerbate the problems related to peak oil by extending reliance further into the future. In order to speed diffusion of alternative fuels, greater awareness must be created about the consequences of an unmitigated oil peak and the urgency with which this problem must be addressed.

Data and expert opinions are mustering in support of peak oil. The debate no longer centers on whether oil will run out as a viable resource in our lifetimes, but rather when in the span of the next few years it will occur. The consequences of allowing oil peaking to occur without dramatic attempts at mitigation will likely result in an unprecedented change to the way of life our culture has grown around. Faced with these challenges, it will prove necessary to prioritize and make sacrifices in alternative energy development with the goal of ending reliance on petroleum as quickly as possible.

Notes

1. Michael K. Heiman and Barry D. Solomon, "Fueling U.S. Transportation: The Hydrogen Economy and Its Alternatives," *Environment* 49, no. 8 (2007): 12.

2. Robert L. Hirsch, Roger Bezdek and Robert Wendling, *Peaking of World Oil Production: Impacts, Mitigation, & Risk Management* (Washington, DC: U.S. Department of Energy, February 2005), http://www.netl.doe.gov/publications/others/pdf/Oil_Peaking_NETL.pdf (accessed March 12, 2009).

3. Heiman and Solomon, "Fueling U.S. Transportation"

4. Hirsch, Bezdek and Wendling, *Peaking of World Oil*.

5. See subsequent analysis for more specific estimates of the world oil peak.

6. See Figure 1.

7. Kenneth S. Deffeys, *Beyond Oil: The View from Hubbert's Peak* (New York: Hill and Wang, 2005), 27.

8. Ibid., 27.

9. Ibid., 27.

10. Ibid., 27.

11. Ibid., 21.

12. Hirsch, Bezdek and Wendling, *Peaking of World Oil*.

13. In 1973, the Middle Eastern oil conglomerate ceased oil shipments to the United States as a result of their supporting Israel during the Yom Kippur War. For more information see U.S. Department of State, "Second Arab Oil Embargo 1973–1974," (Washington DC: Bureau of Public Affairs, n.d.), http://www.state.gov/r/pa/ho/time/dr/96057.htm (accessed April 27, 2009).

14. Hirsch, Bezdek and Wendling, *Peaking of World Oil.*

15. Richard W. England, "Three Reasons for Investing Now in Fossil Fuel Conservation: Technological Lock-In, Institutional Inertia, and Oil Wars," *Journal of Economic Issues* 28 (1994): 766.

16. Energy Information Administration, "Saudi Arabia Energy Data, Statistics and Analysis," (Washington DC: Energy Information Administration, August 2008), http://www.eia.doe.gov/cabs/Saudi_Arabia/Background.html (accessed April 8, 2009).

17. Ibid.

18. Deffeys, *Beyond Oil*, 39.

19. Ibid., 40.

20. See Figure 1.

21. Alexandria Witze, "Energy: That's Oil Folks..." *Nature*, January 4, 2007, 15.

22. Ibid. 17.

23. Deffeys, *Beyond Oil*, 47.

24. Ibid., 3.

25. Hirsch, Bezdek and Wendling, Peaking of World Oil.

26. Witze, "That's Oil Folks," 14.

27. Holland, "Modeling Peak Oil," Pg.

28. Deffeys, Beyond Oil, 33.

29. Energy Information Administration, "Saudi Arabia Energy Data, Statistics and Analysis."

30. Deffeys, *Beyond Oil*, 44.
31. Hirsch, Bezdek and Wendling, *Peaking of World Oil.*
32. Witze, "That's Oil Folks," 14.
33. The so-called "Hirsch Report" is considered a comprehensive analysis of peak oil, and is used extensively in this paper. See bibliography for full citation.
34. Hirsch, Bezdek and Wendling, *Peaking of World Oil.*
35. Ibid.
36. Everett M. Rogers, *Diffusion of Innovations* (New York: Free Press, 2003), 137.
37. Ibid. 234.

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