Peak phosphorus: Quoted reserves vs. production history

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This is a guest post by James Ward. James has a background in science and engineering and is ASPO-Adelaide coordinator for ASPO-Australia. This post appeared previously on Energy Bulletin.

Abstract
By fitting a bell curve to historical phosphate production data, the best fit is obtained by assuming an ultimate recoverable resource of approximately 9 billion tonnes (of which about 6.3 billion tonnes have already been mined). This yields a peak in around 1990. Of course, the USGS claims an ultimate recoverable resource of some 24.3 billion tonnes (i.e. 18 billion remaining); however using this value yields a bell curve that is an inferior match to the historical data. A hypothesis is thus presented whereby phosphorus is considered in two broad forms: “easy” which is able to be mined quickly, but already peaked in 1990, and “hard” which has large remaining reserves and is yet to peak, but cannot be mined as quickly. (In reality there are probably many different forms ranging from very easy to very hard.) Just as with oil, estimates that lump all types of reserve in together will yield a theoretical peak that is high and distant, however the true system may involve periods of decline after exhausting easy-to-get reserves before other supplies come online to replace them. Ultimately we must develop a recyclable phosphorus supply if humans are to continue living on this planet.

Introduction

Phosphorus is absolutely essential to plant, animal and human life. Since the Green Revolution the global human food supply has grown to depend on high-yield agriculture using artificial phosphorus fertilizers. These are derived from finite, exhaustible reserves of guano (bird and animal droppings) and phosphate rock. For those of us who care whether our children will have food to eat, world phosphorus production is literally a life-or-death issue. White & Cordell have already made an excellent start at addressing this critical issue by applying Hubbert-type bell curves to gain insights into “Peak Phosphorus”. Their analysis assumes a known Ultimate Recoverable Resource (denoted RURR), and uses this value to constrain the set of bell curves being fitted to the data.

Calculations

If we assume a remaining resource of 18 billion tonnes of phosphate rock (in line with the stated USGS reserve estimate), and add to this the 6.3 billion tonnes that have already been mined, RURR is 24.3 billion tonnes[*]. Assuming cumulative production Q at time t conforms to the following basic relationship:

$$Q(t) = \frac{R_{URR}}{1 + ae^{-kt}}$$

where a and k are positive constants, and are the fitting parameters.

It follows that the rate of production P is defined as the derivative

$$P = \frac{dQ}{dt} = \frac{R_{URR}ake^{-kt}}{\left(1 + ae^{-kt}\right)^2}$$

which is a symmetrical bell-curve, underneath which the area is equal to RURR. Figure 1 shows the annual and cumulative production predicted using this theory, based on RURR = 24.3 billion tonnes.

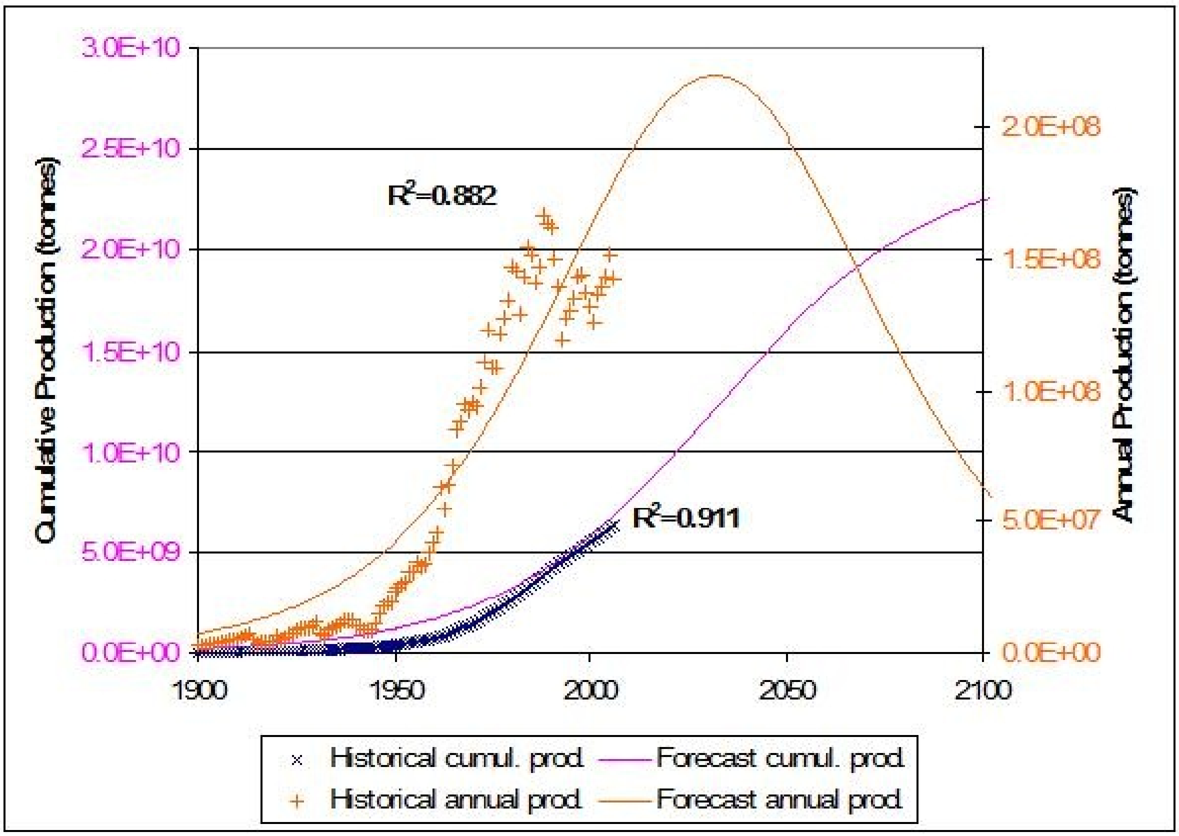

Figure 1

This is, for all intents and purposes, the result of White & Cordell's model, however they use it to urge planning for a low-phosphorus future. However, recent experience of the Peak Oil and Climate Change debates demonstrates the reluctance among politicians, industry, and community to accept a need to plan for even imminent crises. Urging action on a resource peak as far away as 2033 would most likely elicit zero response. White & Cordell's critical message could easily disappear over the planning horizon set by myopic governments. A far more urgent message is needed since the phosphate supply situation is almost certainly more pressing than suggested by White and Cordell's prediction of a 2033 peak at production levels approximately 50% higher than today. This is shown by the compelling predictions obtained when one uses the historical performance of the system (world phosphate mining) to predict future behaviour rather than forcing the behaviour to accommodate the URR estimates of the USGS.

Statistically, the predicted curve for P matches historical production with a coefficient of determination (R2) of 0.882. For Q, the R2 term is 0.911. Visually, it appears that the model could be improved since neither the annual nor cumulative production curves provide a match to historical data. The high production peak of 220 million tonnes per annum in 2033 is therefore questionable.

By allowing the phosphate reserve to be adjusted down from the USGS estimate, we can obtain a better fit to the historical data set, for both annual and cumulative production. Figure 2 shows the curves obtained by assuming an ultimate reserve of 9 billion tonnes (including the 6.3 billion already consumed – i.e. only 2.7 billion remaining).

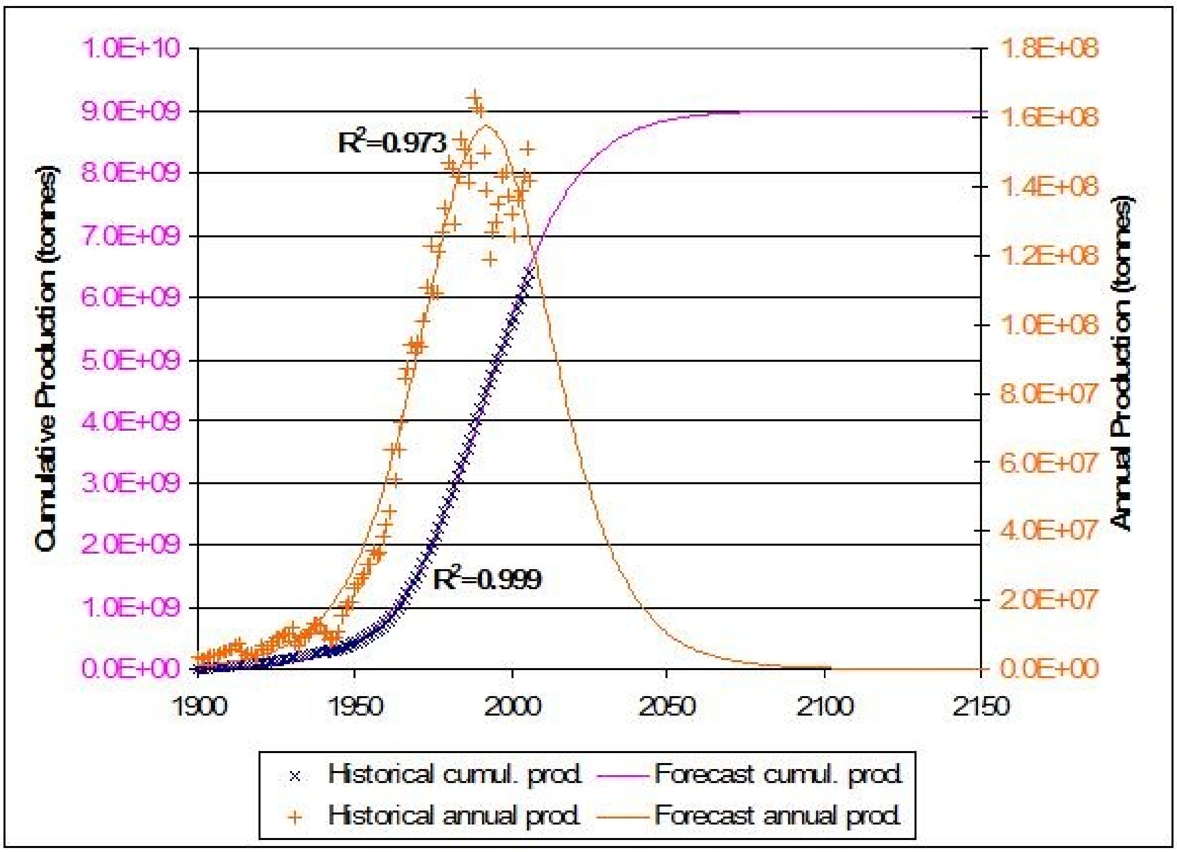

Figure 2

What we see in Figure 2 can only be described as a perfect match for the cumulative production history, and a very good match to the historical annual production figures, including the downturn of the 1990s. The goodness-of-fit is reflected in the R2 values, which are 0.973 and 0.999 for P and Q respectively.

The critical outcome of this analysis is that it suggests the 1990 downturn is a final peak, with no recovery. That indeed presents an urgent message for governments to act on securing renewable, recyclable phosphorus supplies and transitioning towards more appropriate (less wasteful) agricultural methods.

While it may be somewhat overzealous to suggest that the USGS estimate of remaining reserves should be brought down from 18 billion tonnes to a figure as low as 2.7 billion tonnes, it is compelling to see that this figure results in such a good fit to the historical data. This at least suggests that the USGS reserves should be called into question.

Perhaps the best way to frame the debate from here is to suggest that, like oil, the world has been endowed with a given quantity of “easy” phosphorus (e.g. rich island guano deposits in places like Nauru) that can be – and have been – mined quite rapidly, as well as a larger endowment of lower-grade phosphate rock. While the easy phosphate has passed its peak, the low-grade phosphate should be considered separately. Figure 3 shows an example forecast where the total area under both curves (equal to RURR) is 24.3 billion tonnes, but the “easy” phosphorus (purple) is 9 billion tonnes as in Figure 2. Assuming the production history is mostly related to easy phosphorus, the fitting parameters (a and k) for the “hard” phosphorus cannot be established. Therefore, the height and timing of the secondary peak are unpredictable.

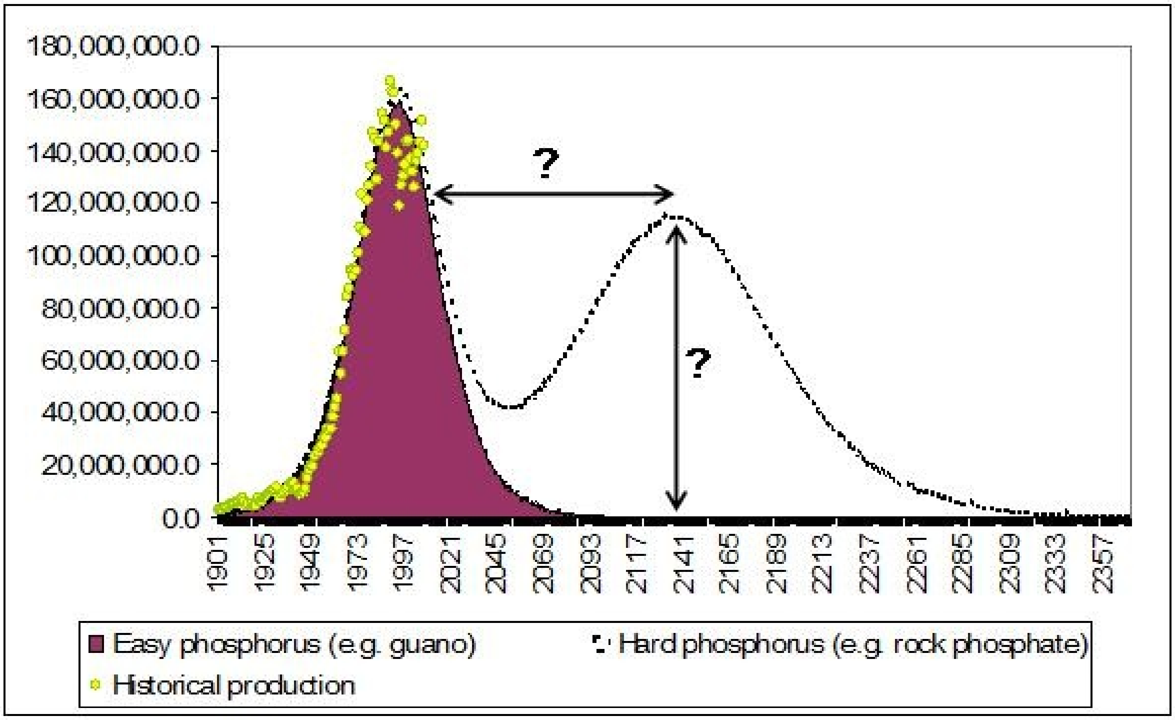

Figure 3

Like unconventional oil, the reserves may be big, and given the crucial role of phosphorus in the world food supply, we can expect heroic efforts to bring new supplies online from low-grade sources. However, several significant questions remain:

How quickly can “unconventional” low-grade phosphate supplies be brought online to replace dwindling conventional supplies, and how will we grow food in the interim?

What is the environmental cost (e.g. waste rock, greenhouse emissions, landscape degradation, heavy metal contamination) of mining low-grade phosphate?

How economic will it be to continue mining low-grade phosphate rock as energy costs rise, and how high must the price of fertilizer be to sustain this?

What will we eat when the low-grade phosphate rock runs out?

This last question is really the main subject of White & Cordell’s website, where they are urgently recommending the rapid, widespread uptake of phosphorus recycling to prevent catastrophic starvation due to exhausting our finite fertilizer sources. Unlike oil (which is simply burnt), we have the opportunity to recover phosphorus by closing loops in our food-nutrient cycle. Furthermore, if we fail to learn how to recycle phosphorus, we will find agriculture disappearing – and us with it.

References:

White & Cordell (2008) Peak Phosphorus – the sequel to Peak Oil
http://phosphorusfutures.net/index.php?option=com_content&task=view&id=1...

Historical data obtained from USGS minerals fact sheets:
http://minerals.usgs.gov/ds/2005/140/

[*] White & Cordell used tonnes of elemental phosphorus, not total phosphate rock, so their reserve and production figures were smaller than those used here; however, we are essentially talking about the same thing.

Related Post:

The Oil Drum reprinted an earlier Energy Bulletin post called Peak Phosphorous, written by Patrick Déry and Bart Anderson.