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Extrapolating phosphorus production to estimate resource reserves

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ABSTRACT

Various indicators of resource scarcity and methods for extrapolating resource availability are examined for phosphorus. These include resource lifetime, and trends in resource price, ore grade and discovery rates, and Hubbert curve extrapolation. Several of these indicate increasing scarcity of phosphate resources. Calculated resource lifetime is subject to a number of caveats such as unanticipated future changes in resource discovery, mining and beneficiation technology, population growth or per-capita demand. Thus it should be used only as a rough planning index or as a relative indicator of potential scarcity. This paper examines the uncertainty in one method for estimating available resources from historical production data. The confidence intervals for the parameters and predictions of the Hubbert curves are computed as they relate to the amount of information available. These show that Hubbert-type extrapolations are not robust for predicting the ultimately recoverable reserves or year of peak production of phosphate rock. Previous successes of the Hubbert curve are for cases in which there exist alternative resources, which is not the situation for phosphate. It is suggested that data other than historical production, such as population growth, identified resources and economic factors, should be included in making such forecasts.

1. Introduction

Phosphorus is an essential nutrient in our food supply, via its use in the form of phosphate as a crop fertilizer. The ultimate source of most of it is mined phosphate rock (PR). According to recent data from the US Geological Survey (USGS) the known global reserves of PR amounts to 16 billion metric tons (Gt), and this is being mined at the rate of 158 million metric tons per year (Mt yr^{-1}) (Jasinski, 2010). If both of these numbers hold, we would expect to completely deplete this critical resource in a century. Of course, there are numerous caveats to that calculation, all of which are subject to significant uncertainty. This paper will examine the uncertainty in one method for estimating available resources from historical production data.

The USGS data have been the most complete and regular assessment of global supply available publically. Recently, however, Van Kauwenbergh (2010) of the International Center for Soil Fertility and Agricultural Development (IFDC) has produced an assessment that places reserves at 3.8 times the USGS figures, and the reserve base at 7.4 times USGS base reserves of 2009 (Reserves are resources that are considered recoverable under current economic conditions). The reserve base is “resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics” (USGS, 2009). Based on the IFDC figures and current usage rates, the reserves would last an additional 90 years, and the reserve base would be sufficient to last over two millennia. If this is the case, the immediate urgency of the scarcity situation may be reduced. In any case, it remains that PR is a finite resource subject to eventual depletion. This should make it imperative to make a close examination of the resource picture for phosphorus to determine whether action is needed to ensure future consumption. Furthermore, the case of phosphorus can be viewed as a case study in the general problem of prediction of mineral resources. If our goal is a sustainable agricultural system, then the desired timeline is not a century, or even five centuries, but indefinitely.

There is no substitute for phosphorus in the food supply (Jasinski, 2010). It can, however, be conserved and recycled, which would reduce the demand for the raw material. Although about 90% of the mined phosphate is used for food, only about 17% makes it into the human food supply (Cordell et al., 2009a). The balance is lost through erosion, runoff from land, food waste and other smaller losses. Most of what does reach our food is subsequently disposed of without recycling. Modern agriculture is greatly dependent on artificial fertilizers, including phosphorus from PR. Without it, it is unlikely we could support our current global population, let alone the 40% increase that is expected between now and the end of this century (United Nations, 2004).

Among the caveats referred to above are: Increased scarcity would increase the price of PR; this in turn would make it more economic to mine lower-grade resources, moving them into the

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reserve category. Similarly, improved technology for mining and processing the PR may make these same lower-grade resources economic to recover. It is possible that new reserves will be discovered in the future. However, these potential increases on the supply side must be balanced by the likelihood of increases in demand as population continues to grow. This growth is most likely to come from increasing fertilizer application to existing agricultural land (FAO, 2008). However, that will produce less increase in production than current application rates due to diminishing returns (Tilman et al., 2002). Cordell (2010) described a number of economic and policy actions that could have either positive or negative effects on production, and therefore resource lifetime. These include deliberate market manipulation by monopoly producers (e.g. cartels or tariffs), political instability in major producing countries, increases in the cost of fertilizer production resources such as energy and sulfur, global or regional economic booms or crashes, and new environmental restrictions.

But do the existing data suggest increasing scarcity? How does one extrapolate from the present? Or more specifically, what, if anything, does the history of production and estimates of known reserves tell us about the resource situation? This paper is an examination of those data and a critical analysis of methodologies for extrapolating them.

2. Indications of phosphorus scarcity

Teitenberg (2003) lists a number of potential indicators that could signal increasing scarcity, including the projected resource life, trends in resource cost, trends in raw resource ore grade, and trends in resource discovery rates.

From 1993 to 2006, the cost of phosphate rock held almost constant, increasing from US$25.48 to US$26.04. But suddenly, it then increased 25% in 1 year, and then 88% in the next, to US$61.39, before settling back down to US$40.13 in 2009, an increase of 54% over 2006 (all figures adjusted to year 2000 dollars using the consumer price index (US Dept. of Labor, 2010)). From 1991 to 2009, the ore grade of US phosphate rock has declined steadily by a total of 5.1%. Liu et al. (2008) reports on a study (Isherwood, 2000) that has shown that the average global ore grade of PR declined by 10% from 1980 to 1996.

The USGS reports that global reserves stand at about 16 000 Mt (Jasinski, 2010). These reserves are currently being mined at the rate of 158 Mt yr^{-1}, yielding a calculated reserve lifetime of 99 years. Until 2009, the USGS also reported the category of "reserve base," which included resources that could be exploited with better technology and a higher price for PR than present conditions allow. In 2008 the reserve base was 47 000 Mt, which would be enough to last 281 years at current production rates. Finally, the United Nations Environment Program in the 1980's made a detailed estimate of all known and inferred phosphate reserves in a detailed country-by-country geological analysis called Project 156 (Cook and Shergold, 1986). This project estimated that there are 163,000 Mt of resources. These would yield a lifetime of over 1000 years. However, the study pointed out that most of this is not exploitable with current technology. For example, two-thirds of the PR is found with levels of carbonate minerals that make phosphoric acid production impractical. (Phosphate is extracted from PR by treating it with sulfuric acid to produce phosphoric acid.) Some of the rest of the resources are unsuitable for use with current technology because of impurities such as cadmium and uranium.

Thus one can see that all these indicators point to increasing scarcity. The trends in cost and grade are not by their nature useful for prediction. The resource lifetime is inherently predictive. However, this calculation is subject to the caveats described above. There are a number of other factors that could be taken into account. The factor likely to have the greatest effect is population growth. Population projects will be used to improve our predictions for phosphorus consumptions. This factor alone would incorporate much of the increase attributed by Steen (1998) to increased grain production. Other factors could be taken into account on both the positive and negative side. Among those that would hasten depletion of resources are: There is the likelihood that some developing countries will upgrade their diet over coming decades, requiring larger inputs from agriculture, including of fertilizer. Also, increased food production would require either increasing the use of marginal lands, which may require increased fertilization to make them productive, or current agricultural lands would need to increase their productivity by increasing agricultural inputs. This latter approach would be subject to the diminishing returns described above. On the other hand, there are factors that would tend to extend the resource lifetime. These include improved mining and beneficiation technology, anticipation of new discoveries based on historical rates, improved fertilization efficiency techniques, and including the effects of rising prices on moving resources into the reserves column. For these reasons the lifetime calculation should only be used for rough planning, or even only as a relative indicator.

Furthermore, society must react to impending depletion of a resource long before it is gone. Time is required for changes in technology and lifestyles. In the case of phosphorus, it would be necessary to greatly increase recycling, reduce losses such as were described above, and possibly reduce per-capita demand such as by dietary changes. Additional phosphate resources are known to exist, beyond those that are considered reserves. Resources may not be included in reserves because of the depth at which they are found, their lower grade, their location under the coastal ocean, or because of toxic impurities. Some of these may become available as the price of PR increases, or as mining and beneficiation technology improves. There may be limitations to this. For example, in the case of lower grade or undersea PR, although an increase in price would tend to make it more economical to mine these resources, their use would likely involve increased energy requirements. This couples phosphorus to issues of energy scarcity. Mudd (2009) performed an analysis of mineral resources for Australia, and concluded that future limitations would come not just from scarcity of the resources themselves, but from increasing environmental impacts of their mining, especially with respect to energy, water and greenhouse emissions.

An analysis of rate of discovery of phosphate resources was performed by Sheldon (1987). He estimated a total of 111 000 Mt of PR that were discovered between 1880 and 1982, corresponding to an average discovery rate of 1090 Mt yr^{-1}. These include reserve base and inferred reserve base. The latter are resources that are not measured but are reasonably likely to exist based on geological evidence. The discovery rate is 8.5 times the global production rate from 1982. Will it be expected to continue? Sheldon states that (pp. 347, 351–352):

"No shortages of industrial minerals, including fertilizer minerals, can be foreseen for long into the future." "…undiscovered speculative phosphate resources of the world are thought by some resource geologists, including myself, to be large. The continental shelves of the world where phosphate is now being deposited are likely to contain more phosphorite at shallow depth. The rocks of the humid and wet-and-dry tropical regions of the world are covered by jungle and deep soils and are themselves deeply weathered, causing exploration for soluble minerals, such as phosphorite, to be very difficult. These regions, which make up 22% of the Earth's land surface, are as likely to contain phosphate rock as the areas of other climate zones, but in fact they contain only 2% of the world's phosphate concentrate reserve base. It is likely that a large, undiscovered resource exists."