Capital Project Cost Estimation in the Phosphate Industry

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Abstract

This paper describes the steps required to prepare capital cost estimates for projects in the chemical processing industry. There are five different classes of estimate accuracy; however three different accuracies are usually prepared:

- Initially an order of magnitude +/- 50% estimate
- The second round is usually a +/- 30% estimate
- Finally, the third round is a +/- 10% estimate

Deliverables required to complete the estimate depend on the accuracy of the estimate, but can include the following:

1. Process Description
2. Process Flow Diagrams
3. Feed & Product Stream Summary
4. Equipment List
5. P&IDs
6. Instrument List
7. Electrical One-line Diagram
8. Piping Line Table
9. Equipment Arrangement Drawings
10. Pipe Route Drawings
11. Civil/Concrete Drawings
12. Structural Drawings
13. Tie-in Drawings
14. Vessel Drawings
15. Demolition Drawings
16. Material Quantification (concrete, steel, pipe, valve, etc.)
17. Major Equipment Quotes
18. Bulk Material Quotes
19. Project Schedule
20. Estimate Summary and Itemized Estimate Detail Report

A few recent projects that have been completed by our team include a couple of sulfuric acid plant converter replacements, a phosphoric acid filter central valve replacement, a clarifier addition, several evaporator installations, and many evaporator fluosilicic acid recovery retrofits. Due to the confidential nature of these specific projects they will not be covered individually. However, production trends and emerging cost reduction technology is reviewed.

Estimate Class Summary

Class of Estimate (Accuracy) – Description

Class 5 Estimate (+/- 50%) – Conceptual Order of Magnitude

Contingency 25%
Purpose: Preliminary feasibility decision making
Required Information:
- Facility Location and Basic Process Data
- Storage and Logistics Requirements
- Engineering Expenditure 0%

Class 4 Estimate (+/- 30%) – Feasibility or Factored Estimates

Contingency 10% to 20%
Purpose: Economic and Technology Comparison
Required Information (additional to Class 5 requirements):
- Block Flow Diagram and Sized Equipment List
- Project Description, Schedule and Design Criteria
- Engineering Expenditure 3% to 5%

Class 3 Estimate (+/- 20%) – Preliminary Budget Estimates

Contingency is developed with risk analysis (typically 10% to 20%)
Purpose: To improve a Class 4 estimate when time does not allow Class 2
Required Information (additional to Class 4 requirements):
- Major Equipment Specifications
- Initial PFDs, P&IDs, Equipment Location, Piping, and One Lines
- Limited material takeoff for major materials such as piping & steel
- Engineering Expenditure 5% to 15%

Class 2 Estimate (+/- 10 %) – Definitive Estimate

Contingency Developed by Risk Analysis (typically 10% to 15%)
Purpose: Used for Client Capital Appropriations, and for project budgets
Required Information (additional to Class 3 requirements):
- Complete set of PFDs, P&IDs, Equipment Location
- Project specific information on contractual terms
- Project specific quoted trade labor rates
- Firm equipment quotations
- Detailed material takeoff and unit price quotations
- Engineering Effort 15% to 50%

Class 1 Estimate (+/- 5%) – Final Design Estimate

Contingency developed by risk analysis (typically 5% to 10%)
Purpose: for construction planning
Required Information (additional to Class 2 requirements):
- All equipment items specified for purchase – vendors selected
- Firm pricing on bulk materials and actual field labor productivity
- Engineering Effort 80% to 100%

Class 5 Estimate (+/- 50%) – Conceptual Order of Magnitude

Contingency: 25%
Purpose: Preliminary feasibility decision making
Approximate cost: 0.1% to 0.2% of project value ($20 MM basis)
Required Information:

- Product and Raw Material Specifications
- Design Capacity
- Facility Location
- Storage and Logistics Requirements
- Engineering Expenditure 0%
- Historical Project Database

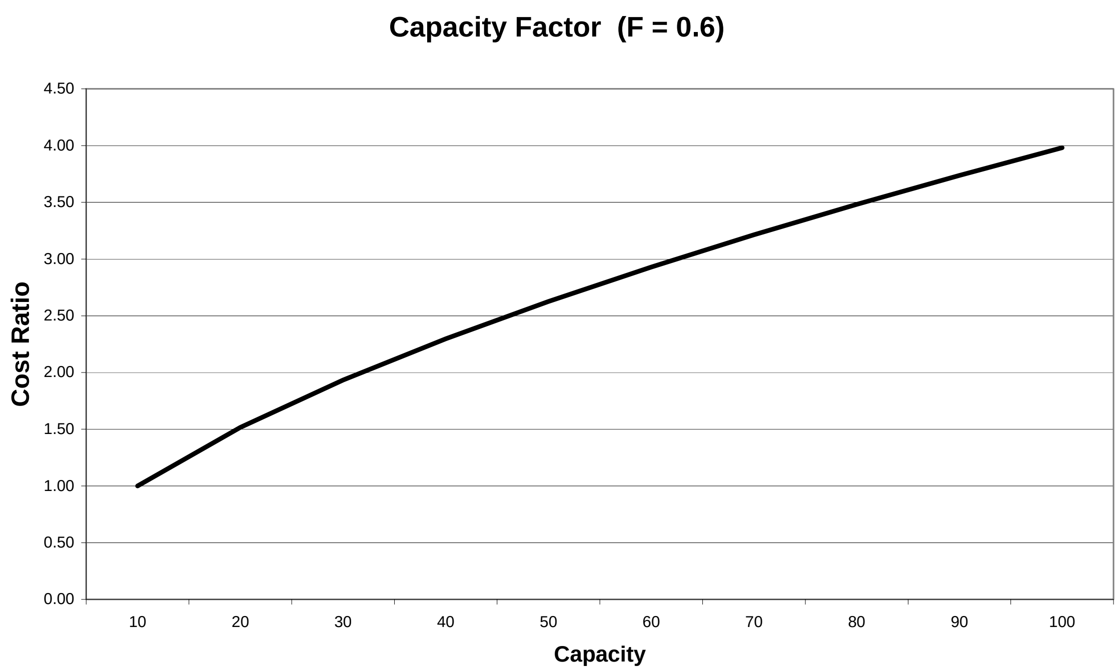
Estimated new project cost is established by adjusting prior project costs for differences such as inflation, plant capacity, site specific costs such as labor rates. Typical plant construction cost indexes such as the Chemical Engineering cost index is used.

Adjustment for capacity vs. prior installations uses the cost capacity factor:

New Project Cost = Old Project Cost x (Capacity New/Capacity Prior) ^{F}

Where the exponent "F" is the cost capacity factor. The cost capacity factor ranges from 0.2 to over 1.0, and averages about 0.6 depending on the process.

It is helpful to pool information to improve the accuracy of Class 5 estimates because the projects being planned are sometimes not the same type as those recently completed within a given company.



Class 4 Estimate (+/- 30%) – Feasibility or Factored Estimates

Contingency: 10% to 20%
Purpose: Economic and Technology Comparison
Technique: Lang Factor Method (LFM)
Approximate cost: 0.2% to 0.5% of project value ($20 MM basis)
Required Information (additional to Class 5 requirements):
- Block Flow Diagram
- Sized Equipment List
- Project Description and Schedule
- Design Criteria
- Engineering Expenditure 3% to 5%

This method is used when the preliminary project scope is being developed, including required process capacity (design basis), process flows (PFD), and required process equipment (equipment list). The Lang Factor Method is a technique that uses equipment pricing and historical factors to estimate the proposed project capital cost.

(Proposed Project Capital Cost) = (Lang Factor) x (Project Equipment Cost)

Lang factors are either for fixed investment (L_f) or total investment (L_t). Additionally, different types of industries have different historical Lang factors. Typical Lang factors from the literature (Arnold & Chilton, 1963) are:

	Liquid Process	Solid Process
Lang Factor Fixed Investment = L_f	4.8	3.9
Lang Factor Total Investment = L_t	5.7	4.6

4A. Major Equipment

Equipment costs are based on in-house cost curves, or budgetary quotes.

4B. Bulk Materials & Field Labor

Bulk materials are factored from major equipment costs and adjusted for the specific facility. Lang factor may be modified if substantial bulk materials are outside of battery limit plants – i.e. long offsite pipe runs. Labor and material ratios for similar work are adjusted for site conditions.

4C. Engineering

Man hours factored by equipment item for similar projects, or as a percentage of total project cost based on historical information.

Four Line Equipment List – Typical Example (various units)

Equipment Type	Equipment Name	Size/Cap.	Basis	MOC
Agitator (AG)	Agitator	3m D x 7M H	200 kW	F255
Blower (BL)	Blower	900 m^3/h	40 C & 60 kPa dis.	CS
	Vacuum Pump	4,000 acfm	10” HgA & 180F	316 SS
Combustor (CB)	Burner	10MMBtu/h	natural gas	FBLS
	Flare	500 cfm	propane	A20
Conveyor (CV)	Screw Conv.	10 T/h	15m L@ 1.3 SPG	NiHrd
	Belt Conv.	200 T/h	80m L @ 1.1 SPG	CLRB
	Airslide Conv.	300 T/h	700m L @ .9 SPG	CS
	Bucket Elevator	600 T/h	40m H @ 1.1 SPG	CS
Fan (FN)	Fan	67,000 acfm	140 F x 30” H2O	317 SS
Heat Exchanger (HX)	Exchanger 1	20’L x 6’D	(900) 1.5” T	C12
	Exchanger 2	50MMBtu/h	50mm D tubes	G35
Mill-Crusher (MC)	Jaw/Cone	40 t/h	>6”magnesite <2”	vend.
	Roller/Roll	50 t/h	>1” DFP to <8mm	ARhf
Mill-Impact (MI)	Ball/Rod/Ham.	300 t/h	4m L x 4m D	RLCS
	Chain/Cage	80 t/h	36” dual rotor	CS
Mixer (MX)	Pugmill /Ribbon	7m L x 2m W	50 T/h x 300 kW	317L
Pump (PP)	Horiz. Centrifugal	25,000 gpm	120 ft @1.3 SPG	RLCS
	Vertical Centrifugal	85 m^3/h	70m @ 1.0 SPG	CD4
	Horiz. Axial	60,000 gpm	14 ft @ 1.45 SPG	F255
Reactor (RX)	Fluid Bed	8m D x 6m H	1,300F	RFLS
	CSTR	20ft D x 20 ft H	194F	ABLR
Pressure Vessel (PV)	Vessel 1	2m D x 5 m H	ASME 100 psig	PFAL
	Vessel 2	8ft D x 60 ft L	ASME 200 psig	CS
Rotary Drum (RD)	Dryer/Cooler	5m D x 30m L	32 rows of 0.4m L lifter	CS
	Granulator	4m D x 12m L	Rubber Liners	316L
Scrubber (SC)	Spray Tower	6ft D x 40 ft H	+/- 5psig	CONC
	Venturi Cyclonic	50,000 acfm	-20” x 140F	317L
	Packed Scrubber	3m D x 8m H	400 gpm	FRP
Separator (SP)	Cyclone	4 @ 8,000 acfm	90% @ 10u, 1SPG	CS
	Filter	3m W x 75m L	240 gpm ff	CBR
	Screener	4ft x 5 ft x (4)	100 t/h	CS
Tank-Atmospheric (TK)	API Tank	300,000 gal	1.6 SPG @170F	RLCS

Class 3 Estimate (+/- 20%) – Preliminary Budget Estimates

Contingency is developed with risk analysis (typically 10% to 20%)
Purpose: To improve a Class 4 estimate when time does not allow Class 2
Approximate cost: 1% to 2% of project cost ($20 MM basis)
Required Information (additional to Class 4 requirements):
- Major Equipment Specifications
- Initial PFDs, P&IDs, Equipment Location, Piping, and One Lines
- Engineering Expenditure 5% to 15%
- Limited material takeoff for major materials such as piping & steel

The direct cost of the project comes from in house data where available or quoted material and labor rates. The estimated indirect cost is usually based on a factor applied to the direct cost. The total project cost is: direct costs + indirect costs + offsites + commissioning allowance + infrastructure + overhead + labor productivity + escalation.

3A. Major Equipment

Major equipment costs are based on recent purchases of like equipment or budget quotes.

3B. Bulk Materials/Field Labor

Preliminary material take-offs are developed for the major accounts such as concrete, steel, pipe, instrument count, and electrical motor list. Historical material and installation rates are applied to these material take-offs. Material installation rates are adjusted based on recent purchases and current labor rates.

3C. Engineering

Man hours factored by equipment item for similar projects or factored as a percentage of TIC, or as a percentage of total project cost based on historical information.

Class 2 Estimate (+/- 10 %) – Definitive Estimate

Contingency Developed by Risk Analysis (typically 10% to 15%)
Purpose: Used for Client Capital Appropriations, and for project budgets
Approximate cost: 2% to 4% of project cost
Required Information (additional to Class 3 requirements):

- Complete set of PFDs, P&IDs, Equipment location drawings
- Project specific information on contractual terms
- Project specific quoted trade labor rates
- Material takeoff for bulk materials
- Engineering Effort 15% to 50%

2A. Major Equipment

Multiple equipment quotes for all equipment. May average multiple quotes or take most likely equipment selection, depending on estimate basis.

2B. Bulk Materials & Field Labor

Material take-offs for pipe, valves, wiring, steel and concrete from preliminary discipline drawings, along with quoted unit pricing. Labor and material ratios for similar work, adjusted for site conditions & using quote contractor unit pricing, and in house site specific labor productivity.

2C. Engineering

Detailed engineering man hours estimated based on project specific required deliverables and individual discipline schedules.

Note: The Class 1 description has been deleted for this publication.

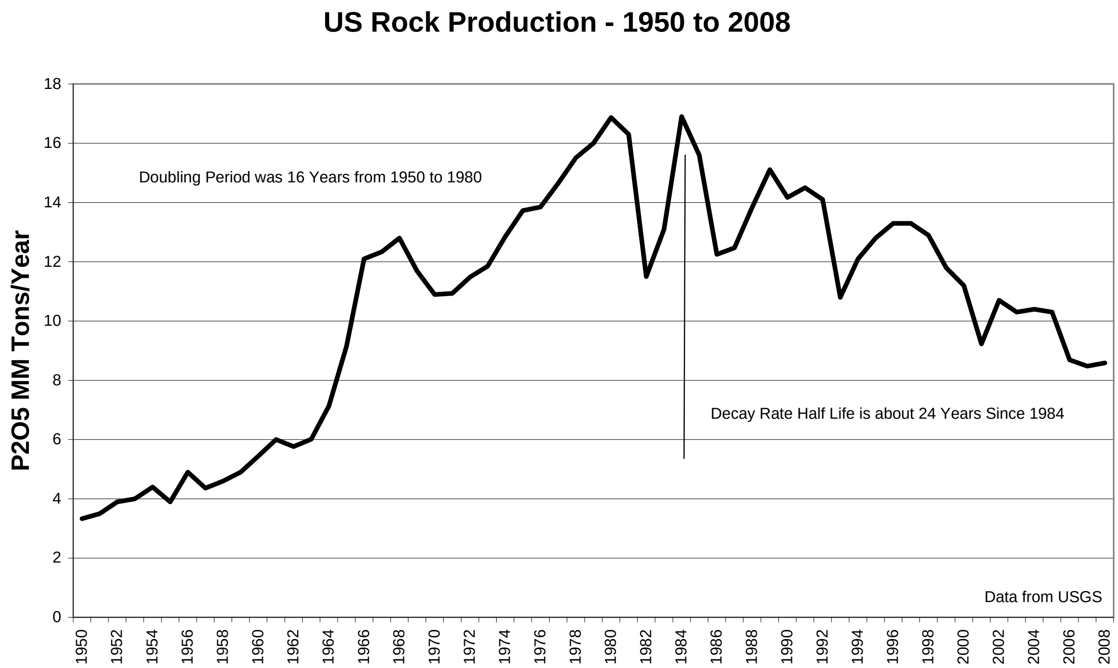
Phosphate Rock Market Conditions – 2010

No treatment of capital investment in the phosphate industry would be complete without mentioning the cyclic nature of the phosphate business. The following charts are intended to supply some historical context to the mining trends.

Heffer & Prud'homme – International Fertilizer Industry Assoc. – May, 2009

"The prospect of pending surpluses is mostly seen in the phosphate and potash sectors, unless global demand recovers more quickly and strongly than anticipated or unless major new capacity projects face significant delays."

http://www.incitec.com.au/zone_files/PDFs/ifa_fertilizer_outlook_2009-2013.pdf



US rock production grew from 1950 to the 1980's by doubling every 15 years. Since 1985 the trend has reversed, and US phosphate rock mining is shrinking with a half-life of about 24 years.

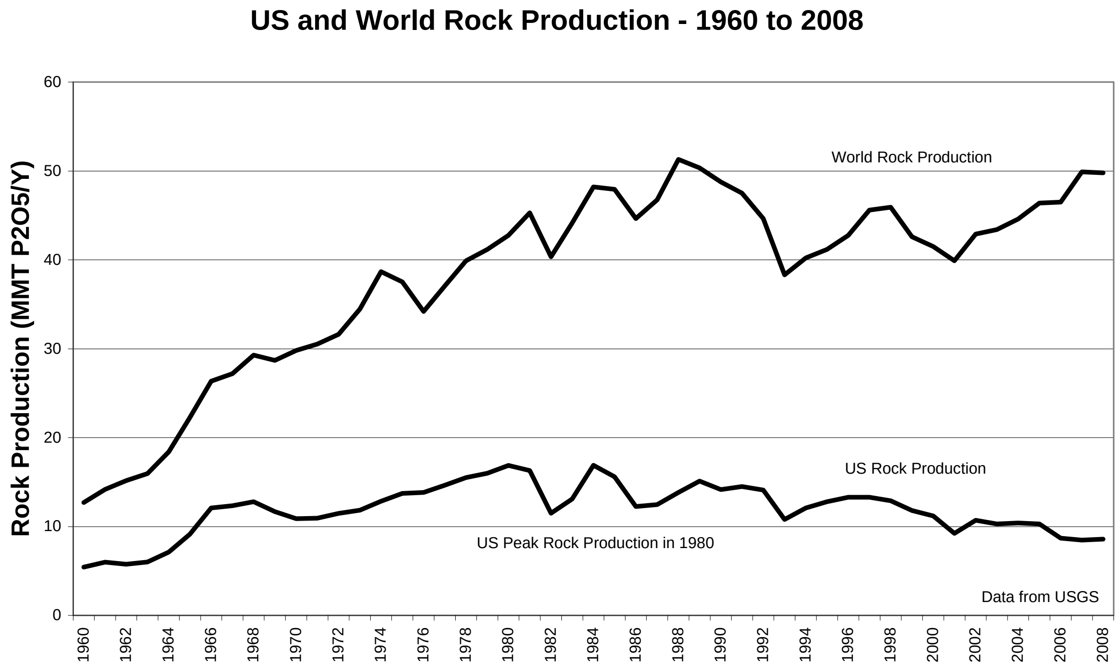
Comparison - Jordan Phosphates Mines Company

The $170 million IJC consists of a 700 tpd phosphoric acid and a 2000 tpd sulfuric acid plant, including a storage terminal at the Red Sea Port of Aqaba.

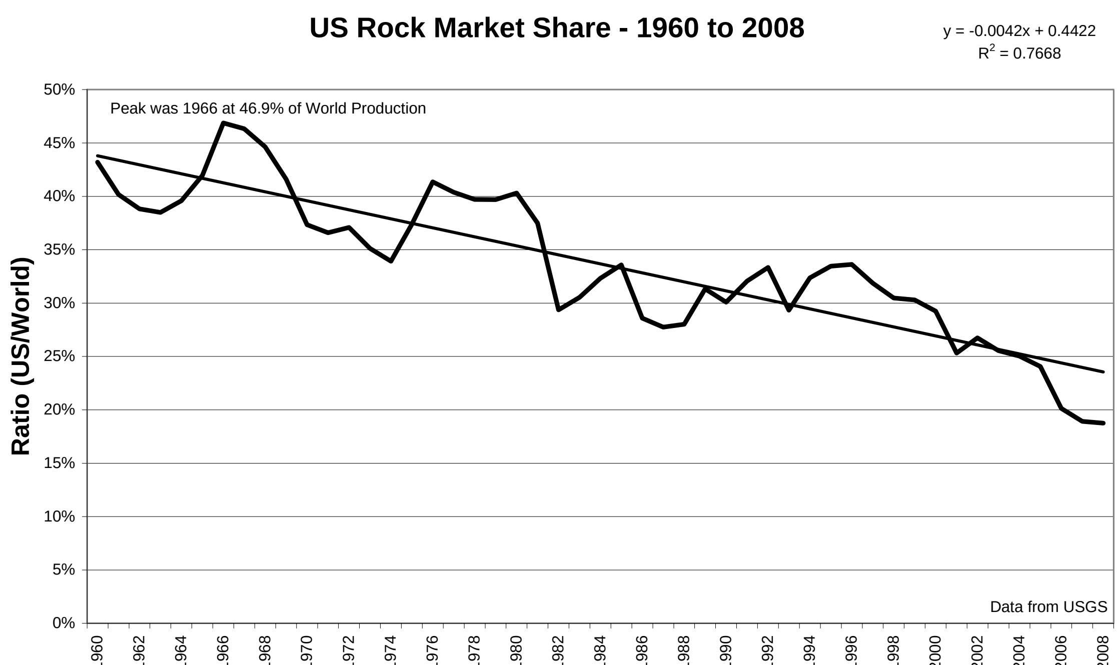
Production Data:

1966 phosphate rock production = 1 MM t/y
2008 phosphate rock production = 6 MM t/y

Mine Growth Rate = 5MM t/y increase over 44 years = 4.15% increase/year

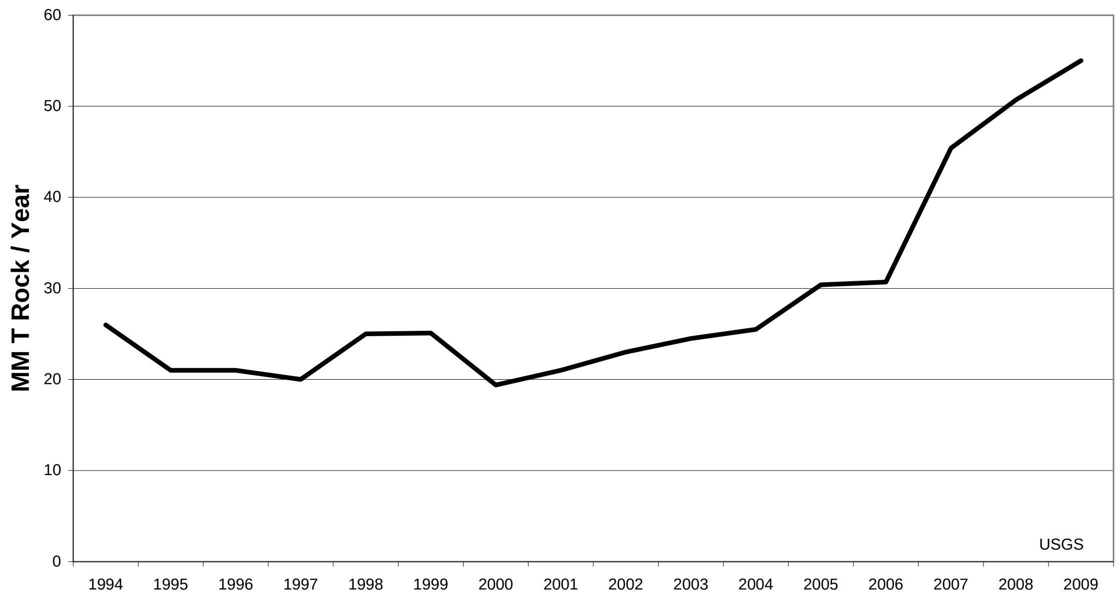


This graph presents World and US phosphate rock production – notice US rock production peaked in 1980 at 54.5 MM t rock/y, while the world record was in 1988 at 166 MM t rock/y.



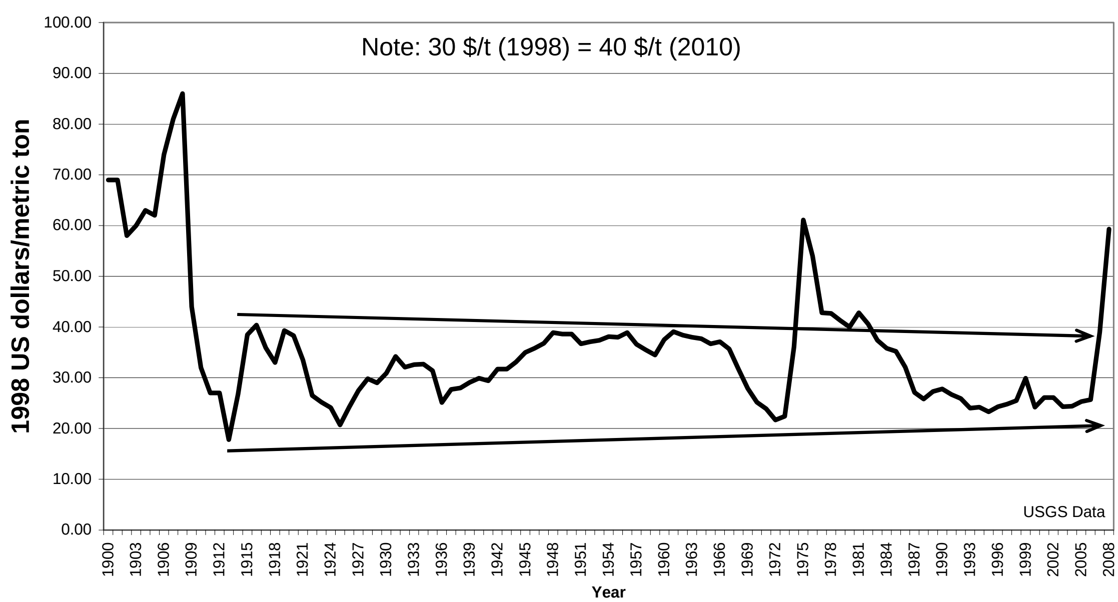
This graph presents the US rock market share – the trend is steadily down since 1966.

China Rock Production - 1994 to 2009



In contrast to the shrinking US mine production, China has significantly increased their rate of investment in the phosphate industry by doubling capacity in a mere 4 years (2004 to 2008).

US Phosphate Rock Cost - ($/metric ton)



The graph above shows the 108 year price trend reported by the US Geologic Service (usgs.gov). Obviously, one should not use market peak pricing in any multi-year capital investment decisions. Based on the US experience the current mid-range rock price expectation is on the order of $40/mt (2010 USD), while the recent 2008 price spike will likely cause near term overcapacity and resulting suppression in rock price below this historical mid-range value for the next decade.

The other side of the CAPEX coin - Simultaneous Expansions:

Bayóvar Project: Vale launches cornerstone Source: Vale website

Vale celebrated the launch of the cornerstone of the Bayóvar Project, in Piura, north of Peru, one of the largest phosphate deposits in South America. The operation will be initiated in 2010 and produce about 3.9 million tons of phosphoric rock concentrate per year.

In the first phase, the Bayóvar Project will include the construction of a phosphate concentrating plant, a 40-km roadway, a 5-km overland conveyor, a drying and storage area, in addition to a port with capacity to ship 7.9 million tons a year.

Vale to sell minority stakes in Bayóvar Source: Vale website

3/31/10 - Vale announces that it has reached an agreement with The Mosaic Company (Mosaic), a company listed on the New York Stock Exchange, and Mitsui & Co. Ltd. (Mitsui), a company listed on the Tokyo Stock Exchange, to sell minority stakes in the Bayóvar project in Peru, through a newly-formed company that will control and operate the project.

Subject to the terms and conditions set forth in the definitive share purchase agreement, Vale has agreed to sell 35% of total capital to Mosaic for US$ 385 million and 25% of total capital to Mitsui for US$ 275 million. Following the consummation of these transactions, Vale will retain control of the Bayóvar project, holding 51% of the voting shares and 40% of total capital of the newly-formed company.

Bayóvar is a phosphate rock project located in Sechura, department of Piura, Peru, which consists of an open-pit mine that is expected to have production capacity of **3.9 million metric tons per** year and a maritime terminal. Completion is expected for the second half of 2010. The sale of these minority stakes will facilitate the offtake of product from the Bayóvar project.

Morocco - OCP Source: l'Economiste Maroc

OCP plans to increase the total production capacity in Morocco and Western Sahara from a today's level of 30 million tonnes, to 45 million tonnes annually in 2015. **A net increase of 15MMt/y.**

Saudi Arabia – Ma'aden Source: Ma'aden website

RIYADH, SAUDI ARABIA March 22, 2010– The Saudi Arabian Mining Company, Ma'aden has announced that it is studying a significant expansion of its phosphate activities involving the exploitation of a second major phosphate resource in the north of Saudi Arabia to supply merchant grade phosphoric acid to the fertilizer, food and animal feed industries. A feasibility study is underway on the project which would mine the Al Khabra deposit in the Umm Wual licence area located 40 kilometres northeast of Turaif. The project envisages an open pit mine and simple beneficiation process adding close to **1.5 million tons** annually to Ma'aden's scheduled phosphate capacity to be marketed locally and internation-ally by Ma'aden.

"The project would use port, rail and infrastructure developments put in place by the Kingdom's government to deliver regional development through the expansion of key industries." commented Khaled Mudaifer, Ma'aden's VP Phosphates. "The feasibility study currently underway will evaluate the viability of the project to supply highly demanded phosphate intermediate products to augment Ma'aden's phosphate product mix. It would not be appropriate to suggest a timetable for development however, until after the study is completed."

The project is based on measured and indicated resources at the Al Khabra mining licence which stand at 234 million metric tons grading at 17% to 19% P2O5. There is very low heavy metals content, ensuring that the phosphoric acid will be of the highest quality and could be used for the food and feed industries. The Umm Wual licence area contains further JORC compliant indicated and inferred resources of 446 million tons as well as significant further resource potential. Ma'aden is continuing exploration activities in the area to expand the resource.

"The progress of the Umm Wual Al Khabra project, our second phosphate initiative, demonstrates that Ma'aden and Saudi Arabia are becoming major contributors to the global phosphate industry and that our desert kingdom will help to feed the world in years to come." added Dr Abdullah Dabbagh, Ma'aden's President and CEO. "The projects help fulfil Ma'aden's commitment to develop the mineral wealth of the kingdom and become a catalyst for downstream industries."

Ma'aden's existing phosphate joint venture with SABIC, Ma'aden Phosphate Company (MPC), which includes a mine and beneficiation site at Al Jalamid and processing plants at Ras Az Zawr is scheduled to begin production later this year and at the end of February was 92.14% complete. When in full production MPC will produce 2.92 million tons per year of Diammonium Phosphate Fertilizer (DAP) for export to markets including the nearby high growth markets of Asia.

China – How do they finance all those phosphate expansions?

Excerpt of 5 of 52 technology transfer projects undertaken by WEC
Source: Wuhuan Engineering Co. website

No.	Project Name and Scale	Capital Source	Process Source	Technical Cooperation Method	Remarks
1	Guixi Fertilizer Complex: 120,000t/a P_2O_5, 6000t/a AlF_3, 240,000t/a DAP	Loaned by France government	P_2O_5: France AlF_3: France	Basic engineering design package is imported; Detail engineering design is undertaken by WEC	Turnkey project
2	Huangmailing Phosphate Co.: 180,000t/a DAP 280,000t/a H_2SO_4 90,000t/a P_2O_5 240,000t/a NPK 6000t/a sodium fluosilicate 30,000t/a NH_3	Loaned by the World Bank	P_2O_5: USA DAP: USA H_2SO_4: Sweden, France	Process package of H_2SO_4 pyrite roasting, Basic engineering design package of H_2SO_4 production, DAP and P_2O_5 are imported. The basic engineering design and detailed engineering design are undertaken by WEC respectively.	Turnkey project

No.	Project Name and Scale	Capital Source	Process Source	Technical Cooperation Method	Remarks
3	Luzhai Fertilizer Complex: 240,000t/a DAP 120,000t/a P_2O_5 (Raytheon) 6000t/a AlF_3 60,000t/a ammonia	Loaned by Japanese OECF	DAP: Japan P_2O_5: USA AlF_3: France	Basic engineering design packages are imported; And all detail engineering design is undertaken by WEC	
4	Zhanjiang Chemical Complex: 100,000t/a NPK 30,000t/a P_2O_5	Domestic loan	NPK: China P_2O_5: USA	P_2O_5 process package is imported, and basic and detail engineering are undertaken by WEC	Turnkey project
5	Wengfu Phosphate Fertilizer Complex: 800,000t/a TSP 300,000t/a P_2O_5 1,200,000t/a DAP	Loaned by Japanese OECF	TSP: Japan P_2O_5: Japan	Basic engineering design package is imported; and detail engineering is undertaken by WEC	

Q. What should a North American Phosphate Company do in the face of massive fertilizer capacity additions and Phytase?

A. Reduce mining capital and operating costs
B. Reduce chemical plant capital and operating costs
C. Improve product analysis and quality
D. Enter higher margin product lines
E. All of the above

One innovative solution that is currently available that fulfills answer E. is offered by our technology partner EcoPhos SA. The process offered consists of digesting the phosphate ore into a slightly acidic HCl medium, resulting in a selective digestion of the P2O5; most of the impurities from the rock remain insoluble (Organic, U2O3, Al2O3, Fe2O3, Ra)

The obtained phosacid solution is then converted into solid dicalcium phosphate (DCP) precipitate. The DCP contains up to 42% P_2O_5. The soluble impurities, including MgO are removed as a liquid phase into solution with calcium chloride.

The DCP is very pure and can be granulated for use as animal feed supplement. Additionally, the DCP can be digested with sulfuric acid, producing high quality phosphoric acid, as well as pure and not radioactive gypsum.

Issues linked to the low cost rock (i.e. High MgO, low P2O5, high CO3) are solved because impurities are separated from the P2O5 either at the digestions step or at the DCP crystallization step. This allows the use of low grade phosphate rock to produce even high value, low impurity products.

The high purity of the DCP and its high P2O5 concentration allows production of a highly concentrated phosphoric acid that can be directly used for DAP production. A supplemental process is available to recycle the HCl by using sulfuric acid as a feed stock. HCl is regenerated and returned back into the process, with pure gypsum being produced as sellable co-product. The end product cost of using the new technology is typically 60% of the product cost using conventional ore beneficiation and digestion processes. Applications for this process include:

- Fertilizer:
    - Chemical beneficiation of low grade phosphate rock
    - Production of Phosphoric acid
- Animal feed: production of DCP or MCP
- High purity: technical grade, food/pharma and electronic grade.

The advantages of the HCl digestion process are:

- Less beneficiation of rock needed, reduced costs
- Increase the mine life, using lower grade or rejected rock
- Solve technical problems due to impurities from rock i.e. high Mg, Ra, etc.
- Reduce the variable cost: Low grade phosphate rock used with high yield (>95%)
- Reduce energy consumption: concentrated phosphoric acid is produced
- Safe process: no use of volatile solvent, low temperature
- Very flexibile process: various grades raw-materials, simple process monitoring
- Pure co-products: $CaCl_2$, gypsum not radioactive (<2.7pci)
- Lower investment cost compared to the classical process

Details about this technology are available on the web: www.ecophos.com. We would be happy to develop a budgetary estimate for this process for your plant.

Conclusions

Change is inevitable. The methods and processes used tomorrow will probably be cheaper and better than those currently employed. We can help you to evaluate the capital and operating economics for your specific projects, including new technologies. Some may be of the opinion that trying to discern the optimum direction for investing capital in the phosphate industry is impossible and not a subject for discussion at a technical conference. However, it is a fundamental engineering assignment to find less costly ways to produce better products - and reviewing the market context is a necessity for the capital allocation process.