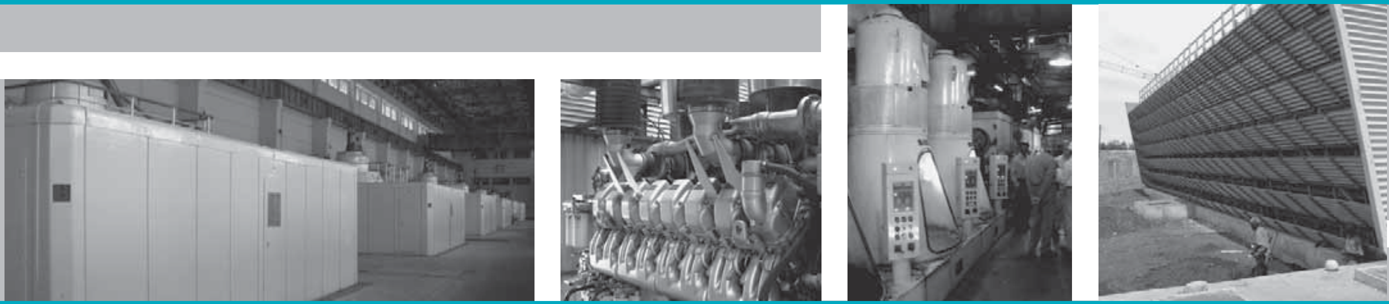
ESMAP Technical Paper 122/09

Study of Equipment Prices in the Power Sector



ESMAP

Energy Sector Management Assistance Program

Study of Equipment Prices in the Power Sector
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Study of Equipment Prices in the Power Sector

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Energy Sector Management Assistance Program

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Abbreviations and Acronyms

AACE	American Association of Cost Engineers
ABMA	American Boiler Manufacturers Association
AC	alternating current
ACAR	aluminum conductor with aluminum alloy reinforced strands
ACF	actual cubic feet
ACFM	actual cubic feet per minute
ACSR	aluminum conductor with steel reinforced strands
AEP	annual energy production
ASTM	American Society for Testing and Materials (now known as ASTM International)
BLS	Bureau of Labor Statistics
Btu/kWh	British thermal units per kilowatt-hour
BOP	balance of plant
ºC	degrees Centigrade
CF	capacity factor
CT	combustion turbine
DC	direct current
DCSF	dry standard cubic foot
EPA	Environmental Protection Agency
ESP	electrostatic precipitator
EU	European Union
ºF	degrees Fahrenheit
FGD	flue gas desulfurization
FOB	at point of production
GDP	gross domestic product
GE	General Electric
GT	gas turbine
GTCC	gas turbine combined cycle
GTW	Gas Turbine World
GW	gigawatt
g/kWh	grams per kilowatt-hour
HHV	higher heating value
HP	horsepower
HRSG	heat recovery steam generator
HZ	Hertz
I&C	instruments and controls
ID	induced draft
in. Hg	inches of mercury

ISCCS	integrated solar combined cycle system
ISO	international Standards Organization
J	joule
Kcmil	thousand circular mils
Kg	kilogram
kV	kilovolt
kW	kilowatt
kWh	kilowatt-hour
LHV	lower heating value
MCR	maximum continuous rating
Mils (measure)	one-thousandth of one inch
Mils (monetary)	one-thousandth of one dollar
Mg/Nm^3	milligrams per normal cubic meter
MMBtu	million British thermal units
MPa	megapascal
MW	megawatt
MWp	peak megawatt output
NA	not Available
NETL	National Energy Technology Laboratory
ng/J	nanograms per joule
Nm3	normal cubic meter
NO_x	nitrogen oxides
NSPS	New Source Performance Standards
OEM	original equipment manufacturer
PC	pulverized coal
PPI	Produce Price Index
PRB	Powder River Basin Coal Wyoming
PTC	production tax credit
PV	photovoltaic
R&D	research and development
ROW	right-of-way
RS	rupees
SCR	selective catalytic reduction
SO_2	sulfur dioxide
SS	stainless steel
ST	steam turbine
STG	steam turbine-generator
SW	southwest
TBD	to be determined
TCR	total capital requirement
TPC	total plant cost (also known as total installed cost)
TPY	tons per year
UK	United Kingdom
US/USA	United States of America
w.g.	water gauge
Wp	Watts peak

Units of Measure

F	fahrenheit
GW	gigawatt
Kg	kilogram
kV	kilovolt
kW	kilowatt
kWh	kilowatt-hour
MW	megawatt
Rs	rupees
US$	U.S. dollar

Executive Summary

Background

Global economic growth, particularly from 2004 to 2007[1], has fueled an expansion in the construction of industrial, power plant, and manufacturing facilities in the United States and a dramatic escalation in the construction of these types of heavy construction projects overseas. In addition, the increase in demand for oil by rapidly growing countries such as China and India and the falling value of the dollar has resulted in an unprecedented rise in the price of oil. This has significantly accelerated oil exploration and resulted in capacity-expansion projects at existing oil refineries. The combination of power plant, infrastructure, and oil-related projects has resulted in significant growth in demand for boilers, rotating equipment, piping, structural steel, concrete, electrical components, and electric wiring.

In the past four years, global demand has led to substantial increases in equipment and material prices in the power sector. This is mainly due to significant increases in the demand for raw materials and labor associated with the manufacture and fabrication of equipment. From 2006 to 2008 alone, energy projects financed by the World Bank experienced 30–50 percent increases above the original cost estimates, requiring additional financing, a reduction in scope of the project, or schedule delays. These delays are costly to the Bank's clients because they depend on timely completion of projects to meet growing demands for energy.

Against this backdrop, this report was developed with the following objectives:

- Identify the current costs of generation options;
- Define the most significant contributors to price increases;
- Provide projections of future escalation rates; and
- Identify the underlying factors "driving" the significant increase in project prices.

Understanding of these factors will allow the Bank to better anticipate the price increases it can expect in the near future.

Study Findings—Escalation and Market Pricing

Table 1 provides a summary of the historical annual average compound escalation for specific power plant-related equipment and materials for the United States, India, and Romania. The table shows two periods:

- January 1996 through December 2003; and
- January 2004 through December 2007.

These periods roughly reflect the time before and the time after: (1) the significant increase in heavy construction projects; and (2) the accelerated increase in the price of oil. A comparison of the two time periods shows that the spike in escalation is common to all

[1] The work preceding the publishing of this report was completed in 2008. Internal, as well as external reviews were conducted through the end of 2009, prior to final clearance by the author and the publishing unit. It is the intention of the author that you find this material interesting and insightful.

Table ES1 Historical Average Annual Compound Escalation

Ranking	Plant Equipment and Materials	Jan. 1996–Dec. 2003, % per year	Jan. 2004–Dec. 2007, % per year
	United States		
	Fabricated Steel Plates	0.3	10.1
	Steel Pipe and Tubing	NA	7.0
	Centrifugal Pumps	2.0	4.7
	Copper Wire and Cable	–0.8	18.7
	Power and Distribution Transformers	NA	13.8
	India		
	Fabricated Metal (Structural Steel/Plate)	NA	7
	Steel Pipe and Tubing	NA	6
	Mechanical Equipment	NA	6
	Electric Wire and Cable	NA	20
	Electric Equipment	NA	7
	Romania		
	Fabricated Metal (Structural Steel/Plate)	NA	7
	Steel Pipe and Tubing	NA	5
	Mechanical Equipment	NA	3

Source: U.S. Bureau of Labor Statistics Producers Price Indexes.
NA—Not available.

of the power-plant-related equipment and materials.

Using the escalation rates from January 2004 through December 2007 and calculating the cumulative increase, the most important drivers of power plant cost have been:

- Fabricated steel shapes: steel plates—47 percent of the cost; structural steel—36 percent; and steel pipe—31 percent;
- Centrifugal pumps—20 percent; and
- Electrical items: copper wire—69 percent; transformers—68 percent.

The tabulation in chapter 3 provides additional categories and further details on escalation of equipment and materials.

Table 2 provides the projections of escalation from 2008 to 2012. The projected escalation rates are lower than they were for the past three years due to the slowdown in the U.S. economy. This slowdown is forecast to continue through 2010, and during this period the economy will be characterized by reduced consumer spending, impacting the import of overseas goods and services into the United States. This in turn will translate into lower rates of escalation in the overseas countries that supply the United States.

In addition to the escalation in the cost of equipment and materials, increases in the cost of craft labor are contributing to the overall price increases for constructing generating facilities in the United States. It should be noted that in the last four to five years, labor has been escalating at about 5 percent per year, compared to about 3 percent per year prior to 2003. Proportionately, labor does not contribute as much to the plant cost increases as equipment and materials, since labor is typically responsible for only 30–40 percent of the total installed cost of power plants.

However, the escalation of equipment and materials costs is not the only contributor to the significant increases in power plant costs. The other aspect responsible for price increases is market demand pricing. In other words, in the last few years the global market has been in a situation

Table ES2 Projected Future Average Annual Compound Escalation

Plant Equipment and Materials	Projected, 2008–2012, % per year
United States	
Fabricated Steel Plates	0 to 2
Structural Steel	2 to 3
Steel Pipe and Tubing	2 to 4
Centrifugal Fans	1 to 3
Electric Wire and Cable	–1 to 2
Power and Distribution Transformers	1 to 3
India	
Fabricated Metal (Structural Steel and Plate)	6 to 8
Steel Pipe and Tubing	8 to 9
Mechanical Equipment	3 to 4
Electric Wire and Cable	1 to 3
Electric Equipment	2 to 4
Romania	
Fabricated Metal (Structural Steel and Plate)	2 to 3
Mechanical Equipment	2 to 3
Steel Pipe and Tubing	2 to 4

Source: URS Washington Division.
Note: Values based on a variety of URS Washington Division in-house sources and analyses.

where demand for power plant equipment and services (and infrastructure in general) has been higher than the manufacturing and engineering firm capacity. Under these conditions, the pricing of equipment and services is often based on what the market will bear rather than on the actual cost of production plus industry profit margins. In response to the unprecedented demand, original equipment manufacturers (OEMs) are pricing equipment above the increase in costs of raw materials and labor costs, and above their "typical" profit margins.

An important statement that supports this finding came in March 2008 from a large company that produces mining equipment, when a company spokesperson asserted "Favorable mining fundamentals continue to drive order growth, while stretched lead times afford considerable pricing power." (Joy Global, Bloomberg.com, March 6, 2008)

In light of this finding, this study compared the cost of power plants without market demand to the actual costs incurred in constructing power plants. The results indicate that owners are purchasing plants in a sellers' market, where unprecedented demand has resulted in market price premiums in the range of 15 percentage points above material, equipment, and labor escalation.

Study Findings—Plant Cost Estimates

The country-level generation technology cost estimates were based on installations located in the United States, India, and Romania. The United States was included as the benchmark. India was selected as representative of Asia and because it is second only to China in addition of new power plants and growth of gross domestic product (GDP). Romania was selected as representative of Eastern Europe.

The plant cost estimates are based on budget quotes for major equipment from OEMs and a project cost database of recent projects. Major

Table ES3 Class 5 Pricing Estimates for Selected Generation Technologies (2008 US$), US$/kW net

Generation Plant—Total Plant Cost	U.S.	India	Romania
Gas Turbine Combined Cycle Plant, 140 MW	1,410	1,170	1,140
Gas Turbine Simple Cycle Plant, 580 MW	860	720	710
Coal-Fired Steam Plant (sub), 300 MW net	2,730	1,690	2,920
Coal-Fired Steam Plant (sub), 500 MW net	2,290	1,440	2,530
Coal-Fired Steam Plant (super), 800 MW net	1,960	1,290	2,250
Oil-Fired Steam Plant (sub), 300 MW net	1,540	1,180	1,420
Gas-Fired Steam Plant (sub), 300 MW net	1,360	1,040	1,110
Diesel Engine-Generator Plant, 1 MW	540	470	490
Diesel Engine-Generator Plant, 5 MW	630	590	600

Source: Author's calculations.

equipment costs reflect market pricing conditions as of January 2008. In addition, piping, electrical, concrete, and all other items reflect market pricing because they were based on the in-house bid databases for actual recent projects. All plant cost estimates are based on grid-connected configurations. Moreover, the equipment, structural steel, piping, concrete, labor, and other plant items reflect costs specific to the respective countries. Table 3 provides the total plant market-based pricing for selected generation technologies in the United States, India, and Romania.

A summary of total plant pricing for all of the study technologies is provided in Chapter 3. In addition, a complete list of the items included in and excluded from the cost estimates for each generation technology can be found later on in this report.

Study Findings—Global Marketplace

Regardless of the country's location, power plant equipment is now being purchased in the global marketplace. While regional markets still retain some unique characteristics, regional differences are being reduced or eliminated. For example, most large Japanese suppliers have established offices in the United States and are getting a significant market share of new power plant equipment. Another aspect of the international power plant market is the entry of new suppliers, in particular suppliers from China.

Within China power plants are being built for one-third to one-half of the international prices for similar plants. It is not clear whether these prices are being subsidized or whether there are other unique market factors. The fact that these prices have stayed at the same level while international commodity prices have experienced substantial increases in the last two to four years raises questions regarding their pricing structure. It is certain that labor costs alone provide China with a competitive advantage, which may be reflected in its 20–40 percent lower production costs.

The most likely focus of Chinese suppliers in the next two to five years is Asia and Africa. Recent projects in these regions suggest that the Chinese suppliers are bidding lower than international prices, but not as low as their domestic market. In India, their pricing is more aggressive (bidding lower than suppliers from other countries). The Chinese market entry strategy is most likely influenced by a strong domestic supplier with a near monopoly in the market.

In general, the potential impact of Chinese suppliers on global power plant prices is likely to be positive, potentially resulting in moderate-to-substantial price reduction in some markets and less in others. Over the long term, the price gap between Chinese suppliers and other suppliers is likely to reach pricing equilibrium (below the level without their presence, but at some price level between their prices and the prices of all other competitors).

1 Project Approach Methodology

This study was focused on selected generation technologies options located in three countries. The objectives were to: (1) collect and update existing price data on equipment in the power sector; and (2) analyze and report on the underlying reasons and correlations for current price fluctuations. These data were assembled to provide a better understanding of price fluctuations for energy equipment within specific country contexts.

For this study, data on prices for energy generation technologies were collected according to the cost classification system defined in subsequent chapters of this document. In order to collect the necessary data, project documents were reviewed, and major equipment suppliers (OEMs) in the United States, Eastern Europe, and India were contacted. As part of the data collection process, major suppliers around the world were identified. The amount of data obtained from suppliers was subject to the degree of their cooperation. Past experience was found to prevail on this project—many suppliers did not provide data for this study due to their current workloads.

The price of equipment depends, in part, on the backlogs of suppliers' production facilities. The study considers the impact of the respective backlogs of gas turbine, steam turbine, boiler, diesel generator, wind turbine, solar technology, and major electrical equipment manufacturers. Assessments of the impact of industry backlogs on escalation and plant pricing were based on market reports and generalized conclusions. All plant costs reflect market-based pricing.

2 Price Escalation, Cost Factors, and Market Pricing

Worldwide Growth and Its Influence on Escalation from 2004 to 2007

In the period from 2004 through 2007, there were substantial increases in escalation of the raw materials used to manufacture equipment for power plants. This includes raw materials or intermediate products used to manufacture boilers, gas turbines, steam turbines, wind turbines, and motors and generators. From January 2005 to December 2006, some significant examples of price increases are the following: condensers and heat exchangers, 18 percent; electric wire and cable, 23 percent; power transformers, 32 percent; and copper wire and cable, 84 percent.

Global economic growth in the past three years, particularly in China and India, has contributed to a worldwide increase in the construction of industrial, power plant, and manufacturing facilities and the resulting increase in demand for raw materials and intermediate manufacturing products. This has led to a significant increase in demand for such items as industrial equipment, power plant equipment, piping, structural steel, concrete, electrical components, and electric wiring. In addition, the economic growth has resulted in a substantial increase in the demand for oil, significantly accelerating exploration and the expansion of the existing capacity of oil refineries.

The dramatic scale of overseas activity is typified by the significant number of heavy construction projects in India and China. Of all overseas countries, China has seen the most substantial growth. The scale of construction of coal-fired electric generating stations is just one indicator: currently, China is building the equivalent of two 500-MW coal-fired electric generating units each week, which is roughly equivalent to building the entire electrical production capacity of the United Kingdom each year! Another indicator of China's growth is GDP. China experienced increases in GDP of about 10 percent in 2004, 2005, and 2006, and about 11 percent in 2007.

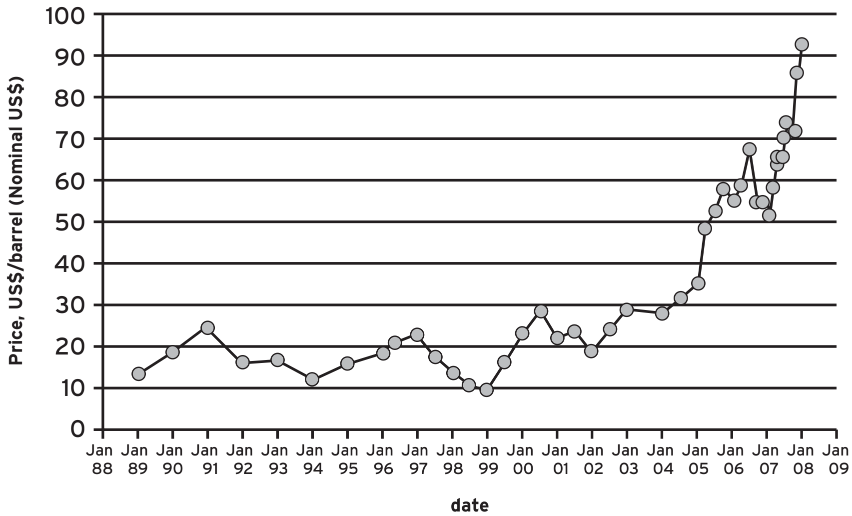
From 2004 to 2007, the combination of significant increases in demand for materials for heavy construction and the historic acceleration in demand and resulting high price of oil has further contributed to dramatic increases in the escalation of costs of major equipment and plant construction materials. As shown in Figure 2.1, the price of oil ranged from US$10/barrel to US$30/barrel from January 1989 to January 2004 and then began climbing at accelerated and historic rates to US$106/barrel in March 2008.

Table 2.1 shows the historical annual average compound escalation for specific power-plant-related equipment and materials for the United States, India, and Romania. The table shows two periods:

- January 1996 through December 2003; and
- January 2004 through December 2007.

These periods reflect the time before and after the significant increase in heavy construction projects and the accelerated escalation in the prices of crude oil and refined petroleum products. A comparison of the two

Figure 2.1 Average Price of Crude Oil Worldwide



Source: U.S. Energy Information Administration.

periods shows the striking difference in annual escalation.

The rightmost column in the table shows the cumulative percentage increase in the cost of equipment and materials over the period from January 2004 through December 2007.

The increase in escalation rates from January 2004 through December 2007 provides quantitative explanation for the 30–50 percent increase between original project estimates to bids actually received. The other driver of price increases is market-demand pricing. In other words, in the last few years, the global market has been in a situation where demand for power plant and infrastructure equipment and services has been higher than the manufacturers' capability to meet the demand. The situation has resulted in equipment and engineering service pricing based on what the market will bear rather than on the actual cost of production (which consists of materials and labor costs).

The project team was not able to locate or obtain publicly available information on specific manufacturer facility loading because in almost all cases this is proprietary information. Research firms sell publications that contain information on overall shop capacity and lead times, but this information is copyrighted and cannot be published in any publicly available reports.

However, even without benefit of these publications, there is enough evidence that OEMs are pricing their equipment above the increase in the costs of raw materials and labor costs, and above their "typical" profit margins. OEMs appear to be increasing their prices because of the overall increase in demand and the heavy loading of their production lines.

Although not specific to individual manufacturers, industry news articles and publications provide market projections that indicate that price increases in commodities and materials will continue. The following are some examples of contributing factors:

- It is predicted that Chinese and Indian demand for commodities including coal and iron ore will continue at an annual rate of 5 percent for the next 10 years.
- Chinese oil demand in 2007 was about 1.9 times its domestic supply. By 2011, it is projected that demand will be 2.3 times domestic supply. This will put increasing demand on the world's oil supply, contributing to continued high prices for refined petroleum products. High costs of oil will put upward pressures on commodities such as iron ore, nickel, and so forth, because of increased mining and transportation costs.

Table 2.1 Historical Average Annual Compound Escalation

Ranking	Plant Equipment and Materials	Jan. 1996–Dec. 2003, % per year	Jan. 2004–Dec. 2007, % per year	Jan. 2004–Dec. 2007, % Increase for Period
	United States			
4	Ready-Mix Concrete	1.9	7.9	36
	Centrifugal Pumps	2.0	4.7	20
	Centrifugal Fans	1.7	4.2	18
	Material Handling Conveyors	1.7	4.7	20
	Pneumatic Conveyors	1.7	3.8	16
	Crushers and Pulverizers	2.9	4.4	19
	Integral Horsepower Motors	0.4	6.4	28
	Fabricated Steel Plates	0.3	10.1	47
2	Structural Steel	0.9	8.0	36
	Steel Pipe and Tubing	NA	7.0	31
	Field Erected Steel Tanks	1.5	5.8	25
3	Heat Exchangers and Condensers	0.8	7.8	35
	Fin Tube Heat Exchangers	1.3	8.4	38
	Industrial Mineral Wool	0.4	3.7	16
	Refractory, Non-Clay	0.4	3.7	16
1	Electric Wire and Cable	1.1	9.1	42
	Power and Distribution Transformers	NA	13.8	68
	Copper Wire and Cable	-0.8	18.7	98
	Industrial Process Control Instruments	NA	3.0	12
	India			
	Fabricated Metal (Structural Steel and Plate)	NA	7	31
	Steel Pipe and Tubing	NA	6	26
	Mechanical Equipment	NA	6	26
	Electric Wire and Cable	NA	20	107
	Electric Equipment	NA	7	31
	Romania			
	Fabricated Metal (Structural Steel and Plate)	NA	7	31
	Steel Pipe and Tubing	NA	5	33
	Mechanical Equipment	NA	3	13

Source: U.S. Bureau of Labor Statistics Producers Price Indexes.

NA—Not available.

- Specialty steel product mills are at capacity and still not able to meet demand. This situation will not change until new production facilities come on line in 2010. Some specialty steel products will have 18- to 24-month lead times until new capacity becomes operational.
- In 2008, Japan was unsuccessful in renewing its iron ore contract with Australian iron ore producing companies, which has

usually been for about five years. Iron ore producers only offered one-year contracts, with a 30 percent escalation clause. Japan has suspended negotiations. Unless there is some significant change in this situation, Japanese steel prices are bound to take a sizable jump.

- In March 2008, a major Taiwanese steel company indicated it had experienced a 40 percent increase in raw material costs. As a result, the company raised its prices for steel plates, electrical coils, rebar, and galvanized wire by about 20 percent for deliveries in the second quarter of 2008.
- GDP in India is expected to grow at 9 percent in 2008.

Projections of Escalation in the United States, India, and Romania

The impact of the sub-prime mortgage crisis in the United States has translated into significant financial losses for the largest home lenders and prominent banking institutions and a significant drop in the U.S. stock market. In addition, housing starts dropped 25 percent during 2007, with the depressed market forecast to continue through 2010. Economists indicate that this period will see reduced consumer consumption, impacting the import of overseas goods and services into the United States. This in turn should result in some slowing in the overseas economies of countries that supply the United States.

In the United States, the slowdown is projected to result in the average annual compound escalation rate for mechanical equipment and concrete declining around 2 percentage points and 4 percentage points, respectively. Fabricated steel shapes will be about 5 to 9 percentage points lower in the 2008 to 2012 period than in the 2004 to 2007 period. Items containing or made up of aluminum or copper are projected to see the largest decline, in the range of 7 to 10 percentage points. This is due to the projected increase in production and the decline in demand for both raw materials. On the other hand, even though the rate of expansion of the economies of India and China will slow, both will have growth above the rates experienced in the past. The high price of oil and the continued expansion in China and India are likely to maintain upward pressure on the rate of escalation, especially in these countries.

GDP in India will increase at a greater rate than in the United States. Consequently, projected escalation will slow, but not nearly as much as in the United States. As shown in Table 2.2, during the 2008 to 2012 period, the annual escalation rates for various items will range from about 1 to 5 percentage points higher in India than in the United States. In Romania,

Table 2.2 Projected Average Annual Compound Escalation for Plant Equipment and Materials, 2008–2012, %/year

Category, India and Romania	Romania, %/year	India, %/year	Category, United States	U.S., %/year
Structural Steel and Plate	2 to 3	6 to 8	Structural Steel	2 to 3
Structural Steel and Plate	2 to 3	6 to 8	Fabricated Steel Plates	0 to 2
Steel Pipe and Tubing	2 to 4	8 to 9	Steel Pipe and Tubing	2 to 4
Mechanical Equipment[a]	2 to 3	3 to 4	Centrifugal Pumps	2 to 3
Mechanical Equipment[a]	2 to 3	3 to 4	Centrifugal Fans	1 to 3
Mechanical Equipment[a]	2 to 3	3 to 4	Material Handling Conveyors	1 to 2

Source: URS Washington Division.

[a] Mechanical equipment is a composite that contains many more items than centrifugal pumps, centrifugal fans, and material handling conveyors. Therefore, this should be considered a partial comparison of the only U.S. equipment projections available.

the projected rates for comparable items will be only slightly higher than for those in the United States. The rate of growth of the Romanian GDP is projected to decline from around 6 percent in 2007 to 5 percent in 2010 and 3 percent in 2012.

Proportionally, labor has not contributed as much to the plant cost increases as have equipment and materials since labor is typically responsible for only 30–40 percent of the total installed cost of plants. Even so, labor needs to be considered in relation to the increased cost of building plants.

In the United States, prior to 2003, labor escalated at a rate of about 3 percent per year. However, in the last five years, craft construction labor has escalated at rates closer to 5 percent per year. This is related to the number of large capital projects, the massive rebuilding of the Gulf Coast areas damaged by hurricanes Katrina and Rita, and the aging of the U.S. workforce. Many craft workers will be retiring over the next 10 years, and the growth in the number of apprentices joining the construction craft ranks each year is currently not sufficient to replace the workers that are projected to retire. This will continue to put upward pressure on the annual rate of escalation for labor costs in the United States.

In India, labor rates are also escalating, and at a faster pace than those in the United States. However, wage rates started at a level that is equivalent to one-sixth or one-eighth of the current U.S. labor wage rate. However, labor in India is estimated to have one-third of the productivity achieved on U.S. construction projects. Therefore, the total effective cost for labor is still less than half of the labor cost in the United States. This means that the labor contribution to escalating plant costs in India is also overshadowed by equipment and material cost escalation.

Romania joined the European Union in 2007. This has resulted in significant increases in labor wage rates due to competition for Romanian labor throughout Europe. Romanians are moving to other European countries seeking higher wages, sometimes two to three times or even higher than their previous wage rate. Workers remaining in Romania are seeking a minimum 50 percent increase in wages. Although these labor wage increases are expected to continue in Romania for many years, nevertheless, it is expected that labor costs will only represent one-fourth to one-third of the installed costs of plants in Romania.

Cost Increases Not Explained by Escalation Indexes

This subsection provides an illustration of the difference between power plant costs and market prices. Using the EPRI PCCost program, the 2005 cost for the pulverized coal (PC) reference plant was compared to the plant cost in 2008 dollars. For this analysis the program was run in the total plant cost mode with no accounting for the market driving forces that have occurred over the past few years. The 2005 total plant cost was escalated to 2008 using the 25 different historical escalation rates that include equipment, material, and labor. This resulted in a total three-year plant cost increase of 11 percent.

Another source of power plant cost increases is the Marshall and Swift (M&S) index. This index indicates an increase of 16 percent in the composite equipment costs of steam power plants from 2005 to 2008.

The PCCost and M&S indexes were compared to the IHS/CERA Power Plant Cost Index (PCCI), which reflects the market price of actually *building* power plants in North America. The PCCI for non-nuclear power plants from 2005 to 2008 indicates an increase of about 27 percent. Consequently, the PCCI indicates that the price of building power plants is 11 percentage points above the M&S composite index. In addition, the PCCI indicates that the price of power plants is 16 percentage points above the cost increase estimated by PCCost. This comparison indicates that PCCost results and the M&S index are under-predicting the prices owners are paying to build power plants by 11 to 16 percentage points.

The North American market is being influenced by the global power sector, including expansive construction in the Middle East and Asia, many infrastructure projects worldwide, and concurrent expansion of power plant construction in the United States. As a result of all of this activity, lead times for engineered equipment have increased by up to 50 percent in the last 6–12 months, impacting prices for some "big ticket" items in a way that is not being captured by escalation alone. Worldwide sourcing of many components adds to cost pressures because both raw materials and shipping have increased, further compounding increases in cost.

The latest increases reflect the worldwide market demand and the corresponding prices currently charged by manufacturers and suppliers. In this sense, the difference can be termed a "market demand charge." *The cost estimates in this report take this demand charge into account and as such are market prices.*

Impacts of the International Marketplace

Power plant owners all over the world are now purchasing equipment on a global basis. For instance, owners are purchasing from U.S. suppliers with a growing number of overseas shops. Over the past few years, U.S. manufacturers have been more likely to manufacture pressure parts in South Korea or Eastern Europe than in the United States. There are still some unique characteristics to regional or country markets (especially China), but regional differences are being reduced or eliminated. For example, most large Japanese suppliers have established offices in the United States and are getting a significant share of market for new power plant equipment.

Currently, Chinese suppliers are starting to make market inroads into selected countries such as Botswana, India, Indonesia, Nigeria, Pakistan, the Philippines, and Vietnam. The presence of Chinese manufacturers is related to the growth of the Chinese economy. If this economy slows from its decade-long annual GDP growth of 10–12 percent, then its manufacturing capacity will be available to compete in the international marketplace. For this reason, it is important to briefly examine the Chinese market and then assess its current or potential future global impacts.

At present, China has an installed coal-fired capacity of approximately 400 gigawatts (GW) that is growing by 50–120 GW per year. Before the late 1990s, the Chinese power sector consisted exclusively of subcritical coal-fired plants ranging from a few megawatts (1–10 megawatts [MW]) to standardized 200-MW, 300-MW, and 600-MW units. All of these power plants were manufactured within China under licensing agreements with foreign suppliers. These power plants were and are being built for 33 to 50 percent of the international costs for similar plants. Nevertheless, it is not clear whether these prices reflect subsidies or manufacturing costs based on international commodity prices. Approximately one-half of the costs are estimated to be material costs.

While international commodity prices have experienced the substantial increases described in this paper, China's power plant prices have remained unchanged. This raises questions regarding China's pricing structure. Aside from these questions, it is certain that labor costs provide China with a competitive advantage (which may be reflected in 20–40 percent lower production costs). This is likely to give Chinese suppliers a competitive advantage in the global marketplace (even when international commodity prices are used).

Within the next five years, the most likely entry of the Chinese manufacturers into the global marketplace will be in Asia and Africa. Recent projects in these regions suggest that the Chinese suppliers are bidding lower than international prices, but not as low as their domestic market. In India, their pricing is more aggressive (bidding lower than in other countries). This market entry strategy is most likely due to the fact that they are facing a strong domestic supplier with a near monopoly in the market. In other markets, their pricing (e.g., on circulating fluidized bed plants) is slightly below international prices.

In general, the impact of Chinese suppliers on global power plant prices is likely to be positive, potentially resulting in moderate-to-substantial price reductions in some markets and less in others. Over the long term, the price gap between Chinese suppliers and other suppliers is likely to reach price equilibrium (that is, below the level it would be without their presence, but at some price level between their prices and the prices of all other competitors). More detailed discussion of this topic is provided later in the report.

Impact of Plant Size on Technology Cost

This part of the assessment investigated the impact of plant size on technology costs in two ways:

1. Impact of plant size on cost for a broad range of unit sizes; and
2. Cost estimates for discrete plant sizes in the United States, India, and Romania.

The objective of the broad-range cost evaluation was to provide an overall perspective on the impact of size on cost. The broad-spectrum cost evaluations were based on the following technologies:

- Aeroderivative simple cycle gas turbine units,
- Heavy-frame simple cycle gas turbine units,
- Gas turbine combined cycle units,
- Pulverized coal-fired plants, and
- Wind farms.

The objective of the discrete plant analysis was to provide country-specific and size-specific conceptual market-price plant cost estimates based on: (1) recent detailed project cost pricing and OEM bid prices; and (2) budget quotes for major equipment to the extent provided by OEMs (tempered with bid prices from the in-house database). All of the cost estimates were based on grid-connected configurations. The generation technologies and sizes were as follows:

- Gas turbine simple cycle: 5 MW, 25 MW, and 150 MW
- Gas turbine combined cycle: 140 MW and 300 MW
- Pulverized coal-fired steam plant: 300-MW and 500-MW subcritical and 800-MW supercritical
- Oil-fired steam plant: 300 MW
- Gas-fired steam plant: 300 MW
- Diesel generator plant: 1 MW and 5 MW
- Wind farm: 12 MW, 50 MW, and 100 MW
- Photovoltaic array: 5 MW
- Solar thermal: on hold

The total plant prices are basically for the same sizes as the respective technologies included in the World Bank's Electrification Study[1] (see the grid-connected sizes shown in Table 2 of the Electrification Study).

Examples of Cost Comparisons for a Broad Size Range

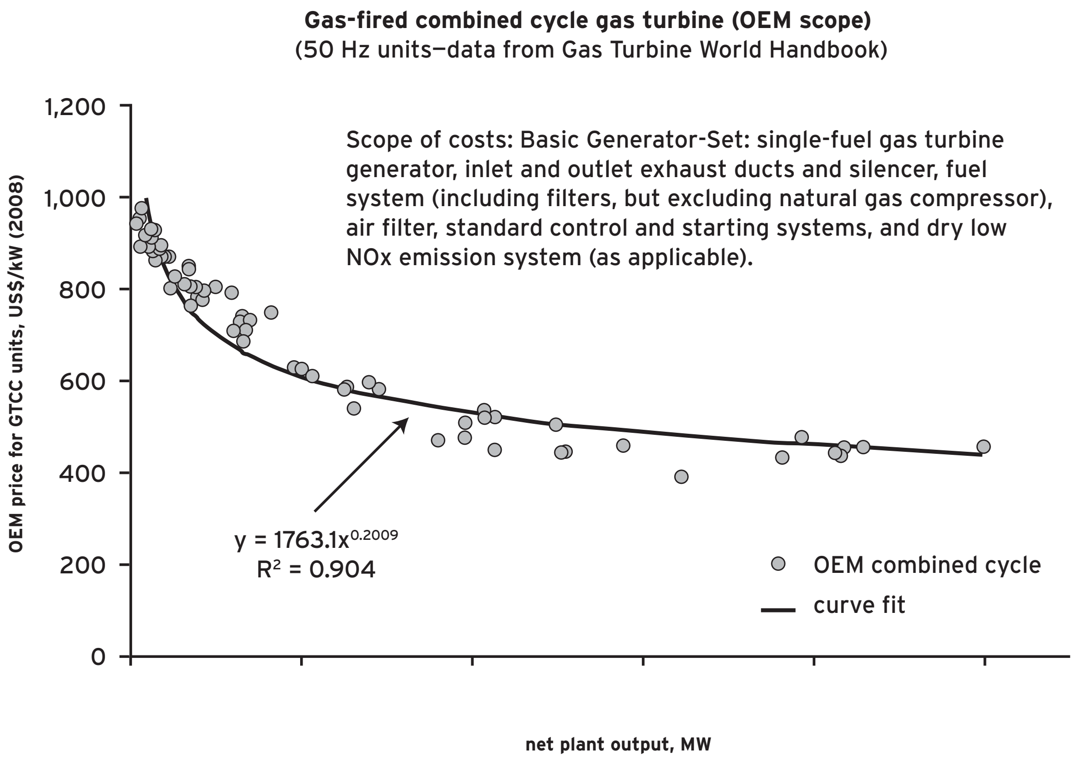
This section provides cost curves for the gas turbine combined cycle and pulverized coal-fired plant technologies. Cost curves for aeroderivative simple cycle units, heavy-frame simple cycle units, and wind farms are presented later in the report.

Figure 2.2 provides the impact of size on the price of OEM-provided combined cycle units based on data from the Gas Turbine World (GTW) Handbook. The data points represent nine different manufacturers and 69 different configurations of gas turbine combined cycle units. The combined cycle units are all 50 Hz and range in size from 7 MW to 1,000 MW. The graph includes the OEM scope as noted within the box on the graph. The price data reflected in this curve include both aeroderivative-based and heavy-frame-based combined cycle units. The results indicate that the OEM prices range from about US$950/kW to US$450/kW as the unit outputs increase from 7 MW to 1,000 MW.

Figure 2.2 reflects the prices as purchased and supplied by the OEMs. *The OEM prices do not include earthwork, foundations, structural*

[1] Technical and Economic Assessment of Off-Grid and Grid Electrification Technologies, Summary Report, The World Bank Group, Energy Unit, Energy Transport & Water Department, September 2006.

Figure 2.2 Effect of Size on Cost of Gas Turbine Combined Cycle Units



Source: 2007–08 GTW Handbook, Volume 26, Gas Turbine World, Pequot Publishing, ISBN 0747-7988, 2008.

steel, water treatment, gas compressor, buildings, and all other items necessary for a fully operational and functionally complete plant. The costs for earthwork, foundations, structural steel, and so forth, are added to the OEM price to get the total plant price; total plant prices are provided later in this report.

The cost curve for the pulverized coal-fired plant is presented in Figure 2.3. The costs were estimated by the PCCost program run with the marketplace factors included. This cost-scale curve shows that total plant costs range from about US$2,700/kW for a 300-MW PC plant to about US$2,000/kW for an 800-MW plant.

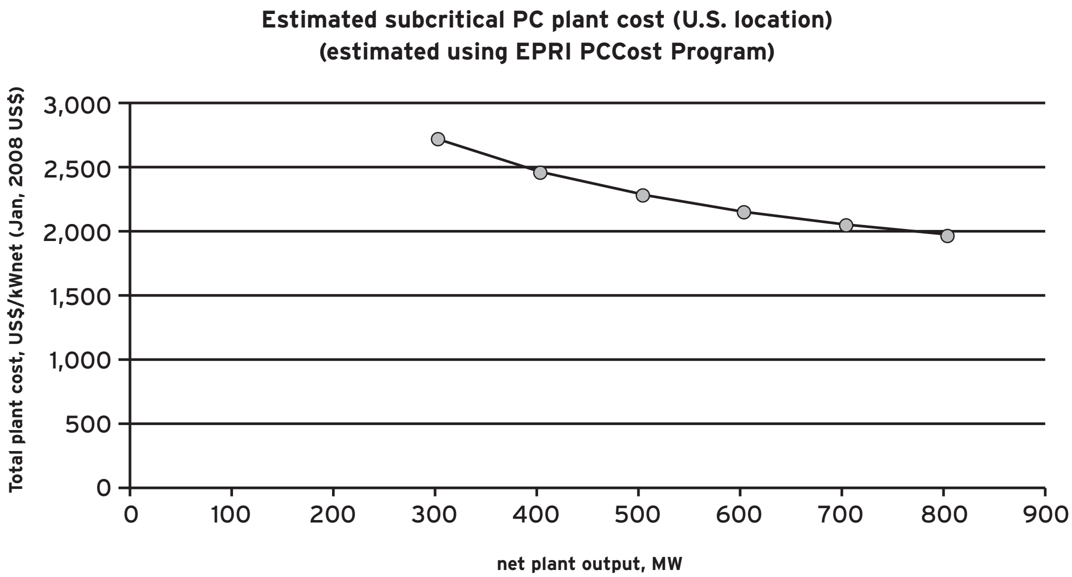
Cost Estimates at the Country Level

The cost estimates at the country level were based on installations located in the United States, India, and Romania. The United States was included as the benchmark. India was selected as representative of Asia and because it is second only to China in addition of new power plants and growth of GDP. Romania was selected as representative of Eastern Europe.

The plant cost estimates were "calibrated" with budget quotes for major equipment. Budget quotes were requested from one to three OEMs for the respective major equipment items. Despite diligent efforts and numerous follow-ups, there was very limited response. OEMs were forthright in advising the project team that their workload did not permit them to support study work at this time. (Note: Annex 3 and Annex 4 provide a complete list of OEMs for various types of equipment for Romania and India, respectively).

The quotes obtained consisted of diesel engine, gas turbine, and steam turbine, and one cursory quote for 300-MW coal-fired and 300-MW gas-fired boilers. Fortunately, the project team had the in-house project-based major equipment library consisting of multiple OEM bids received within the last 18 months (reflecting market prices). To the extent necessary, major equipment bid prices were escalated with accepted corporate escalation rates specific to each major piece of equipment, allowing the

Figure 2.3 Effect of Size on Cost of Pulverized Coal-Fired Plants



Source: URS Washington Division Internal Cost Estimation Database.

prices to reflect market conditions as of January 2008. In addition, piping, electrical, concrete, and all other items reflected market pricing because they were based on the respective in-house bid databases for actual projects.

A summary of major equipment prices is provided in Table 2.3. This table contains the adjusted pricing from the in-house library of bids, as well as quotes obtained for this study (budget quotes were tempered with actual bids to reflect market pricing). The scope of the equipment cost estimates is defined in the Design Basis (located in Annex 1).

The plant cost estimates are based on OEM pricing and a project cost database of recent projects. Major equipment, piping, electrical, concrete, and all other plant items incorporate recent project data and market pricing conditions as of January 2008. Moreover, the equipment, structural steel, piping, concrete, labor, and other plant items reflect costs specific to the respective countries. Table 2.4 provides a summary of the total plant pricing for the generation technologies in the three countries.

A description of the common scope included in all cost estimates is as follows:

- Earthwork
- Concrete
- Structural steel
- Plant equipment
- Piping
- Electrical
- Instruments and controls
- Painting
- Insulation
- Buildings and architectural

Complete descriptions of the scope of the cost estimates specific to each generation technology are provided later in this report.

The general list of items *excluded* from the generation plant costs estimates is:

- Switchyard
- Connection to the grid
- Pipelines outside the plant fence (as applicable)
- Access roads outside the plant fence
- Raw water acquisition
- Bonds, taxes, and insurance
- Project financing
- Customs or import duties
- Owner's costs
- Land

Complete descriptions of the exclusions specific to each generation technology are provided later in this report.

Table 2.3 Estimated Costs of Major Equipment (2008 US$)

Equipment Item	Estimated Cost, US$/kW net
Pulverized Coal Boiler, subcritical, 325-MW gross	300
Pulverized Coal Boiler, subcritical, 540-MW gross	270
Pulverized Coal Boiler, supercritical, 860-MW gross	250
Steam Turbine, subcritical, 325-MW gross	130
Steam Turbine, subcritical, 540-MW gross	120
Steam Turbine, supercritical, 860-MW gross	110
Oil-Fired Boiler, subcritical, nominal 300 MW (cursory bid)	200
Gas Turbine (from large simple cycle case), 144 MW	240
Gas Turbine (from large combined cycle case), 191 MW	220
Diesel Engine-Generator, 1.4 MW	290
Diesel Engine-Generator, 4.8 MW	450

Source: URS Washington Division Internal Cost Estimation Database.

Table 2.4 Class 5 Plant Pricing Estimates for Generation Technologies (2008 US$), US$/kW net

Generation Plant-Total Plant Cost	U.S.	India	Romania
Simple Cycle Plant, 5 MW	1,380	1,190	1,240
Gas Turbine Simple Cycle Plant, 25 MW	970	830	870
Gas Turbine Simple Cycle Plant, 150 MW	530	440	480
Gas Turbine Combined Cycle Plant, 140 MW	1,410	1,170	1,140
Gas Turbine Simple Cycle Plant, 580 MW	860	720	710
Coal-Fired Steam Plant (sub), 300-MW net	2,730	1,690	2,920
Coal-Fired Steam Plant (sub), 500-MW net	2,290	1,440	2,530
Coal-Fired Steam Plant (super), 800-MW net	1,960	1,290	2,250
Oil-Fired Steam Plant (sub), 300-MW net	1,540	1,180	1,420
Gas-Fired Steam Plant (sub), 300-MW net	1,360	1,040	1,110
Diesel Engine-Generator, 1 MW	540	470	490
Diesel Engine-Generator, 5 MW	630	590	600
Wind Farm, 1 MW x 100 = 100 MW	1,630	1,760	1,660
Photovoltaic Array, ground mounted, US$/kW (AC)	8,930	7,840	8,200

Source: Author's calculations.

3 Assessment of Price Trends for Generation Plant Equipment

Impacts of Increase in Heavy Construction Projects in the United States and Overseas

The growth in the economies of countries around the world has led to a worldwide increase in the demand for residential, commercial, and industrial products. Of the overseas countries, China and India have experienced the most substantial growth in demand for items such as:

- Equipment, steel, concrete, and other bulk materials for a resurgence in the growth of large industrial, power plant, and environmental equipment retrofit projects in the United States;
- Equipment, steel, concrete, and other bulk materials for a very significant growth in large industrial and power plant projects overseas, particularly in China and India;
- Building materials and concrete for commercial buildings and manufacturing facilities overseas; and
- Building materials, concrete, and heavy construction equipment for infrastructure projects worldwide.

The scale of construction of coal-fired electric generating stations is just one indicator of China's growth. Currently, China is building the equivalent of two 500-MW coal-fired electric generating units per week, which is comparable to building the capacity of the entire U.K. power grid each year (McRae, Gregory, testimony at hearing before Clean Coal Technology—Science, Technology, and Innovation, United States Senate Committee on Commerce, Science, and Transportation, April 27, 2007). This level of power plant construction represents an enormous demand for steel, rotating equipment, electric wiring, other electrical components, and concrete. It also results in fierce competition for shop space at steel fabricators and equipment suppliers. Further, it translates into significant demand for the raw materials needed by steel mills, equipment manufacturers, and ready-mix concrete companies.

Another indicator of the magnitude of China's growth is its GDP. China experienced year-to-year increases in GDP in the range of 10 percent from 2004 through 2006. In 2007, the GDP increased 11.4 percent. Forecasts indicate a slowing of GDP growth due to the slowing of the U.S. economy. However, the year-to-year increase in China's GDP will still remain high compared to the rest of the world, with forecasts of 10 percent in 2008 and 9 percent in 2009. In contrast, the composite increases in year-to-year GDP of all countries in the world were 2 to 4 percent from 2004 through 2007 and forecast increases in GDP of 2 to 3 percent in 2008 and 2009. This indicates that economic growth and increases in demand outside the United States have fueled significant increases in the escalation of consumer and industrial products in the last three to four years. Because of world sourcing and the growth in the global economy in the last three to four years, the United States has also experienced significant increases in the escalation of costs for products used in heavy construction projects.

Aside from the increase in overseas construction, the substantial jump in oil and other fuel prices in the last year has contributed to increases in the costs to produce steel, manufacture heavy equipment, and process the raw materials needed to make ready-mix concrete. The high price of oil has also led to a dramatic jump in exploration for new U.S. oil fields. In addition, many large oil companies have or will embark on major expansion projects at their existing U.S. refineries. A number of these projects have estimated costs in the range of US$1 to 2 billion, resulting in additional demands for piping, vessels, concrete, and construction labor. Increases in the price of oil have also led to massive plans for expansion of the tar sands processing plants in northern Alberta, with some estimates putting the total expenditures exceeding US$50 billion over the next five years.

Additionally, the 2005 Gulf Coast hurricanes contributed to some of the increases in the escalation of certain labor and materials. The conditions contributing to escalation occurred primarily in 2005 and 2006 and were a result of the significant demand for labor, equipment, and materials to rebuild the infrastructure, industrial facilities, commercial structures, and residential dwellings damaged or destroyed by the hurricanes. The rebuilding effort continues into 2008.

Added to all of the above is the resurgence in the U.S. construction of new coal-fired units (announced between 2000 and 2006) and retrofits of emissions control systems on existing coal-fired plants (starting in about 2004). As of May 2007, the National Energy Technology Laboratory (NETL) was tracking a total of about 150 new coal-based units in all phases of planning and development, or under construction. However, by the end of 2007, 59 of the proposed plants had been cancelled, abandoned, or put on hold, due in part to concerns over global warming or because of the significant cost increases described in this chapter. On the other hand, by the end of 2007, 10 of the units were already in operation, with 25 others under construction. Although this number of new coal-fired power plants is small in comparison to the numbers being built in China and India, it still represents competition for the shop space of manufacturers of power plant equipment and materials.

The new overseas and U.S. coal-based and/or coal-fired plants will require significant quantities of concrete, large fans, large pumps, material handling systems, structural steel and steel plate, piping, electrical wiring and electrical components, material handling systems, turbine generators, emission control systems, and other major equipment. These materials, systems, and equipment will be installed at all new coal-fired plants throughout the world.

With regard to environmental control retrofits in the United States, each Flue Gas Desulfurization (FGD) system will require significant quantities of structural steel and steel plate, piping, electrical wiring and electrical components, large fans, large absorber circulation pumps, large motors, and other major equipment. Each Selective Catalytic Reduction (SCR) system will require significant quantities of structural steel and steel plate, large amounts of catalyst, large fan upgrades or replacements, and reagent handling and injection systems.

The growth in demand for industrial-scale equipment and materials in the U.S. power sector is and will continue to be dwarfed by the growth in the number of projects in the global industrial and power sectors (primarily due to the expansive growth in China and India). In addition, from the early part of the twenty-first century through 2007 the global increase in the number of heavy construction projects played a major role in the growing upward pressure on the costs of most industrial-scale equipment and commodities. The dramatic increase in the price of oil has also contributed to upward pressure on the costs of items used in heavy construction projects. However, with the downturn of the housing market, the U.S. economy is slowing down. The significant cost escalation evident in the last few years is projected to moderate worldwide in the near future.

U.S. Trends in Cost Indexes for Power Plant Equipment and Materials

The U.S. Producer Price Indices (PPIs) provide the historical escalation trends for 19 equipment and material items associated with utility generation plants and electricity distribution systems. The historical PPIs cover the period from the beginning of 1996 through the end of 2007. These escalation trends are provided in the form of graphs in Annex 2.

Table 3.1 provides a side-by-side summary of the escalation of the 19 items determined from the graphs of Annex 2. As shown in the legend boxes on the graphs, the historical period is divided into two parts: (1) January 1996 through December 2003; and (2) January 2004 through December 2007. These two periods roughly correspond to the times before and after the rapid worldwide expansion in the construction of large industrial, utility, and manufacturing projects. The table also contains a third column that provides projected average annual compound escalation rates from 2008 through 2012.

Table 3.1 shows a significant increase in average annual compound escalation for the

Table 3.1 Average Annual Compound Escalation for Plant Equipment and Materials—United States

Figure Number	Equipment or Material Item	Jan. 1996–Dec. 2003, %/year	Jan. 2004–Dec. 2007, %/year	Projected, 2008–2012, %/year
1	Ready-Mix Concrete	1.9	7.9	2 to 4
2	Centrifugal Pumps	2.0	4.7	2 to 3
3	Centrifugal Fans	1.7	4.2	1 to 3
4	Material Handling Conveyors	1.7	4.7	1 to 2
5	Pneumatic Conveyors	1.7	3.8	NA
6	Crushers and Pulverizers	2.9	4.4	NA
7	Integral Horsepower Motors	0.4	6.4	NA
8	Fabricated Steel Plates	0.3	10.1	0 to 2
9	Structural Steel	0.9	8.0	1 to 3
10	Steel Pipe and Tubing	NA	7.0	2 to 4
11	Field Erected Steel Tanks	1.5	5.8	NA
12	Heat Exchangers and Condensers	0.8	7.8	NA
13	Fin Tube Heat Exchangers	1.3	8.4	NA
14	Industrial Mineral Wool	0.4	3.7	NA
15	Refractory, Non-Clay	0.4	3.7	NA
16	Power and Distribution Transformers	NA	13.8	1 to 3
17	Electric Wire and Cable	1.1	9.1	-1 to 2
18	Copper Wire and Cable	-0.8	18.7	NA
19	Industrial Process Control Instruments	NA	3.0	NA

Source: U.S. Bureau of Labor Statistics Producers Price Indexes and URS Washington Division Internal Cost Estimation Database.

NA—Not available.

period from January 2004 to the end of 2007 compared to the period from January 1996 through December 2003. The significant jump in escalation common to this diverse group of power plant equipment and commodities is a strong indication of the impact of the global building boom that has occurred in the last three to five years. This boom transformed the cost of power-sector construction from nominal annual cost increases prior to 2004 to significant annual cost increases after 2004. These historical data are directly applicable to this study because the items are included in many of the generation plant or electrical distribution options and are reflected in the cost estimates.

For the period from January 2004 through December 2007, the items most responsible for power plant cost increases were as follows:

- Electrical items: transformers, 68 percent; electric wire, 42 percent; and copper wire, 69 percent;
- Fabricated steel shapes: steel plates, 47 percent; structural steel, 36 percent; and steel pipe, 31 percent;
- Heat exchangers and condensers, 35 percent;
- Fin tube heat exchangers, 38 percent; and
- Concrete, 36 percent.

Composite cost trends from Marshall & Swift that include the above 19 items (as well as additional items) exhibit trends similar to those reflected for the equipment and commodities in Table 3.1. The composite index for all steam power equipment and commodities indicates that steam power plants had an average compound escalation rate of about 1 percent per year for the period 1997 to 2003. Then, similar to the general trends previously shown, the average compound escalation for the composite of all steam power plant equipment increased significantly at about 6.5 percent per year for the four-year period from January 2004 through the end of 2007.

The third column in Table 3.1 also shows the projected annual average compound escalation in the United States from 2008 through 2012. The rate of escalation from 2008 through 2012 is projected to moderate and/or flatten compared to the 2004-through-2007 time period. The projections of much lower escalation rates reflect the impact of the sub-prime mortgage crisis, which has resulted in a 100 percent increase in home foreclosures in the United States. This is reflected in significant financial losses for the largest home lenders and prominent banking institutions and a significant drop in the U.S. stock market indexes. The slowdown in the U.S. economy is also reflected in a 25 percent drop in housing starts over the last 12 months. The projections of much lower U.S. escalation rates reflect the economic slowdown in the United States This slowdown is forecast to continue through 2010, and during this period will reduce consumption and impact the import of overseas goods and services into the United States. This in turn will result in some slowing of the rate of escalation in the overseas countries that supply the U.S. market. The impact on overseas countries will be discussed in the next chapter.

The housing slump and overall condition of the U.S. economy will also reduce near-term growth of U.S. electrical consumption. All of these factors taken together are projected to reduce the rate of escalation of power plant equipment and commodities from the dramatic increases seen in the last four years to levels similar to or slightly above those experienced in the 1996 to 2003 timeframe.

Trends in Escalation for Power Plant-Related Items in India and Romania

Escalation Trends in India

Table 3.2 defines the items for which historical and projected escalation are available. The number of items in the dataset is not as extensive as it is for the United States, but it still provides an understanding of the historical escalation and potential future growth of generation plant costs.

The historical and projected escalation rates from 2004–2012 are shown in Table 3.3. Starting in 2008, except for steel pipe and steel plate, annual escalation in India is predicted to moderate in a manner similar to the trend in the United States. The most significant change in escalation

Table 3.2 Power Plant Equipment and Materials Included in the India and Romania Escalation Data

Category	Representative Items Included
Pipes and Wires	Ferrous Pipe
	Ferrous Wire
Steel Sheet	Fabricated Steel Plates
	Mechanical Equipment Steam Turbines
	Combustion Turbines
	Industrial Pumps
	Industrial Fans
	Industrial Material-Handling Equipment
Electric Equipment	Power and Distribution Transformers
	Switchgear
	Motors
	Relay and Industrial Controls
Electric Wires and Cables	Power Wire and Cable
	Building Wire and Cable

Source: Pauschert 2008.

Table 3.3 India—Average Annual Compound Escalation for Plant Equipment and Materials

Category	Jan. 2004-Dec. 2007, %/yr	Projected, 2008-2012, %/yr
Fabricated Metal (Structural Steel and Plate)	7	6 to 8
Steel Pipe and Tubing	6	8 to 9
Mechanical Equipment	6	3 to 4
Electric Equipment	7	1 to 3
Electric Wire and Cable	20	2 to 4

Source: URS Washington Division.

will be the dramatic flattening of escalation for electrical equipment, wire, and cable. Electrical equipment, wire, and cable are all related to the forecast flattening in the price of copper. Although there will be some slowing in the near term, the Indian economy is expected to continue to grow at a rapid pace compared to the United States. India will be impacted by the slowing of the U.S. economy, but not nearly as much as China. This is reflected by the real GDP, which in 2006 and 2007 was over 9 percent. The GDP in India is expected to slow modestly to an annual average of 7 to 8 percent during the period from 2008 to 2012.

Although the respective escalation rates in India will be lower during 2008–2012 than they were during 2004–2007, pipe, steel sheet, and mechanical equipment are still predicted to have a higher escalation rate than they will in the United States The average annual escalation rates for steel pipe, steel sheet, and mechanical equipment in India are predicted to be about 3, 5, and 1 to 2 percentage points higher, respectively, than in the United States.

Escalation Trends in Romania

For Romania, the historical and projected escalation rates from 2004 to 2012 are shown in Table 3.4. Starting in 2008, except for mechanical equipment, annual escalation in Romania is

Table 3.4 Romania—Average Annual Compound Escalation for Plant Equipment and Materials

Category	Jan. 2004-Dec. 2007, %/year	Projected, 2008–2012, %/year
Fabricated Metal (Structural Steel and Plate)	7	2 to 3
Steel Pipe and Tubing	5	2 to 4
Mechanical Equipment	3	2 to 3

Source: URS Washington Division.

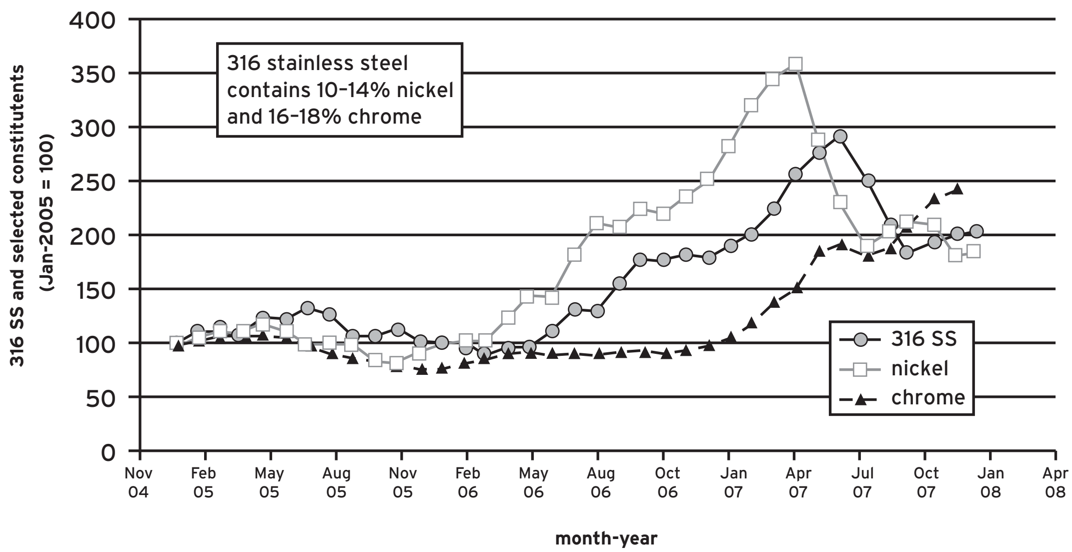
predicted to drop in a manner similar to the trend in the United States. The escalation in cost of mechanical equipment in the 2008–2012 timeframe is expected to slow, but only moderately compared to 2004–2007. In fact, during the 2008–2012 timeframe, escalation for the three items in Table 3.4 is projected to be in the same general range as the respective items in the United States.

Other Assessments and Items Related to Escalation

In the United States, the graphs for fabricated ferrous materials (steel plates, structural steel, and carbon steel pipe and tubing) show that after steep price increases from late 2003 to mid-2004, the price escalation subsided to modest levels through the end of 2005. In early 2006, fabricated metal prices resumed their cost increases, but not to the extent that had occurred during the first half of 2004. The increases generally continued through 2007. Additional information related to metals is important because: (1) they are used directly to make pipe, plate, and structural steel; and (2) they are used to make boilers, pumps, fans, motors, and electrical wiring, and/or are a significant part of many other power plant components. Information related to assessments or forecasts of metals is as follows:

- The price of nickel peaked at about US$53,000/ton in May of 2007, dropped to about US$26,000/ton in August 2007, increased to about US$33,000/ton in October 2007, and ended 2007 at about US$26,000/ton.
- At the end of January 2007, the price of nickel was US$26,000/ton and was projected to rise to US$40,000/ton over the next three years due to unexpected delays in production from new mines, according to a mining analyst from the United Kingdom.
- The price of 316 stainless steel stayed relatively flat from January 2005 through May 2006, increased by 160 percent from June 2006 through July 2007, decreased by 40 percent from August 2007 through October 2007, and increased 11 percent through December 2007. Overall, 316 stainless steel escalated at an average annual escalation rate of 43 percent over the two-year period. The price trends from January 2005 through January 2007 for 316 stainless steel, nickel, and chrome are shown in Figure 3.1.
- Forecasts indicate that the price increases of seamless carbon steel pipe will be 3 to 5 percent in the first quarter of 2008. However, the cost increases of steel pipe are expected to moderate through the rest of 2008.
- Over the five-year period from January 2003 through December 2007, the price of copper increased from about US$2,100/ton to about US$6,600/ton.
- One very large French investment bank has forecast a worldwide surplus of aluminum of 1 percent in 2008. There is excess production capacity available and producers continue to deliver aluminum to the market. This will lead to some ups and downs, but aluminum prices will change little in 2008.
- For November 2007, shipments by North American steel producers were down about 8 percent compared to the same month in 2006.
- The availability of skilled workers in Romania is a very significant issue affecting large construction projects. After Romania became a member of the European Union (EU) in 2007, skilled workers could go to

Figure 3.1 Cost Indexes for 316 Stainless Steel, Nickel, and Chrome



Source: Modified after Stainless Steel News.

Western European countries and make many times the hourly wage that they could make in Romania.

- The demand for cement in Eastern Europe is so high that a large plant is being built in Bulgaria and one is being considered for Romania. The supply of cement in Eastern Europe is further restricted by Eastern European import restrictions.
- Construction in the Romanian commercial sector is booming, but construction in the manufacturing sector is languishing. Manufacturing facilities are old, outdated, and surrounded by the cities' populations. Owners are selling their properties to commercial developers instead of refurbishing or rebuilding these facilities.
- The demand for Portland cement in the United States is expected to decrease about 2 percent in 2008 and increase about 3 percent in 2009.
- World crude steel consumption is projected to be 6 percent higher in 2008 than in 2007. China's consumption has the largest impact on global steel consumption and is expected to represent about 60 percent of global growth in 2008.
- Crude steel consumption in the EU in 2008 is expected to be about the same as it was in 2007.
- Crude steel consumption in India in 2008 is expected to be about 10 percent higher than it was in 2007.
- World refined copper production is expected to be about 6 percent higher in 2008 than it was in 2007, but global consumption will only slightly exceed production.
- The world refined copper price is expected to be about 2 percent lower in 2008 than it was in 2007.

The weak U.S. dollar is making the international export market more economically attractive to buyers of U.S. industrial equipment. The United States has seen substantial increases in the export of fabricated steel, heavy mobile construction equipment (bulldozers, earthmovers, and so forth), transformers, and generators.

Evolution of the International Marketplace—Major Equipment Suppliers

Regardless of the country or the location of the power plants, equipment and materials are now being purchased in the global marketplace. Regional or country markets still retain some unique characteristics (especially in China), but regional differences are being reduced. For example, most large Japanese suppliers have established offices in the United States and are getting a significant share of the recently constructed or contracted power plants. In addition, Chinese suppliers are bidding on power plants especially in Africa, South Asia, and Southeast Asia.

Among the key developments, the potential participation of industrial or heavy equipment suppliers from China may have the most dramatic impact on the global market, including power plant equipment prices. Chinese suppliers are starting to make inroads into selected countries such as Botswana, India, Indonesia, Nigeria, Pakistan, the Philippines, and Vietnam. Another factor affecting the level of their presence is likely to be related to the Chinese economy. If the growth of the Chinese economy (which has experienced consistent increases in GDP of 10–12 percent annually for more than a decade) slows down, its manufacturing capacity will be available to compete in the international marketplace. For this reason, it is important to briefly examine the Chinese market and its potential global impacts.

Currently, China has an installed coal-fired capacity of approximately 400 GW. Its capacity is growing by 50–120 GW per year. Before the late 1990s, the Chinese power sector consisted exclusively of subcritical coal-fired plants ranging from a few megawatts (1–10 MW) to standardized 200-MW, 300-MW, and 600-MW units. All of these power plants were manufactured domestically under licensing agreements with foreign suppliers. Units above 200–300 MW utilized technology obtained through licensing agreements with Western suppliers. One such agreement for boiler technology was with Combustion Engineering Inc., which was later acquired by Alstom. The technology was made available to all of the leading local manufacturers (Harbin Boiler Group, Shanghai Boiler Group, and Dongfang Boiler Industrial Group, as well as smaller manufacturers such as Beijing Boiler Works and Wuhan Boiler Co.).

China started using supercritical technology in the 1990s, first with 10 units (4x320MW; 4x500MW; and 2x800MW) procured from Russia. The first plant utilizing Western technology was the Shi Dong Kou plant, commissioned in 1992. It consisted of 2x600-MW units with 25.4 MPa/538ºC/565ºC steam conditions. The second plant utilizing Western technology was the Waigaoqiao plant in Shanghai (next to the Shi Dong Kou), which consists of two 900-MW units with steam conditions of 24.7 MPa/538ºC/565ºC. The project was financed with a World Bank loan in the mid-1990s. Since then, many more supercritical units have been built.

As of the end of 2006, China had 46 supercritical plants in operation representing 30 GW of installed capacity; most of them have been designed for 24.7 MPa/565ºC/565–593ºC, but two have ultra-supercritical (USC) steam conditions of 24.7 MPa/600ºC/600ºC. The first USC plants (Huadian's Zouxian and Huaneng's Yuhuan power plants) started operating in November–December 2006. By the end of 2007, approximately 120 GW of installed capacity was expected to utilize supercritical steam conditions.[2] Sixty percent of the future plants are expected to utilize supercritical and USC steam conditions.

An interesting development is that each of the Chinese manufacturers has developed a joint venture or licensing agreements with one of the international suppliers. This is a departure from the past, when all the Chinese suppliers obtained "blanket licensing agreements." More specifically, Shanghai Boiler Works has teamed up with Alstom and Siemens; Harbin Boiler Group works with Mitsubishi; and Dongfang Boiler Industrial Group has a joint venture with Hitachi. Additionally, the fifth-largest manufacturer (Wuhan) was recently acquired by Alstom, which reportedly plans to expand its capability to produce both subcritical and supercritical plants.

[2] Prof. Mao, Jianxiong, "Electrical Power Sector and Supercritical Units in China," presented at the Workshop on Design of Efficient Coal Power Plants, Vietnam, October 15–16, 2007.

The manufacturing capacity of China is estimated in the range of 100–120 GW per year. While no specific estimates are available, 30–50 percent of this comes from second- and third-tier manufacturers (the first tier being Harbin Boiler Group, Shanghai Boiler Group, and Dongfang Boiler Industrial Group), each of which is capable of manufacturing subcritical units up to 300 MW.

Reportedly, the first-tier manufacturers are booked for the next two to three years (2008–2010) with domestic orders for supercritical and USC plants. However, even these manufacturers have expressed interest or have already participated in recent commercial projects outside China. The second- and third-tier Chinese manufacturers are facing a shrinking domestic market and are under pressure either to upgrade to supercritical or to seek markets outside China. As a result, the potential for exports of both subcritical and supercritical plants by Chinese manufacturers is real. Export of subcritical plants is possible and is already taking place; supercritical plants are likely to follow in the coming years, especially if China's rate of economic growth slows down.

In this context, it is important to review the prices of power plants manufactured by Chinese suppliers. The following prices are quotes from within China during the last two to three years:

- US$600–650/kW for 300-MW subcritical units;
- US$540/kW for 600-MW supercritical units; and
- US$540/kW for 1,000-MW ultra-supercritical units.

These units do not include the emission controls systems required on U.S. plants. Even so, these prices are one-half to one-third of the international prices for similar plants. Nevertheless, it is not clear whether these prices reflect actual manufacturing costs and international commodity prices. Approximately 50 percent of the costs is estimated to be material costs. The fact that these prices have stayed at the same level while international commodity prices have experienced a substantial increase in the last two to four years raises questions regarding their pricing structure. It is certain that labor costs alone provide China with a competitive advantage that may be reflected in its 20–40 percent lower production costs. This (even when international commodity prices are used) is likely to give Chinese suppliers an advantage to compete in the global marketplace.

The nature of Chinese entry into the external market is not completely clear. In the near term (two to five years), the most likely scenario is for Chinese suppliers to focus on Asia and Africa. Recent large PC power plant projects in these regions suggest that the Chinese suppliers are underbidding international prices, but not as low as their domestic market. In other markets, Chinese pricing (e.g., on circulating fluidized bed plants) is slightly below international prices. In India, their pricing for large power plant equipment is more aggressive (they bid lower than other countries). Part of a market entry strategy may be a result of the Chinese boiler manufacturers facing Bharat Heavy Electricals Limited (BHEL), the dominant Indian supplier with a near monopoly (BHEL equipment generates 73 percent of the total power produced in India).

In general, the impact of the potential entry of Chinese suppliers on global power plant prices is likely to be positive, potentially resulting in moderate-to-substantial price reduction in some markets and less in others. Over the long term, the price gap between Chinese suppliers and other suppliers is likely to reach an equilibrium point (below the level without their presence, but at some price level between their prices and the prices of all other competitors). The magnitude of the price reduction and how long it will last will depend on a number of factors. In general, the following should be taken into account:

- Large markets such as India and South Africa may experience very low bid prices in the short term, until the Chinese suppliers establish a substantial position in these markets. Longer term, they are likely to bring their prices closer to international levels.
- The Chinese suppliers are expected to be more aggressive in their pricing of subcritical plants because there is plenty of excess manufacturing capacity for such plants in China.

- The India Brand Equity Foundation predicts that Chinese companies could supply as much as 30 percent of the power equipment market from 2007 through 2012.
- The domestic demand for new power plants will certainly impact the ability of the Chinese suppliers to become international market players. Continuing high economic growth is likely to delay their entry into the global market or make them less aggressive in pricing.
- Whether the Chinese suppliers will elect to enter the international market by themselves or through joint ventures with international suppliers will impact their pricing strategy. Commercial agreements that they have signed with international suppliers may constrain them in terms of what markets they can serve and when.
- China has had an increasing reliance on ore imports for a number of years. As of mid-2007, China imported 55 percent of its total iron ore requirements. India, a major exporter of iron ore to China, has announced an export tax. This will increase the price of steel in China. In the long run, China's significant percentage of imported iron ore will make it vulnerable to world market price increases and in turn make Chinese steel more expensive.
- As an example, the price of iron ore from India rose from US$100/ton in January 2007 to US$220/ton in January 2008. Over the same period, the price of medium steel plate exported from China went from US$500/ton to US$740/ton. Further, from January 2008 to mid-April 2008 the price increased to about US$900/ton.
- Finally, it is important to mention that inflation in China is increasing and expected to continue its upward trend both in materials and labor costs, as was indicated above by the price of steel. So the competitive advantage of Chinese suppliers is likely to close in the future.

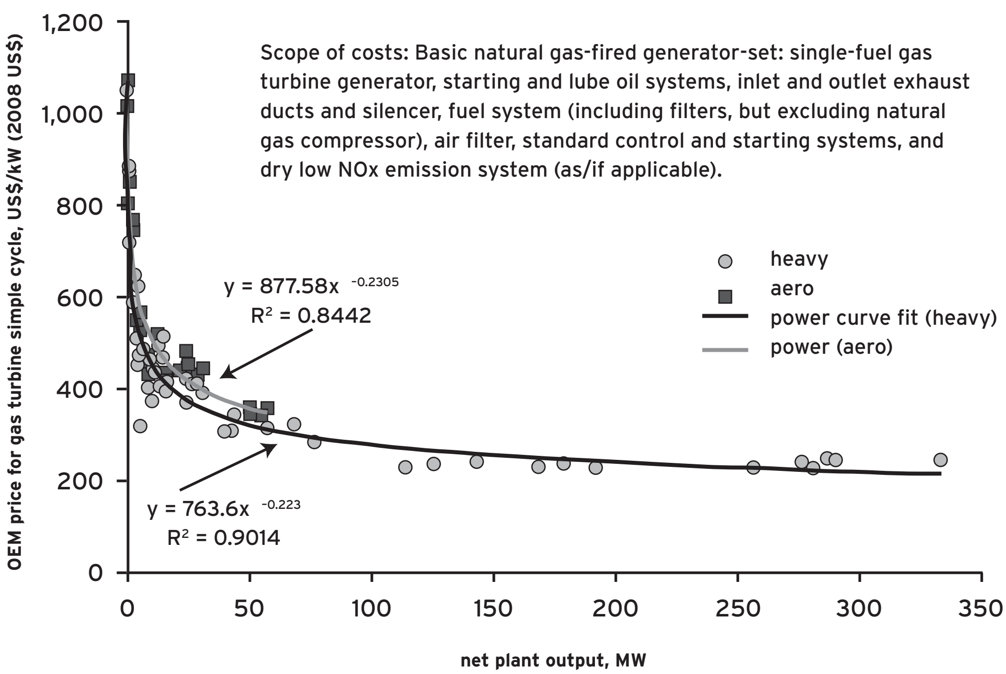
4 Impact of Plant Size on Cost

Impact of Size on Cost for Simple Cycle Gas Turbines

Cost data were compiled for aeroderivative and heavy-frame-type gas turbines from 11 different manufacturers and 90 different models. The simple cycle gas turbine units range in size from about 1 MW to 334 MW. All of the models evaluated in this report are available either as a 50- or 60-Hz option—this analysis only examined the 50-Hz configuration. Figure 4.1 provides a picture of the impact of size on the cost for simple cycle gas-fired combustion turbine units. These data are from the 2008 GTW Handbook and reflect current marketplace pricing.

The graph shows two regression curves: one for the aeroderivative gas turbines and one for the heavy-frame gas turbines. These curves indicate that in the 10- to 50-MW range, aeroderivative units average US$40 to US$60/kW more than comparably sized heavy-frame units. Aeroderivative machines weigh less (kg/MW of output) than heavy-frame machines, but

Figure 4.1 Impact of Size on OEM Cost for Simple Cycle Units



Source: 2007–08 GTW Handbook, Volume 26, Gas Turbine World, Pequot Publishing ISBN 0747-7988, 2008.

are more costly due to materials of construction and technology development costs. Economic evaluations of the two classes contrast the higher capital cost and superior heat rate (efficiency) of aeroderivative models against the lower capital cost and lower efficiency of heavy-frame models.

Figures 4.2 and 4.3 compare the cost of gas turbines in constant 2008 dollars for aeroderivative and heavy-frame machines, respectively. The costs are for corresponding machines that were available from manufacturers/suppliers in both 2003 and 2008.

The aeroderivative gas turbines are from six different manufacturers/suppliers. This graph shows that for six of the eight gas turbines, the prices increased (total difference from 2003 to 2008 ranging from 6 to 23 percent). The real average annual compound escalation for the five years from 2003 to 2008 for all eight of these aeroderivative turbines was about 2.5 percent (escalating at an average annual compound rate of about 2.5 percent above U.S. inflation).

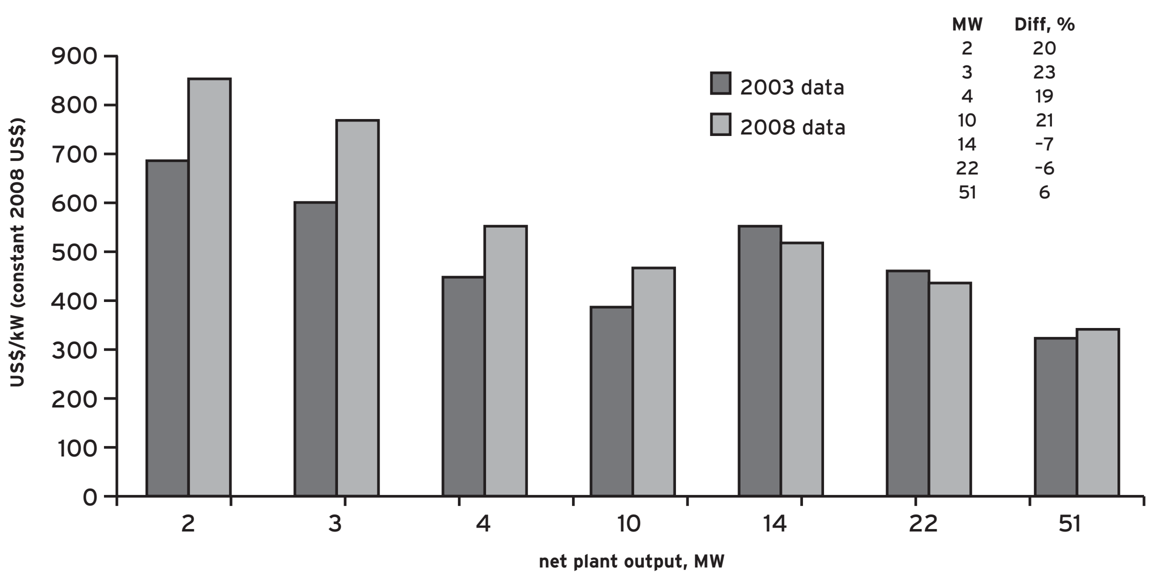
The heavy-frame gas turbines are from six different manufacturers/suppliers. This graph shows that for 9 of the 11 turbines, the prices increased (total difference from 2003 to 2008 ranging from 1 to 26 percent). The real average annual compound escalation for the five years from 2003 to 2008 for all 11 of these heavy-frame turbines was also about 2.5 percent.

Impact of Size on Cost for Gas Turbine/Combined Cycle

Cost data were compiled from nine different manufacturers and 69 different configurations of gas turbine combined cycle plants. The combined cycle plants range in size from about 7 MW to 1,000 MW. The combined cycle models included in this study are either available as a 50-Hz option or are manufactured in the 50-Hz configuration.

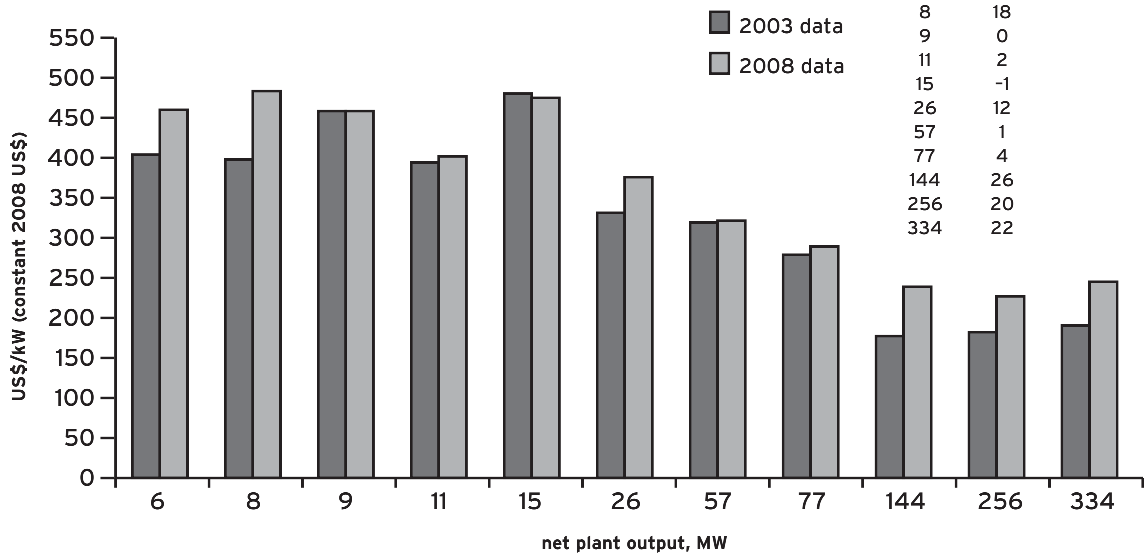
Figure 4.4 provides the cost in US$/kW versus MW output. As for the simple cycle, these data are from the 2008 GTW Handbook. The graph includes a box that contains a description of the items included in the OEM costs. The graph also shows the power law regression curve with no differentiation between combined cycle plants utilizing aeroderivative or heavy-frame gas turbines. The data indicate that the OEM costs range from about US$950/kW to US$450/kW as the plant

Figure 4.2 Change in OEM Prices for Simple Cycle Aeroderivative Gas Turbine Units (Constant 2008 US$)



Source: 2007–08 GTW Handbook, Volume 26, Gas Turbine World, Pequot Publishing ISBN 0747-7988, 2008.

Figure 4.3 Change in OEM Prices for Simple Cycle Heavy-Frame Gas Turbine Units (Constant 2008 US$)

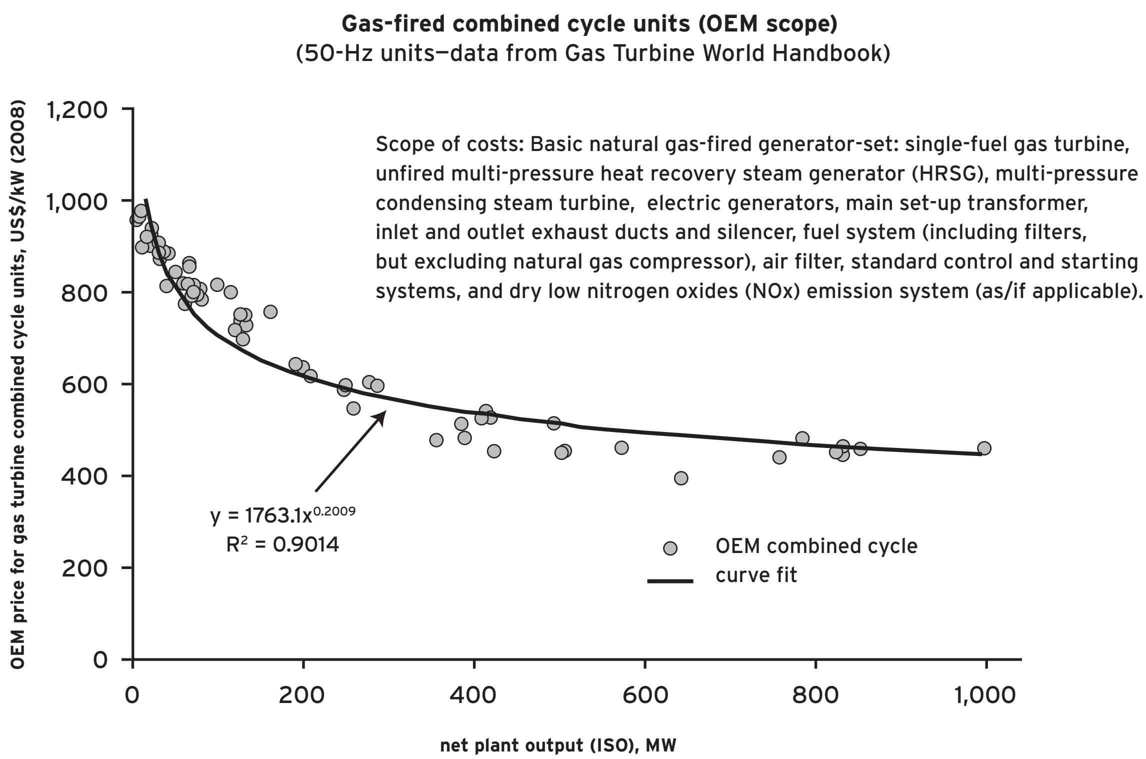


MW	Diff, %*
6	12
8	18
9	0
11	2
15	−1
26	12
57	1
77	4
144	26
256	20
334	22

Source: 2007–08 GTW Handbook, Volume 26, Gas Turbine World, Pequot Publishing ISBN 0747-7988, 2008.

*Total % difference from 2003 to 2008.

Figure 4.4 Impact of Size on OEM Costs for Combined Cycle Units

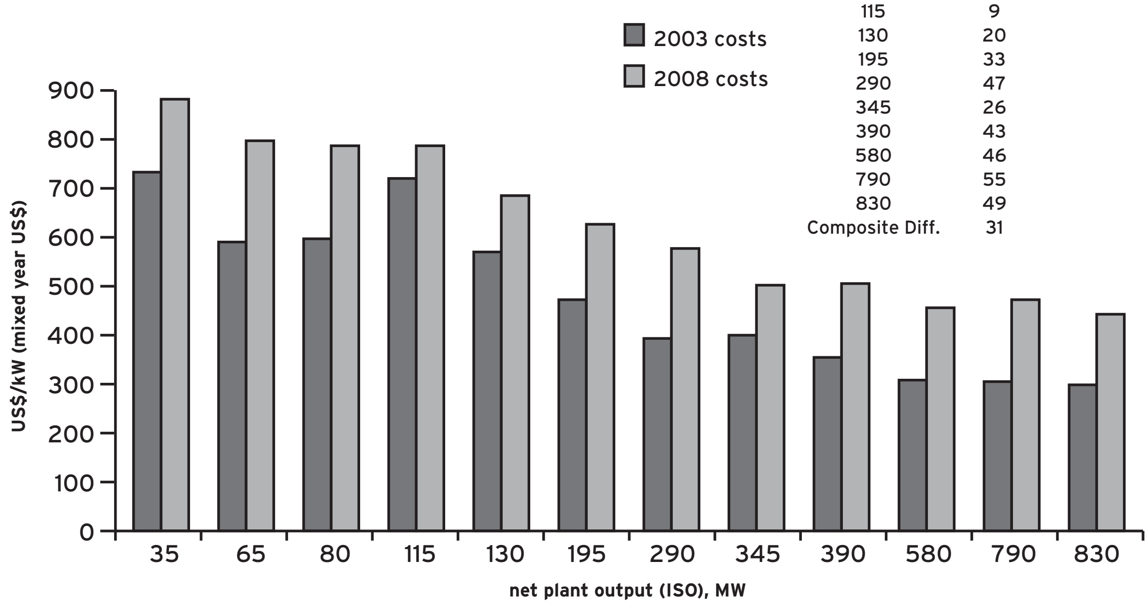


Source: 2007–08 GTW Handbook, Volume 26, Gas Turbine World, Pequot Publishing ISBN 0747-7988, 2008.

output increases from 7 MW to 1,000 MW. It is of interest to note that the cost-scale exponents for simple cycle and combined cycle are about the same (–0.22/–0.23 vs. –0.20, respectively). This indicates that the cost-scale factor for steam turbines is also about –0.2 (on a US$/kW basis).

Figure 4.5 compares the OEM price of combined cycle plants in 2003 (2003 US$) to the corresponding price in 2008 (2008 US$). This graph differs from the previous two graphs in that it compares nominal dollars rather than constant dollars. The data are for 12 combined cycle plant "models" from five different manufacturers/suppliers. The graph shows that the increases for the combined cycle plant prices range from 9 percent to 55 percent—11 of the 12 have five-year increases of 20 percent or greater. The composite increase for these 12 combined cycle plants is 31 percent and the composite annual compound escalation rate for this five-year period is 5.5 percent (nominal basis).

Figure 4.5 Change in OEM Prices for Combined Cycle Units (Nominal 2008 US$)



MW	Diff, %*
35	20
65	36
80	31
115	9
130	20
195	33
290	47
345	26
390	43
580	46
790	55
830	49
Composite Diff.	31

Source: 2007–08 GTW Handbook, Volume 26, Gas Turbine World, Pequot Publishing ISBN 0747-7988, 2008.

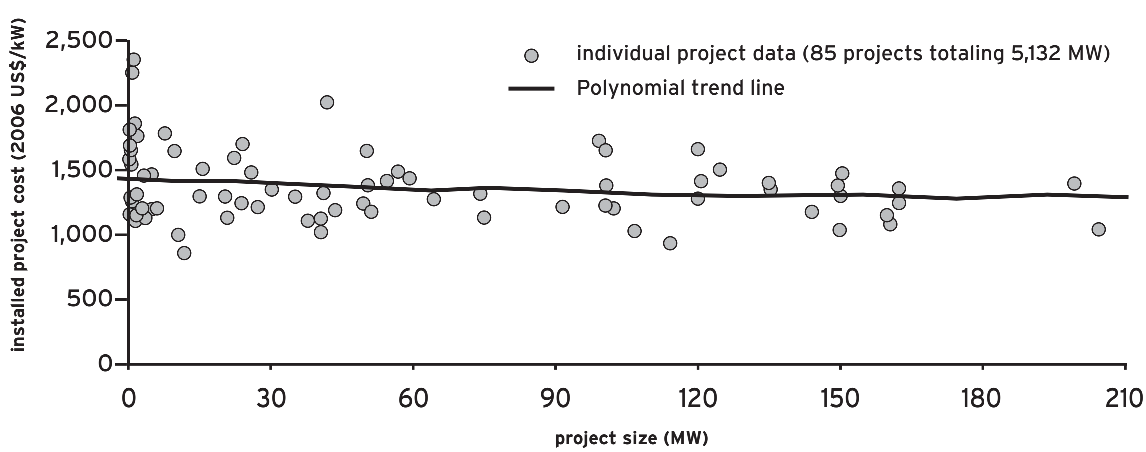
*Total % difference from 2003 to 2008.

The significant increase in the cost of gas turbines and combined cycle plants is just one striking illustration of the impact of the U.S. economy, which was very strong for the five-year period prior to the sub-prime mortgage crisis. The extended period of U.S. economic growth was accompanied by strong demand for consumer goods, increasingly manufactured overseas. This in turn resulted in very strong growth in the construction of manufacturing and industrial facilities in India, EU countries, and China. The expansive growth in these countries fueled an increasing worldwide demand for equipment, steel, concrete, and other commodities, particularly in China. This demand was at or above the capability of supply, leading to worldwide escalation in the cost of the materials needed to construct manufacturing and industrial plants. This resulted in market demand costs that added to the cost increases of materials and equipment. The market demand factor and its influence are explained in the summary section of this report.

Impact of Size on Cost for Wind Farms

Although larger-size individual wind turbines generally offer an economy of scale, Figure 4.6 shows that there is very little statistically significant difference in installed cost per kW for wind farms between 30 MW and 200 MW. This is likely due to the fact that larger wind farms are simple integer multiples of each wind turbine. Manufacturers may offer discounts for large orders of wind turbines, but in general, this does not offer exponential economy of scale associated with fossil plants. Variations in cost of wind projects are more likely due to previously discussed regional differences, including variations in developments costs, site and permitting requirements, and construction expenses.

Figure 4.6 Installed Cost of Wind Projects as a Function of Project Size: U.S. Projects 2003–2006



Source: Berkeley Lab Database.

5 Cost Estimates for Power Plants in the United States, India, and Romania

The capital costs for the generation plants in this chapter are Class 5 as defined by The American Association of Cost Engineers (AACE) International standard practice 18-R97, 2/2/2005. The costs are based on budget quotes (to the extent available), equipment factoring, and/or parametric models. Class 5 is defined as a study or feasibility-level cost estimate. The overall accuracy of the plant cost estimates herein is within the Class 5 standard practice guidelines and for this study it is –20 percent/+25 percent. All costs are in January 2008 U.S. dollars.

The basis or items included in the cost estimates are specific to each technology and are defined in subsequent chapters of this report. The following items are common to all of the cost estimates:

- Concrete, structural steel, and piping are obtained from suppliers within the respective countries.
- Basis of foundations is spread footings.
- Sites are assumed flat with minimal balanced cut and fill earthwork.
- Generic site locations within the United States, India, and Romania.
- Financing costs are not included.
- Costs for bonds, taxes, and insurance are not included.
- Customs costs or import duties are not included.
- Owners costs are not included.
- Costs for spare parts are not included.
- Land is not included.

The plant size for most of the generation technologies covered in this report are the same as those for the corresponding grid-connected generation technologies shown in Table 2 of the September 2006 "Electrification" report.[3] Plant sizes in this study were selected be consistent with the Electrification study.

Gas Turbine Simple Cycle

Simple Cycle Market Trends and Technology Description

Market Trends. According to available data (from a database that starts in 1978), worldwide sales of all gas turbines peaked at an all-time high in 2001. In 2002, sales plummeted 45 percent, followed the next year by an additional drop of 30 percent. Subsequent year-to-year results were as follows:

- 2004—Sales increased by 15 percent.
- 2005—Sales were flat.
- 2006—Sales increased 16 percent.
- 2007—Sales increased 10 percent.

In the future, it is expected that sales will continue to increase, with the majority coming from outside the United States, primarily China and India. China, India, Thailand, Vietnam, and the Middle East are experiencing rapid growth in manufacturing and other power-consuming sources and will need to expand the respective capacities of their power infrastructure to serve this growth.

[3] Technical and Economic Assessment of Off-Grid and Grid Electrification Technologies, Summary Report, The World Bank Group, Energy Unit, Energy Transport and Water Department, September 2006.

Between 2008 and 2012, the sales of gas turbine units are projected to grow at an average annual compound rate of 5 to 7 percent. Gas-turbine-based power will be a significant contributor to increased gas consumption because these plants emit less CO_2 per kWh than do conventional fossil steam plants. In addition, energy demand is expected to more than double within the next 7 to 10 years, especially in Asia, with China being the most expansive consumer of oil, gas, and coal. Other leading users will be India, Mongolia, and Vietnam. As a result, consumption of natural gas is projected to exceed that of coal within the next two to three years (on an energy content basis).

Lead Times. Lead time for gas turbines in the 2004–2005 timeframe was about 12 months, but by 2007, the lead time for gas turbines had extended to 16–18 months.

Technology Description. As previously noted, gas turbines are grouped into two classes, aeroderivatives and heavy-frame. Aeroderivative turbines are available with ratings up to about 50 MW. They generally have better efficiency, quicker start-ups, and lower fuel costs than heavy-frame units. Consequently, aeroderivative machines are well suited to the simple cycle configuration. They also have an advantage as peaking units because overhaul intervals are typically based on fired hours, not on the number of starts. Overhauls of turbine cores are typically performed off-site at a specialized repair facility, and lease units can be used to maintain operation while the original unit is being overhauled. The overhaul and repair cycle is well structured in the United States due to the number and proximity of specialized repair facilities. On the other hand, the repair facility "infrastructure" is lacking in many cases, and this should be considered as part of any evaluation to locate aeroderivative units in developing countries.

Heavy-frame units are available up to 300 MW for 50-hertz (Hz) ratings. Maintenance costs are lower, but overhauls are performed on-site, which requires significant outage times. These outage durations can range from a few days for a combustor inspection to about a month for a major overhaul. Heavy-frame units generally start more slowly than aeroderivatives. Inspection and overhaul intervals on heavy-frame units are typically based on "equivalent hours," which are affected by many factors, such as actual operating hours, number of starts, number of trips, number of fast ramp rates, and so forth.

The simple cycle gas turbines evaluated in this study are based on natural gas. The advantages of simple cycle units compared with other power generation options are low cost, compact footprint, and quick start-up times. The major disadvantage of simple cycle gas turbines is the high operating cost due to high fuel costs.

Both types of gas turbines are sensitive to ambient temperature and suffer significant derating on hot days. The high temperature derating can be reduced by employing evaporative cooling or mechanical chilling on the compressor inlet air. Evaporative cooling works best for low-humidity operation. Mechanical chilling can be employed for either high- or low-humidity applications, but the chilling equipment is more costly than evaporative cooling.

Simple Cycle Plant Costs

The simple cycle cases include 5-MW, 25-MW, and 150-MW sizes. The 5-MW and 25-MW gas turbines are based on the aeroderivative class and the 150-MW is based on the heavy-frame class. The estimates are based on completely constructed and operable units. The total plant costs (prices) are shown in Table 5.1, Table 5.2, and Table 5.3, respectively.

The costs for the gas turbine are from the 2008 GTW Handbook (2008 US$), and are adjusted as described in the narrative following in this subsection.

Basis of Estimates. The simple cycle plant cost estimates are based on the following:

- OEM Gas Turbine Package with Standard Components: Single-fuel gas turbine (natural gas), generator, starting and lube oil systems, gas turbine controls, air filter, silencer, exhaust stack with silencer, vibration

Table 5.1 5-MW Simple Cycle Plant—Aeroderivative Gas Turbine

Each Item Costs for Equipment, Material, and Labor (January 2008 US$)

Cost Estimate Summary	**U.S. (thousands $)**	**India (thousands $)**	**Romania (thousands $)**
Civil/Structural	400	310	300
Mechanical			
Gas Turbine (OEM Price)[1]	2,920	2,920	2,920
SCR	300	0	290
Gas Compressor	640	630	620
Electrical	550	490	460
Piping	140	100	130
Instruments and Controls	90	80	80
Balance of Plant/General Facilities	340	310	310
Total Direct Costs	5,380	4,840	5,110
Indirect Costs	280	110	90
Engineering and Home Office Costs	630	260	220
Process Contingency	0	0	0
Project Contingency	940	1,040	1,080
Total Plant Cost	7,230	6,250	6,500
Gas Turbine Cost (FOB-OEM), $/kW	560	560	560
Total Plant Cost, $kW	1,380	1,190	1,240

Source: 2007–08 GTW Handbook, Volume 26, Gas Turbine World Pequot Publishing ISBN 0747-7988, 2008, and URS Washington Division Internal Cost Estimation Database.

[1] OEM Price, Excluding Installation Labor.

monitoring, and plant control system. This simple cycle package is based on the GTW Handbook adjusted with factors based on OEM bid prices contained in the in-house database of major equipment and auxiliary equipment prices.

The simple cycle plant price is based on the price as defined above plus the prices for the following additional items resulting from the design by the engineering firm: separate purchases of all necessary auxiliary equipment and purchases of bulk materials such as piping, concrete, electrical, and so forth (purchases based on bid packages). The auxiliary equipment and bulk material items that are included in the plant and added to the simple cycle price are as follows:

- No combustion air cooling or chilling. Gas turbine performance and output based on International Standards Organization (ISO) conditions (see Annex 1 for definition of ISO conditions for gas turbine).
- Selective catalytic reduction (SCR) NO_x control system for the United States and Romania (no SCR for India).
- Gas compressor.
- Spread footings, no pile foundations.
- Control building for 5-MW unit; combination office/control/warehouse building for 25-MW and 150-MW units.
- Fire water system.
- Instruments and controls.
- Foundations.
- Piping.
- Structural steel.

Table 5.2 25-MW Simple Cycle Plant—Aeroderivative Gas Turbine

Each Item Costs for Equipment, Material, and Labor (January 2008 US$)

Cost Estimate Summary	**U.S. (thousands $)**	**India (thousands $)**	**Romania (thousands $)**
Civil/Structural	1,260	930	900
Mechanical			
Gas Turbine (OEM Price)[1]	9,770	9,770	9,770
SCR	970	0	930
Gas Compressor	1,000	970	970
Electrical	1,790	1,560	1,500
Piping	470	330	420
Instruments and Controls	240	210	200
Balance of Plant/General Facilities	890	800	790
Total Direct Costs	16,390	14,570	15,480
Indirect Costs	750	270	230
Engineering and Home Office Costs	1,680	660	580
Process Contingency	0	0	0
Project Contingency	2,820	3,100	3,260
Total Plant Cost	21,640	18,600	19,550
Gas Turbine Cost (FOB-OEM), $/kW	440	440	440
Total Plant Cost, $kW	970	830	870

Source: URS Washington Division Internal Cost Estimation Database.

[1] OEM Price, Excluding Installation Labor.

- Electric wiring.
- Switchgear.
- Motor controls.

Scope/Terminal Points of Estimate:

- Fuel—natural gas piping from plant fence.
- Water—drinking water piping from plant fence.
- Electricity—high side of transformer.
- Natural gas and drinking water pipelines outside the plant fence are not included.
- Access roads outside the plant fence are not included.
- Freight is not included.

The simple cycle plant performance at each of the three locations is based on ISO conditions. This puts the comparison on a common footing. If specific site conditions were used within each country, then performance would influence the cost estimate. By using ISO conditions, the cost estimates reflect the differences in construction labor wages, construction labor productivity, engineering wages, concrete costs, structural steel costs, and piping costs and are not masked by the differences in site ambient conditions.

The tables show that that costs for all of the simple cycle cases are less in India and Romania than in the United States. This is primarily due to the lower labor wage rates. The tables also show that the cost in India is lower than the cost in Romania. This results from the lower cost for structural steel, piping, and concrete in India.

Cost Considerations and Comparison to Other Cost Estimates. Figure 5.1 shows the timeline of average OEM price per kW of capacity for

Table 5.3 150-MW Simple Cycle Plant—Heavy-Frame Gas Turbine

Each Item Costs for Equipment, Material, and Labor (January 2008 US$)

Cost Estimate Summary	U.S. (thousands $)	India (thousands $)	Romania (thousands $)
Civil/Structural	4,650	3,380	3,320
Mechanical			
Gas Turbine (OEM Price)[1]	34,030	34,030	34,030
SCR	4,250	0	4,100
Gas Compressor	1,380	1,350	1,340
Electrical	7,590	6,760	6,520
Piping	1,920	1,370	1,790
Instruments and Controls	820	710	680
Balance of Plant/General Facilities	3,000	2,660	2,610
Total Direct Costs	57,640	50,260	54,390
Indirect Costs	2,660	920	810
Engineering and Home Office Costs	6,010	2,210	2,080
Process Contingency	0	0	0
Project Contingency	9,940	10,680	11,460
Total Plant Cost	76,250	64,070	68,740
Gas Turbine Cost (FOB), $/kW	240	240	240
Total Plant Cost, $kW	530	440	480

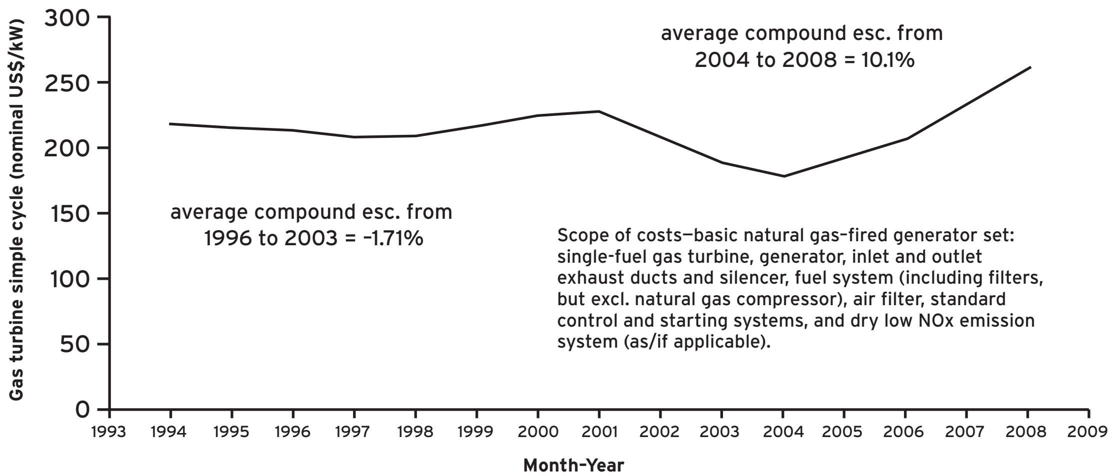
Source: URS Washington Division Internal Cost Estimation Database.

[1] OEM Price, Excluding Installation Labor.

heavy-frame simple cycle units each year from 1994 to 2008. The average prices are for all of the heavy-frame units in the GTW Handbook list that are greater than 50 MW. The trends displayed in the curve correlate in a general way with the previously discussed changes in year-to-year sales trends of gas turbine units. The average costs in this curve show one peak in 2001, which is the same year that gas turbine sales reached an all-time record. The average price of about 30 units ranging in size from 50 to 330 MW was about US$230/kW. Then in 2004, right after sales reached their lowest point since 1990, the average price had dropped to about US$180/kW, a price decline of about 28 percent. By 2006, the price had rebounded by 9 percent, followed by an additional 21 percent by 2008. Therefore, the industry had seen an overall increase of 32 percent in just four years. However, this increase had followed the 28 percent decline from 2001 to 2004. The overall increase in the average OEM prices of simple cycle units from 2001 to 2008 was 13 percent.

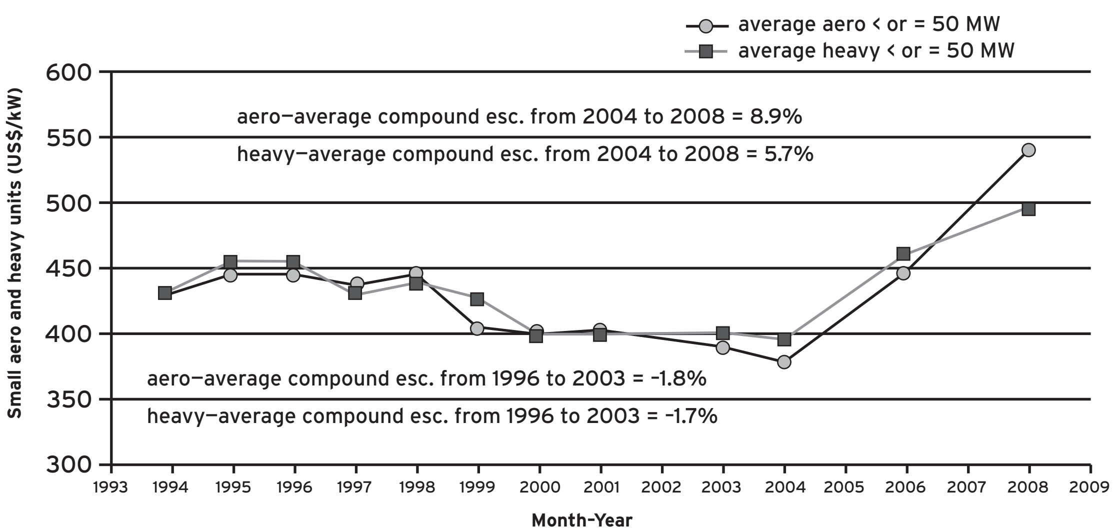
Figure 5.2 shows the timeline of average OEM prices for smaller aeroderivative (aero) and heavy-frame (heavy) simple cycle units for the same period as the larger heavy-frame units. The average prices are for all of the aero and heavy units in the GTW Handbook list that are less than or equal to 50 MW. The trends in the cost curves of the two types of smaller gas turbines are similar, but are different than the larger heavy-frame units. Neither curve shows the peak in 2001, the overall record sales year. The curves show the following cost profiles for units less than or equal to 50 MW:

Figure 5.1 Year-to-Year Change in Average Price of Heavy-Frame Simple Cycle Units (>50 MW)



Source: Modified from 1994–2007 GTW Handbook, Gas Turbine World, Pequot Publishing.

Figure 5.2 Year-to-Year Change in Average Price of Aero and Heavy Simple Cycle Units (< or = 50 MW)



Source: Gas Turbine World Handbook.

- In 2001, the average price of aero units was about US$403/kW.
- In 2001, the average price of heavy units was about US$402/kW.
- In 2004, the average price of aero units was about US$380/kW—a drop of 6 percent from 2001.
- In 2004, the average price of heavy units was about US$395/kW—a drop of 2 percent from 2001.
- In 2008, the average price of aero units was about US$535/kW—an increase of 41 percent from 2004.
- In 2008, the average price of heavy units was about US$495/kW—an increase of 25 percent from 2004.

One comparison to costs from other sources is a generic statement from the 2007–2008 issue of the GTW Handbook. The GTW Handbook has many years of experience and, in addition to obtaining prices directly from OEMs, has analyzed the total installed costs of numerous U.S. projects after construction was completed. The GTW Handbook source indicates that "project managers conservatively estimate that installation and complete plant costs can easily add 60 to 100 percent on top of the equipment-only (OEM) prices of simple cycle units."[4] The 25-MW and 150-MW U.S. simple cycle plant costs estimated for the World Bank are compared to this statement. The 5-MW simple cycle plant cost is not included because its small size skews the percentages. The comparison for the United States is as follows:

- 25-MW simple cycle—OEM cost + 121 percent with contingency.
- 150-MW simple cycle—OEM cost + 124 percent with contingency.

Thus, the simple cycle cost estimates in this report are in the realm of the GTW statement, especially when using the word "conservatively."

Another comparison is from Libya—it was announced on February 18, 2008, that BHEL (India) had awarded US$163.4 million for engineering, procurement, and construction of 2 × 150-MW simple cycle plants (size based on Siemens V94.2 gas turbine, also known as SGT5–2000E). Per the GTW Handbook, the 2008 OEM price for the V94.2 model is US$37.8 million. The cost for two would be US$75.6 million. Labor and material data are not available for Libya, but using the factors from this study for India, the total plant cost would be US$75.6 million × 1.88 = US$142 million.

Gas Turbine Combined Cycle

Combined Cycle Market Trends and Technology Description

Market Trends. The statements in the simple cycle market trends section with regard to the growth of overseas areas (China, India, Thailand, Vietnam, and the Middle East) and the statements regarding the growth and use of natural gas generally apply to the combined cycle. In addition, the combined cycle portion of the gas turbine is expected to grow in the future—in the last five years of the twentieth century, combined cycle plants represented about 26 percent of all gas turbine plants built. It is projected that over the next 8 to 10 years the combined cycle plants will approach one-half of all gas turbine plants built.

Lead Times. Lead time for gas turbines in the 2004–2005 timeframe was about 12 months.

- In 2007, the lead time for gas turbines had extended to 16–18 months.
- In the United States, plant construction time for combined cycle plants in the 2004–2005 timeframe was in the range of 16 to 18 months.
- In 2007, plant construction time for combined cycle plants located in the United States had extended to 22 to 26 months. The lead times for gas turbines and the shortage of skilled craft labor are both contributing to the longer construction period in the United States.

In regard to the worldwide sales of gas turbines:

- The worldwide purchase of gas turbines is much more dispersed than it is for steam boilers or steam turbines (see subsequent discussion under coal-fired plants).
- In the first three quarters of 2007, China placed about 2 percent of the worldwide combustion turbine orders on a capacity basis. This compares to 2 percent for India and about 9 percent for the United States. The Middle East region placed the largest proportion of orders, at 25 percent.

Technology Description. Combined cycle gas turbines are commonly used for generating electrical power from natural gas. The primary

[4] 2007–2008 GTW Handbook, Volume 26, Gas Turbine World, Pequot Publishing, ISSN 0747-7988, 2008.

advantage of combined cycle units compared with other power-generation options is high efficiency; overall efficiencies of large combined cycle units approach 60 percent on a lower heating-value basis.

Combined cycle units can be based on both aeroderivatives and heavy-frame gas turbine technology. Several aeroderivative gas turbines are suitable as the prime mover for plants with ratings of up to about 100 MW. Larger plants will generally be based on heavy-frame gas turbines because of their lower cost and, unlike simple cycle gas turbines, heavy-frame units generally provide combined cycle overall plant efficiency that is higher than the efficiency of a simple cycle-based combined cycle plant.

A combined cycle power block consists of three basic units: the gas turbine, a heat recovery steam generator (HRSG) that produces steam from the turbine exhaust heat, and a condensing steam turbine that generates electricity from that steam. Combined cycles based on "old" gas turbine technology typically use a non-reheat steam cycle and provide steam at two pressures, about 100 bar for the main steam and 5 bar for a low-pressure admission to the steam turbine. Large combined cycles based on "F-Class" gas turbines typically employ a reheat steam cycle and provide steam at three pressure levels: 140 bar for main steam, 30 bar for intermediate pressure steam that supplements reheat steam flow, and 5 bar for low-pressure admission. Several gas turbine/HRSG trains can be attached via manifold to a single steam turbine-generator (STG), or a multi-unit plant can comprise independent gas turbine/HRSG/STG trains. The manifold configuration will have a lower cost and smaller footprint, while the independent trains will have better operating flexibility since an STG outage will not bring down the entire plant.

Start-up times for combined cycle plants are highly dependent on steam turbine size and on whether the plant is going through a cold start or a hot start. Start times can range from 30 minutes for a small unit undergoing a hot start to six hours for the cold start on a large, multi-unit plant.

One feature commonly implemented on combined cycle plants is the provision of supplemental firing in the HRSG to generate additional steam cycle power. This provides a peaking power increment of about 10 percent of the plant's nominal unfired rating. The incremental efficiency of supplemental firing is about 40 percent, lower than the efficiency of an unfired combined cycle plant, but higher than the efficiency of most simple cycle gas turbines.

Combined cycle units are sensitive to ambient temperature and suffer derating on hot days, but they are less sensitive than simple cycle gas turbines. The high temperature derating can be reduced by employing evaporative cooling or mechanical chilling on the compressor inlet air. Evaporative cooling works best for low-humidity operation. Mechanical chilling can be employed for either high- or low-humidity applications, but the chilling equipment is more costly than it is for evaporative cooling.

Gas Turbine Combined Cycle Plant Costs

The combined cycle cases include 140-MW and 580-MW sizes. The gas turbines used in both plants are heavy-frame. The estimates are based on completely constructed and operable units. The costs for the 140-MW and 580-MW combined cycle plants are provided for the United States, India, and Romania in Tables 5.4 and 5.5, respectively.

Basis of Estimates. The combined cycle plant cost estimates are based on the following:

- OEM Gas Turbine—Combined Cycle Package with Standard Components: Single-fuel gas turbine (natural gas), generator, steam turbine-generator, heat recovery steam generator, starting and lube oil systems, gas turbine controls, air filter, silencer, exhaust stack with silencer, vibration monitoring, and plant control system. This combined cycle package is based on OEM bid prices obtained from the in-house database of major equipment prices and auxiliary equipment

Table 5.4 140-MW Combined Cycle Plant—Heavy-Frame Gas Turbine

Each Item Includes Costs for Equipment, Material, and Labor (January 2008 US$)

Cost Estimate Summary	U.S. (thousands $)	India (thousands $)	Romania (thousands $)
Civil/Structural	7,240	5,130	5,280
Mechanical			
Gas Turbine (OEM Price)[1]	99,740	99,740	99,740
SCR	1,260	630	450
Gas Compressor	2,840	2,790	2,780
Electrical	9,720	8,070	7,590
Piping	9,480	6,680	8,680
Instruments and Controls	1,660	1,510	1,470
Balance of Plant/General Facilities	21,640	14,810	12,830
Total Direct Costs	153,580	139,360	138,820
Indirect Costs	13,490	4,960	3,470
Engineering and Home Office Costs	13,040	5,180	3,840
Process Contingency	0	0	0
Project Contingency	12,060	9,950	9,280
Total Plant Cost	192,170	159,450	155,410
Gas Turbine Cost (FOB-OEM), US$/kW	730	730	730
Total Plant Cost, US$/kW	1,410	1,170	1,140

Source: Author's calculations.

[1] OEM Price, Excluding Installation Labor.

prices. The combined cycle package bid price is based on detailed technical specifications and represents market pricing for both the 140-MW and 580-MW plant cases.

The combined cycle plant price is based on the OEM bid price as defined above plus the prices for the following additional items resulting from the design by the engineering firm: separate purchases of all necessary auxiliary equipment and purchases of bulk materials such as piping, concrete, electrical, and so forth (purchases based on bid packages). The auxiliary equipment and bulk material items that are included in the plant and added to the simple cycle price are as follows:

- No combustion air cooling or chilling system. Combined cycle plant performance and output based on ISO conditions.[5]
- SCR NO_x control system for the United States and Romania (no SCR for India).
- Natural gas compressor.
- Wet mechanical draft cooling tower.
- Raw water treatment and boiler feedwater treatment systems.
- Combination office/control/warehouse building.
- Water treatment building.
- Fire water system.
- Instruments and controls.
- Foundations.
- Piping.

[5] ISO conditions—15°C sea level, and 60 percent relative humidity.

Table 5.5 580-MW Combined Cycle Plant—Heavy-Frame Gas Turbine

Each Item Includes Costs for Equipment, Material, and Labor (January 2008 US$)

Cost Estimate Summary	**U.S. (thousands $)**	**India (thousands $)**	**Romania (thousands $)**
Civil/Structural	20,120	14,100	14,620
Mechanical			
Gas Turbine (OEM Price)[1]	262,930	262,930	262,930
SCR	3,460	1,730	1,230
Gas Compressor	3,480	3,410	3,390
Electrical	28,990	24,500	23,180
Piping	28,190	20,250	26,880
Instruments and Controls	4,300	3,890	3,760
Balance of Plant/General Facilities	46,700	34,380	30,810
Total Direct Costs	398,170	365,190	366,800
Indirect Costs	33,870	12,810	9,210
Engineering and Home Office Costs	32,750	13,380	10,210
Process Contingency	0	0	0
Project Contingency	30,280	25,690	24,660
Total Plant Cost	495,070	417,070	410,880
Gas Turbine Cost (FOB-OEM), $/kW	460	460	460
Total Plant Cost, $/kW	860	720	710

Source: Author's calculations.

[1] EM Price, Excluding Installation Labor.

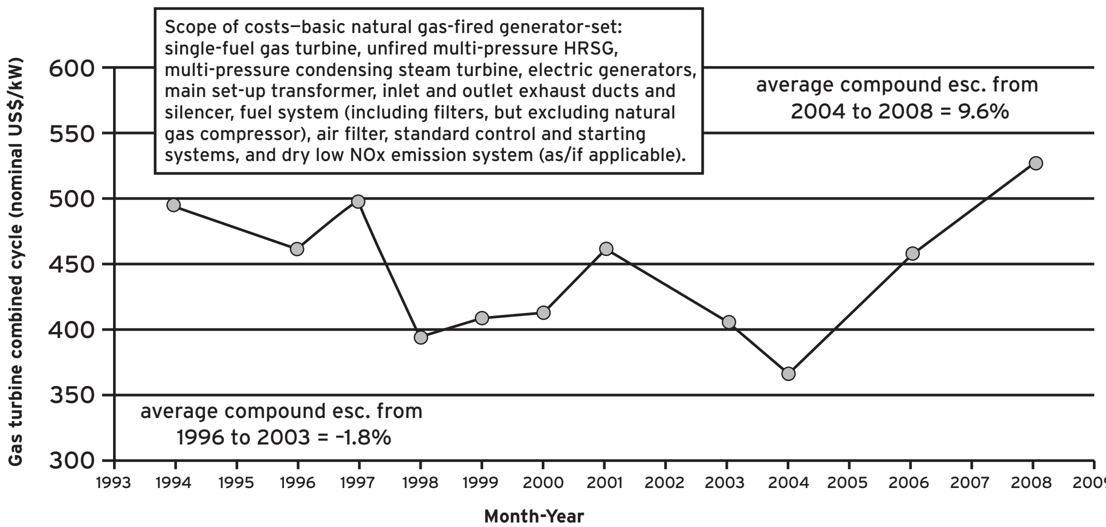
- Structural steel.
- Electric wiring.
- Switchgear.
- Motor controls.

Scope/Terminal Points of Estimate:

- Fuel: natural gas piping from plant fence.
- Make-up water: raw water piping from plant fence.
- Water effluent: effluent piping to plant fence
- Electricity: high side of transformer.
- Natural gas, make-up water, and effluent water pipelines outside the plant fence are not included.
- Access roads outside the plant fence are not included.
- Freight is not included.

The cost estimates are not based on specific sites within the respective countries. The combined cycle plant performance at each of the three locations is based on ISO conditions. This puts the comparison on a common footing. If specific site conditions were used within each country, then performance would influence the cost estimate. Common ambient conditions were used so that the cost differences would reflect the differences in construction labor wages, construction labor productivity, engineering wages, concrete costs, structural steel costs, and piping costs in the three countries. The tables show that costs for all of the simple cycle cases are less in India and Romania than they are in the United States. This is primarily due to the lower labor wage rates. The tables also show that the cost in India is

Figure 5.3 Year-to-Year Change in Average Price of Combined Cycle Units (> 130 MW)



Source: Gas Turbine World Handbook.

lower than the cost in Romania. This is a result of the lower cost in India for structural steel, piping, and concrete.

Comparison to Other Cost Estimates. Figure 5.3 shows the timeline of average OEM prices for combined cycle units for the same time period as the simple cycle units. The average prices are for about 50 combined cycle units in the GTW Handbook list ranging from 130 MW to over 700 MW. The trends displayed in the combined cycle curve are more varied, but the period from 2001 correlates in a general way with the previously discussed changes in year-to-year sales trends of gas turbine units. The average prices from 1996 through 2008 show a second peak in 2001, which is the same year that gas turbine sales reached the all-time record. The combined cycle curve shows the following cost profiles for units larger than 130 MW:

- In 2001, the average price of combined cycle units was about US$465/kW.
- In 2004, the average price of the units was about US$369/kW—a drop of 26 percent from 2001.
- In 2008, the average price of units was about US$533/kW—an increase of 44 percent from 2004.

Coal-Fired Steam Plant

Technology Development, Plant Descriptions, and Scope

Market Trends. In the United States, between 2000 and 2006, over 150 utility coal plants were under construction or in the planning stages. By the end of 2007, 10 of those proposed plants had been constructed and 25 plants were under construction. However, during the same year, 59 of the proposed plants were cancelled, abandoned, or put on hold. The reasons for cancellation were reported as follows:

- Climate concerns had begun to play a major role in plants being abandoned and cancelled. Concerns about global warming played a major role in 15 cases.
- Increasingly, coal plants were being cancelled very early in the process due to increasing regulatory scrutiny of long-range integrated resource plans and dramatic escalation in the estimated installed costs.
- Regulators in a number of states had begun favoring utility-scale renewable energy over coal. In addition, citizens in some states voted in favor of referendums that require utilities to have 10 to 20 percent of their

generation portfolio consist of renewable energy.

Aside from the above and the U.S. economy, the American Boiler Manufacturers Association's (ABMA) 2008 Annual Report by its President indicated that the economic slowdown would not appreciably affect the boiler industry. It was indicated that the boiler market would continue to benefit from sales and inquiry volumes not seen in years. Although the U.S. coal-fired plant market slowed considerably, the overseas market, particularly from China, was contributing to the ABMA assessment (and to a lesser, but important, extent from India).

With regard to the worldwide major equipment market, some additional data are available. These data incorporate the sales from all manufacturers in the world (of boilers and steam turbines):

- In the first three quarters of 2007, China placed 60 percent of the worldwide steam boiler orders on a capacity basis. This compares to 20 percent for India and 4 percent for the United States. India had the second-highest number of boiler orders of all countries in the world.
- In the first three quarters of 2007, China placed about 49 percent of the worldwide steam turbine orders on a capacity basis. This compares to 18 percent for India and about 4 percent for the United States. India had the second highest number of steam turbine orders of all countries in the world.

Lead Times:

- Steam turbines > 300 MW—22 to 26 months.
- Large boiler feed pumps—14 to 18 months.
- Steam turbines > 300 MW—22 to 26 months.
- Large boiler feed pumps—14 to 18 months.
- Large motors > 5000 kW—11 to 14 months.
- Centrifugal fans, 300 to 400 m3/sec or larger—12–15 months.
- Main steam piping or other heavy wall piping for units larger than 300 M—14 to 18 months (the alloy fitting shortage is a partial contributor to the long lead time).
- Large high-pressure valves—6 to 8 months.
- Pneumatic ash handling system—11 to 13 months.
- Extra-heavy structural steel—10 to 14 months two years ago; now 17 to 23 months.

Technology Description. The subcritical pulverized coal (PC) plant is based on the following cycle conditions:

- Main steam temperature—538ºC.
- Main steam temperature—16.6 MPa.
- Reheat steam temperature—538ºC.
- Feedwater temperature—257ºC.

The steam generator for the subcritical PC plant is a drum-type, wall-fired, balanced draft, natural circulation, enclosed dry bottom furnace, with superheater, reheater, economizer, and ljungstrom air heater.

The steam generator for the supercritical PC plant is a once-through, spiral wound, Benson-boiler, wall-fired, balanced draft, enclosed dry bottom furnace, with superheater, reheater, economizer, and ljungstrom air heater.

The supercritical PC plant is based on the following cycle conditions:

- Main steam temperature—566ºC.
- Main steam temperature—24.1 MPa.
- Reheat steam temperature—593ºC.
- Feedwater temperature—305ºC.

Pulverized Coal-Fired Plant Costs

The conceptual cost estimates for the 300-MW, 500-MW, and 800-MW PC power plants are provided for the United States, India, and Romania in Table 5.6, Table 5.7, and Table 5.8, respectively. The fuels burned in the respective cases are Powder River Basin (PRB) coal, Australian coal, and Romanian lignite. The estimates reflect the differences in construction labor wages, construction labor productivity, engineering wages, concrete costs, structural steel costs, and piping costs in the three countries. The criteria used to develop the cost estimates are in the Design Basis that is located in Annex 1.

Table 5.6 300-MW Pulverized Coal Power Plant—Costs for 1 x 300 MW Subcritical Pulverized Coal-Fired Plant

Each Cost Item Includes Equipment, Material, and Labor (January 2008 US$)

Conceptual Cost Estimate Summary Coal —>	**U.S. PRB (thousands $)**	**India Mt. Author-AU (thousands $)**	**Romania Rom-Lignite (thousands $)**
Earthwork/Civil	52,600	19,300	36,500
Structural Steel	29,400	10,500	28,600
Mechanical Equipment			
Boiler	113,400	87,100	141,500
Steam Turbine	40,200	37,800	38,800
Coal Handling	38,200	17,000	31,600
Ash Handling	13,400	9, 600	34,900
Particulate Removal System	17,800	9,609	22,000
Wet Flue Gas Desulfurization (FGD) System	61,800	0	67,800
Selective Catalytic Reduction	26,400	0	32,500
Total Mechanical Equipment	311,200	163,800	369,100
Electrical	47,200	26,500	25,400
Piping	32,000	15,000	13,700
BOP/General Facilities	130,400	140,000	183,200
Direct Field Cost	602,800	375,100	656,500
Indirect Costs[1]	46,000	20,100	25,300
Engineering and Home Office Costs[2]	62,600	27,100	47,100
Process Contingency	0	0	0
Project Contingency	106,700	84,500	145,800
Total Plant Cost	818,100	506,800	874,700
Total Plant Cost, US$/kWnet	2,730	1,690	2,920
Project Contingency, %	15	20	20
Plant Output, MWnet	300	300	300
Boiler Efficiency, %	84.4	89.2	72.6
Fuel Heating Value Higher Heating Value (HHV), MJ/kg	18.4	27.5	8.8
Ratio of Flows to U.S. Coal			
Coal	1.0	0.6	2.5
Ash	1.0	1.4	9.5
Air	1.0	0.9	1.2
Flue Gas	1.0	0.9	1.3
Limestone for FGD	1.0	NA	6.6
FGD Solids	1.0	NA	6.6

Source: Author's calculations.

[1] Field office nonmanual labor, craft support labor, and temporary facilities.

[2] Engineering, start-up, and general and administrative costs.

Table 5.7 500-MW Pulverized Coal Power Plant—Costs for 1 x 500 MW Subcritical Pulverized Coal-Fired Plant

Each Cost Item Includes Equipment, Material and Labor (January 2008 US$)

Conceptual Cost Estimate Summary Coal —>	**U.S. PRB (thousands $)**	**India Mt. Author-AU (thousands $)**	**Romania Rom-Lignite (thousands $)**
Earthwork/Civil	75,500	28,100	67,000
Structural Steel	40,400	14,600	49,800
Mechanical Equipment			
Boiler	151,700	118,900	209,400
Steam Turbine	60,400	56,900	58,400
Coal Handling	55,600	24,400	57,900
Ash Handling	16,800	11,900	67,600
Particulate Removal System	26,800	18,800	33,500
Wet FGD System	78,000	0	87,400
Selective Catalytic Reduction	40,900	0	50,400
Total Mechanical Equipment	430,200	230,900	564,600
Electrical	66,600	37,700	45,100
Piping	47,200	22,300	25,400
BOP/General Facilities	186,000	200,800	200,200
Direct Field Cost	845,900	534,400	952,100
Indirect Costs[1]	62,900	27,600	35,700
Engineering and Home Office Costs[2]	87,700	38,500	68,200
Process Contingency	0	0	0
Project Contingency	149,500	120,100	211,200
Total Plant Cost	1,146,000	720,600	1,267,200
Total Plant Cost, US$/kWnet	2,290	1,440	2,530
Project Contingency, %	15	20	20
Plant Output, MWnet	500	500	500
Boiler Efficiency, %	84.4	89.3	72.6
Fuel Heating Value (HHV), MJ/kg	18.4	27.5	8.8
Ratio of Flows to U.S. Coal			
Coal	1.0	0.6	2.5
Ash	1.0	1.4	9.5
Air	1.0	0.9	1.2
Flue Gas	1.0	0.9	1.3
Limestone for FGD	1.0	NA	6.6
FGD Solids	1.0	NA	6.6

Source: Author's calculations.

[1] Field office nonmanual labor, craft support labor, and temporary facilities.

[2] Engineering, start-up, and general and administrative costs.

Table 5.8 800-MW Pulverized Coal Power Plant—Costs for 1 x 800 MW Subcritical Pulverized Coal-Fired Plant

Each Cost Item Includes Equipment, Material and Labor (January 2008 US$)

Conceptual Cost Estimate Summary Coal –>	**U.S. PRB (thousands $)**	**India Mt. Author-AU (thousands $)**	**Romania Rom-Lignite (thousands $)**
Earthwork/Civil	102,800	40,600	104,000
Structural Steel	53,900	21,700	76,000
Mechanical Equipment			
Boiler	212,900	180,600	337,400
Steam Turbine	89,600	84,500	86,500
Coal Handling	74,600	33,300	87,200
Ash Handling	20,000	18,200	105,700
Particulate Removal System	36,500	25,600	46,000
Wet FGD System	95,300	25,600	113,200
Selective Catalytic Reduction	57,100	0	70,000
Total Mechanical Equipment	57,100	0	846,000
Electrical	586,000	54,200	70,000
Piping	70,300	35,500	43,300
BOP/General Facilities	253,900	275,300	217,200
Direct Field Cost	1,158,300	769,500	1,356,500
Indirect Costs[1]	83,000	37,500	47,900
Engineering and Home Office Costs[2]	120,000	55,400	97,100
Process Contingency	0	0	0
Project Contingency	204,200	172,500	300,300
Total Plant Cost	1,565,500	1,034,900	1,801,800
Total Plant Cost, US$/kWnet	1,960	1,290	2,250
Project Contingency, %	15	20	20
Plant Output, MWnet	800	800	800
Boiler Efficiency, %	84.5	89.3	72.6
Fuel Heating Value (HHV), MJ/kg	18.4	27.5	8.8
Ratio of Flows to U.S. Coal			
Coal	1.0	0.6	2.5
Ash	1.0	1.4	9.5
Air	1.0	0.9	1.2
Flue Gas	1.0	0.9	1.3
Limestone for FGD	1.0	NA	6.6
FGD Solids	1.0	NA	6.6

Source: Author's calculations.

[1] Field office nonmanual labor, craft support labor, and temporary facilities.

[2] Engineering, start-up, and general and administrative costs.

Basis of Estimate. The PC plant cases include 300-MW subcritical, 500-MW subcritical, and 800-MW supercritical units. The PCCost program was used to develop the total plant cost for each case. For these estimates the program included market demand factors. The PC plant cost estimates are based on completely constructed and operable units that include the following equipment and systems:

- Steam generator and accessories.
- Steam turbine and accessories.
- Main steam and reheat steam systems.
- Condensate and feedwater heating system.
- Turbine and steam line drains.
- Heater vents and drains.
- Auxiliary steam and condensate return systems.
- Condenser and circulating water system.
- Wet mechanical cooling tower.
- Condensate storage and transfer.
- Plant make-up water system and service water system.
- Demineralized water system.
- Closed cooling water system.
- Compressed air system.
- Boiler chemical feed system.
- Combustion air and flue gas system.
- Auxiliary boiler system.
- Particulate control system (fabric filter for the United States and electrostatic preciptator [ESPs] for India and Romania).
- FGD system (not required for India).
- Selective catalytic reduction system (not required for India).
- Coal handling system.
- Fly ash handling system and bottom ash handling system.
- Wastewater treatment system.
- Fire protection system.
- Instruments and controls.
- Foundations.
- Piping.
- Structural steel.
- Electric wiring.
- Switchgear.
- Motor controls.
- Buildings.

Scope/Terminal Points of Estimate:

- Coal: coal bunker underneath railroad tracks.
- Ash: outlet of ash silo.
- FGD solids: discharge of vacuum filter.
- Make-up water: raw water piping from plant fence.
- Water effluent: effluent piping to plant fence.
- Electricity: high side of transformer.
- Railroad track outside the plant fence is not included.
- Make-up water and effluent water pipelines outside the plant fence are not included.
- Access roads outside the plant fence are not included.
- Ash/FGD solids disposal area is not included.
- Evaporation ponds are not included.
- Freight is not included.

The tables show that the costs for all three plant sizes in India are much less than they are in the United States. This is due to the lower labor wage rates and lower prices of concrete and the substantially lower prices for structural steel and piping. The tables also show that the cost in Romania is higher than it is in either India or the United States. Although Romania has much lower labor wage rates and slightly lower concrete prices, these are offset by the higher price of structural steel and piping. More important is the impact of the Romanian lignite compared to the coals burned in the other two cases. The lignite has a heating value of 8.8 MJ/kg compared to the heating values of 26.4 for India and 18.4 for the U.S. PRB. In addition, the Romanian lignite has very high in moisture and ash content.

As shown at the bottom of the cost estimate tables, the high moisture content and other characteristics of the Romanian lignite result in a boiler efficiency that is about 15 percentage points lower than the coal burned in India and 11 percentage points lower than the coal burned in the United States. In addition, there are even more striking differences in the Romanian fuel compared to the United States and Indian coals. The differences and impacts are exemplified by the ratio of respective flows of coal, ash, air, and flue gas. For purposes of this comparison, the United States is used as the base case (see ratios of the Indian coal to the U.S. coal and the Romanian lignite to the U.S. coal at the bottom of each cost estimate table). The items below delineate the relative impacts of the Romanian lignite compared to the U.S. coal:

- The lower efficiency of the Romanian boiler results in a much larger furnace, boiler backpass, and air heater. Overall, the boiler in Romania burning the lignite is 2.1 times the size of the boiler in the United States burning PRB coal.
- The lignite burn rate is 2.5 times the U.S. coal burn rate, resulting in a much larger coal storage and coal handling system.
- Ash flow is 9.5 times the U.S. flow, resulting in an exceedingly large ash handling system and much larger ESP hoppers.
- Air flow is 1.2 times the U.S. flow, translating into larger combustion air fans and combustion air ductwork.
- Flue gas flow is 1.3 times the U.S. flow, translating into larger ductwork, ESP, FGD absorber cross-sectional area, induced draft (ID) fans, and diameter of the stack flue.
- The limestone flow for FGD is 5.6 times the U.S. flow, resulting in a much larger limestone storage and handling system.
- The flow of FGD waste solids is 6.6 times the U.S. flow, resulting in a much larger FGD waste handling system.

As a comparison to the costs estimated for this study, the list below provides the locations and reported costs for pulverized coal-fired plants:

- Illinois—2 × 800-MW supercritical mine-mouth plant, mid-2007, US$1,810/kW.
- Texas—1 × 900-MW supercritical plant, PRB coal, 2007, US$1,830/kW.
- Oklahoma—1 × 950-MW ultra-supercritical plant, PRB coal, 2007, US$1,900/kW.
- Iowa—1 × 830-MW supercritical plant, mid-2005, US$1,450/kW.
- South Carolina—1 × 600-MW supercritical plant, 2006, US$1,640/kW.
- Colorado—1 × 750-MW supercritical plant, 2006, US$1,800/kW.
- India—The Maharashtra State Mining Corporation announced plans to build 1 × 540-MW coal-fired power plant in Chandrapur (tender already issued), 2/16/2008, Rs 3,000 crore, which is approximately US$750 million or about US$1,400/kW. This compares to the study estimate for the 500-MW unit of US$1,440/kW in January 2008 US$.
- India—The Aravali Super Thermal Power Project 3 × 500-MW coal-fired power plant in Jhajjar district of Haryana, 6/1/2007, Rs 82.94 billion, which is approximately US$2.07 billion or about US$1,380/kW. This compares to the study estimate for the 500-MW unit of US$1,440/kW in January 2008 US$.

Oil-Fired Steam Plant

Technology Basis

The oil-fired plant case is for a 300-MW subcritical unit. The unit burns No. 2 fuel oil. The cost estimates are based on completely constructed and operable units.

Oil-Fired Plant Costs

The conceptual cost estimates for the 300-MW oil-fired power plants are provided for the United States, India, and Romania in Table 5.9. The estimates reflect the differences in construction labor wages, construction labor productivity, engineering wages, concrete costs, structural steel costs, and piping costs in the three countries. Similar to the coal-fired plant, these data are in Annex 1.

The table shows that total plant costs for India and Romania are less than they are in the United States due to the lower labor rates in both countries and the lower prices of concrete and steel in India. The cost of the plant in India is less than it is in the United States and Romania because the plant in India does not require a

Table 5.9 300-MW Oil-Fired Power Plant—Costs for 1 x 300 MW Subcritical Oil-Fired Plant

Each Item Costs for Equipment, Material, and Labor (January 2008 US$)

Conceptual Cost Estimate Summary	**U.S. (thousands $)**	**India (thousands $)**	**Romania (thousands $)**
Earthwork/Civil	34,400	22,900	21,200
Structural Steel	17,800	11,400	19,600
Mechanical Equipment			
Boiler	86,600	74,300	70,000
Steam Turbine	40,200	37,800	38,800
Coal Handling			
Ash Handling			
Particulate Removal System			
Wet FGD System			
Selective Catalytic Reduction	17,600	0	16,800
Total Mechanical Equipment	144,400	112,100	125,600
Electrical	33,300	23,000	26,100
Piping	26,900	12,800	15,100
Balance of Plant/General Facilities	70,900	68,500	99,600
Direct Field Cost	327,700	250,700	307,200
Indirect Costs[1]	24,000	14,200	11,600
Engineering and Home Office Costs[2]	34,000	18,100	22,000
Process Contingency	0	0	0
Project Contingency	77,100	70,700	85,200
Total Plant Cost	462,800	353,700	426,000
Total Plant Cost, US$/kW	1,540	1,180	1,420

Source: Author's calculations.

[1] Field office nonmanual labor, craft support labor, and temporary facilities.

[2] Engineering, start-up, and general and administrative costs.

selective catalytic reduction (SCR). The cost of the plant in India is also less than it is in Romania because the price of concrete is lower and the prices of structural steel and piping are substantially lower than they are in Romania.

Basis of Estimate. The oil-fired plant cost estimates include market demand factors and are based on the following equipment and systems:

- Steam generator and accessories.
- Steam turbine and accessories.
- Main steam and reheat steam systems.
- Condensate and feedwater heating system.
- Turbine and steam line drains.
- Heater vents and drains.
- Auxiliary steam and condensate return systems.
- Condenser and circulating water system.
- Wet mechanical cooling tower.
- Condensate storage and transfer.
- Plant make-up water system and service water system.
- Demineralized water system.
- Closed cooling water system.
- Compressed air system.

- Boiler chemical feed system.
- Combustion air and flue gas system.
- Auxiliary boiler system.
- Selective catalytic reduction system (not required for India).
- Wastewater treatment system.
- No. 2 fuel storage tanks.
- Fire protection system.
- Instruments and controls.
- Foundations.
- Piping.
- Structural steel.
- Electric wiring.
- Switchgear.
- Motor controls.
- Buildings.

Scope/Terminal Points of Estimate:

- Make-up water: raw water piping from plant fence.
- Water effluent: effluent piping to plant fence.
- Electricity: high side of transformer.
- Make-up water and effluent water pipelines outside the plant fence are not included.
- Access roads outside the plant fence are not included.
- Freight is not included.

Natural Gas-Fired Steam Plant

Technology Development, Plant Descriptions, and Scope

The gas-fired plant case is for a 300-MW subcritical unit. The unit burns natural gas and is based on the fact that the natural gas is delivered to the plant at the pressure required by the boiler burners. The cost estimates are based on completely constructed and operable units.

Natural Gas-Fired Plant Costs

The conceptual cost estimates for the 300-MW natural gas-fired power plants are provided for the United States, India, and Romania in Table 5.10. The estimates reflect the differences in construction craft labor wages, construction labor productivity, engineering wages, concrete costs, structural steel costs, and piping costs in the three countries. Similar to the coal-fired plant, these data are in Annex 1.

Basis of Estimate. The oil-fired plant cost estimates include market demand factors and are based on the following equipment and systems:

- Steam generator and accessories.
- Steam turbine and accessories.
- Main steam and reheat steam systems.
- Condensate and feedwater heating system.
- Turbine and steam line drains.
- Heater vents and drains.
- Auxiliary steam and condensate return systems.
- Condenser and circulating water system.
- Wet mechanical cooling tower.
- Condensate storage and transfer.
- Plant make-up water system and service water system.
- Demineralized water system.
- Closed cooling water system.
- Compressed air system.
- Boiler chemical feed system.
- Combustion air and flue gas system.
- Auxiliary boiler system.
- Selective catalytic reduction system (not required for India).
- Wastewater treatment system.
- Fire protection system.
- Instruments and controls.
- Foundations.
- Piping.
- Structural steel.
- Electric wiring.
- Switchgear.
- Motor controls.
- Buildings.

Scope/Terminal Points of Estimate:

- Make-up water: raw water piping from plant fence.
- Water effluent: effluent piping to plant fence.
- Electricity: high side of transformer.
- Switchyard is not included.
- Natural gas is delivered to the plant fence at the pressure required by the boiler burners.

Table 5.10 300-MW Natural Gas-Fired Power Plant—Costs for 1 x 300 MW Subcritical Natural Gas-Fired Plant

Each Item Costs for Equipment, Material, and Labor (January 2008 US$)

Conceptual Estimate Summary	U.S. (thousands $)	India (thousands $)	Romania (thousands $)
Earthwork/Civil	32,100	20,700	19,100
Structural Steel	16,700	10,800	18,300
Mechanical Equipment			
Boiler	73,200	62,800	58,900
Steam Turbine	40,200	37,800	38,800
Coal Handling	0	0	0
Ash Handling	0	0	0
Particulate Removal System	0	0	0
Wet FGD System	0	0	0
Selective Catalytic Reduction	14,000	0	13,400
Total Mechanical Equipment	127,400	100,600	111,100
Electrical	24,800	17,200	19,000
Piping	26,800	12,900	15,100
Balance of Plant/General Facilities	61,300	59,400	55,500
Direct Field Cost	289,100	221,600	238,100
Indirect Costs[1]	21,500	12,400	8,400
Engineering and Home Office Costs[2]	30,000	16,000	17,100
Process Contingency	0	0	0
Project Contingency	68,100	62,500	65,900
Total Plant Cost	408,700	312,500	329,500
Total Plant Cost, US$/kW	1,360	1,040	1,100

Source: Author's calculations.

[1] Field office nomanual labor, craft support labor, and temporary facilities.

[2] Engineering, start-up, and general and administrative cost.

- Make-up water and effluent water pipelines outside the plant fence are not included.
- Natural gas pipeline outside the plant fence is not included.
- Access roads outside the plant fence are not included.
- Freight is not included.

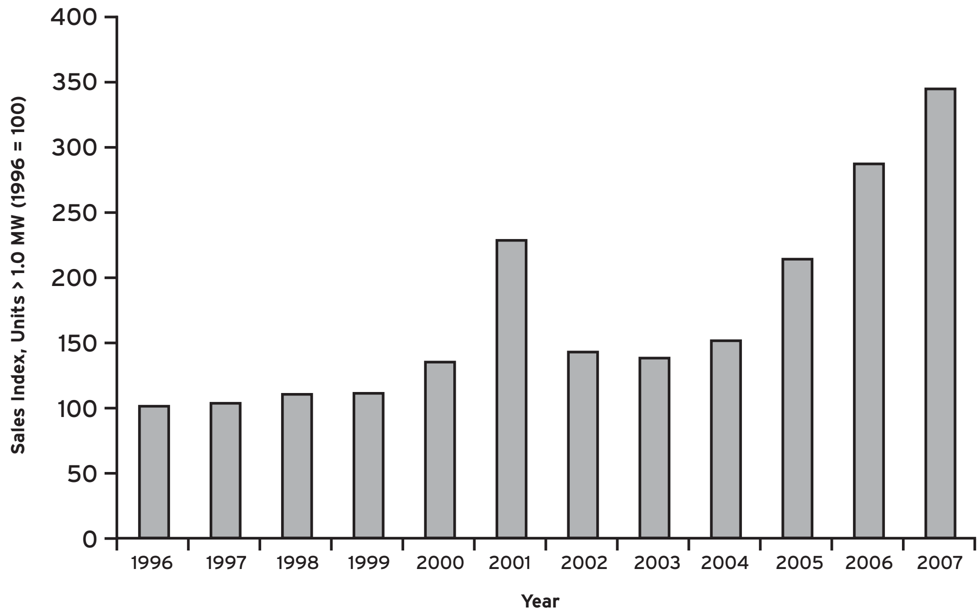
The table shows that costs for India and Romania are less than they are in the United States due to the lower labor rates in both countries and the lower prices of concrete and steel in India. The cost of the plant in India is less than it is in the United States and Romania because the plant in India does not require an SCR. The cost of the plant in India is less than it is in Romania because the price of concrete is lower and the prices of structural steel and piping are substantially lower than they are in Romania.

Diesel-Generator Plant

Technology Development, Plant Descriptions, and Scope

Market Trends. According to available data (from a database starting in 1978), worldwide sales of diesel engine-generators from 1 to 30 MW

Figure 5.4 Profile of Worldwide Stationary Reciprocating Engine Sales



Source: Author's calculations.

roughly followed the trend of gas turbines by peaking in 2001. Then in 2002, sales plummeted. After 2002, sales roughly followed the trend of gas turbines, except that in 2005 and after sales grew more rapidly. The trend is shown in Figure 5.4.

Starting in 2000, the year-to-year-before change for diesel engines greater than 1 MW was as follows:

- 2001—Sales increased by 68 percent.
- 2002—Sales decreased by 38 percent.
- 2003—Sales decreased by 2 percent.
- 2004—Sales increased 8 percent.
- 2005—Sales increased 41 percent.
- 2006—Sales increased 34 percent.
- 2007—Sales increased 20 percent.

In 2007 worldwide sales based on the number of units, the 1.01- to 2.0-MW range represented 84 percent of the market and the 2.01- to 5.0-MW range represented 12.5 percent of the market. From 2006 to 2007, the areas of the world that experienced the largest increases in number-of-unit sales were North America and Eastern Europe and Russia. In North America, the sales of units in the 1.01- to 5.0-MW range increased 12 percent and in Eastern Europe and Russia, sales in the 1.01- to 5.0-MW range doubled. In 2007, North America had the largest portion of worldwide sales in the 1.01- to 5.0-MW range, at 29 percent.

Diesel-Generator Plant Description. Diesel engines differ from the previously discussed technologies in that they are of a size amenable to distributed generation. This analysis is for 1-MW and 5-MW units. Even at 5 MW, the engine is prefabricated and requires minimal engineering to be installed and begin operation. Over the past 20 years, efficiencies have improved and emissions have been reduced with refined combustion control. The reciprocating engine in this study is a compression ignition engine fired with No. 2 fuel oil.

Historically, reciprocating engines have been used in standby and emergency applications, for peaking power service on intermediate to base-loaded facilities and cogeneration applications. Larger oil-fired engines are more frequently used outside the United States for stationary utility and base-load applications, and this is the basis of the engines being included in this study.

Diesel Engine-Generator Plant Costs

The engine manufacturer in the United States that provided the budget quotes for this project indicated that its engines were being sold in India, and, as such, worldwide market pricing is assumed. On this basis, the price of the engine package is the same for each country. The additional items in Table 5.11 apply to the 1-MW and 5-MW diesel engine-generator units.

The costs in Table 5.12 are based on budget quotes for units delivered in 2008. The build-up of costs from the engine price to the "bottom-line" price is based on the relationship of balance of plant (BOP) equipment prices, installation labor, market demand factors, etcetera.

The BOP costs have the most effect on the variations between the countries. Because the engine represents such a large part of the cost and because budget quotes were provided specifically for this study, the project contingency is reduced from 15 percent to 10 percent in the United States and 20 percent to 15 percent in India and Romania.

Basis of Estimate. The diesel engine package typically provided by the OEMs consists of:

- Engine.
- Generator.
- Lube oil system.
- Radiator for cooling.
- Electric start system.
- Air intake filter.
- Stack.

In addition, the plant scope includes:

- Fuel oil storage tank.
- Concrete.
- Piping.
- Electrical.
- Instruments and controls.

Table 5.11 Diesel Engine Information

Engine Rating (ISO)	**1.36 MW**	**4.84 MW**
Engine Speed, rpm	1800	900
Engine Configuration	V-12, 4-stroke	V-16, 4-stroke
Lead Time, order to delivery, months	12	24

Source: Author's calculations.

Table 5.12 Total Plant Prices for Diesel Engine-Generator Plants in India, Romania, and the United States

Plant Cost (US$/kW)—January 2008 US$	**India**		**Romania**		**U.S.**	
	1 MW	**5 MW**	**1 MW**	**5 MW**	**1 MW**	**5 MW**
Generation Module Equipment Cost	287	444	287	444	287	444
BOP Equipment	63	29	95	44	81	38
Installation	41	21	29	15	81	42
General Facilities and Engineering*	19	25	13	18	38	50
Subtotal Cost	410	519	424	521	487	574
Process Contingency	0	0	0	0	0	0
Project Contingency	61	78	64	78	49	57
Total Plant Cost (Rounded)	470	590	490	600	540	630

Source: Author's calculations.

*Includes home office and indirect costs.

Scope/Terminal Points of Estimate:

- Electricity: no grid interconnection costs.
- Fuel oil unloading facilities.
- Access roads outside the plant fence are not included.
- Freight is not included.

As evidenced by the costs in the table, reciprocating engines demonstrate a reverse economy of scale. Costs per kW actually increase with larger engines because of the reduction in crank-shaft speed (the decrease in power per unit of cylinder displacement) and increased engine mass. Additionally, smaller engines have a fairly large production base, whereas larger units are usually built only upon order and so do not benefit from mass production economies.

The table shows that project costs in the overseas countries range from US$50/kW to US$70/kW lower than in the United States for the 1-MW diesel engine-based plant and US$30/kW to US$40/kW less for the 5-MW plant. The cost differences, as previously indicated, are due to the cost of labor and the cost of materials in the balance of plant support equipment.

One way to reduce the capital costs of a diesel engine plant is to purchase reconditioned engines. Diesel engines lend well to the second-hand engine market, as relatively inexpensive components may be replaced, while the costly engine block can be reused. Prices of used or reconditioned engines are generally one-half the cost of a comparable new engine. This could be a favorable choice for some users in India and Romania and an even more desirable option for third-world countries.

Comparison to Published Costs:

- Texas—203-MW reciprocating engine-generator plant with 24 Wartsila engines (nominal 8 MW), announced 2/19/2008 and scheduled to begin operation in two phases in 2009 and 2010. Wartsila's scope includes all related mechanical and electrical auxiliaries, SCRs, installation, and start-up. The reported cost is US$120 million or US$590/kW. (This is the same scope as the cost estimates listed above.)
- Kansas—76-MW reciprocating engine-generator plant with 8 Wartsila engines (same engines as Texas), announced 2/19/2008 and scheduled to begin operation in September 2008. The contract is with Wartsila for US$30 million (for the engine-generators supply only). This translates to an engine-only cost of about US$390/kW.
- Northern California—116-MW reciprocating engine-generator plant with 14 Wartsila engines (same engines as Texas, but designed for very low emissions), announced April 2007 and scheduled to begin operation in May 2009. The contract is with Wartsila for US$50 million (for the engine-generators supply only). This translates to an engine-only cost of about US$430/kW.

Onshore Wind Farms

Technology Development, Plant Descriptions, and Scope

Wind Turbine Description. Wind turbine components include the rotor blades, generator (asynchronous/induction or synchronous), power regulation, aerodynamic (Yaw) mechanisms, and the tower. Wind turbine component technology continues to improve, including the blades (through increasing use of carbon epoxy and other composite materials to improve the weight/swept area ratio); generators (doubly-fed induction generators and direct-drive synchronous machines providing improved efficiency over broader wind speed ranges); power regulation (through active stall pitch controls); and towers (tubular towers minimize vibration, allow for larger machines to be constructed, and reduce maintenance costs by providing easier access to the nacelle).

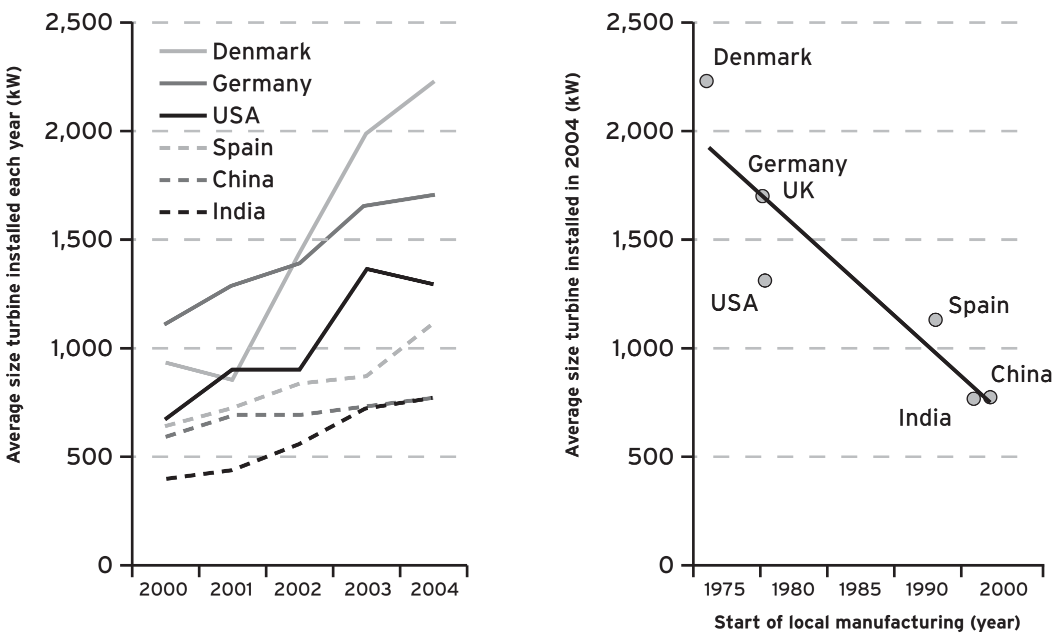
Wind Turbine Development and Market. Wind generation technology is growing faster than any other renewable energy source in the world, as evidenced by the 20 GW of new generation capacity installed in 2007. This brings the total generation capacity to more than 94 GW worldwide at the end of 2007, according to the Global Wind Energy Council. In 2007, the United States was the leader in new generating capacity installations, increasing its generating capacity by 45 percent by adding 5.2 GW. Spain and China were second in installations, adding 3.5 GW and 3.4 GW, respectively. Europe has consistently been the leading market for wind in the past few years, with Germany and Spain being the main players, while other regions are catching up. China more than doubled its wind power capacity, and has been encouraging domestic production, with more than 40 Chinese companies involved in manufacturing in 2007.

Just a few years ago, 1–2-MW turbines were considered the large industrial scale. Today, however, many major manufacturers are advancing to 3–5-MW turbines. Figure 5.5 from BTM's Wind Energy Development World Market Update shows the relationship between a country's turbine manufacturing experience and the average turbine size installed. These graphs indicate that longer manufacturing experience correlates to larger average turbine installations. As such, smaller turbines are generally preferred in the developing Asian markets. In 2006, the average turbine size delivered to India was 930 kW, versus 1,950 kW to the United Kingdom and 1,670 kW in the United States. Additionally, smaller turbines can be very useful in markets with limited infrastructure for construction or challenging topography.

The world market for wind generation has seen consistent growth in the past several years, and is likely to continue the boom with rising environmental concerns for fossil-fueled power plants. Wind has established itself as the largest and most experienced renewable power producer and as such is likely to hold a market share of renewable power as CO_2 emissions and water supply concerns grow.

Wind Market in the United States. From 1999 to 2004, the U.S. wind market was plagued with highs and lows in annual growth, correlating to the short-term extensions of the federal production tax credit (PTC). This cycle appears to have been broken, however, with consistent implementation of the PTC and corresponding steady growth in the wind market for the past three years. This sustained growth is attributed to federal tax incentives, state-imposed renewable portfolio standards, possible future environmental restrictions, and uncertain fuel costs for fossil plants.

Figure 5.5 Manufacturing Experience and Average Turbine Size



Source: Author's calculations.

General Electric (GE) has been the dominant wind turbine manufacturer in the United States, providing 60 percent of new wind generation in the United States in 2005 and 47 percent in 2006. Manufacturing competition continues to increase with increasing demand for wind, evidenced by GE's decreased market share from 2005 to 2006. As wind demand increases, overseas manufacturers have begun to establish plants in the United States. Vestas began building a blade manufacturing plant in Colorado in summer 2007; Siemens is building a plant in Iowa; and Clipper Windpower maintains its manufacturing of 2.5-MW wind turbines in Cedar Rapids, Iowa. Other companies active in the U.S. market include Mitsubishi Heavy Industries, Suzlon Wind Energy Company, and Gamesa.

Wind Market in India/Asia. According to the Global Wind Energy Council (GWEC), India had over 8 GW of wind capacity installed at the end of 2007, up from 6.2 GW at the end of 2006. Growth in China has more than doubled in the past year, adding over 3.4 GW of capacity in 2007. Emerging Energy Research (EER) predicts that, alongside North America, Asia will have the largest growth in wind power through 2015, estimating over 4.6 GW of additional wind power within the next 10 years. Governments in this sector are showing increasing support for renewable energy, evidenced in India by new policies aiming to increase energy independence and improve environmental image.

Suzlon, an Indian-owned company, has been the dominant market player in India, holding 52 percent of total installed capacity in 2006. Enercon and Vestas were the next largest players, with GE and Gamesa holding smaller shares in India. In China, Goldwind (Jinfeng) and Vestas have been major market players, each holding nearly 30 percent of the wind market in 2006. Other companies in the Indian market include Gamesa, GE, Acciona, Nordex, REPower, and Suzlon.

Wind Market—Romania/Eastern Europe. While Western Europe has traditionally led in worldwide wind generation capacity, Eastern Europe has significant potential for growth. EER estimates that this market will grow from about 550 MW to greater than 7.5 GW by 2015, with the main growth potential in Poland, Turkey, the Czech Republic, and Hungary. Targets set by the European Commission call for 20 percent of power generation from renewable sources by 2020. In order to achieve this goal, it is likely that Eastern European countries will need to employ the use of more wind power, particularly because wind is the most advanced large-scale renewable generation technology. This motivation for growth in the wind market is counteracted by these countries' traditional dependency on fossil power plants. Also, Eastern European countries tend to lack the mature regulatory framework and established subsidies and tax incentives that Western counterparts may have in place. Nonetheless, Eastern European governments do seem to be moving toward support of such programs and some of the major market players are positioning themselves in this emerging marketplace. Iberdrola, Acciona, EuroTrust, and Good Energies are all starting to position themselves, often in partnership with local firms, for the Eastern European development of wind power.

Wind Farm Costs

Advancements in wind turbine technology, increased operating experience, and mass production of components have driven the costs of wind power down more than 80 percent over the past 20 years. A compilation of data from the Lawrence Berkeley National Lab shows the cost of U.S. wind projects as between US$3,000–4,000/kW in the early 1980s, while the current cost of projects is between US$1,000–2,500/kW. The bulk of an installed cost is accounted for by the turbine itself, which generally makes up about 65–80 percent of the total installed cost. Civil work, including the foundation and roads, is the second biggest piece, typically making up 5–15 percent of the installed cost, followed by project financing/overhead, grid connection, and electrical installation, each of which generally accounts for 1–10 percent of the total installed cost. Last, land accounts for 1–3 percent of the total installed cost of a wind farm.

Table 5.13 provides estimated capital and operating costs of three wind farms of varying

Table 5.13 Wind Farm—Cost Estimate Summary, United States

(Prorated per Individual Turbine, Except as Noted)

Cost Component (2008 US$)	Units	12-MW Farm	50-MW Farm	100-MW Farm
Turbine Size		750 kW	1 MW	2.5 MW
Number of Turbines		16	50	40
Rotor Diameter	meters	50	65	85
Hub Height	meters	55	55	100
Rotor	1000 US$	160	180	430
Drive Train, Nacelle	1000 US$	480	660	1,520
Control, Safety System, and Condition Monitoring	1000 US$	50	50	50
Tower	1000 US$	120	140	430
Turbine Capital Cost, per Turbine	1000 US$	**810**	**1,030**	**2,430**
Balance of Plant				
Foundations	1000 US$	50	60	90
Roads and Civil Work (Other Than Foundations)	1000 US$	67	86	176
Turbine Installation	1000 US$	30	41	114
Electrical Interface and Connections	1000 US$	120	150	310
Direct Field Cost per Turbine (Rounded)	1000 US$	**1,080**	**1,370**	**3,120**
Engineering and Home Office	1000 US$	30	40	65
Project Contingency	1000 US$	170	280	640
Total Plant Cost per Turbine (Rounded)	1000 US$	1,310	1,690	3,830
Total Plant Cost for Farm (Rounded)	1000 US$	**21,000**	**84,500**	**153,200**
Total Plant Cost (US$/kW)	**$/kW**	**1,750**	**1,690**	**1,530**
Annual Energy Production (AEP)	GWh/yr	32	132	263

Source: Wind Turbine Cost and Scaling Model, NREL/TP-500-40566, December 2006.

sizes installed in the United States. These costs are based on a class 4 location, assuming a 98 percent availability of the turbine, and a 30 percent capacity factor. Installed turbine costs were derived from the wind turbine design cost model described in Fingersh et al.

Basis of Estimate. The wind farm cost estimates are based on the following:

- Wind turbine.
- Tower.
- Control systems.
- Electrical interconnection within the farm.
- Foundations.
- Roads and civil work within the farm.

Scope/Terminal Points of Estimate:

- Electricity: no grid interconnection costs.
- Access roads outside the farm boundary are not included.
- Freight is not included.

For each of the estimates in Table 5.14, the turbine accounts for about 70 percent of the direct field cost, indicating that only about 30 percent of project costs are site-specific, including civil and road work, transportation costs, assembly, and electrical work.

The wind turbine market is now world sourced so that the same wind turbine costs

Table 5.14 Cost Estimate Summary per 1-MW Wind Turbine 100-MW Wind Farm in India, Romania, and the United States

Cost Component (2008 US$)	Units	India	Romania	U.S.
Project Contingency	%	20%	20%	15%
Turbine Size	MW	1	1	1
Number of Turbines		100	100	100
Turbine Capital Cost (1000 US$)	**1000**	**1,030**	**1,030**	**1,030**
Balance of Plant				
Foundations	1000	39	54	57
Roads and Civil Work (Other Than Foundations)	1000	82	59	86
Turbine Installation	1000	21	14	41
Electrical Interface and Connections	1000	270	210	150
Total Direct Field Cost per Turbine	1000	**1,450**	**1,360**	**1,370**
Engineering and Home Office	1000	20	20	40
Project Contingency	1000	290	280	220
Total Plant Cost per Turbine (Rounded)	**1000**	**1,760**	**1,660**	**1,630**
Total Plant Cost for Farm (Rounded)	**1000**	**176,000**	**166,000**	**163,000**
Total Plant Cost (Rounded)	**$/kW**	**1,760**	**1,660**	**1,630**
Annual Energy Production (AEP)	GWh/yr	100	120	132

Source: Author's calculations.

apply to all three countries. The variation in cost is for the balance of plant material, which would be obtained in the respective countries. With the above in mind, Table 5.14 provides costs for 100-MW wind farms located in each of the three countries. The wind farms are made up of 1-MW wind turbines.

Site variations in the cost of wind projects are likely due to the extent of the electrical work needed, which may be inflated in areas where connection to the grid may be difficult and could be the case in India and Romania. The availability of local turbine manufacturers will cut down on transportation costs. Foundations and road work will be site-specific and may add significantly to the costs, although for all three locations in this analysis, it is reasonable to assume average soil and site conditions. To reiterate, a majority of the project costs can be attributed to the wind turbine costs themselves. Annual energy production for each site was based on the average wind resource available in each country. It was assumed that class 4 wind was available in the United States, class 3 wind in India, and somewhere between class 3 and 4 was available in Romania.

As a comparison, publications and industry news articles indicate the following wind farm projects planned or about to be built. The list below provides the locations and reported costs for wind farm projects:

- Texas—80 miles SW of Dallas: 60 MW (24 × 2.5-MW turbines), project cost: US$1,670/kW. By BP and Clipper. Project broke ground September 2007.
- Texas panhandle—Four-phase 4,000-MW facility to break ground in 2009, eight years expected to complete. Cost estimated: US$1,700–1,850/kW. By Mesa Power.
- Poland and Bulgaria—In 2008, Gamesa signed contracts for wind farm projects, which total 180 MW; cost: 201 MM euros, which equals US$1,640/kW.
- European clients—Gamesa reported total multi-annual contracts for a total of 777 MW;

cost: 700 MM euros, which equals US$1,300/kW contracted.

- Canada—50 MW (1.5-MW turbines), Acciona Energy; cost: CAN$103.5, which equals US$2,030/kW United States, awarded January 2008.

The costs cited in the tables above compare to the published costs as follows:

- The published wind farm costs range from US$1,300 to US$2,030/kW, with the published mid-range project costs being between US$1,640 and US$1,850/kW.
- The estimated costs in the table shown above for the 100-MW and 50-MW U.S. wind farms range from US$1,530 to US$1,690/kW.
- The estimated costs in Table 5.14 for the 100-MW wind farms in the three countries range from US$1,630 to US$1,760/kW.

Market Trends in Wind Turbine Costs. Some references have predicted that over the long term, wind turbine costs will decline. This is related to advancements in the technology and increases in individual turbine size. In 2003, the European Wind Energy Association predicted that wind energy costs would decline according to the graph shown in Figure 5.6. This graph portrays the decline in costs for Europe.

Despite predictions of decreasing costs from technology advancement and increased operating experience, in the United States, the cost of wind power in the past few years has shown a general upward trend. Increasing project costs have been attributed mainly to the increase in wind turbine demand, a tighter market, rising materials costs, and a move toward manufacturing profitability. Increasing materials costs are the predominant driver of increasing turbine costs. The significant increases in material costs, particularly from 2004 to 2008, are shown in the graphs in Chapter 4.

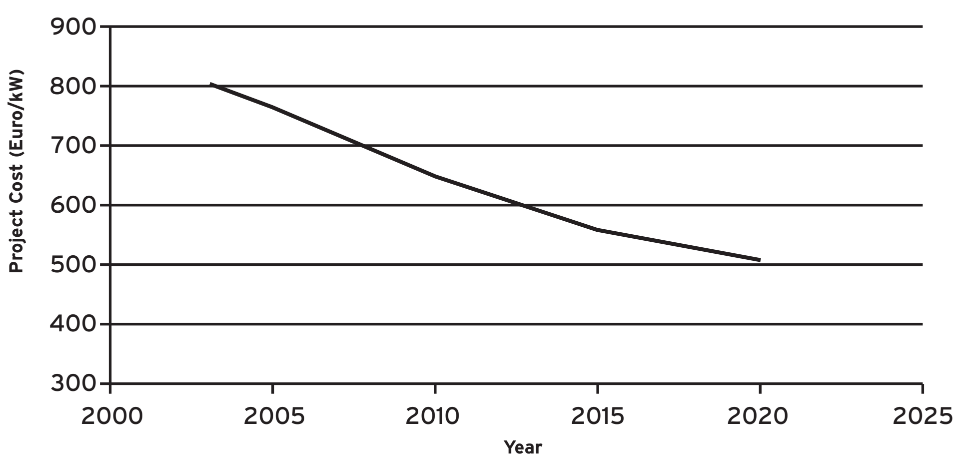
Figure 5.7 from the Berkeley Lab database illustrates this trend. This graph shows that wind turbine prices in the United States did decline from 1997 until 2001. During 2001, however, prices began to rise and in fact increased by more than US$400/kW between 2002 and 2007. Offsetting this trend has been a decline in the cost of financing a project. Financing costs have decreased in response to the higher demand for wind projects and associated investor interest. This factor has reduced the overall escalation, with project costs increasing about US$200/kW in the past few years.

Photovoltaic Array

Technology Development, Plant Descriptions, and Scope

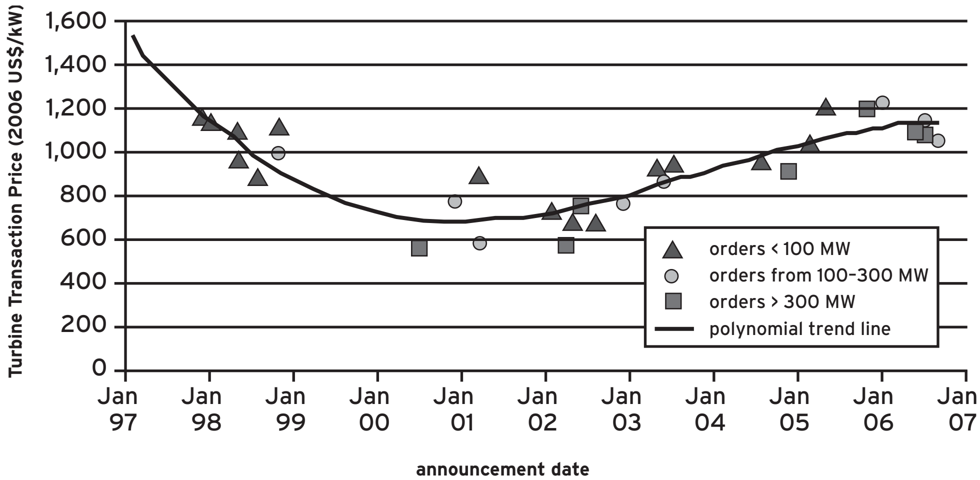
Description of Photovoltaic Technology. This study focuses on the most common installation for direct electricity generation, a fixed-angle

Figure 5.6 Projections of Long-Term Trends in Wind Turbine Costs in Europe



Source: European Wind Energy Association.

Figure 5.7 Reported U.S. Wind Turbine Transaction Prices



Source: Berkeley Lab Database.

mounted, flat panel array, including necessary system components such as an inverter, support structures, wiring, and land.

Photovoltaic (PV) cells have traditionally been made with crystalline silicon, putting PV manufacturers in competition with electronics manufacturers for highly purified silicon wafers. More recent technology has been moving toward thin films for PV cells that require just a fraction of the material needed for silicon crystal PV cells. Thin film cells can be made using amorphous silicon, copper indium diselenide (CIS), or cadmium telluride (CdTe). Although more efficient materials exist for PV, amorphous silicon is most commonly used for thin film PV cells because of its low cost and functionality.

Sunlight intensity and the operating temperature of the PV cell will determine power output. PV arrays are rated by the watts produced under peak sunlight, denoted as Peak Megawatt Output (MWp). Solar cell efficiency is defined as the amount of light that hits the cell that is converted to electricity. Of the electricity produced by the cell, 20 percent is typically lost en route to the busbar electricity due to wiring losses, Direct Current (DC)-to-Alternating Current (AC) conversion, and power conditioning. Overall cell efficiencies for crystalline silicon are in the 15–20 percent range, with thin film technologies at around 10 percent or less.

Photovoltaic Power Development and Market/ PV System Installations Worldwide. Photovoltaic installations have increased more than tenfold over the last 10 years, while costs have dropped by about 20 percent for each doubling of installed PV capacity. The overall growth rate for PV systems had maintained a fairly steady 30 percent per year from 1995–2003. However, in 2004 the growth jumped to 60 percent, bringing worldwide installed capacity to more than 4 GW. Market growth has been very much influenced by government incentives and rooftop programs mainly offered in Germany, Japan, and the United States. Market installations in 2006 reached a record high of 1,744 MW, totaling more than 9 GW of installed capacity worldwide. Germany held the largest market share, accounting for 55 percent of grid-connected PV installations in 2006, while Japan and the United States had 17 percent and 8 percent, respectively. All three of these countries have implemented financial incentives for solar systems, including rooftop programs encouraging residential and commercial installations.

Over the past few years, utility-scale installations have increased noticeably. A 154-MW concentrating solar PV system was recently commissioned for start-up in 2013 in Australia, while a 40-MW station is to be installed in Toronto, Canada, in response to a strong government subsidy. North America's largest PV installation, rated at 15 MW, was completed at the Nellis Air Force Base in Nevada in December 2007. Commercial installations continue to be explored, as corporations such as Macy's, Wal-Mart, and Google plan rooftop installations in the United States. Residential customers also make up a small segment of the market, as builders such as McStain, in the state of Colorado, offer solar panels as a standard feature of their homes, allowing buyers to finance the cost in their mortgage. Residential systems are further encouraged by individual tax incentives as well as utility-based incentive programs.

PV Cell and Module Manufacturing. PV cells manufactured worldwide reached more than 2,200 MW in 2006, with Japan overtaking the United States for the largest net exporter of PV cells and modules. Nearly 40 percent of total global cell production in 2006 can be attributed to Japan. While PV production rose approximately 33 percent from 2005 to 2006, production of crystalline silicon increased by only 16 percent. Costs of PV cells are widely being driven by supply, demand, and availability of materials for the cells. Thus, while the supply of PV cells is increasing, silicon prices are rising due to competition with computer chip manufacturers. As such, manufacturing activity in the thin film world is booming, where cells can be produced with a fraction of the material as that needed for conventional crystalline cells. The thin film market is projected to grow from US$1 billion in 2007 to nearly US$7.2 billion in 2015, with over half of the projected growth destined for industrial and commercial building applications.

Japan has four of the top 10 solar cell manufacturing companies: Sharp, Kyocera, Mitsubishi Electric, and Sanyo. U.S. manufacturing companies include BP Solar, Shell Solar, GE Energy, United Solar Ovonics, Evergreen Solar, First Solar LLC, and SunPower Corp. Emerging thin film manufacturers include Miasole, Nanosolar, and HelioVolt behind some of the major thin film manufacturers such as Kaneka, United Solar, Mitsubishi, First Solar, and Antec. India's primary solar producer is Tata BP solar, which as of 2004 had production capacity up to 38 MW. Other Indian manufacturers include Central Electronics, Bharat Heavy Electrical, and WEBEL SL Solar. Heliodomi S.A. is a thin film manufacturer in Greece, representing the small Eastern European market share.

Solar Array Plant Costs

Photovoltaic energy costs have decreased approximately 5 percent per year over the past 15 years, driven by increased conversion efficiencies and increased manufacturing capacity. The PV module itself generally makes up over half of the installed cost of the system, and as a result, mass manufacturing has significantly decreased installed system costs. The inverter, mounting equipment, electrical wiring work, and site engineering design and installation also contribute significantly to the cost of the system. Inverter costs for large-scale (greater than 100 kW) systems are expected to decrease as inverters become more efficient and reliable. Table 5.15 shows a typical cost breakdown for the components of an installed PV system.

Table 5.16 shows estimated costs for a utility-size crystalline PV system in the United States, Romania, and India. Costs are based on a plant net rating 5 MW_p (DC) connected to the grid with a capacity factor of 20 percent and efficiency of 15 percent. Land use is based on the land area required, including a 50 percent packing factor (50 percent is a typical ratio of array area to actual land area required for the system). Costs in Table 5.15 exclude any available rebates or tax incentives. As stated above, the PV cell and module account for about half the installed cost of the system, depending on site-specific installation costs. Module cost variations according to location are expected to be small, with the installed cost differential between locations attributed mainly to materials and labor expenses.

Basis of Estimate. The PV array cost estimates are based on the following:

- PV panels.
- Panel supports.

Table 5.15 Cost Breakdown for a Small PV Grid-Connected System

Component	Percent of Total Cost
PV Cell	40%
PV Cell and PV Module	20%
Balance of System	25%
Design and Installation	15%
Total	100%

Source: Author's calculations.

- Foundations.
- Electric wiring and DC-to-AC inverter.
- Roads within the immediate area of the array.

Scope/Terminal Points of Estimate:

- Electricity: no grid interconnection costs.
- Access roads outside the immediate array vicinity are not included.
- Freight is not included.

Costs for the installed system are lowest in India primarily because of the price of steel (support structures). It should be noted that most manufacturing activities are slated for Asia, the United States, and Western Europe, with little activity in Eastern Europe. With rising demand in those areas, availability of systems in Eastern Europe, including Romania, could be an issue. Land costs in India as well as Romania are significantly lower than they are in the United States (assuming rural location of the solar plant), with the other major ongoing operation and maintenance (O&M) costs attributed to labor rates for system maintenance. As with other renewable technologies, the major cost for a PV system is capital expense. In this regard, country-specific tax incentives, low-interest financing, and offered production credits can go far in enticing growth in PV generation. Monthly data collected from Solarbuzz indicates the average retail price of a module at US$4.81/watts peak [Wp] in the United States and 4.74/Wp (US$6.87/Wp) in Europe (based on a single module, excluding sales tax). Module prices in Table 5.16 demonstrate an economy of scale discount based on prices quoted on Solarbuzz. SU SolarTech in India advertises unloaded module prices of US$6,500–$7,500/kW.

The following published costs provide a comparison to the costs estimated for the PV systems:

- An 11-MW system that started up in Portugal in 2007 was reported to cost US$78.5 million (US$7,100/kW).
- A 410-kW plant in India was estimated at approximately US$2.5 million (US$8,800/kW) in 2005.

Table 5.16 Cost Estimate for a 5-MW Photovoltaic System in India, Romania, and the United States[a]

Cost Component (US$/kW, AC)—2008 US$	India	Romania	U.S.
Direct Module Production Cost	3,610	3,510	3,945
Power-related BOP[b]	1,020	940	1,100
Structures (Including Foundations)	1,350	2,000	1,640
Installation/Engineering	550	390	1,090
Total Installed Capital Cost	6,530	6,840	7,770
Project Contingency	1,310	1,360	1,160
Total Plant Cost	7,840	8,200	8,930
Average Solar Insolation (kWh/m^2-yr)	1,900	1,200	1,800
Net Annual Energy Delivery (GWh/yr)[c]	8–10	8–10	8–10

Source: Author's calculations.

[a] Costs adapted from utility-scale data in the EPRI/DOE Report, Renewable Energy Technology Characterizations.

[b] Power-related BOP includes wiring and DC-to-AC inverter.

[c] Annual energy delivery will depend on solar insolation for each location, among other things.

- A 5-MW plant in Australia is estimated to cost some US$60 million (US$10,700/kW, including tracking systems).
- A 425-kW system in New England completed in October 2006 cost US$3.1 million (US$7,300/kW).

Solar Thermal Array

Technology Development, Plant Descriptions, and Scope

Solar Thermal Description. There are three types of solar thermal technologies, each at a different stage of development: parabolic trough, dish/engine, and power tower. Dish/engine technology has been demonstrated at the kW scale, and power tower demonstrated at the MW scale, while parabolic trough is the only technology truly at the commercial stage. Therefore, the solar thermal technology evaluated in this report is the parabolic trough.

Parabolic trough technology uses a series of parabolic mirrors to track the sun from east to west, reflecting and concentrating the sun 30 to 100 times its normal intensity onto a receiver tube. A heat transfer liquid contained in the receiver, typically an oil, is heated as high as 450°C (700°F) and pumped through a series of heat exchangers to produce steam to run a turbine/generator producing electricity. As such, the steam side of these plants looks and operates much like a traditional fossil-fueled plant. Parabolic trough plants have traditionally been supplemented with fossil-fueled generation, either a natural gas-fired oil heater, gas/steam boiler/reheater operating in parallel with the solar heat exchangers or integrating the system with a natural gas combined cycle or coal-fired plant. As an alternative to fossil hybridization, solar thermal plants may include energy storage through the use of molten salt technology to ensure generation when sunlight is unavailable. Currently, most systems include some portion of fossil generation in lieu of energy storage due to relative inexperience as well as the added cost of storage systems.

The main components for a parabolic trough collector system are the reflector and the receiver tube. Individual concentrator modules are parabolic-shaped glass mirrors with aluminum or silver coating for maximum reflectance, and a clear protective coating over the metal. Concentrator modules are mounted on steel support structures designed for single axis tracking from east to west. Cleaning of the mirrors is imperative to maintain maximum system efficiency, as buildup will impact the reflectance of light. The receiver tube is a coated steel tube enclosed in a glass tube. The glass tube and corresponding annular vacuum space are designed to minimize conductive and convective heat losses from the receiver. The coating, a composite of a heat-resistant compound such as titanium carbide and a metal, such as nickel, is designed to improve absorption of solar energy.

Economic viability of solar thermal technology depends on the availability of direct normal solar radiation, land availability, topography, and access to transmission lines. Locations generally well suited to solar thermal include Australia, India, the Mediterranean countries (the Middle East, North Africa, and South Europe), northern Mexico, South America, and western United States.

Solar Thermal Power Development and Market. Large-scale plant development of parabolic trough solar thermal technology began in the 1970s. The first notable commercial installations were the Solar Energy Generating Systems (SEGS) built in the Mojave Desert in southern California from 1985–1991. The first plant capacity, SEGS I, was 13.8 MW. By the last installation, SEGS IX, the plants had reached 80 MW in size, for total generation capacity of 354 MW. The plants were designed with 25 percent natural gas generation backup for times of low solar insolation. Activity on the solar thermal generation front between the 1990s and 2005 was limited to research and development work. Restored interest in renewable energy and the corresponding public policies have spurred commercial activity for solar thermal plants once again at the start of the twenty-first century.

Since the SEGS plants were built, improvements in tracking systems and receivers have improved plant efficiency. Additionally, at least one project has taken an energy storage option to commercial scale, although many of the planned projects are integrated solar combined cycle systems (ISCCS), in order to provide reliable generation. The following is a list of current or recent solar thermal, parabolic trough projects:

- A 1-MW plant in Arizona, United States, employs Solargenix solar collectors, with the possibility for adding energy storage to increase the capacity factor from 23 percent to 40 percent.
- A 64-MW plant in Nevada, United States, started up June 2007 as the third-largest solar plant in the world. This plant requires only 2 percent fossil fuel backup.
- A 50-MW plant in Granada, Spain, start-up in 2008, demonstrates six to seven hours of energy storage using a two-tank molten salt system.
- A 25-MW parabolic trough solar thermal generation in Algeria is to be integrated with a 150-MW combined cycle plant.
- A 20-MW parabolic trough solar thermal generation was incorporated into a 140-MW ISCCS in Egypt.
- A 35-MW parabolic trough solar thermal was integrated into a 135-MW ISCCS firing naphtha instead of natural gas.
- A 30-MW solar trough was integrated into a 220-MW ISCCS in Morocco.
- 177-MW and 400-MW solar plant plans have gone through the application process in California.

Companies involved in these solar projects or that manufacture components include: Acurex (tracking devices, California), M.A.N (Czech Republic, France, Germany, others), Solargenix (North Carolina), Industrial Solar Technology Company (trough technology, Colorado), Solel (receiver manufacturer, Israel), Microsol (India), Usha India Ltd., Tata/BP Solar (India), Solilem (Germany), Solar Millennium (Germany), Ausra (California), Schott (receivers, Germany), and Flabeg (troughs, Germany). Many of these ventures are small scale or part of larger, broader companies.

In the United States, 2006 realized a 76 percent increase in the shipping of solar thermal collectors, mainly resulting from the 64-MW installation in Nevada. Forty-four domestic companies were actively involved in shipping collectors, with about 20 percent of the collectors imported. A majority of the imports were received from Israel. The residential sector is the major market for solar collectors over electric generation, but this trend could easily be flip-flopped if other large solar concentrating generation systems come on-line.

Operating experience at existing plants has resulted in design improvements in the receiver, mirrors, and hoses connecting the solar collectors. Solargenix (previously Duke Solar) has developed an all-aluminum frame for the collectors in lieu of the more costly traditional alternative, steel. This aluminum frame design is used in the 64-MW Nevada Solar One plant. Further research and development (R&D) aims to reduce the costs of the collector structure as well as increase the accuracy of focusing sunlight, as the collector assembly is the most costly item of the system. Direct steam generation, which aims to generate steam at the receiver point, as well as thermal storage are other concepts being investigated. Although this technology is at the commercial stage, there is definite potential for further cost savings and efficiency improvements as the number of installations increases.

Solar Thermal Plant Costs

Per the conference call with World Bank personnel on February 13, 2008, it was decided to put the cost estimates for solar thermal on hold.

Annex 1 Design Basis

Table A1.1	British to Metric Conversion Factors			
To Convert British		**Multiply By**	**To Obtain Metric (SI = Systems Intern)**	
ac	acre	0.405	ha	hectare
acfm	actual cubic feet per minute	0.02832	am^3/min	actual cubic meters/min.
Btu	British thermal unit	0.252	kcal	kilocalories
Btu	British thermal unit	1055.1	J	joule
Btu/lb	Btu/pound	2.236	kJ/kg	kilojoules/kilogram
Btu/kWh	Btu/kilowatt-hour	1.0551	kJ/kWh	kilojoules/kilowatt-hour
ºF	Deg. Fahrenheit—32	0.5556	ºC	degree Centigrade
ft	feet	0.3048	m	meters
ft^2	square feet	0.0929	m^2	square meters
ft^3	cubic feet	0.02832	m^3	cubic meters
ft/m	feet per minute	0.00508	m/s	meters per second
ft^3/m	cubic feet per minute	0.000472	m^3/s	cubic meters/second
gal	gallons (U.S.)	3.785	L	liters
gpm	gallons per minute	0.06308	L/s	liters per second
gpm/Kacfm	gallons per minute thousand actual cubic feet/min	133.65	liters/Am^3	liters per actual cubic meter
gr	grains	0.0648	g	grams
gr/ft^3	grains per cubic foot	2.2881	g/m^3	grams per cubic meter
hp	horsepower	0.746	kW	kilowatts
in.	inches	0.0254	m	meters
in. w.g.	inches water pressure (gage)	249.089	Pa	pascals (newton/m^2)
lb	pounds	0.4536	kg	kilograms
lb/ft^3	pounds per cubic foot	16.02	kg/m^3	kilograms/cubic meter
lb/hr	pounds per hour	0.126	g/s	grams per second
lb/hr	pounds per hour	0.4536	kg/hr	kilograms per hour
lb/MMBtu	pounds per million Btu	*Depends on Fuel Type	mg/Nm^3	milligrams per normal cubic meter
mi	miles	1609	m	meters
MMBtu/hr	million Btu per hour	1,055	Mjoule/hr	million joules per hour
oz	ounces	28.3495	g	grams
psi	pounds per square inch	6895	Pa	pascals (newton/m^2)
rpm	revolutions per minute	0.1047	rad/s	radians per second
scfm	std. (60ºF) cubic feet/minute	1.6077	nm^3/hr	normal cubic meters/hr
ton	short tons	0.9072	ton	metric tons
t/hr	short tons per hour	0.252	kg/s	kilograms per second
$/ton	dollars per short ton	1.1023	$/ton	dollars per metric ton

Brief Descriptions of Major Generation Options

The costs of the items or systems listed below are provided as part of the total plant cost (TPC) estimates. The scope of the plant cost estimates is described in a subsequent Annex. The following provides brief and basic descriptions of the generation plants, equipment, or system options. The purpose is to provide a basic definition of the technologies.

This Annex also includes a list of major or typical equipment. The list of equipment for the options is not exhaustive, but rather provides the highlights of equipment or components typically included with each technology. The brief generation option descriptions are as follows.

Gas Turbine Simple Cycle

The gas turbine (also known as combustion turbine) features a compressor, combustor, and turbine on a single shaft coupled to the generator either directly or through a gearbox. The gas turbine in this study is based on natural gas firing. The scope as typically provided by OEMs includes single-fuel gas turbine, starting and lube oil systems, generator, air intake filter and silencer, exhaust stack, vibration monitoring, gas compressor, gas turbine controls, and plant control systems.

There are two types of gas turbines: heavy-frame and aeroderivative. Heavy-frame machines are built with heavy casings and rotors and are the dominant type in use today. Aeroderivative gas turbines use engines adapted from aircraft turbofan technology. The aeroderivative machines are characterized by lighter construction and have higher pressure ratios than do heavy-frame machines. The higher pressure ratios result in lower exhaust gas temperatures and higher efficiency.

Gas Turbine Combined Cycle

This generation technology includes the combustion turbine and associated equipment outlined for the simple cycle, as well as a heat recovery steam generator (HRSG) downstream of the combustion turbine. The HRSG generates steam that is then used to generate additional power via a steam turbine-generator. In addition to the equipment listed for the simple cycle gas turbine, the combined cycle plant includes the HRSG, steam turbine, condenser, cooling tower, and water treatment.

Coal-Fired Steam Plant

The coal-fired steam boiler in this plant will utilize pulverized coal to generate steam. The boiler will be the reheat type, which generates main steam and reheat steam. The steam is piped to a steam turbine-generator to generate electricity. The cost of the boiler will include the furnace, backpass, pulverizers, primary and secondary fans, low NO_x burners, coal day silos, ljungstrom air heater, and structural support steel. The plant will also include the condenser, cooling tower, coal handling system, ash handling system, stack, piping, electrical, and control systems. In the United States, the plant includes selective catalytic reduction (SCR) for post-combustion NO_x removal and flue gas desulfurization for SO_2 removal.

Oil-Fired Steam Plant

The oil-fired steam boiler in this plant will generate steam using No. 2 fuel oil. The boiler and scope are similar to the coal-fired boiler, except that they do not include the pulverizer, coal day silos, coal handling system, ash handling system, or flue gas desulfurization.

Gas-Fired Steam Plant

The gas-fired steam boiler in this plant will utilize natural gas to generate steam. The boiler and scope are similar to the coal-fired boiler, except that they do not include the pulverizer, coal day silos, coal handling system, ash handling system, or flue gas desulfurization.

Diesel Engine-Generator

The diesel engine power plant is based on a reciprocating engine that will utilize No. 2 fuel oil to generate electricity. The two basic types of reciprocating engines are compression ignition (CI) and spark-ignition (SI), distinguished by the method of combustion ignition. Historically, and on a worldwide basis, oil-fueled CI diesel cycle reciprocating engines have been the most utilized type for both small and large power generation applications. The technology as provided by the OEMs typically consists of engine, generator, lube oil system, radiator for cooling, electric start system, air intake filter, and stack.

Wind Turbine

A wind turbine converts the kinetic energy in the wind into mechanical power that turns a generator, producing electricity. The wind turbines will be the three-bladed, pitch-controlled, variable-speed machines located in an onshore wind farm. The data in this report are based on 10-MW, 50-MW, and 100-MW wind farms.

Photovoltaic Solar

A photovoltaic (PV) or solar cell is made of semiconducting material. The two main categories of technology are defined by the choice of the semiconductor, either: (1) crystalline silicon (c-Si) in a wafer form or: (2) thin films of other materials. Typically, each c-Si cell generates about 0.5 V, so 36 cells are usually soldered together in a series to produce a module with an output of 12 V. The cells are hermetically sealed under toughened, high-transmission glass.

The electricity produced by a PV cell is direct current (DC) and an inverter is used to convert the electricity to alternating current (AC). Other than the PV module, additional system components include support structures, inverters, and wiring.

The PV cost estimate in this study is based on a ground-mounted crystalline installation. Currently, the crystalline technology makes up the bulk of the market sales compared to thin film. However, thin film is less expensive than crystalline and the thin film market is growing. Because thin film's part of the market share is estimated to be around 35 percent by 2015, the study also contains a technical assessment and market discussion of the thin film technology.

Solar Thermal

There are three types of solar thermal technologies:

- Parabolic trough;
- Dish/engine; and
- Power tower.

Each of these solar thermal technologies is at a different stage of development. Currently, the most mature technology is the parabolic trough, which is commercial. Therefore, the costs in this study are based on the parabolic trough.

Parabolic trough power plants consist of the following main components: mirrors, receivers, heat exchangers, and a steam turbine. Solar energy is focused on a receiver tube containing a heat transfer fluid using a series of parabolic-curved, trough-shaped mirrors. The receiver tube is located at the focus of the parabola or centerline of the trough. The heat transfer fluid (typically oil) is heated and pumped through a series of heat exchangers that produce steam to run a conventional steam turbine/generator.

The basis of this study is a stand-alone parabolic trough using a secondary heating fluid. It is a hybrid, and as such includes a gas turbine combined cycle plant burning natural gas.

Generation Plant Cost Estimates

Generation Plant Options

Installed capital cost estimates are developed for the following generation options:

- Gas turbine simple cycle plant.
- Gas turbine combined cycle plant.
- Coal-fired steam plant.
- Oil-fired steam plant.
- Gas-fired steam plant.
- Diesel generator plant (oil-fired).
- Wind-power turbine farm (onshore).
- Photovoltaic solar array.
- Solar thermal array.

The generation technology plant cost estimates for the nine generation plant options include equipment, materials, and labor. The items listed in each subsection are not meant to be a complete definition of scope, but rather are intended to describe the highlights of the items included. The cost estimates included in the report are based on fully constructed, functionally complete, and operational plants that generate electricity.

Gas Turbine Simple Cycle Plant

The cost for a gas turbine simple cycle plant is based on the following scope:

1. Single fuel gas turbine.
2. Dry low NO_x control.
3. Starting and lube oil systems.
4. Fuel forwarding system.
5. Gas turbine controls.
6. Air-cooled generator.
7. Air intake filter and silencer.
8. Exhaust stack.
9. Plant control system.
10. Selective catalytic reduction (SCR) for post-combustion NO_x control (if needed or required: the requirement varies according to country).
11. Earthwork.
12. Foundations.
13. Structural steel.
14. Piping.
15. Electrical.
16. Construction labor.
17. Engineering and home office expenses.
18. Indirect costs.

The gas turbine output is based on ISO conditions, the standard measure of output for all gas turbines (15º C, sea level, and 60 percent relative humidity). The output will be as published in the 2007–2008 Gas Turbine World Handbook. The supplier (OEM) price for the simple cycle gas turbine typically includes items 1–9.

Gas Turbine Combined Cycle Plant

The costs for a gas turbine combined cycle plant are based on the following scope:

1. Single fuel gas turbine.
2. Steam turbine.
3. Dry low NO_x control.
4. Starting and lube oil systems.
5. Fuel forwarding system.
6. Gas turbine controls.
7. Air-cooled generator.
8. Air intake filter and silencer.
9. Exhaust stack.
10. Plant control system.
11. SCR (if required).
12. Water treatment.
13. Earthwork.
14. Foundations.
15. Structural steel.
16. Piping.
17. Electrical.
18. Construction labor.
19. Engineering and home office expenses.
20. Indirect costs.

The combined cycle performance is based on ISO conditions. The output will be as published in the 2007–2008 Gas Turbine World Handbook. The supplier (OEM) price for the gas turbine combined cycle plant typically includes items 1–10.

Coal-Fired Steam Plant

The cost for a coal-fired steam plant is based on the following scope:

1. Steam generator (boiler).
2. Steam turbine.
3. Cooling tower.
4. FGD/SO_2 control (if required).
5. Particulate Control (ESP for India and Romania and fabric filter for the United States).
6. Coal handling (rail delivery, bottom-dump cars).
7. Ash handling.
8. Water treatment.
9. Auxiliaries.
10. SCR (if applicable: the requirement is country dependent).
11. Earthwork.
12. Concrete.

13. Structural steel.
14. Piping.
15. Electrical.
16. Instruments and controls.
17. Painting and insulation.
18. Buildings and architectural.
19. Construction labor.
20. Engineering and home office expenses.
21. Indirect costs.

Additionally, the coal-fired plant is based on the following:

- One coal analysis per country.
- Boilers will be equipped with low NO_x burners.
- The cooling tower will be wet mechanical draft.
- Coal will be delivered by rail with bottom-dump rail cars.
- The FGD process will be wet limestone forced oxidation (if required).
- Particulate control: ESP for India and Romania and pulse jet fabric filter for the United States.

Oil-Fired Steam Plant

The cost for an oil-fired steam plant is based on the following scope:

1. Steam generator (boiler).
2. Steam turbine.
3. Cooling tower.
4. Water treatment.
5. Auxiliaries.
6. Earthwork.
7. Concrete.
8. Structural steel.
9. Piping.
10. Electrical.
11. Instruments and controls.
12. Painting and insulation.
13. Buildings and architectural.
14. Construction labor.
15. Engineering and home office expenses.
16. Indirect costs.

Gas-Fired-Steam Plant

The cost for a natural gas-fired steam plant is based on the following scope:

1. Steam generator (boiler).
2. Steam turbine.
3. Cooling tower.
4. Water treatment.
5. Auxiliaries.
6. SCR (if required).
7. Earthwork.
8. Concrete.
9. Structural steel.
10. Piping.
11. Electrical.
12. Instruments and controls.
13. Painting and insulation.
14. Buildings and architectural.
15. Construction labor.
16. Engineering and home office expenses.
17. Indirect costs.

Diesel Engine-Generator Plant

The cost for a diesel engine-generator plant is based on the following scope:

1. Diesel engine.
2. Engine lubrication and cooling system (radiator).
3. Combustion air intake filter.
4. Synchronous generator.
5. Electric start system.
6. Stack.
7. Earthwork.
8. SCR (if required).
9. Concrete.
10. Structural steel.
11. Piping.
12. Electrical.
13. Instruments and controls.
14. Construction labor.
15. Engineering and home office expenses.
16. Indirect costs.

Additionally, the diesel engine-generator plant cost is based on the following criteria:

- Fuel will be No. 2 fuel oil.
- The engine rating (output) is based on the manufacturers' specifications.
- The engine rating is based on ISO standard conditions for reciprocating engines (77º F and 29.61 in. Hg; 25º C and 100 kPa).
- The supplier (OEM) price for the diesel engine-generator typically includes items 1–5.

Wind Farm

The cost for wind turbines for a wind farm is based on the following scope:

1. Rotor assembly (including hub).
2. Tower.
3. Generator.
4. Electrical/power electronics and instruments and controls (I&C).
5. Transmission, shaft brakes, nacelle, and yaw system.
6. Earthwork.
7. Concrete.
8. Miscellaneous.
9. Construction labor.
10. Engineering and home office expenses.
11. Indirect costs.

The rotor assembly; tower, generator; electrical/power electronics and I&C; and transmission, shaft brakes, nacelle, and yaw system will constitute the wind turbine as typically quoted by OEMs. The breakdown shown here is necessary for assessing the forecasts of future escalation since each item will escalate at a different rate (the combination of forecast escalation for these items is the composite forecast escalation for the wind turbine). In addition, the earthwork and miscellaneous may be combined into one category in the cost estimates. The foundation cost is presented with a number of caveats because it can vary so much for different wind turbine models/manufacturers and varying soil conditions.

Photovoltaic Solar Array

The cost for a ground-based photovoltaic solar array is based on the following scope:

1. PV modules.
2. Module support structure.
3. Power-related balance of system.
4. Earthwork.
5. Concrete.
6. Miscellaneous.
7. Construction labor.
8. Engineering and home office expenses.
9. Indirect costs.

The earthwork, concrete, and miscellaneous costs for the photovoltaic solar technology may be combined into one category in the cost estimates.

Solar Thermal Array

The cost for a hybrid solar thermal power plant is based on the following scope:

1. Structures and improvements.
2. Collector system.
3. Heat exchange system.
4. Steam turbine.
5. Gas turbine.
6. Auxiliary heater/boiler.
7. Balance of plant.
8. Construction labor.
9. Engineering and home office expenses.
10. Indirect costs.

Cost Estimate Breakdown for the Generation Technologies

The cost estimate breakdown for the nine technologies discussed above differs to fit the nature of each of the technologies. All of the generation plants include civil/structural, mechanical, electrical, I&C, and general facilities. The craft labor costs are based on the different wage rates and productivity in each of the three countries. In some cases, the cost elements may include labor. The thermal power and engine technologies have more cost line items than do the wind, photovoltaic, and solar thermal technologies.

An example of a cost estimate breakdown for a coal-fired plant is as follows:

- Civil/structural.
- Mechanical
  - Boiler
  - Steam turbine
  - Coal handling
  - Ash handling
  - Particulate removal system
  - FGD system (if applicable).
- Electrical.
- General facilities.
- Indirect costs (construction equipment, small tools, and field support labor).
- Professional services costs (engineering, start-up, and field office).
- Process contingency (if applicable).
- Project contingency.

The generation technology assessments also include indicative percentages for owners' costs and spare parts.

Size Classification of Generation Plants

Most of the generating plant cost estimates are developed for several different sizes.

Note: Cost estimates are developed for each of the three countries (India, Romania, and the United States). The following nominal sizes are proposed to reflect the respective characteristics of the particular countries and are generally consistent with the electrification report. The study includes the following sizes:

Gas turbine simple cycle plants (nominal sizes):

- 5 MW.
- 25 MW.
- 150 MW.
- Graph of costs for simple cycle gas turbines as supplied by OEMs (based on costs from Gas Turbine World [GTW]—see Figure 5.4 in Chapter 5). The graph shows one curve for aeroderivative and one curve for heavy-frame units. The curves on the graph reflect around 100 different combustion turbines, ranging in size from 2 MW to 330 MW. The graph of the OEM costs for all of the simple cycle combustion turbines is only being developed for the United States.

Gas turbine combined cycle plants:

- 140 MW.
- 580 MW.

Coal-fired steam plant (pulverized coal [PC]):

- 300 MW (subcritical).
- 500 MW (subcritical).
- 800 MW (supercritical).

Oil-fired steam plant:

- 300 MW (subcritical). See Table A1.1.

Gas-fired steam plant:

- 300 MW (subcritical). See Table A1.1.

Diesel engine plant (oil-fired):

- 1 MW.
- 5 MW.

Wind farm:

- 0.75 × 16 = 12-MW wind farm. Done for United States only.
- 50 × 1 MW = 50-MW wind farm. Done for United States only.
- 40 × 2.5 MW = 100-MW wind farm. Done for United States only.

- Curve of capital costs for wind farms ranging from 2 to 200 MW. U.S. cost basis only.
- 100 × 1 MW = 100-MW wind farm. Done for India, Romania, and United States.

Solar-photovoltaic (PV) array:

- 5 MW (same size as grid-connected case in Table 2 of the Electrification study)

Solar-thermal array:

- On hold

Summary of Sizes for Generation Plant Cost Estimates

Table A1.2 summarizes the size classifications for the generation plants as outlined above. The same sizes are proposed for all three countries. The sizes are generally consistent with the ones used in the World Bank Electrification study (for the grid-connected configuration). The study develops installed generating plant costs for each size summarized in Table A1.2.

Other Generation-Related Criteria

Environmental Emissions

Table A1.3 provides the emission standards for the three countries included in this study. Emissions for India are subject to World Bank Guidelines for New Thermal Power Plants, July 1998. Emissions for Romania and the United States are subject to the standards of the European Union and the Environmental Protection Agency (EPA), respectively. The generating plants' environmental control systems in the respective countries are based on these emission guidelines and standards.

Anticipated Emission Control Technologies

Table A1.5 indicates the anticipated emission control technologies for the three plant locations based on the emission guidelines/emission limits shown in the previous tables.

Table A1.2 Size Classifications for Cost Estimate

Generating Technology	Plant Size/Configuration
Gas Turbine Simple Cycle	5 MW, 25 MW, and 150 MW
Gas Turbine Combined Cycle	140 MW: 2 CTs and 1 ST; 580 MW: 2 CTs and 1 ST
Coal-Fired Steam Boiler	300 MW, 500 MW, and 800 MW
Oil-Fired Steam Boiler	300 MW[1]
Natural Gas-Fired Steam Boiler	300 MW[2]
Diesel Generator (Oil-Fired)	1 MW and 5 MW
Wind Turbine	12-MW wind farm (16 x 0.75 MW) 50-MW wind farm (50 x 1-MW wind turbines) 100-MW wind farm (40 x 2.5-MW wind turbines) 100-MW wind farm (100 x 1-MW wind turbines)
Photovoltaic Solar	5 MW
Thermal Solar	On hold

Source: Author's calculations.

[1] The economy of scale of a 500-MW coal-fired boiler relative to a 300-MW coal-fired boiler is indicative of the relative economy of scale between a 500-MW oil-fired and a 300-MW oil-fired boiler.

[2] The economy of scale of a 500-MW coal-fired boiler relative to a 300-MW coal-fired boiler is indicative of the relative economy of scale between a 500-MW gas-fired and a 300-MW gas-fired boiler.

Table A1.3 Emission Standards or Guidelines

Emission Source	India	Romania	United States
Steam Power Plants	(WB Guidelines)	(EU Standards)	(NSPS Standards)
Sulfur Dioxide (SO_2)	0.20 metric tons/ day per MWe[a]	See Table A1.4	1.4 lb/MWh (0.52 kg/MWh) or 5% of potential combustion concentration (95% reduction)
Nitrogen Oxides (NO_x)			
Coal-Fired	260 ng/J	See Table A1.4	1.0 lb/MWh (0.37 kg/MWh)
Oil-Fired	130 ng/J	See Table A1.4	1.0 lb/MWh (0.37 kg/MWh)
Gas-Fired	86 ng/J	See Table A1.4	1.0 lb/MWh (0.37 kg/MWh)
Particulate Matter	150 mg/Nm^3/	See Table A1.4	0.14 lb/MWh (0.052 kg/MWh) 50 mg/Nm^3 (large plants)
Gas Turbine NO_x Limits[b]			
Oil	165 mg/Nm^3	See Table A1.4	74 ppmv or 460 ng/J [c] (80 ppmv)
Gas	125 mg/Nm^3	See Table A1.4	25 ppmv or 150 ng/J [d] (60 ppmv)
Engine-Driven Units NO_x Limits (No. 2 oil)	2,000 mg/Nm^3 or 13 g/kWh[e]	See Table A1.4	Later

Source: Author's calculations.

[a] And 0.10 metric tons/day per megawatt electrical for each additional MWe over 500 MWe.

[b] Emission limits for both gas and oil are on a dry basis at 15 percent oxygen.

[c] 74 parts per million by volume on dry basis at 15 percent oxygen for units > 50 MMBtu/hr and less than 850 MMBtu/hr. 42 ppmv on dry basis at 15 percent oxygen for units > 850 MMBtu/hr (50 MMBtu/hr ~ 3.5 MW and 850 MMBtu/hr ~ 110 MW).

[d] 25 ppmv on dry basis at 15 percent oxygen for units > 50 MMBtu/hr and less than 850 MMBtu/hr. 15 ppmv on dry basis at 15 percent oxygen for units > 850 MMBtu/hr.

[e] World Bank emission guidelines are on dry basis at 15 percent oxygen. NO_x emission of 2,000 mg/Nm^3 ~ 970 ppmv.

Table A1.4 Emission Standards for Large Combustion Plant Directive (LDPD)—Applicable to Romania

Pollutant	Coal-Fired Plants	Oil-Fired Plants	Gas-Fired Plants
SO_2	**New plants:** 50–100 MWt: < 850 mg/Nm^3 > 100 MWt:< 200 mg/Nm^3	**New plants:** 50–100 MWt: < 850 mg/Nm^3 100–300 MWt: < 400 to 200 mg/Nm^3 (linear decrease) > 300 MWt: 200 mg/Nm^3	**New and existing plants:** Natural gas: < 35 mg/Nm^3 LNG: < 5 mg/Nm^3
NO_2	**New plants:** 50–100 MWt: < 400 mg/Nm^3 > 100 MWt:< 200 mg/Nm^3	**New plants:** 50–100 MWt: < 400 mg/Nm^3 > 100 MWt: 200 mg/Nm^3	**New gas-fired plants:** 50–300 MWt: 150 mg/Nm^3 > 300 MW: <100 mg/Nm^3 New plants/gas turbines: Natural gas: 50 mg/Nm^3 Gaseous other than natural gas: 120 mg/Nm^3
Particulate Matter	**New plants:** 50–100 MWt: 50 mg/Nm^3 > 100 MWt: 30 mg/Nm^3	**New plants:** 50–100 MWt: 50 mg/Nm^3 > 100 MWt: 30 mg/Nm^3	**New and existing plants:** All sizes: < 5 mg/Nm^3

Source: Author's calculations.

Table A1.5 Anticipated Emission Control Processes

Emission Source	India	Romania	United States
Steam Power Plants	(Based on WB Guidelines)	(Based on EU Limits in Table A1.4)	(Based on NSPS limits)
Sulfur Dioxide (SO_2)	None	Wet FGD (coal only)	Wet FGD (coal only)
Nitrogen Oxides (NO_x)			
Coal-Fired	Low NO_x burners (LNB)	LNB/SCR	LNB/SCR
Oil-Fired	LNB	LNB/SCR	LNB/SCR
Gas-Fired	LNB	LNB/SCR	LNB/SCR
Particulate Matter	ESP (coal only)	ESP (coal only)	Fabric filter (coal only)
Gas Turbine NO_x Limits			
Oil	DLN or H_2O injection	DLN/SCR	DLN/SCR
Gas	DLN or H_2O injection	DLN/SCR	DLN/SCR
Engine-Driven Units NO_x Limits (No. 2 oil)	Combustion controls	Combustion controls	Combustion controls and SCR

Source: Author's calculations.

Coal Analyses

Table A1.6 Romanian Coal Analysis—Romanian Lignite

Coal Ultimate Analysis (ASTM as received)	Lignite Weight %
Moisture	43.00
Carbon	22.57
Hydrogen	2.05
Nitrogen	0.70
Chlorine	0.01
Sulfur	1.00
Ash	21.00
Oxygen	9.68
Total	**100.00**
HHV, Btu/lb	3,930.00
HHV, MJ/kg	8.79

Source: Author's calculations.

Table A1.7 Indian Coal Analysis—Australian Coal

Coal Ultimate Analysis (ASTM, as received)	Australian Weight %
Moisture	3.50
Carbon	69.29
Hydrogen	4.63
Nitrogen	1.69
Chlorine	0.01
Sulfur	0.70
Ash	11.99
Oxygen	8.20
Total	**100.00**
HHV, Btu/lb	11,830
HHV, MJ/kg	26.46

Source: Author's calculations.

Table A1.8 U.S. Coal Analysis—Powder River Basin (PRB) Subbituminous Coal

Coal Ultimate Analysis (ASTM, as received)	PRB Weight %
Moisture	30.24
Carbon	48.18
Hydrogen	3.31
Nitrogen	0.70
Chlorine	0.01
Sulfur	0.37
Ash	5.32
Oxygen	11.87
Total	**100.00**
HHV, Btu/lb	8,230
HHV, MJ/kg	18.40

Source: Author's calculations.

Cost/Site Criteria

Table A1.9 shows the cost and site criteria used for the generation technologies.

Table A1.9 Cost and Site Criteria Applicable to Cost Estimates

Cost/Site Criteria	India	Romania	United States
Construction Craft Labor, US$/hr (fully loaded)	$10	$8.50	$60
Productivity Factor (referenced to United States)	3.0	2.5	1.0
Structural Steel, US$/ton	$970	$1,550	$1,110
Concrete, US$/ton	$75	$105	$110
Date of Costs	Jan 2008	Jan 2008	Jan 2008
Contingency	20%	20%	15%
Foundation Type	Spread footings[1]	Spread footings[1]	Spread footings[1]
Rail Access (applicable technologies)	Yes	Yes	Yes
Indoor/Outdoor Construction (applicable technologies)	Indoor	Indoor	Indoor
Site Elevation, ft (m)	Generic	Generic	Generic
Fresh Water Available Nearby	Yes	Yes	Yes
Plant Life, yrs.	30	30	30
Gas Turbine Rating Conditions (output and heat rate)	See note 2	See note 2	See note 2
Boiler Efficiency (coal-, oil-, and gas-fired boilers)	See note 3	See note 3	See note 3
Diesel Engine Rating Conditions (output and heat rate)	See note 4	See note 4	See note 4
Plant Site (with regard to earthwork and clearing)	See note 5	See note 5	See note 5

Source: Author's calculations.

1 Spread footings apply primarily to major equipment within thermal plants.

2 Basis for gas turbine-generator output and heat rate: 15ºC, sea level, and 60 percent relative humidity.

3 Basis for boiler efficiency: 27ºC, sea level, and 60 percent relative humidity.

4 Basis for diesel engine-generator output and heat rate: 25ºC and atmospheric pressure of 100 kPa.

5 Plant site topography: Site is basically level without need for: (1) significant fill or removing hills; (2) removing major wooded areas; or (3) blasting and removal of above-ground or below-ground rock formations.

Annex 2 Cost Indexes from U.S. Bureau of Labor Statistics (Graphs of Cost Indexes for Equipment and Materials)

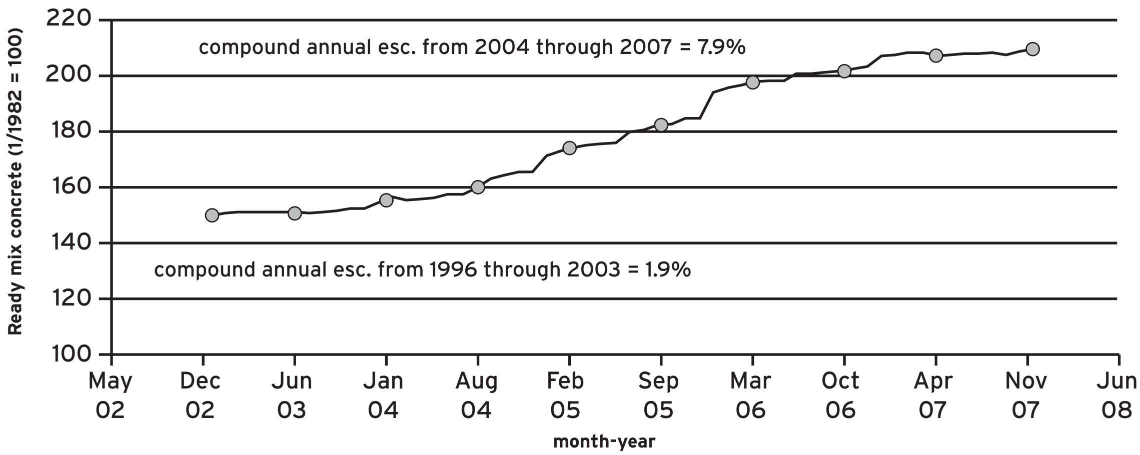
Cost Indexes for Power Plant Equipment and Materials in the United States

The U.S. Producer Price Indices (PPI) provided in Figures A2.1 through A2.19 document the historical escalation trends for selected equipment and materials associated with utility-generation plant systems. The historical PPIs cover the period from the beginning of 1996 through the end of 2007.

As shown in the legend boxes on the graphs, the historical period is divided into two parts: (1) January 1996 through December 2003 and (2) January 2004 through December 2007. These two periods roughly correspond to the times before and after the rapid worldwide expansion in construction of large industrial, utility, and manufacturing projects.

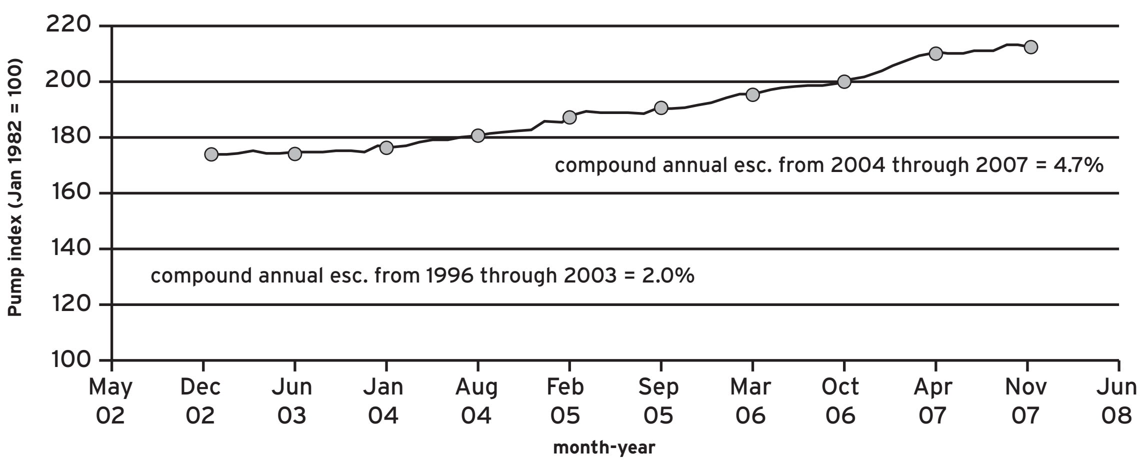
Cost indexes are illustrated as follows:

Figure A2.1 Cost Index for Ready-Mix Concrete



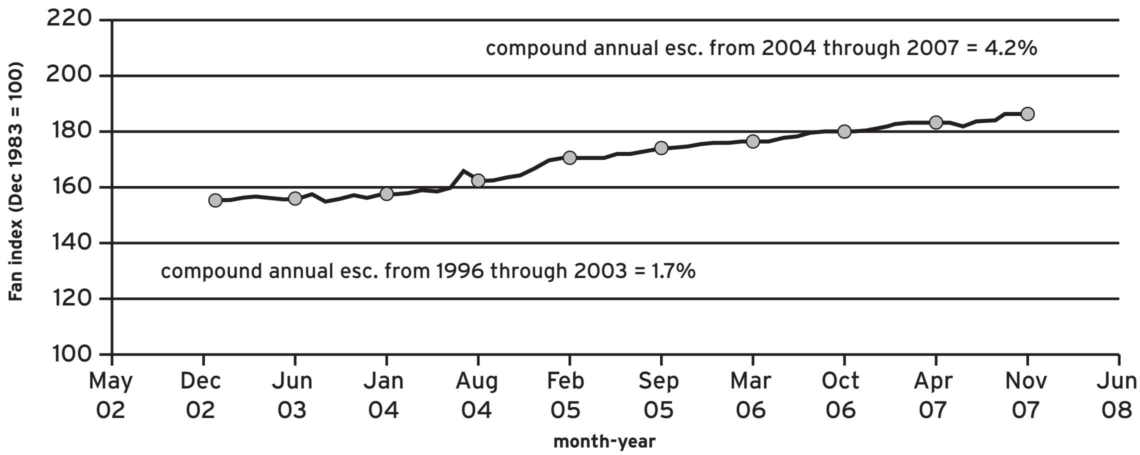
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.2 Cost Index for Large Centrifugal Pumps



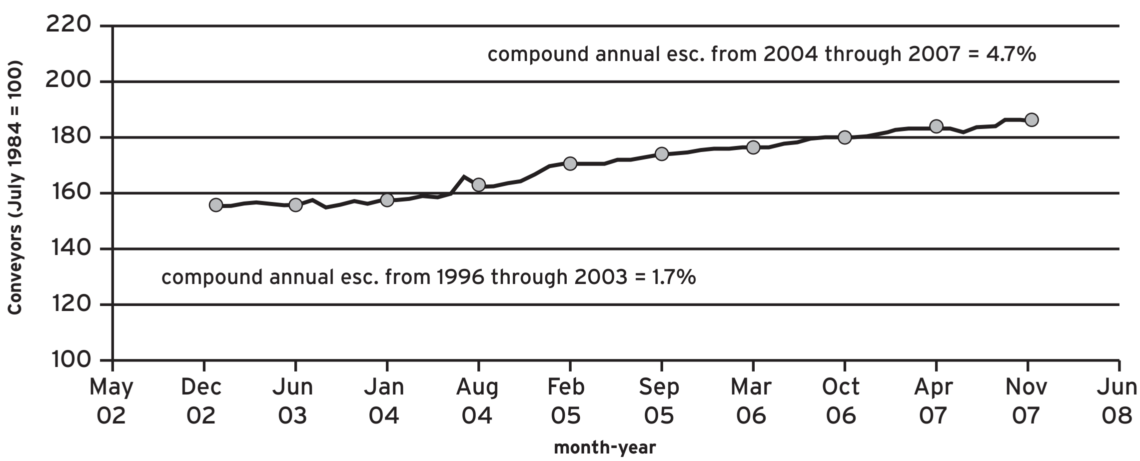
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.3 Cost Index for Large Centrifugal Fans



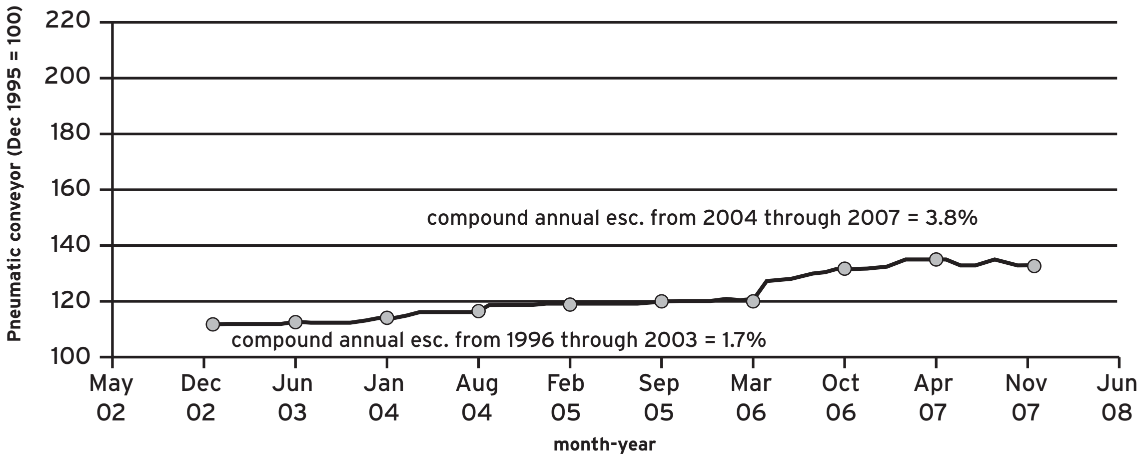
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.4 Cost Index for Bulk Material Handling Conveyors



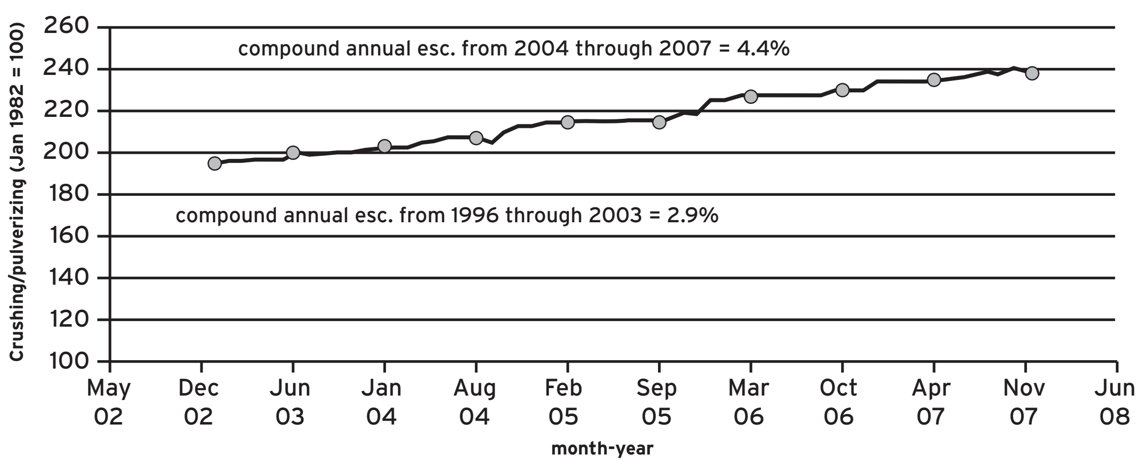
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.5 Cost Index for Pneumatic Conveyors



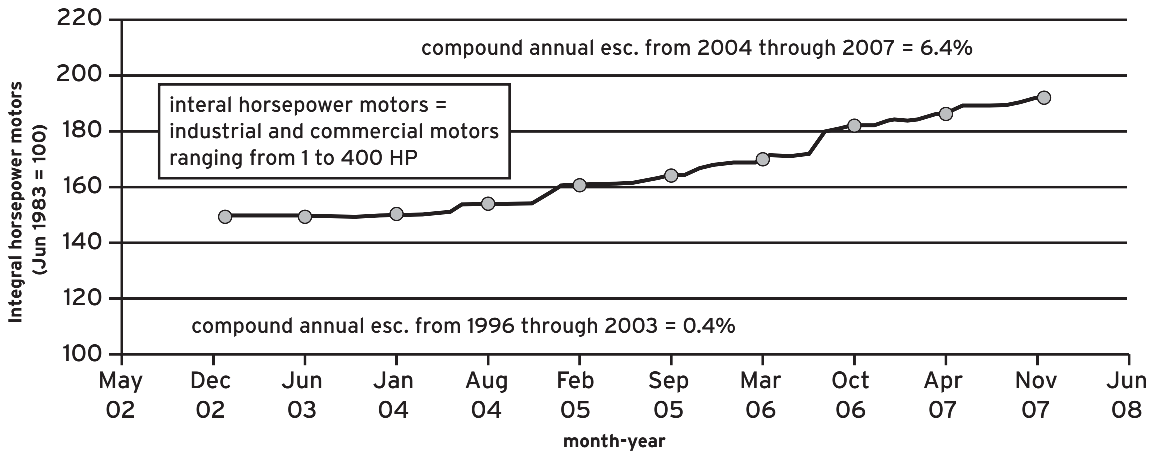
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.6 Cost Index for Crushing, Pulverizing, and Screening Machines



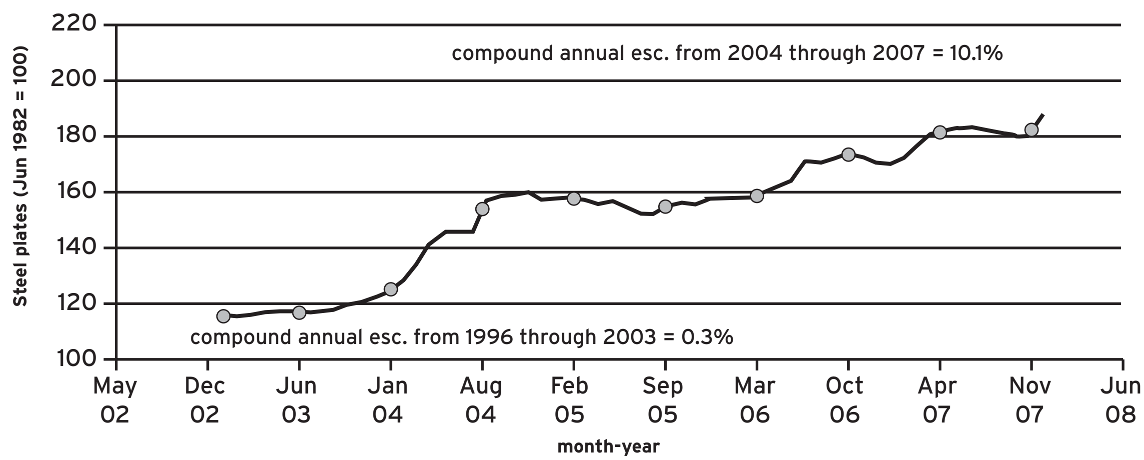
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.7 Cost Index for Integral Horsepower Motors



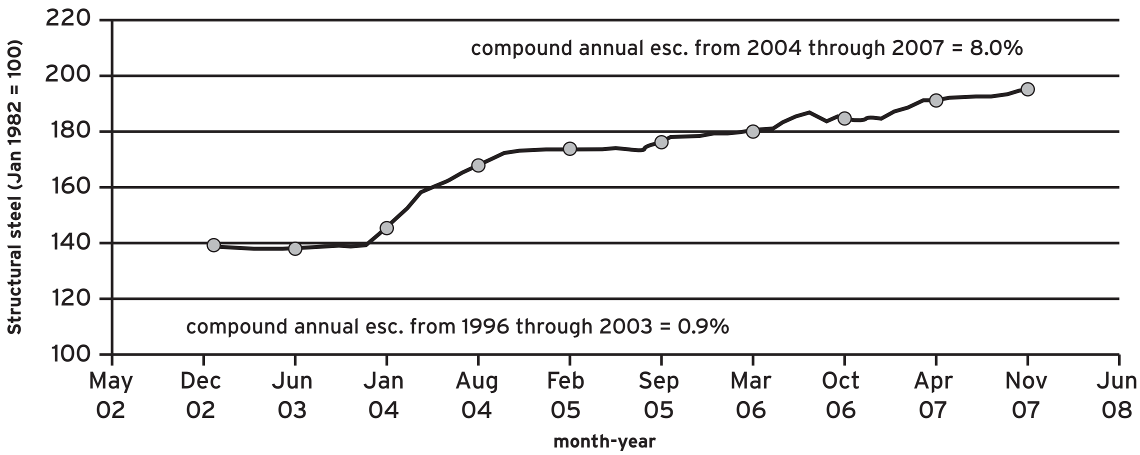
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.8 Cost Index for Fabricated Steel Plates



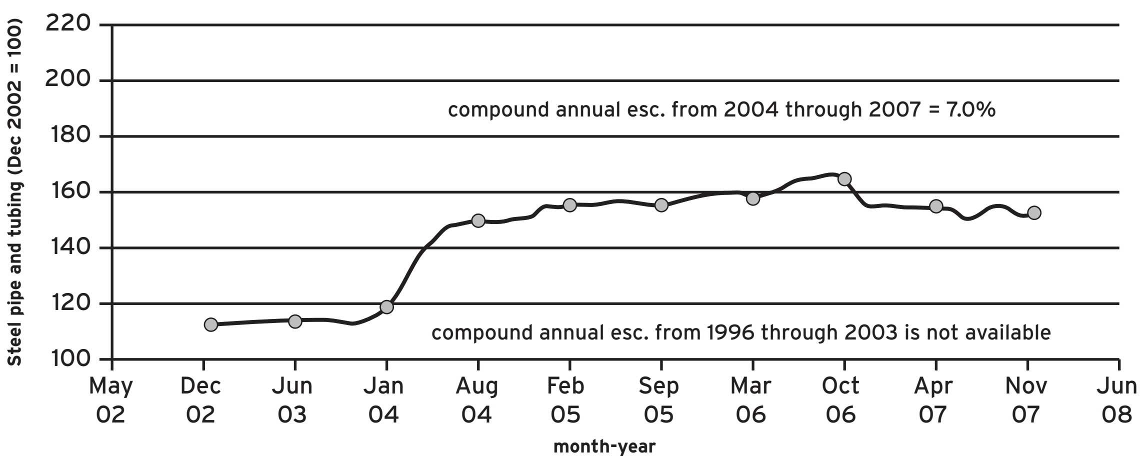
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.9 Cost Index for Structural Steel



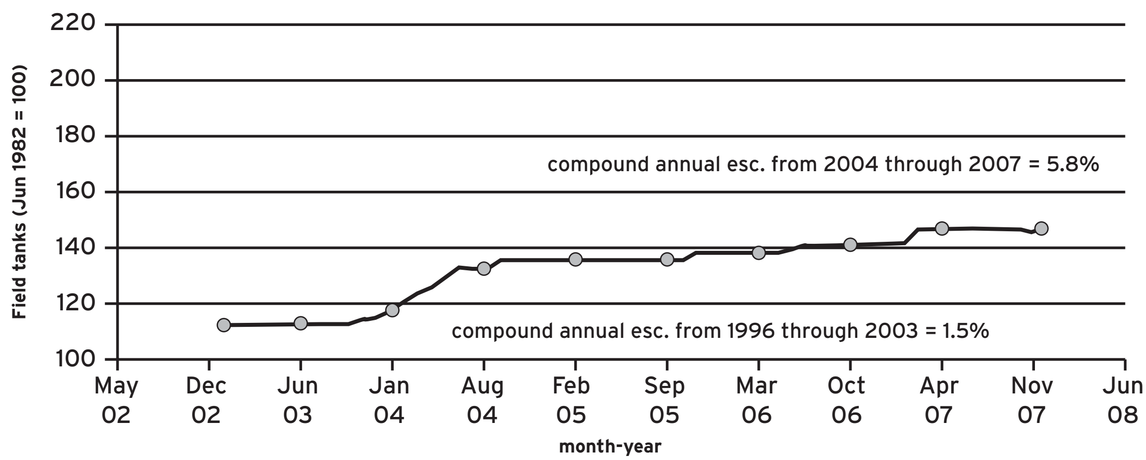
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.10 Cost Index for Carbon Steel Pipe and Tubing



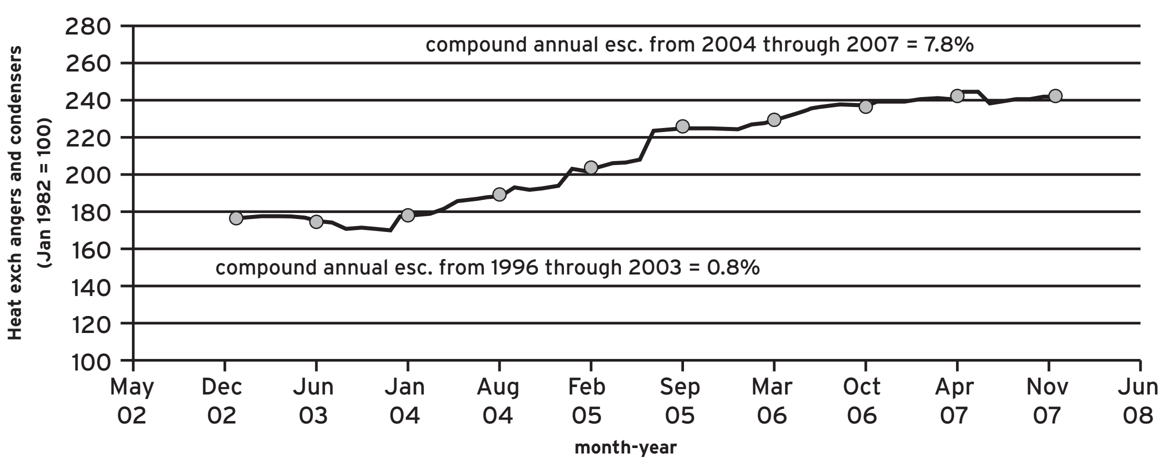
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.11 Cost Index for Field Erected Steel Tanks



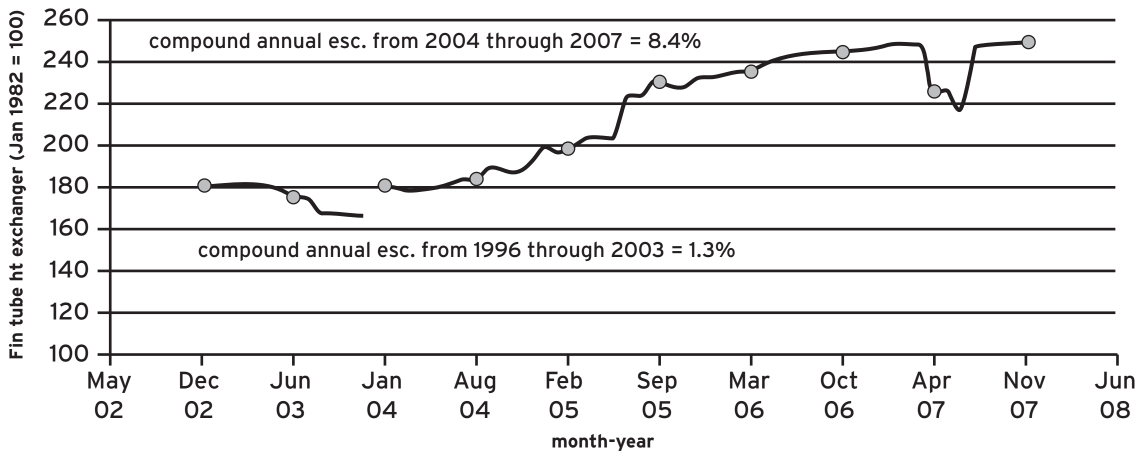
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.12 Cost Index for Heat Exchangers and Condensers



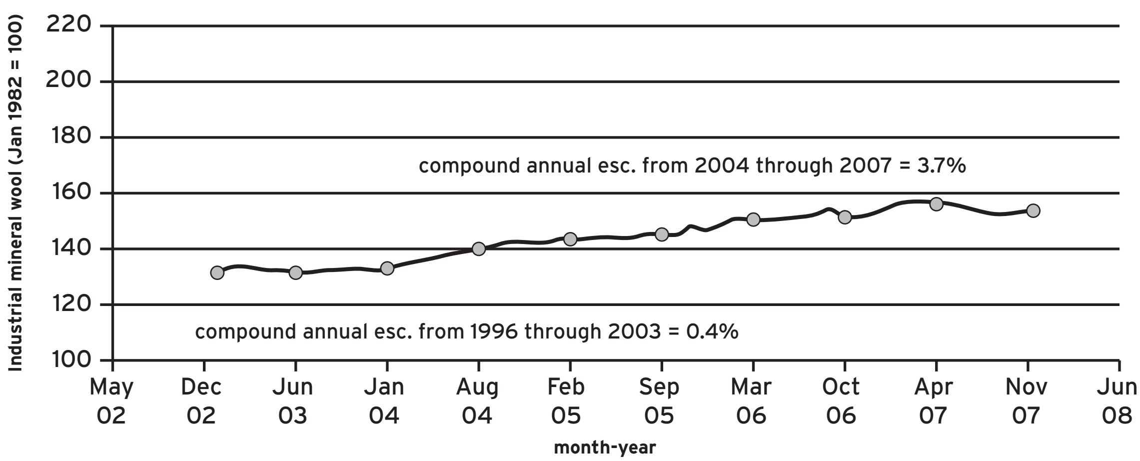
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.13 Cost Index for Fin-Tube Heat Exchangers



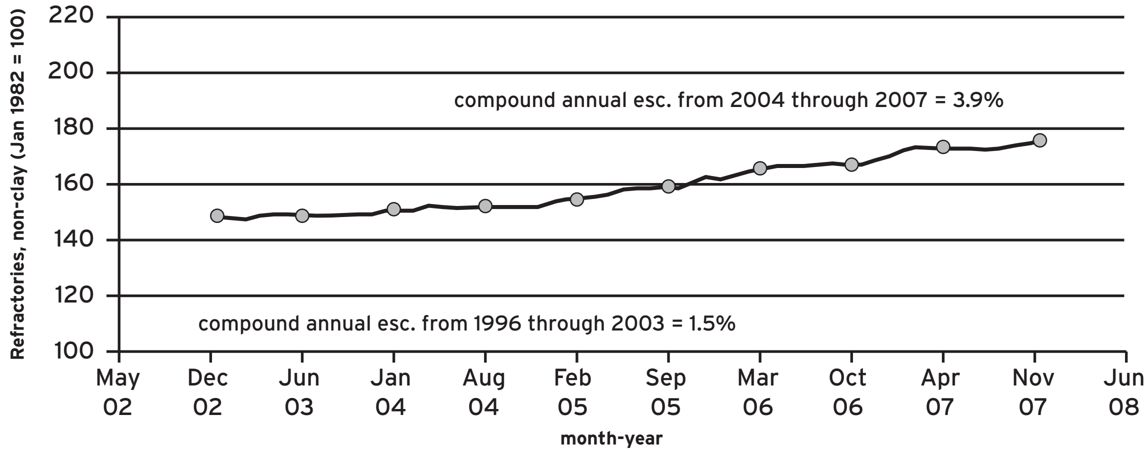
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.14 Cost Index for Industrial Mineral Wool



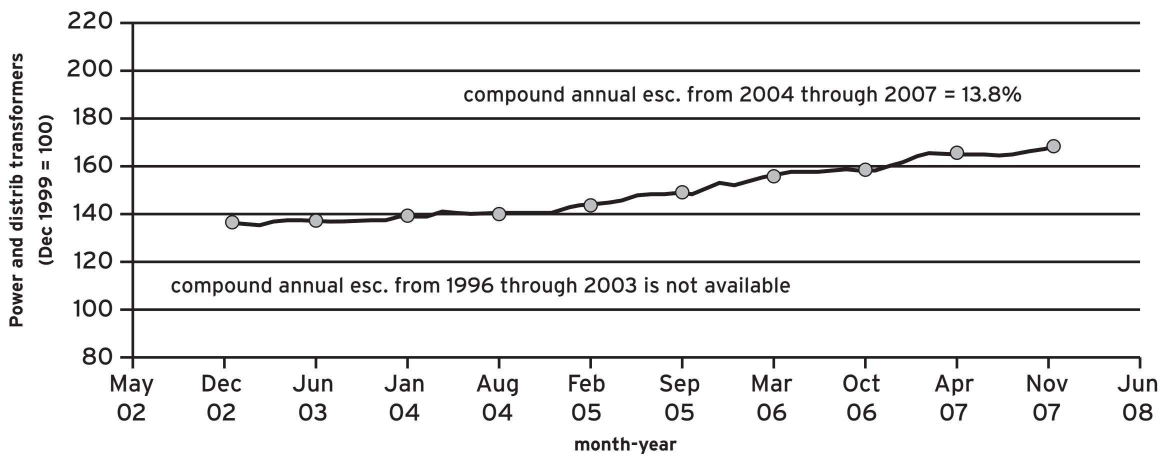
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.15 Cost Index for Refractories, Non-Clay



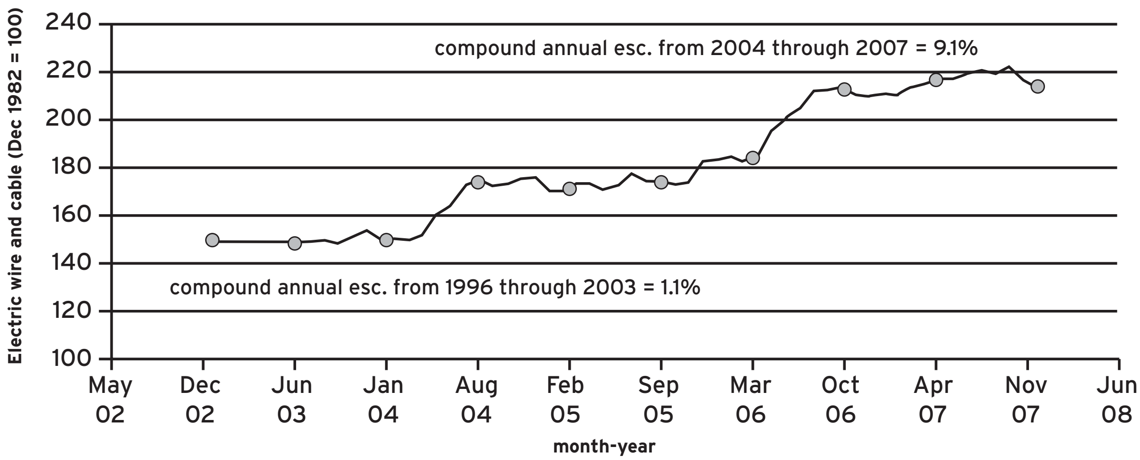
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.16 Cost Index for Power and Distribution Transformers



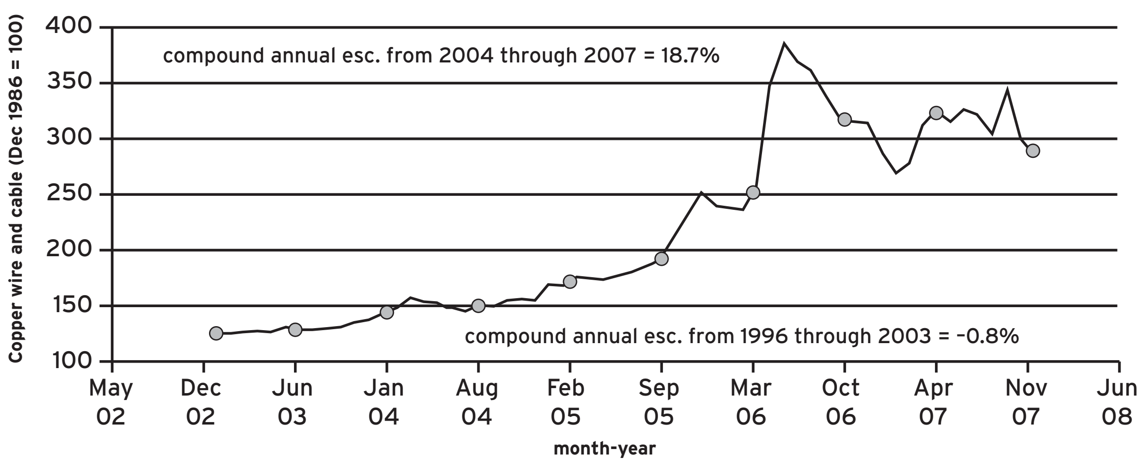
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.17 Cost Index for Electric Wire and Cable



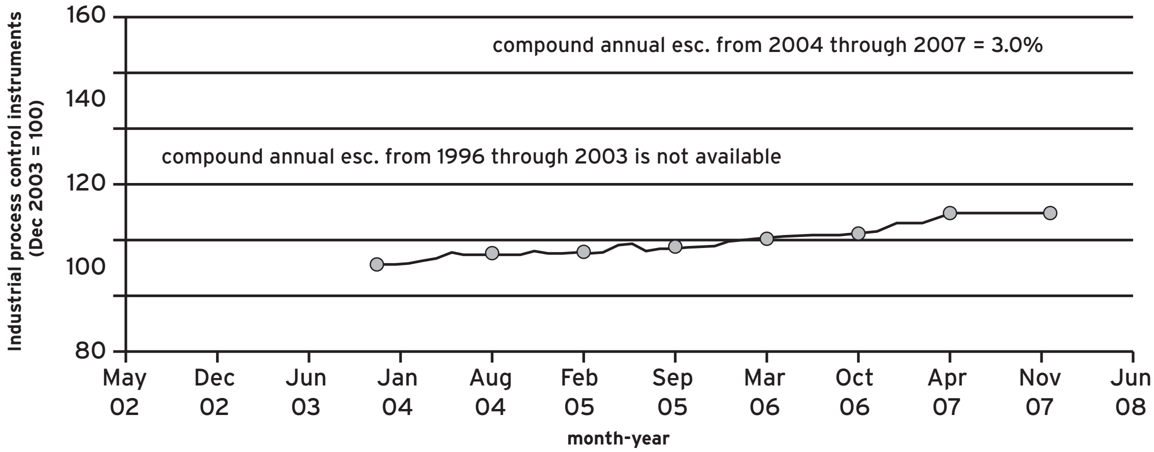
Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.18 Cost Index for Copper Wire and Cable



Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Figure A2.19 Cost Index for Industrial Process Control Instrument



Source: Producer Price Index, Bureau of Labor Statistics. Curve from January 1996 to January 2003, not shown.

Annex 3 OEMs in Romania

Coal-Fired Boilers

UTON

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Telefon: +40 234 32.42.22
Fax: +40 234 31.50.20
Fax: +40 234 32.59.01
http://www.uton.ro

UTON has the expertise and equipment required for the engineering, manufacturing, transport, on-site assembly, and maintenance of welded and machined assemblies and units intended for industrial chemicals, petrochemicals, iron and steel industry, energy generation, cement manufacturing, and food processing.

Product range:

- Pressure vessels.
- Shell and tube heat exchangers, air coolers.
- Skid-mounted process units, per customer design, including structure, vessels, pumps, filters, heat exchangers, and interconnecting valves and fittings, as required by the application.
- Industrial boilers.
- Pump casings.
- Fired heaters.

Export: America de Nord, Orientul Mijlociu, Africa, European Union

Import: European Union

ALSTOM POWER ROMANIA

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București 032091 Sector 3
România
Telefon: +40 21 346.54.08
Telefon: +40 21 346.54.38
Telefon: +40 21 346.54.39
Telefon: +40 21 346.54.40
Telefon: +40 21 346.54.41
Fax: +40 21 346.54.27
Fax: +40 21 346.54.35
http://www.alstom.com

Activities (EN):

- Power units rehabilitation and upgrading.
- Know-how for design and total/partial replacement of mechanical, electric, and automation equipment.
- Spare parts for steam turbines, generators, boilers.
- Current repairs and overhauls, maintenance, and service.
- Turnkey design for electric and thermal power production, including financing.

Export: Parts and auxiliaries of steam boilers to Germany, United States.

Blades for steam turbines to France, Germany, Hungary, Italy, and Poland.

Export: Polonia, Statele Unite ale Americii, Ungaria Europa Centrală/de Est, Europa de Vest

Import: Europa Centrală/de Est, Europa de Vest

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Fax: +40 248 61.55.99
Fax: +40 248 61.56.00
http://www.geostar.ro/imuc

Activities (EN):

Manufacturer of:

- Tube or pipe fittings (e.g., couplings, elbows, sleeves), of iron or steel.
- Tanks, casks, drums, cans, boxes, and similar containers, for any material (other than compressed or liquefied gas), of iron or steel.
- Metal tanks, chemical, and petrochemical use boilers.
- Parts of central heating boilers.
- Prefabricated buildings.

UZUC

Strada Depoului 16
Ploieşti 100335
România
Telefon: +40 244 40.11.19
Telefon: +40 244 51.09.82
Fax: +40 244 51.03.29
Fax: +40 244 51.77.25
http://www.uzuc.ro

Activities (EN):

Design, execution, and repair work for pressure equipment (heat exchangers, vessels, columns, boilers, towers), metallic expansion compensators, metallic structures, roller bearings (medium size), turnings, and support bearings.

Export: Statele Unite ale Americii, Italia, Germania, Olanda, Marea Britanie, Franţa

Import: Italia, Germania, Marea Britanie, Franţa Asia-Pacific, Europa de Vest, America de Nord

TECNOSERVICE BUCUREŞTI

Bulevardul Timişoara 5C
Bucureşti 061301 Sector 6
România
Telefon: +40 21 318.50.23
Telefon: +40 21 318.50.29
Fax: +40 21 318.50.28
Fax: +40 21 318.50.19
http://www.tsb.ro
http://www.tecnoservice.ro

Activities (EN):

General Supplier of:

- Power plant parts, industrial boilers, and related equipment.
- Equipment for chemical, petrochemical, and building materials industries.

Design of:

- Energetic and industrial boilers.
- Auxiliary thermo-mechanical equipment.

Manufacture:

- Power plant equipment.
- Pressure equipment according to PED 97/23/EC, ASME (S, U, NB), AD-Merkblatt HP0/TRD 201 and ISCIR requirements.
- Pipelines for energetic use and for natural gas transport and distribution.

Activities:

- Building and service works.
- Technical consultancy.
- Authorized provider of ESAB for welding and oxi-gas cutting equipment and consumables.

BETA

Strada Şantierului 39
Buzău 120226
România
Telefon: +40 238 72.55.00
Telefon: +40 238 71.05.55
Fax: +40 238 71.07.79
http://betabuzau.ro

Activities (EN):

Manufacturer of products and equipment for chemical, petrochemical industry, refineries:

- Industrial furnaces for refineries.
- Pressure vessels, storage tanks.
- Tubular heat exchangers.
- Butt-welded fittings: caps, tees, reducers, elbows, bends.
- Lens-type expansion joints.
- Bag filters.
- Metallic constructions.
- LPG and water distribution micro-stations.

Export: Franţa, Belgia, Italia, Spania, Marea Britanie, Danemarca, Austria, Federaţia Rusă, Ucraina, Republica Arabă Siriană, Iran, Iraq, Iordania, Pakistan, Kazakhstan, Statele Unite ale Americii, Canada, Mexic, Columbia, Venezuela, Algeria, Egipt

Europa Centrală/de Est, Europa de Vest, Asia-Pacific, Asia Centrală, America de Nord, America Centrală, America de Sud, Africa

Import: Bulgaria, Italia, Franţa, Germania, Marea Britanie, Ucraina

Europa de Vest, Europa Centrală/de Est

VILMAR

Strada Platforma Industrială 1
Râmnicu Vâlcea 240050
România
Telefon: +40 250 70.38.00
Fax: +40 250 70.38.06
http://www.vilmar.ro

Activities (EN):

- VILMAR S.A. is a privately owned company with 100 percent French authorized share capital, being the prime plant held by the company GENOYER S.A. Vitrolles, France, its main shareholder.
- GENOYER S.A. has industrial and commercial subsidiaries almost all over the globe, which provide relational, financial, and logistical support in the promotion of VILMAR products in all the world's marketplaces.
- VILMAR is based on a 24.94-hectare site, of which 10.42 hectares are covered by buildings, in the southern industrial zone of Râmnicu-Vâlcea town, at 180 kilometers northwest of Bucharest.
- VILMAR manufactures and trades a diversified range of technological equipment and components destined for several industries: chemical, petrochemical, petroleum and natural gas, energy, steel milling, mechanical constructions, metal processing, etcetera.
- The products are manufactured in a wide variety of shapes and sizes, standard or customized, in compliance with European, American, or specific standards, in all steel grades: carbon steels, alloy steels, low-alloy steels, high-alloy steels (including monel, incoloy, hastelloy, inconel), stainless steels (including duplex and super-duplex), corrosion-resistant steels, cladded steels, etcetera.
- VILMAR's production is made up of four divisions: FORGING (drop-forged pieces, including flanges and ball valve components; hammer-forged pieces; hot-rolled flanges and rings, with rectangular or profiled cross-section); MACHINING (flanges; rings; ball valve components; vitjoints; various machined pieces); FITTINGS (hot-formed fittings: welded elbows, caps, heads; cold-formed and welded fittings: concentric and eccentric reducers (conical shapes), miter bends, tees); and PRESSURE VESSELS (a large range of pressure vessels; heat exchangers; columns; storage tanks; SKIDS-modulated equipment for the separation and drying of the natural drilled gas, sea water desalting; structural steel with varied utilizations; static or dynamic mechanic-welded assemblies made according to the client's technical documentation).

Export: Franţa, Statele Unite ale Americii, Germania, Marea Britanie, Belgia, Peru, Italia, Spania, Brazilia, Republica Arabă Siriană, Emiratele Arabe Unite, Japonia, Norvegia, Olanda, Austria, Turcia, Elveţia, Egipt, Tunisia, Algeria, Iran, Qatar, Azerbaidjan, Arabia Saudită, India, Malaezia, Singapore, Filipine, Australia

Import: Franţa, Republica Cehă, Germania, Italia, Marea Britanie, Suedia, Elveţia, Austria, Ungaria, Olanda, Ucraina, Federaţia Rusă, Europa Centrală/de Est, Europa de Vest

24 JANUARY

Strada G-ral Dragalina 18
Ploieşti 100157
România
Telefon: +40 244 52.63.50 [mai multe]
Telefon: +40 244 52.19.50
Telefon: +40 344 40.11.44
Fax: +40 244 51.03.25
http://www.24january.ro

Activities (EN):

Being widely experienced in the machine construction field, "24 IANUARIE" manufactures a wide range of equipment and plants for various fields of activity:

- Metallurgical and siderurgical industries: fixed-hearth furnaces, roller-hearth furnances, multiple-hearth furnances, coke ovens, economizers, transfer tables and conveyors, sand mixers, continuous casting equipment.
- Chemical and petrochemical industries: heat exchangers, tanks with fixed or mobile cover, PECO type tanks of 5 to 60 cu.m. and two or three compartments, SKID-type monitoring systems for oil products, metallic drums of 40 to 220 liters, with plugs or removable covers.
- Painting and plating plants: painting cabins, drying ovens, evaporating and drying tunnels, hot-air generators, bath lines for plating operation, etcetera.
- Environmental medium protecting equipment: hydraulic dusters, cyclones, tubs and containers for storage and transport.
- Food industry: truck-mounted food tanks, stainless steel tanks, 200-liter drums made of zinc-coated sheet.
- Various equipment, metallic structures: distributors, excavator counter-weights, auto subassemblies, pelletizers, flintab electronic systems for auto and railway weighing.
- After any delivery, provides warranty and post-warranty service, spare parts, repairs, and general repairs for all the equipment manufactured.

Export: Belgia, Germania, Olanda, Austria, Italia, Franţa, Marea Britanie, Spania, Danemarca

Steam Turbines

GENERAL TURBO

Şoseaua Berceni 104
Bucureşti 041919 Sector 4
România
Telefon: +40 21 319.39.83
Telefon: +40 21 319.39.97
Telefon: +40 21 319.39.87
Telefon: +40 21 319.43.19
Fax: +40 21 300.20.23
Fax: +40 21 319.43.11
http://www.generalturbo.ro

Manufacturer of:

- Steam turbines for power generation and industrial turbines, 1–1,000-MW rating power.
- Boiler water feed pumps.
- Turbo-compressors for the chemical industry: air, hydrogen, ammonia, pit gas.
- Dynamic balancing of heavy rotors weighing 0.5–80,000 kg, at 300–40,000 rpm.
- Dynamic balancing and overspeeding of rotors with weights between 30,000–220,000 Kg on rotations up to 4,320 rpm for rotors with weights less than 120 t and 2,160 rpm for rotors with weights ranging between 120 t and 220 t.
- Cargo and ballast turbine-driven pumps aboard very large crude oil supertankers.
- Machining of large parts that require high accuracy.

- Upgrade and retrofit power generation units.
- Large generators rating 1–1,000 MW, in joint venture with ALSTOM GENERAL TURBO.
- Spare parts for GENERAL TURBO's own products and also for other machines and equipment.

Export:

- Complete turbo-generators to China, Egypt, Syria, and Turkey.
- Steam turbines to Austria.
- Steam turbine carcasses to Germany.
- Diaphragms and palettes for steam turbines to India.
- Parts for steam turbines to the Austria, France, and United States.
- Parts for hydraulic turbines and water wheels, including regulators (subassemblies for hydroelectric plants) to Austria.
- Generator casings, burners, base plates, bearings for gas turbines to the United States.
- Subassemblies for compressors to Italy.

Services:

- Technical assistance for installation/assembly works in technological upgrading of power assemblies.
- Technical assistance for installation/assembly works for power pumps and compressors for the chemical and petrochemical industries.
- Balancing of turbine and generator rotors within 3–700 MW and 3,000 rpm speed and overspeeding; balancing of driving turbine rotor and compressors within the speed range of up to 40,000 rpm.
- Heavy parts machining according to customer's documentation.
- Spare parts manufacturing according to customer's documentation or according to reverse engineering.

Export: Republica Arabă Siriană, Turcia, Egipt, Austria, Germania, Statele Unite ale Americii, India, China, Italia, Republica Cehă, Ungaria, Bulgaria

Import: Germania, Franța, Italia

FORTPRES CUG

Bulevardul Muncii 18
Cluj-Napoca 400641
România
Telefon: +40 264 41.51.14
Telefon: +40 264 41.52.50
Telefon: +40 264 41.56.07
Fax: +40 264 41.52.21
http://www.fortpres.ro

Activities (EN):

Manufacturer of: metallurgical equipment:

- Rolling lines, continuous casting lines, forging lines, dry casting moulds.
- Dried-sand fluidized beds.
- Forge manipulators.
- Metal-sheets transportation equipment.
- Roller conveyors.
- Sand-blasting machines.
- Shot-blasting tunnels.
- Shot-blasting cleaning and priming lines.
- Heat treatment furnaces.

Power equipment and turbines:

- Steam boilers.
- Generating turbines.
- Power units over 150 MW.
- Coal pneumatic crushers.

Plastic deformation equipment:

- Mechanical drawing presses.
- Mechanical joint presses.
- Maxi-presses.
- Electro hydraulic gasket presses.
- Friction screw presses.
- Forge hammers.
- Automated power welding.
- Heavy metal structures.

Export: Italia, Germania, Austria, Olanda, Franța, Ungaria European Union

Import: Israel, Italia, Germania, India, European Union

Combustion Turbines

TURBOMECANICA

Bulevardul Iuliu Maniu 244
București 061126 Sector 6
România
Telefon: +40 21 434.32.06
Telefon: +40 21 434.07.41
Telefon: +40 21 434.07.50
Telefon: +40 21 434.07.53
Fax: +40 21 434.31.65
Fax: +40 21 434.07.93
http://www.turbomecanica.ro

Activities (EN):

TURBOMECANICA was established in 1975 in Bucharest under the name of "Engine Plants"; its production facilities became operational in 1977. At that time, the company's main activity was the production of aircraft engines for the Romanian Ministry of Defense. Licenses from Rolls-Royce (UK), Turbomeca (France), and Aerospatiale (France) were bought from the beginning. Until the mid-1980s state-of-the-art Western equipment was purchased to keep pace with world-class aircraft engine manufacturers. After 1993, the company was reorganized, according to new requirements of the market, based on a restructuring program.

Since July 2000 TURBOMECANICA has been a private company.

TURBOMECANICA manufactures parts, subassemblies, and accessories and repairs aeronautical engines, helicopter gearboxes, spark-ignition and rotorheads, airframe components, hydraulic and gas turbines and waterwheels, high-tech equipment for industrial power generating systems, medical and military application, and transport equipment.

Export: Statele Unite ale Americii, Marea Britanie, Italia, Canada, Israel, Franța

Stationary Diesel Engine Turbines

TIMPURI NOI

Splaiul Unirii 165
București 030133 Sector 3
România
Telefon: +40 21 318.83.00
Telefon: +40 21 318.83.04
Telefon: +40 788304860
Fax: +40 21 318.83.12
Fax: +40 21 318.83.14
Telex: 10846
http://www.timpurinoi.ro

Manufactures and trades:

- Screw and piston, motor and electric, air compressor units.
- Gases or oil-free electric compressors.
- Electric compressors for ships.
- Centrifugal and diaphragm motor pumps.
- Generating sets driven by diesel engines.
- Spare parts.
- Precision machining.

Agent: Companies represented: ROTORCOMP Germania

Export: Germania, Grecia, Ungaria, Franța Asia Centrală, Orientul Mijlociu, Europa Centrală/de Est, Europa de Vest

Import: Germania, Olanda, Suedia, Italia Europa Centrală/de Est, Europa de Vest

FAUR

Bulevardul Basarabia 256
București 030352 Sector 3
România
Telefon: +40 21 255.02.75
Telefon: +40 21 255.15.13
Fax: +40 21 255.00.70
Fax: +40 21 255.00.71
http://www.faur.ro

Production and trade of:

- Diesel electric locomotives.
- Diesel hydraulic locomotives.
- Motor railers.
- Machines for railway maintenance and repairs.
- V3A Trams.
- Spare parts for rolling stock.
- Diesel engines (175–1.250 PH; 1.000–2.300 rpm); spare parts, power sets (130–800 KVA); and generating sets.
- Equipment for: machinery, metallurgy industries, building materials industry (cement factories), and chemical and petrochemical industry.
- Cast parts: steel, non-ferrous alloys, cast iron (grey and nodular black-leaded).
- Forged parts.

Export: Germania, Egipt, Italia, Franța, Belgia

Africa, Europa de Vest

ELECTRO EXIM SRL

21, IALOMICIOAREI St. sect.1
Bucharest—ROMANIA
Code:011277
Phone: 40-21-2231347; 40-21-5691080;
Fax: 40-21-2231201
E-mail: office@electroexim.com

ELECTRO EXIM S.R.L. is a private company performing a variety of export-import activities in the fields of electric power production, transmission, and distribution. Electro Exim was one of the first Romanian companies to be privatized, is well regarded abroad, and has successfully established strong relationships with more than 300 Romanian and international companies. Works with speed and flexibility to deliver products on time to exact specifications.

On the Romanian market, focused on distributing electric generators between 10–2264 KVA and uninterruptible power supply units (UPS) between 1–1000 kVA. For these products, ELECTRO offers full service, from consulting for the best option to servicing the generators after the purchase.

Annex 4 OEMs in India

Table A4.1 Partial List of OEMs in India

S1 No.	Description	Manufacturer Name	Manufacturer Address
1.	Coal-Fired Boiler	*BHARAT HEAVY ELECTRICALS LTD (BHEL)* ISGEC JOHN THOMPSON THERMAX LTD THYSSEN KRUUP INDUSTRIES INDIA	1. 18–20, Kasturba Gandhi Marg, New Delhi-110001. 2. 33A,Jawaharlal Nehru Road, Kolkata-700071. 3. D–1 Block, Plot no. 7/2 R.D.Aga Road, M.I.D.C, Chinchwad, Pune-411019. 4. Pimpri, Pune-411018 Tel No. - +91-20-7474461
2.	Steam Turbine	BHEL *GEC ALSTHOM TRIVENI LTD*	1. 18–20, Kasturba Gandhi Marg, New Delhi-110001 2. P.B. No. 5848,12A, 1st Phase Peenya Industrial Area, Bangalore-560058
3.	Combustion Turbine	BHEL	1. 18–20, Kasturba Gandhi Marg, New Delhi-110001
4.	Stationary Diesel Engine-Generator	KRILOSKAR CUMMINS LTD *WARTSILA INDIA*	1. Kothrud, Pune-411029 2. Banaras House Ltd, Wartsila Diesel Division, 11th Floor, New Delhi House, 27, Barakhamba Road, New Delhi-110001

Source: Author's calculations.

Note: OEMs in italicized letters have been contacted, but did not provide requested budget quotes.

List of Technical Reports

Region/Country	Activity/Report Title	Date	Number
	SUB-SAHARAN AFRICA (AFR)		
Africa Region	Power Trade in Nile Basin Initiative Phase II (CD Only)	04/05	067/05
	Part I: Minutes of the High-level Power Experts Meeting; and Part II: Minutes of the First Meeting of the Nile Basin Ministers Responsible for Electricity	10/06	104/06
	Introducing Low-cost Methods in Electricity Distribution Networks Second Steering Committee: The Road Ahead. Clean Air Initiative In Sub-Saharan African Cities, Paris, March 13-14, 2003	12/03	045/03
	Lead Elimination from Gasoline in Sub-Saharan Africa. Sub-regional Conference of the West-Africa group. Dakar, Senegal March 26-27, 2002 (Deuxième comité directeur: La route à suivre - L'initiative sur l'assainissement de l'air. Paris, le 13-14 mars 2003)	12/03	046/03
	1998-2002 Progress Report. The World Bank Clean Air Initiative in Sub-Saharan African Cities. Working Paper #10 (Clean Air Initiative/ESMAP)	02/02	048/04
	Landfill Gas Capture Opportunity in Sub-Saharan Africa	06/05	074/05
	The Evolution of Enterprise Reform in Africa: From State-owned Enterprises to Private Participation in Infrastructure-and Back?	11/05	084/05
	Market Development	12/01	017/01
Cameroon	Decentralized Rural Electrification Project in Cameroon	01/05	087/05
Chad	Revenue Management Seminar, Oslo, June 25-26, 2003. (CD Only)	06/05	075/05
Côte d'Ivoire	Workshop on Rural Energy and Sustainable Development, January 30-31, 2002. *(Atelier sur l'Energie en régions rurales et le Développement durable 30-31, janvier 2002)*	04/05	068/05
East Africa	Sub-Regional Conference on the Phase-out Leaded Gasoline in East Africa. June 5-7, 2002	11/03	044/03

Ethiopia	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Ethiopia - Action Plan	12/03	038/03
	Sub-Saharan Petroleum Products Transportation Corridor: Analysis and Case Studies	03/03	033/03
	Phase-Out of Leaded Gasoline in Sub-Saharan Africa	04/02	028/02
	Energy and Poverty: How can Modern Energy Services Contribute to Poverty Reduction	03/03	032/03
Ghana	Poverty and Social Impact Analysis of Electricity Tariffs	12/05	088/05
	Women Enterprise Study: Developing a Model for Mainstreaming Gender into Modern Energy Service Delivery	03/06	096/06
	Sector Reform and the Poor: Energy Use and Supply in Ghana	03/06	097/06
Kenya	Field Performance Evaluation of Amorphous Silicon (a-Si) Photovoltaic Systems in Kenya: Methods and Measurement in Support of a Sustainable Commercial Solar Energy Industry	08/00	005/00
	The Kenya Portable Battery Pack Experience: Test Marketing an Alternative for Low-Income Rural Household Electrification	05/01	012/01
Malawi	Rural Energy and Institutional Development	04/05	069/05
Mali	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Mali - Action Plan *(Elimination progressive de l'essence au plomb dans les pays importateurs de pétrole en Afrique subsaharienne Le cas du Mali — Mali Plan d'action)*	12/03	041/03
Mauritania	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Mauritania - Action Plan *(Elimination progressive de l'essence au plomb dans les pays importateurs de pétrole en Afrique subsaharienne Le cas de la Mauritanie – Plan d'action)*	12/03	040/03
Nigeria	Phase-Out of Leaded Gasoline in Nigeria	11/02	029/02
	Nigerian LP Gas Sector Improvement Study	03/04	056/04
	Taxation and State Participation in Nigeria's Oil and Gas Sector	08/04	057/04
Senegal	Regional Conference on the Phase-Out of Leaded Gasoline in Sub-Saharan Africa *(Elimination du plomb dans l'essence en Afrique subsaharienne Conference sous regionales du Groupe Afrique de l'Ouest Dakar, Sénégal, March 26-27, 2002)*	*03/02* 12/03	*022/02* 046/03
	Alleviating Fuel Adulteration Practices in the Downstream Oil Sector in Senegal	09/05	079/05
	Maximisation des Retombées de l'Electricité en Zones Rurales, Application au Cas du Sénégal	05/07	109/07

South Africa	South Africa Workshop: People's Power Workshop.	12/04	064/04
Swaziland	Solar Electrification Program 2001 2010: Phase 1: 2001 2002 (Solar Energy in the Pilot Area)	12/01	019/01
Tanzania	Mini Hydropower Development Case Studies on the Malagarasi, Muhuwesi, and Kikuletwa Rivers Volumes I, II, and III	04/02	024/02
	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Tanzania - Action Plan	12/03	039/03
Uganda	Report on the Uganda Power Sector Reform and Regulation Strategy Workshop	08/00	004/00
	EAST ASIA AND PACIFIC (EAP)		
Cambodia	Efficiency Improvement for Commercialization of the Power Sector	10/02	031/02
	TA For Capacity Building of the Electricity Authority	09/05	076/05
China	Assessing Markets for Renewable Energy in Rural Areas of Northwestern China	08/00	003/00
	Technology Assessment of Clean Coal Technologies for China Volume I-Electric Power Production	05/01	011/01
	Technology Assessment of Clean Coal Technologies for China Volume II-Environmental and Energy Efficiency Improvements for Non-power Uses of Coal	05/01	011/01
	Technology Assessment of Clean Coal Technologies for China Volume III-Environmental Compliance in the Energy Sector: Methodological Approach and Least-Cost Strategies	12/01	011/01
	Policy Advice on Implementation of Clean Coal Technology	09/06	104/06
	Scoping Study for Voluntary Green Electricity Schemes in Beijing and Shanghai	09/06	105/06
Papua New Guinea	Energy Sector and Rural Electrification Background Note	03/06	102/06
Philippines	Rural Electrification Regulation Framework (CD Only)	10/05	080/05
Thailand	DSM in Thailand: A Case Study	10/00	008/00
	Development of a Regional Power Market in the Greater Mekong Sub-Region (GMS)	12/01	015/01
	Greater Mekong Sub-region Options for the Structure of the GMS Power Trade Market A First Overview of Issues and Possible Options	12/06	108/06
Vietnam	Options for Renewable Energy in Vietnam	07/00	001/00
	Renewable Energy Action Plan	03/02	021/02
	Vietnam's Petroleum Sector: Technical Assistance for the Revision of the Existing Legal and Regulatory Framework	03/04	053/04
	Vietnam Policy Dialogue Seminar and New Mining Code	03/06	098/06

Regional	The Population, Energy and Environmental Program (EAP) (English and Spanish)	08/02	027/02
	Bank Experience in Non-energy Projects with Rural Electrification Components: A Review of Integration Issues in LCR	02/04	052/04
	Supporting Gender and Sustainable Energy Initiatives in Central America	12/04	061/04
	Energy from Landfill Gas for the LCR Region: Best Practice and Social Issues (CD Only)	01/05	065/05
	Study on Investment and Private Sector Participation in Power	12/05	089/05
	Distribution in Latin America and the Caribbean Region Strengthening Energy Security in Uruguay	05/07	116/07
Bolivia	Country Program Phase II: Rural Energy and Energy Efficiency Report on Operational Activities	05/05	072/05
	Bolivia: National Biomass Program. Report on Operational Activities	05/07	115/07
Brazil	Background Study for a National Rural Electrification Strategy: Aiming for Universal Access	03/05	066/05
	How do Peri-Urban Poor Meet their Energy Needs: A Case Study of Caju Shantytown, Rio de Janeiro	02/06	094/06
	Integration Strategy for the Southern Cone Gas Networks	05/07	113/07
	Estrategia de integración de la red de gasoductos del Cono Sur	12/07	113/07
Chile	Desafíos de la Electrificación Rural	10/05	082/05
Colombia	Desarrollo Económico Reciente en Infraestructura: Balanceando las necesidades sociales y productivas de la infraestructura	03/07	325/05
Ecuador	Programa de Entrenamiento a Representantes de Nacionalidades Amazónicas en Temas Hidrocarburíferos	08/02	025/02
	Stimulating the Picohydropower Market for Low-Income Households in Ecuador	12/05	090/05
Guatemala	Evaluation of Improved Stove Programs: Final Report of Project Case Studies	12/04	060/04
Haiti	Strategy to Alleviate the Pressure of Fuel Demand on National Woodfuel Resources (English) *(Stratégie pour l'allègement de la Pression sur les Ressources Ligneuses Nationales par la Demande en Combustibles)*	04/07	112/07
Honduras	Remote Energy Systems and Rural Connectivity: Technical Assistance to the Aldeas Solares Program of Honduras	12/05	092/05
Mexico	Energy Policies and the Mexican Economy	01/04	047/04
	Technical Assistance for Long-Term Program for Renewable Energy Development	02/06	093/06

Nicaragua	Aid-Memoir from the Rural Electrification Workshop (Spanish only)	03/03	030/04
	Sustainable Charcoal Production in the Chinandega Region	04/05	071/05
Peru	Extending the Use of Natural Gas to Inland Perú (Spanish/English)	04/06	103/06
	Solar-diesel Hybrid Options for the Peruvian Amazon Lessons Learned from Padre Cocha	04/07	111/07
	GLOBAL		
	Impact of Power Sector Reform on the Poor: A Review of Issues and the Literature	07/00	002/00
	Best Practices for Sustainable Development of Micro Hydro Power in Developing Countries	08/00	006/00
	Mini-Grid Design Manual	09/00	007/00
	Photovoltaic Applications in Rural Areas of the Developing World	11/00	009/00
	Subsidies and Sustainable Rural Energy Services: Can We Create Incentives Without Distorting Markets?	12/00	010/00
	Sustainable Woodfuel Supplies from the Dry Tropical Woodlands	06/01	013/01
	Key Factors for Private Sector Investment in Power Distribution	08/01	014/01
	Cross-Border Oil and Gas Pipelines: Problems and Prospects	06/03	035/03
	Monitoring and Evaluation in Rural Electrification Projects: A Demand-Oriented Approach	07/03	037/03
	Household Energy Use in Developing Countries: A Multicountry Study	10/03	042/03
	Knowledge Exchange: Online Consultation and Project Profile from South Asia Practitioners Workshop, Colombo, Sri Lanka, June 2-4, 2003	12/03	043/03
	Energy & Environmental Health: A Literature Review and Recommendations	03/04	050/04
	Petroleum Revenue Management Workshop	03/04	051/04
	Operating Utility DSM Programs in a Restructuring Electricity Sector	12/05	058/04
	Evaluation of ESMAP Regional Power Trade Portfolio (TAG Report)	12/04	059/04
	Gender in Sustainable Energy Regional Workshop Series: Mesoamerican Network on Gender in Sustainable Energy (GENES) Winrock and ESMAP	12/04	062/04
	Women in Mining Voices for a Change Conference (CD Only)	12/04	063/04

Energy Sector Management Assistance Program (ESMAP)

Purpose

The Energy Sector Management Assistance Program is a global knowledge and technical assistance program administered by the World Bank and assists low-income, emerging and transition economies to acquire know-how and increase institutional capability to secure clean, reliable, and affordable energy services for sustainable economic development.

ESMAP's work focuses on three global thematic energy challenges:

- Energy Security
- Poverty Reduction
- Climate Change

Governance And Operations

ESMAP is governed by a Consultative Group (CG) composed of representatives of the Australia, Austria, Canada, Denmark, Finland, France, Germany, Iceland, Norway, Sweden, The Netherlands, United Kingdom, and The World Bank Group. The ESMAP CG is chaired by a World Bank Vice President, and advised by a Technical Advisory Group of independent, international energy experts who provide informed opinions to the CG about the purpose, strategic direction, and priorities of ESMAP. The TAG also provides advice and suggestions to the CG on current and emerging global issues in the energy sector likely to impact ESMAP's client countries. ESMAP relies on a cadre of engineers, energy planners, and economists from the World Bank, and from the energy and development at large to conduct its activities.

Further Information

For further information or copies of project reports, please visit www.esmap.org. ESMAP can also be reached by email at esmap@worldbank.org or by mail at:

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