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# Titanium

## Industrial Base, Price Trends, and Technology Initiatives

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Somi Seong, Obaid Younossi, Benjamin W. Goldsmith

With Thomas Lang, Michael Neumann

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## Summary

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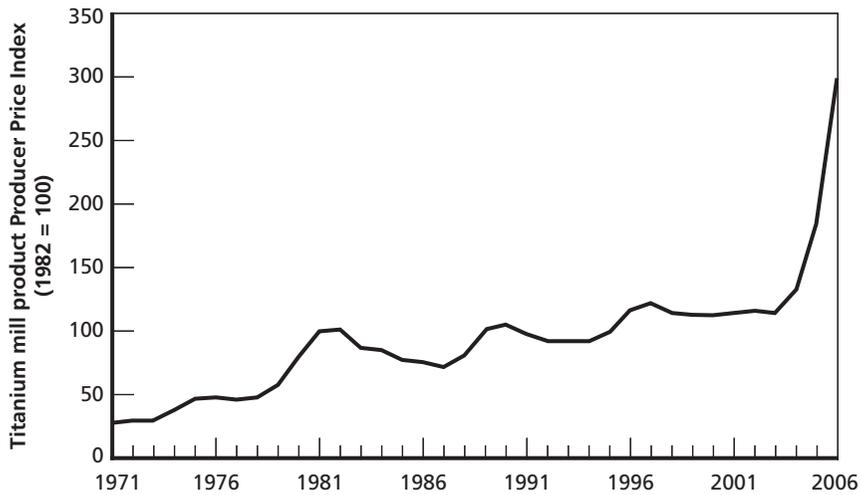
Titanium is an important raw material accounting for a significant portion of the structural weight of most military airframes. It offers an excellent set of properties, such as high strength-to-weight ratio, high strength at high temperatures, corrosion resistance, and thermal stability, that make it ideal for airframe structures. However, in recent years a combination of factors caused a major spike in titanium prices that is expected to influence the acquisition costs of future military aircraft.

Between 2003 and 2006, the price of this expensive metal increased at an unprecedented rate, more than doubling during this period. Government and industry observers said this was the first time a global materials supply concern has affected the defense sector since the steel shortage after World War II (Murphy, 2006). They also noted that the short supply of titanium might influence delivery schedules for military aircraft and weapons (Toensmeier, 2006). There are worries that titanium shortages may substantially raise the program cost of the F-35 (Murphy, 2006; *Defense Industry Daily*, 2006). Although prices of titanium products have fluctuated over the years, the recent price surge was extreme compared to previous fluctuations (see Figure S.1).

### Study Objective and Approach

The Office of the Assistant Secretary of the Air Force for Acquisition asked PAF to conduct this study in order to better understand the factors underlying price fluctuations in the titanium metals market, to better forecast economic risks involved in the market, and to improve

**Figure S.1**  
**Producer Price Index Trend for Titanium Mill Products, 1971–2006**



SOURCE: Producer Price Index data from the Bureau of Labor Statistics.

RAND MG789-S.1

estimates of the future cost of military airframes. To do so, we attempted to answer three primary questions:

- What triggered the recent titanium price surge?
- What are the future market prospects and emerging technologies?
- What are the policy implications for U.S. military buyers of airframe structures and other titanium-intensive weapons?

Although a previous RAND study (Younossi, Kennedy, and Graser, 2001) focused on the costs of processing raw materials into airframe parts, this study analyzes the actual raw material markets. It also reviews new manufacturing techniques and assesses their implications for the production cost of future military airframes.

Based on literature reviews and analyses of historical data available in defense and commercial industries, this monograph assesses the past trends, current changes, and future prospects for each of the titanium price determinants and their relative importance. In particular,

the study analyzes both supply- and demand-side price determinants and their future prospects.

To widen our understanding of the titanium industry, we conducted interviews with experts from the titanium manufacturing and processing industries, the aircraft manufacturing industry, and government agencies compiling titanium price data, such as the United States Geological Survey and the Bureau of Labor Statistics.<sup>1</sup> (See pp. 1–6.)

## Titanium Is Expensive to Produce

Titanium is expensive to refine, process, and fabricate. In terms of processing cost per cubic inch, titanium is five times more expensive than aluminum to refine and more than ten times as expensive as aluminum to form into ingots and to fabricate into finished products. Titanium sponge is the commercially pure form of titanium metal that is refined from titanium ore.<sup>2</sup> Titanium ingot is produced from titanium sponge, titanium scrap, or a combination of both.<sup>3</sup> Titanium mill products, such as plate, sheet, billet, and bar, are produced from titanium ingot through such primary fabrication processes as rolling and forging. Titanium parts are then produced from mill products by means of secondary fabrication processes, such as forging, extrusion, hot and cold forming, machining, and casting. Fabrication is the most costly processing stage, followed by sponge production. (See pp. 7–20.)

## What Triggered the Recent Titanium Price Surge?

It is a common belief that cyclical fluctuations of titanium prices are mainly driven by demand-side events, especially aircraft demand cycles. However, the Producer Price Index (PPI) for titanium mill shapes in the United States was relatively insensitive to the declining demand from

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<sup>1</sup> Appendix B contains questions asked of industry experts.

<sup>2</sup> It is called *sponge* because of its porous, sponge-like appearance.

<sup>3</sup> Titanium scrap is a by-product of the fabrication processes.

the commercial aircraft industry during the previous downturn (1998–2003), contrary to common belief. This is because world titanium demand did not decrease as severely as *commercial* aerospace demand. In the global titanium market, industrial demand, historically more stable than aerospace demand, had dominated aerospace demand since the mid 1990s. The industrial titanium market bottomed out in 2001, earlier than the aerospace market, which hit bottom in 2003. Driven by the growth in industrial demand, global titanium demand was already at its previous peak level in 2004. This contributed to amplifying the impact on titanium price and supply availability of the historic aircraft order surge in 2005 and 2006. Given that industrial demand dominates the global market, commercial aerospace demand is not the only major driver of titanium market prices. In fact, the extreme price volatility in the recent titanium market resulted from the coincidence of various supply-side and demand-side price drivers.

### Supply-Side Drivers

On the supply side, prices of titanium sponge and scrap began increasing sharply even before the significant surge in commercial aircraft orders in 2005 and 2006. There was an extreme shortage of titanium scrap in 2003, because of the low aircraft production rate, which resulted in less recycled scrap. This coincided with the period during which China's dramatic growth in steel consumption<sup>4</sup> drove up the prices of ferrotitanium,<sup>5</sup> an alloy used in the steel production process. The ferrotitanium price surge led to increased demand for titanium scrap and sponge, both of which are close substitutes for ferrotitanium in steel production. The cross-market substitution effect was significant, because the steel market size was 10,000 times that of titanium. In addition, the Defense Logistics Agency titanium sponge stockpile depletion in 2005 also coincided with the sponge and scrap market shortage, worsening the titanium raw material supply shortage. The

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<sup>4</sup> World steel prices increased dramatically in 2003–2004, driven mainly by China's strong demand and world economic recovery.

<sup>5</sup> Ferrotitanium is used in steel production processes for deoxidation, achieving a finer grain structure, and controlling carbon and nitrogen.

stockpile depletion, which had been authorized by Congress, started in 1997; by 2005, there was no titanium sponge left in the stockpile. Since the supply of titanium raw materials was already tight in 2003–2005, the additional demand shock from the record-high level of commercial aircraft orders in 2005 and 2006 intensified the shortage. In addition, titanium metal suppliers were not able to respond quickly to ameliorate the supply shortage. In particular, expanded sponge capacity required building an additional factory, which would take about three years and an investment of \$300 million to \$400 million. Right before the recent demand surge, titanium producers had suffered from several lean years, and some producers were on the verge of bankruptcy. As a result, the producers hesitated to invest in capacity expansion until they were assured that increased demand would continue for at least the next several years. (See pp. 35–50.)

### **Demand-Side Drivers**

On the demand side, there have been three main demand drivers in the aircraft manufacturing industry in recent years. First, commercial aircraft orders skyrocketed as both Boeing and Airbus received record levels of orders during 2005 and 2006.<sup>6</sup> Second, the average level of titanium content per aircraft rose significantly, which meant that increases in aircraft orders in turn amplified the demand for titanium. Third, the demand for titanium in military aircraft production also increased significantly, as full-time production of the F-22A Raptor began in 2003.<sup>7</sup> These three demands coincided to create a record-breaking increase in titanium demand.

In addition, increases in military armor and industrial demand for titanium added to the demand surge from the aircraft industry. Even before the surge in aircraft demand, the global titanium market

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<sup>6</sup> We obtained commercial aircraft order and delivery data from the Boeing and Airbus Web sites.

<sup>7</sup> Full production of the F-22 was funded in fiscal year (FY) 2003. Refer to the Defense Acquisition Management Information Retrieval Web site, Selected Acquisition Report for the F-22A, December 31, 2006.

was already tight because of high demand from the industrial equipment industry, the steel industry, and other titanium users.

Titanium price volatility was further exacerbated by an increase in spot transactions on the titanium market in 2005 and 2006. During this period of demand surge, even aircraft manufacturers, which normally rely on long-term contracts for their titanium, had to procure titanium on the spot market because of the supply shortage and long lead times.<sup>8</sup> In such a strong seller's market, titanium prices were subject to the titanium producer's bargaining power.

On the whole, increased demand for titanium exceeded the available supply of scrap and sponge, as well as the production capacity for new titanium metal. Given the fact that titanium sponge production capacity expansion requires a high capital investment and long lead times, sponge supply expansion was simply not responsive enough to meet the unexpected surge in demand over the short run. Moreover, given the long record of excess capacity in the industry, titanium producers were reluctant to invest in capacity expansion until they were assured that the strong demand was not temporary. The market imbalance was further worsened by the spurt of speculative purchasing on the spot market, which amplified price volatility. Titanium prices skyrocketed and remained extremely volatile from 2003 to 2006. (See pp. 51–71.)

## **Market Prospects and Emerging Technologies**

### **Titanium Markets in the Near Future**

By the end of this decade, the world titanium sponge production capacity is expected to almost double its 2005 capacity, growing to approximately 217,970 tons per year. In response to the recent demand surge, many titanium metal producers have announced increases in titanium sponge capacity or have taken steps to increase in the near future. If

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<sup>8</sup> Some of the military aircraft contractors had minimal protection of long-term contracts and were exposed to the risk of price volatility and supply shortage to a greater extent, as they had to purchase titanium for one lot production at a time.

new titanium sponge plants become fully operational as planned, Japan and China will be the top titanium sponge producers in the world, followed by Russia and the United States.

For market prospects, we examined three potential scenarios of world titanium demand: optimistic, base, and pessimistic. In each scenario, we assumed a certain combination of annual average growth rates in titanium demand from the aerospace and industrial market segments and then calculated the projected demand in 2010 in relation to the actual 2005 demand.

We do not attach probabilities to each of the potential future scenarios; rather, we use the scenarios to bound predictions for the future. As a result, different combinations of demand and supply scenarios will result either in a variety of potential market imbalances or in market equilibrium.

Assumptions regarding the following three factors heavily influence the future titanium market outlook:

1. realization of the capacity expansion plans by titanium suppliers, including American and Chinese producers
2. the Boeing 787 build rate and demand from other titanium-intensive aircraft
3. continued Chinese economic growth and Chinese consumption of steel, titanium, and other metals that are related to world titanium demand and supply conditions.

By comparing the demand scenarios and production capacity expansion plans, we determined that the titanium industry's current capacity expansion plans appear to be based on the future demand expectations inherent in the optimistic scenario. Therefore, if the base demand scenario is realized (instead of the optimistic scenario) and the world titanium production capacity expands as planned, we expect there will be excess production capacity in the titanium market by 2010. (See pp. 73–82.)

## Emerging Technologies

**Breakthroughs.** Of the experts we interviewed, only a few were optimistic about any dramatic changes in titanium metal extraction, processing, and production technologies that may be realized within the next ten years. In addition, the titanium industry has not identified any particular technology that is worthy of an aggressive investment for a medium-term (three- to five-year) return. Titanium companies are taking a “wait and see” position on significant technological breakthroughs.

**Technologies with Cost-Saving Potential.** After reviewing the literature and conducting discussions with industry experts, we developed a list of emerging technologies with at least marginal cost-saving potential. These technologies are classified into five categories:

- improved extraction and refinement
- powder metallurgy
- single-melt refining
- solid freeform fabrication
- improved machining.

We then assessed these technologies based on their time frame, feasibility of application to the market, and potential for cost savings.

The greatest potential cost savings lie in the combination of improved extraction processes and powder metallurgy, a specialized titanium production process that would limit waste and remove many steps from the current production process. If successful, the higher yield and increased speed of this process would expand the amount of titanium on the market and considerably shorten lead times, dramatically changing the titanium industry over the next decade. However, this combination of developments is unlikely to occur in the near or mid term and is still technically uncertain.

Single-melt refining (instead of multiple-melt refining) and improved machining also would improve production yields and save time and energy. Although the savings from these improvements are expected to be smaller than the savings offered by improved extraction

and powder metallurgy, they are also expected to be much steadier and more consistent.

Across these new technologies, most savings will be realized by improved yields resulting from reduced waste during processing and part fabrication. Improved labor efficiency will yield some savings, especially during the fabrication process. Energy savings should be an important, but much smaller, proportion of the savings, primarily concentrated in improvements during initial extraction and melting.

The emerging technologies have the potential to reduce costs sufficiently to open new markets, such as military ground vehicles. However, it will take a long time for these technologies to influence the cost of aerospace-grade titanium substantially.

**Barriers to Adopting New Technologies.** A major barrier to adoption of new technologies in aerospace applications is the required certification of new materials. Aerospace manufacturing standards are typically based either on judgments by a government body, such as the Federal Aviation Administration or the U.S. Air Force, or on standards set by the primary aircraft manufacturers. Within the Air Force, materials and processes must be certified separately for each program. The certification process typically lasts 18 to 24 months and requires extensive qualification processes. In the course of this process, a company must manufacture test articles and validate their properties at its own expense. The cost of this process prevents companies from attempting to certify materials until they are quite certain of their performance and properties. Consequently, an innovative titanium product or process must be used for several years in other applications before designers will consider it for aerospace uses. (See pp. 82–94.)

## Policy Implications

Based on the findings of this study, we suggest policy measures in five areas: improving contract practices, monitoring market trends, reducing buy-to-fly ratios, optimizing scrap recycling, and exploring new technological opportunities. (See pp. 95–107.)