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Greener Plants, Grayer Skies?

A REPORT FROM THE FRONT LINES OF CHINA'S ENERGY SECTOR

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I. Introduction*

China's emergence as the world's largest emitter of carbon dioxide and second largest consumer of energy overall (behind the United States) has caused observers worldwide to become aware of a basic fact. To a significant degree, our planet's energy and environmental future is now being written in China. Consequential energy decisions are being made throughout this rapidly transforming nation. Every new building, every new urban transport system, and every new factory involves decisions about energy. Collectively, this vast array of decisions has implications not just for China's own environment, but more generally for global resource availability, global energy prices, and global environmental conditions.

In no domain are China's energy-related decisions more crucial and the linkages to the global environment more direct than in electric power. China's power sector is critical for a number of reasons. First, it is very large in global terms. In 2007, installed generating capacity in China stood at 713 thousand megawatts, or gigawatts (GW), second only to the United States' roughly 1075 GW.¹ Second, the power sector in recent years has been expanding at a frenetic pace, more than doubling in size since 2000. In 2006 alone, 102 GW of new generating capacity was added, an increment substantially larger than the United Kingdom's entire electric power system. It is reasonable to estimate that during the past three years, the equivalent of three or four 500 megawatt (MW) power plants have been coming on line in China every single week. In terms of physical energy infrastructure, what took the United States the better part of a century to construct has gone up in China in less than a decade. Third, China's power sector is fueled overwhelmingly by coal. Roughly 80 percent of Chinese electricity is generated through coal combustion, as compared to 50 percent in the United States, the world's second largest coal user. Coal is also used extensively in China's industrial

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¹ China figure from China Electricity Council, 2008; US figure from Energy Information Agency, U.S. Department of Energy, "Existing Capacity by Energy Source" (<http://www.eia.doe.gov/cneaf/electricity/epa/epat2p2.html>)

sector and as a source of chemical feedstocks. That said, coal demand is increasing much more rapidly in the power sector, which today already accounts for over half of total consumption.²

This matters partly because the byproducts of coal combustion have major environmental consequences. Atmospheric emissions of sulfur oxides (SO_x) and nitrogen oxides (NO_x) have long been recognized as the primary drivers of acid precipitation. Other harmful emissions include fine particulates, volatile organic compounds, and toxic trace metals like mercury and arsenic. And now, carbon dioxide, because of its link to global warming, has become the most prominent item on the pollutant list. Coal is the most abundant energy resource globally and the most carbon-intensive. Its combustion worldwide is the largest single driver of anthropogenic climate change. In 2005, coal accounted for 42 percent of global CO₂ emissions. In that year, coal combustion accounted for 82 percent of China's CO₂ emissions, and 36 percent of America's CO₂ emissions.³

Despite much current attention to alternative energy technologies such as wind and solar power, fuel cells, biomass, and nuclear power, the likelihood is that coal will remain the world's largest source of electricity for decades to come. Thus the most important questions for the earth's environmental future, at least over the coming decades, concern how coal will be utilized. Will it be used cleanly or destructively? Will it be used efficiently or inefficiently? And will its pollutant byproducts be dealt with effectively or effectively ignored? These questions matter wherever coal is being used, but they matter most where coal is being used most extensively, China.

The scale of China's coal use makes it a global concern. Furthermore, since China is still setting the regulatory, technological, and economic parameters that will govern exactly how coal is used, there is at least the possibility of achieving constructive change in China with global reach. In essence, the power sector encompasses a series of potential 'leverage points'. These include, for example, the type and quality of the coal consumed, the mechanisms and prices by which coal is sourced, the technologies used to burn coal, and the systems employed

² National Bureau of Statistics, *China Energy Statistical Yearbook*, 2006.

³ Energy Information Agency, "World Carbon Dioxide Emissions from the Consumption of Coal, 1980-2006" (<http://www.eia.doe.gov/pub/international/iealf/tableh4co2.xls>); Energy Information Agency, "World Carbon Dioxide Emissions from the Consumption and Flaring of Fossil Fuels, 1980-2005," (<http://www.eia.doe.gov/pub/international/iealf/tableh1co2.xls>).

to deal with its emissions. Most of these leverage points intersect at the level of analysis of this paper, the power plants coming on line in China every week.

It must be noted that this paper does not directly address any efforts on China's part to deal specifically with CO₂ emissions. China – like other countries including the United States -- has yet to embark on a serious effort here. What the paper does do, however, is to examine two sets of issues that will be of great importance should serious efforts at climate change mitigation ultimately move forward. The first pertains to the efficiency with which fossil fuel-based energy production is being carried out. The second concerns the overall responsiveness of the system to change and innovation. By examining how the Chinese system is responding today to a variety of new economic and environmental pressures – namely, rising fuel costs and growing concerns over air pollution – this paper aims to illuminate the system's ability to deal in the future with the even greater regulatory, economic, technological, and operational innovations that will be necessary to deal with carbon.

The Conventional Wisdom

The phrase “opportunities for leverage” has a hopeful ring. The conventional wisdom about China's power sector today, however, suggests anything but hope. Observers focusing on this topic – particularly those from outside China – have for the most part arrived at a consensus view on what the sector is really like. The picture is essentially as follows.

First, China's energy infrastructure is expanding rapidly, but it is being built with retrograde, antiquated, and inefficient technologies. Furthermore, these technologies are being deployed in small plants, which neither capture minimum scale economies nor are subject to effective regulatory supervision. Basically, in this view China is building the quickest, cheapest, dirtiest system possible – a 21st century infrastructure with Eisenhower-era technology. In so doing, the country is locking itself into a sub-standard energy system for decades to come.

A second component of the conventional wisdom is that the main fuel for that infrastructure, domestically-sourced coal, is heavily subsidized and of low quality. Because coal prices are controlled by the state, utility operators face few incentives to switch to cleaner

alternative fuels or use technologies that burn coal more efficiently. In addition, artificially low coal prices lead to underpriced electricity, which then pushes China's overall industrial structure toward more energy-intensive sectors. China as a result becomes a repository for the world's most energy-intensive industries, and in an environment in which few price incentives exist for the efficient operation of those industries.

Third, China has neither the political will nor the governmental capacity to shift from the environmentally destructive, resource intensive path it is currently on. Some observers suggest that this stems from problems at the top, an overarching leadership ethos that privileges economic enrichment and national power over environmental sustainability. Others suggest that the problem has more to do with the peripheries, and with an inability on the part of environmentally-conscious leaders in Beijing to control the local officials who build and operate power plants. In the end, both views arrive at a similar conclusion; the officials who count, whether in the center or at the peripheries, will not push for more sound environmental practices.

Taken together, these three points – about technology, fuels, and political context – fit together into a single punch line. In the bluntest terms, “China builds crap, it burns crap, and it doesn't give a crap.”

Conventional Wisdom Challenged: MIT's 2007 China Energy Survey

At least initially, the picture sketched in the preceding paragraphs resonated with our research team in the MIT Industrial Performance Center's China Energy Group. Having carried out substantial amounts of China-based field work in recent years, we had all witnessed many of the darker aspects of the Chinese energy system – the intense urban air pollution, the antiquated technologies, the substandard operational practices, and the haphazard, spotty pattern of regulatory enforcement. Yet these views were often impressionistic and were complicated by instances we had witnessed of almost the complete opposite – investment in very advanced technologies, rapid uptake of advanced managerial practices, and serious attention to environmental cleanup. As we struggled to make sense of our own experiences, we were continually struck by the extent to which the emerging conventional wisdom was

based on precious little systematic data. Nobody, whether in academia, government, or industry, seemed to have the kind of comprehensive data -- particularly firm-level data -- needed to back up such an assessment. It was not only the outsiders who were lacking data. Chinese regulators themselves, especially at the center, seemed at a loss to identify exactly what was happening on the ground. While it may have been plausible to believe that China could “build crap, burn crap, and not give a crap,” our experience told us that the system was far more complex and varied than that. Meanwhile, as our own impressions were getting increasingly confused and ambivalent, the conventional wisdom, especially outside China, seemed to be getting more blunt, more certain, and more entrenched, especially as it was articulated alongside the policy question of whether the United States should do anything about climate change if China was just continuing along an environmentally retrograde path.

In 2005, our MIT team decided to tackle the information problem by embarking on a first-of-its-kind data collection effort, a full-scale survey of China’s coal-fired electric power sector. The survey, done in partnership with a domestic Chinese research firm, was ultimately conducted in 2007 and completed in early 2008. Administered at the level of the power plant, it involved an extensive 26-page Chinese-language survey instrument covering multiple areas of power plant infrastructure, investment, operations, and environmental cleanup. In total, the survey sample encompassed 85 power plants, many of which had multiple generating units. Two-hundred ninety-nine separate generating units were included in total. Senior specialists within each plant – plant managers, chief engineers, senior environmental officers, and chief financial officers – were called upon, via telephone or face-to-face interview, to answer portions of the survey corresponding to their respective areas of professional responsibility.

The survey results uncovered a reality far more complicated than anything suggested by the conventional wisdom. The findings are briefly summarized below, and then addressed in detail in the main body of the paper.

First, particularly with the onset of the most rapid phase of energy sector expansion, the period dating from 2002 through 2007, the system could not unequivocally be described as dominated by small-scale facilities. Many new generating units have been built in recent years, and they have come in a variety of sizes and types. We see on the one hand the building of

many smaller scale units (capacity under 50 MW), but on the other hand the appearance of more and more large scale units (capacity over 300 MW). Thus, while small-scale units, just in terms of sheer numbers, account for the majority of new units coming on line, large units account for the bulk of the new generating capacity added to the system. It is worth noting that such size variation is consistent not only with China's power sector expansion, but also America's.

Second, across power plants of all scales in China, there has in recent years been significant uptake of advanced combustion and turbine technologies. China's power sector exhibits a wide range of equipment types. The survey sample certainly revealed older systems no longer commonly found in advanced industrial economies. Yet, it also revealed substantial representation at the other end of the spectrum, with a sizable portion of plants employing state-of-the-art equipment, much of it sourced from global suppliers. Interestingly, some of the newest and most advanced coal combustion technologies currently used in China are most suitable for – and most frequently found in – smaller to medium size generating units. Contrary to what the conventional wisdom might suggest, it is not simply the case in Chinese – or even global – power generation that “small equals bad” in terms of operational efficiency and environmental performance.

Third, technologies for environmental cleanup, most notably those for handling SO_x emissions, are appearing with increasing frequency in Chinese coal-fired power plants. In some cases, “clean coal” technologies have been installed that permit SO_x neutralization and removal in the combustion unit. In other cases, flue-gas desulfurization (FGD) systems, or “scrubbers,” enabling post-combustion capture of SO_x, have been added to conventional units. Again, these systems are being sourced from a variety of suppliers, multinational and domestic. Evidently some kind of institutional pressure exists in the Chinese system to push at least some kinds of power producers to purchase environmental cleanup technologies.

Fourth, a substantial portion – and possibly the bulk -- of all coal consumed by Chinese power plants is now sourced on open markets at market-determined prices. Subsidized prices and state-controlled allocation channels have been largely phased out. Instead, the majority of Chinese electric utilities secure fuel by dealing directly with mines either through long-term

(one year) supply contracts or, not infrequently today, through immediate spot market purchases. With coal demand now exceeding supply, Chinese coal prices have risen significantly, converging in recent years to global levels. It is fair to say that in fuel acquisition, a core aspect of day-to-day operations, Chinese power producers are now functioning in a marketized environment. Facing rapidly rising fuel costs, they are experiencing a variety of both long and short-term pressures to economize.

Within this environment, Chinese power utilities burn a wide range of coal types sourced from a wide range of mines, both local and more distant. Interestingly, regardless of which type they access, plants on the whole seem to be purchasing coal of relatively low sulfur content. Again, this suggests that even in a rising cost environment, power producers are being pushed by certain institutional pressures to purchase more expensive, more environmentally-friendly low-sulfur fuels.

Fifth, and of critical importance, in terms of actual environmental performance, Chinese power plants operate quite poorly. The data for SO_x emissions show this most clearly. The MIT survey depended on self-reported data by plant-level respondents, but even here, plants were reporting SO_x emission levels far above global standards, and in some cases, levels exceeding China's own domestic legal limits.

This last finding in particular makes for a complex picture. Important aspects of marketization are clearly underway in China's energy sector. Power plants, now falling under a variety of ownership schemes, for the most part operate as autonomous economic actors. In terms of infrastructure, they must choose their own technologies and cobble together the financing necessary to secure them. In terms of operations, they must source most of their fuel, their largest operating expense, on open markets at variable prices. In terms of regulatory environment, they must cope with a series of new rules and strictures, some of which are ambiguously defined, and many of which have changed repeatedly in recent years. Meanwhile, these utilities are expected to be commercially-viable entities, realizing operating profits in the near term and positive returns on investment over the long run.

What do they do under such conditions? Some – a substantial fraction, in fact – install modern generating technologies, offering far greater operational efficiencies, and thus lower

costs over the lifetime of the plant, than had previously been achievable in China. After all, more efficient electric power generating technologies permit less fuel to be burned per unit of electricity produced. The environmental side benefit is that greater fuel efficiency means fewer pollutants emitted per unit of electricity generated. Escalating coal prices and mandatory emission control policies clearly serve as an important lever for encouraging change in this direction.

At the same time, while a substantial number of power producers invest in expensive environmental cleanup technologies, the emissions data suggest that these technologies are not being operated on a regular basis. Here, we may perhaps be witnessing the downside of rising coal prices, for plants can balance fuel price hikes by cutting back on the operational costs associated with using cleanup systems.

The bottom line is that in environmental terms, Chinese coal-fired power plants are performing poorly today, but they are investing in the sorts of physical infrastructure necessary for better performance in the future. As MIT's 2007 China Power Survey shows, it is not simply the case that "China builds crap, burns crap, and does not give a crap." Yet it is also clearly not the case that China has already arrived at a solution for sustainable energy production. Somehow, enough leverage – whether commercial, regulatory, or political – exists in the Chinese context to get plants to spend money on modernization and to purchase the kinds of technologies necessary for achieving better environmental outcomes in the future. Yet there does not appear to be sufficient leverage to employ those technologies so as to realize better environmental outcomes today. Meanwhile, all of this is taking place in a rapidly marketizing environment. The real question is whether societal pressure and political determination – governance, in effect – will tilt the balance, transforming the potential for better environmental performance into actual reality.

II. Description of the Survey and Sampling Technique

MIT's 2007 China Power Survey covered 85 power plants across 14 Chinese provinces. The geographic distribution of the respondents is illustrated in Chart 2.1 and Table 2.1.

Chart 2.1 Location of Power Plants in MIT 2007 China Energy Survey



These plants encompass 299 separate generating units, the vast majority of which are coal-fired. The exceptions are 9 small units that burn oil, one that burns coke oven gas, and 13 that burn coal gangue, a solid waste product from the processing of coal. These ended up in the survey because they happen to be ancillary units of some of the coal-burning utilities that responded. Similarly, the survey also captured 7 units that are either planned or currently under construction, and 35 units that have already been shut down. Among the closed units are two oil-burning facilities.

The plants surveyed comprise a total combined generating capacity of 32.68 GW, though 2.2 GW of that total pertains to units no longer in operation, and 2.7 GW pertains to plants not yet completed. Power plants within China are categorized as “large sized” if total capacity equals exceeds 300 MW, “medium-sized” if capacity is below 300 MW but above 50 MW, and “small-sized” if capacity is below 50 MW. Of the 85 power plants in the survey, 24, or 28.2 percent of the total, are large scale, 18 (21.2 percent of the total) are medium scale, and 43 (50.6 percent of the total) are small scale. Not surprisingly given the relatively recent expansion

of China's energy sector, for over three-quarters of the plants surveyed, their first unit came on line after 1980. For just under half of the sample, the first unit came on line during the 1980s and 1990s. And for about a quarter of the sample, the first unit came on line after 2000. Many of the plants surveyed have either built new units or expanded and upgraded older units in the last five years. Of the 299 units surveyed, 71 came on line after 2001, and 14 older units underwent upgrading during that period.

The MIT survey captured a significant fraction of the “known universe” of coal-fired power plants in China, at least in terms of what Chinese governmental figures officially recognize. Industrial boilers or other “within the fence” forms of power generation by major industrial energy users are included neither in the MIT survey nor in official state statistics on the electric power sector.⁴ The 257 units in the survey that are currently in operation represent a total capacity of 27.8 GW, which amounts to 5 percent of all coal-fired generating capacity and 4 percent of total generating capacity nationwide in China.

In terms of the number of generating units in the MIT sample versus the total number of units nationally, the data issues become tricky. Chinese official figures for 2006 note the existence of 2794 power generating units nationally in 2006. That would mean that the MIT survey, extending into 2007 and encompassing 257 operating units, captured roughly 9 percent of China's total. But these standard official figures do not include small generators rated below 100 MW capacity. Table 2.2, based on a variety of Chinese governmental reports and our own calculations, presents what we believe is a more accurate summation of the total number of coal-fired generating units nationally. The table then compares the size distribution of units in our sample against the size distribution of units nationally. As indicated by the table, the distribution of scale among our survey respondents, at least in comparison to our understanding of the known universe of Chinese coal-fired units, tended to skew slightly toward the larger and smaller ends of the spectrum. In other words, if one were to extrapolate

⁴ Results of earlier MIT studies on the efficiency, emissions and health effects of small industrial boilers in China are discussed in: Fang, J., T. Zeng, L.I. Shen Yang, K.A. Oye, A.F. Sarofim and J.M. Beér, “Coal Utilization in Industrial Boilers in China – a Prospect for Mitigating CO₂ Emissions”, *Applied Energy*, v 63, n 1, pp. 35-52, 1999., and Fang, J., G.Li, K. Aunan, H.Vennemo, H.M.Seip, K.A.Oye and J.M.Beér, „A proposed industrial efficiency program in Shangxi: potential CO₂-mitigation, health benefits and associated costs”, *Applied Energy* 71 (2002) pp 275-285

directly from the MIT sample, the universe would have fewer medium-sized plants, and more small-scale and large-scale plants than is suggested by the official Chinese statistics.

This point is important because it leads to questions about what the total population of Chinese power plants really looks like. As in so many aspects of China's political economy, data, while often available, tend to be inconsistently reported, incomplete, and at times extremely confusing. This is true not just for publicly available data, but also for the internal data upon which policy decisions are made. In energy, as in many other industrial sectors, the information appears to become more confused as it is aggregated across broader domains of the system. Producers at the micro-level report information selectively, if at all, and when these reports are aggregated, data reported using entirely different terms, standards, or units not infrequently are merged into single categories.

The way researchers in the central government's State Electricity Regulatory Commission (*Dianjianhui* or "SERC") cope with this is not very different from the strategy employed by the MIT research team. Both the MIT team and Chinese governmental researchers employ what may be termed "purposive stratified sampling." In the MIT case, our sample was stratified in terms of power plant location (province) and size (generating capacity), yet it was "purposive" in that we relied on the personal networks of our Chinese partners to identify plants willing to participate. The reliance on network-based sampling was necessitated by the sensitivities in the Chinese context surrounding energy sector performance, particularly at the individual plant level. Put simply, most Chinese utility operators are disinclined to reveal the sorts of information we were seeking.

Interestingly, they tend to be no more inclined to reveal such information to the Chinese government than to independent academic researchers. In the Chinese government's version of purposive sampling, SERC and National Bureau of Statistics researchers survey the power sector via partnerships with local energy research institutes that have preexisting relationships with local power producers. Data from separate locally-based survey efforts are then aggregated into what is purported to be a representative sample. This sample is then compared to data submitted by those plants across the system that are willing to report. Of course, not all plants cooperate with these data collection efforts. As one governmental researcher noted,

statisticians in the Chinese system end up trying to understand the whole system by “looking through a straw.”⁵ Both the MIT survey and official state efforts end up relying on samples that are at once small and driven by network relationships. In the MIT case, these tended to be informal personal networks. In the government’s case, these tend to be the networks of the particular local energy research institutes that partner with the center in data collection efforts. It is fair to assume that in the government’s case, these networks lead to a sample skewed toward coastal (where local energy institutes are usually found), larger, and more compliant (in regulatory terms) firms. In the MIT case, the sample also is arguably skewed toward coastal areas, especially Shandong province, but we seem to have picked up a greater proportion of smaller and less environmentally compliant firms. It is conceivable that along these dimensions of scale and compliance, the MIT sample presents a more accurate picture of the universe of Chinese power producers.

III. Capacity: Chinese power sector scaling up over time

The conventional wisdom about China’s power sector often begins with the assertion that the Chinese are building coal-fired power plants of inordinately small scale. Our survey results, though, reveal a more complex reality. If one looks at the size of new generating units in our sample added during various time periods in China (Chart 3.1), the story seems to be that average size rises in the early 1990s, and then steadily declines (red bars in chart). For reference purposes, U.S. size averages are also included in the chart (blue bars).

Chart 3.2 shows how the population of generating units in the MIT sample is distributed across size categories (red bars). Chart 3.3 shows how the generating capacity in the sample is distributed by unit size. For comparison purposes, the charts also show the corresponding unit size distributions for all coal-fired generating units built in the United States over the past fifty years

The charts indicate that while many small-scale units populate the system, the bulk of the system’s total generating capacity is accounted for by large-scale units. Some of these units are among the largest in the world. In short, the data suggest that China is both building small and

⁵ Authors’ interview, August 9, 2007.

building big, and that the broad range of unit sizes coming on line in China is characteristic of the size range of units added in the U.S. over a similar period.

IV. Technology: The mix is becoming more advanced over time

The question of unit size is important for several reasons. Outside observers and Chinese state regulators alike frequently use scale as a proxy for other features they are more interested in, such as plant-level operational efficiency, technological sophistication, and environmental “friendliness.” As will be discussed in this section, it is not just that Chinese power plants are bigger – or at least more varied in size -- than many people recognize, but also that scale turns out to be a poor proxy for the issues mentioned above. That is, size does not relate to environmental impact or operational efficiency in a simple, linear way.⁶

In general, the relationship between generating unit size and environmental impact is complicated by two sets of factors: the nature of the technology the unit uses to generate electricity, and the manner by which that technology is operated by plant managers. In this section we consider only the physical equipment found in Chinese power plants. We shall see that even absent the operational issues, the connections between technology, scale, and pollutant levels may still be very complicated, often involving a multitude of choices and tradeoffs. These issues are not unique to China, but rather are encountered wherever coal-fired power generation takes place.

Scale and Generating Efficiency

As a first step in assessing environmental impact, it is useful to consider the overall efficiency with which a generating unit converts coal into electricity. The more efficient the plant, the less fuel burned – and the fewer pollutants emitted – per unit of energy generated. Also lessened are the amount of limestone consumed; the size of front-end and flue-gas treatment equipment; water use; waste generated; and parasitic energy consumption.

⁶ Indeed, for fouling ash coals, boiler availability is actually better for smaller units because of the higher surface-to-volume ratio of the combustion chamber, resulting in more effective cooling of the coal ash entering the convective pass of the boiler. We are grateful to Janos Beer for pointing this out.

Particularly in countries like China where the energy system is expanding so rapidly and so much new infrastructure is being built, the efficiency characteristics of the new technologies being installed will likely prove one of the biggest determinants of long-term environmental impact.

With respect to efficiency, our 2007 survey indicates some progress in China. In recent years, a number of larger scale units have come on line, and those units are usually associated with more efficient performance (higher steam conditions). These larger units employ advanced pulverized coal combustion technologies, for which efficiency increases with scale. An overall picture is presented in Charts 4.1 and 4.2.

Chart 4.1, presenting a current snapshot of all the generating units in the sample, illustrates the frequency with which different steam conditions are encountered within the three size categories of units: small, medium, and large. In each category, we see a variety of performance levels representing a variety of different technologies currently employed in Chinese plants. Smaller size units (below 50 MW) tend to operate at low temperatures and pressures, whereas large-scale systems (above 300 MW) tend to be associated with higher temperature, higher pressure conditions. It should be noted that our sample includes several supercritical plants, i.e., those with steam conditions at or above 22.19 Mpa/540C. As of 2007 when the survey was conducted, China had 22 supercritical units, several of which were captured in the survey, and the first of which came on line in the early 1990s.⁷ A number of ultra supercritical plants are under construction in China and are soon slated to come on line.

Chart 4.2 illustrates how steam conditions in Chinese coal plants have evolved over time. Note that the chart illustrates the frequency of occurrence of units of different performance type, but says nothing about the scale of those units. Also, the temporal categories are not of equal duration. The middle period covers 17 years, while the most recent period covers 7 years. The logic behind this presentation is that the power sector experienced very little growth before 1985, underwent an important growth phase between 1985 and 2001, and then entered an extremely rapid growth phase – doubling its total capacity, in fact – between 2002 and 2007. What the chart suggests is that across its two major post-1985 growth phases, China's

⁷ "Power Becomes Supercritical," *China Daily*, Sept. 7, 2007.

power sector has employed a range of technologies with a range of steam conditions. Over time, though, the system has been migrating away from low pressure, low temperature units, toward higher temperature, higher pressure units. Moreover, these higher performance units tend to be of larger scale. Chart 4.3 shows how the total generating capacity represented in the sample is distributed across different performance conditions.

Boiler Technologies and Environmental Impact

Long-term environmental impact is influenced by the choice of technology, as well as scale and efficiency.

In China today, coal-fired units employ one of three main classes of combustion systems: chain grate stoker boilers, pulverized coal combustion (PCC), and fluidized bed combustion (FBC). Chart 4.4 shows how these technologies are distributed across different size categories of generating units. Chart 4.5 shows how the distribution of technologies has evolved over time.

As Chart 4.6 shows, pulverized coal combustion (PCC) accounts for the vast bulk of coal-fired power generation in China. Within the MIT survey, of the 32.68 GW of total generating capacity contained in the sample, 22.04 GW (67 percent) use PCC, 2.90 GW (8 percent) use FBC, and 0.534 (2 percent) use chain grate stokers. An additional 5 percent of total capacity was fueled by coal gangue and oil, and plants representing 14.5 percent of total capacity did not answer the question.

As indicated by Chart 4.4, almost all large scale units in China use PCC, as do many medium and even small-scale units. Chain grate stokers are found almost exclusively in small-scale units. Over time, as indicated by Chart 4.5, chain grate stokers have been phased out and replaced by FBC technologies at the lower end of the scale spectrum. New units employing PCC are fewer in number but larger in size. The basic picture then is of a system in which PCC dominates the higher end of the scale spectrum, and FBC has replaced chain grate stoker technologies at the lower end. FBC has also made inroads against PCC in medium-sized plants.

What does this all signify? Of the three technology types noted above, chain grate stokers are the oldest and least advanced, dating back to mid-19th century. In such systems, raw or semi-processed coal chunks, often several inches in diameter, are fed into the combustor on a moving chain grate, and burned in place on that conveyor. In more modern pulverized coal combustion, rough coal -- rather than being burned directly -- is ground into a fine powder. The coal powder is then combined with heated air, and injected into the combustion chamber as a cloud of pulverized particles. The particles then combust rapidly at high temperature, in some respects more like a gas or atomized liquid than a solid fuel.

Compared with chain grate stokers, PCC technology allows for far greater fuel and operational efficiencies. So, as the Chinese system has shifted away from chain grate stokers towards larger scale PCC, the average generating efficiency has risen, and environmental gains have also been realized as a result.

PCC produces a series of atmospheric pollutants: sulfur oxides (SO_x) and nitrogen oxides (NO_x) associated with acid rain, carbon dioxide (CO₂) associated with global warming, and particulates and trace metals, including mercury, associated with human health issues. In terms of CO₂, it is only recently that people in advanced industrial nations, let alone China, have begun to understand this as an environmental threat. Solutions involving carbon capture and sequestration have yet to be demonstrated at scale. Mercury emissions from coal-fired power plants have also eluded effective remediation in many parts of the world, including the United States. With respect to SO_x and NO_x, on the other hand, a variety of proven cleanup technologies are now available to power producers.

Compared with PCC, fluidized bed combustion technology (FBC) offers both advantages and disadvantages. FBC works by feeding minimally processed solid fuel into a combustor which is comprised of a bed of inert particles through which gas is blown upward.⁸ The fuel is then suspended in an airborne and turbulent state, making it behave in a fashion somewhat akin to a bubbling liquid.⁹ This allows for efficient burning and heat transfer – on par with

⁸ World Coal Institute, “Fluidised Bed Combustion,” (<http://www.worldcoal.org/pages/content/index.asp?PageID=420>).

⁹ United States Department of Energy, “Fluidized Bed Technology – An Overview,”

many PCC systems – but at substantially lower temperatures. The SO₂ that is produced as a by-product of combustion is mostly neutralized by the limestone in the fluidized bed (and of which it is mostly comprised). This may obviate the need for expensive stack gas scrubbers or other costly-to-operate post-combustion cleanup technologies (though to achieve very low SO_x emissions in the absence of flue-gas cleanup requires the use of low-sulfur coal.). Because combustion takes place at lower temperatures than in PCC, the production of NO_x is somewhat reduced. On the other hand, nitrous oxide (N₂O), a potent greenhouse gas, is produced at the lower temperatures characteristic of FBC, and this adds a significant increment to overall GHG emissions relative to PCC.

It should be noted that in China today there is an intensifying debate regarding whether FBC technology should be encouraged by state policy. Some experts on the technical side argue that under strict emissions standards -- levels of sulfur dioxide stack gas emission concentrations below 200 mg/m³ (in the range of current US and EU standards, but lower than current Chinese levels) -- absorption of SO_x emissions in the fluidized bed would not be adequate except for very low-sulfur coal. To meet such standards, FBC units would have to add on post-combustion flue-gas desulfurization systems. Should Chinese environmental regulations strengthen in the near term, it is argued, this retrofitting cost could become considerable for FBC plants.¹²

Chinese power producers are choosing FBC systems for many of the smaller scale units being built today. This choice may have less to do with FBC's environmental qualities than its flexibilities on the fuel side. FBC systems can burn virtually any combustible fuel, from the full gamut of coal types to coal mining waste products and municipal refuse. This is an important feature in China, where power plants often face challenges in controlling fuel type and quality. Regardless of the reasons driving it, the proliferation of FBC systems means that at the lower end of the size spectrum, Chinese power plants are accessing technologies considered by many

(http://www.fossil.energy.gov/programs/powersystems/combustion/fluidizedbed_overview.html). See also, IEA Clean Coal Centre, "Clean Coal Technologies – Fluidised Bed Combustion," (http://www.iea-coal.org.uk/site/ieacoal_old/clean-coal-technologies-pages/clean-coal-technologies-fluidised-bed-combustion-fbc?).

¹² Authors' interviews, July, 2008.

observers to be state-of-the-art for controlling several key pollutants. Basically, infrastructure is being built at the lower end of the scale spectrum that, if operated appropriately, can provide real leverage over the SO_x and NO_x problems. At the very least, this raises questions about two of the simplifying assumptions often used to analyze China's power sector: the idea that bigger is better, and the notion that China has too many small-scale plants.

Prevalence of Stack Gas Scrubbers

Although technological upgrades may be obviating the need for post-combustion cleanup systems in smaller power plants, the bulk of China's electric power infrastructure burns pulverized coal. To address SO_x and NO_x emissions, pulverized coal units have to employ post-combustion cleanup systems. Some sulfur can also be removed prior to combustion through coal washing. One of the goals of the MIT survey was to gain insight into the prevalence of at least one variety of such technologies – flue gas desulfurization (FGD) systems – across China's power sector. Governmental regulations now require most new plants to install and operate such systems, but observers have long questioned the extent of regulatory enforcement in this area. MIT's survey results speak to this issue, but some caveats are in order regarding the data.

For the data to be most useful, they would need to be reported at the generating unit, rather than plant level. A single plant, after all, may operate several different units employing several different kinds of technologies. Some of the units, if employing boiler technologies like FBC, would not necessarily need post-combustion cleanup systems. Others that would require FGD, such as pulverized coal systems, might simply not have installed them, thus falling out of compliance with state regulations. Unfortunately, our data were reported only at the plant level. Thus we can only say whether a given plant has an FGD system installed on at least one of its generating units. We can present a rough sense of FGD penetration in the industry, but not the kind of fine-grained, unit-level analysis contained in other parts of the study.

As indicated in Chart 4.7, 82 of the 85 power plants in our sample provided information about FGD. Of those 82 plants, 67 reported purchasing and installing FGD systems on at least one of their generating units. It could be the case, of course, that FGD has been installed

on *only* one of the units of a multiple unit power plant. It could also be the case that some plants operate only FBC boilers, which would not likely utilize FGD for SO_x cleanup. Within the group of 67 plants with at least one FGD-equipped unit, fifty plants reported also having continuous emissions monitoring systems, and 17 plants reported having systems limited to periodic testing. The presence of continuous emissions monitoring is important because such systems provide real time, verifiable data -- presumably also accessible by third party observers -- regarding the environmental performance of the generating unit. Again, through a combination of punitive regulations and positive incentive programs, the Chinese government's State Environmental Protection Administration (now Ministry for Environmental Protection), often with the support of a variety of NGOs and international agencies, has been promoting the spread of such monitoring systems.

FGD systems represent a fairly significant capital expenditure for power plants. That roughly 80 percent of the plants surveyed reported installing at least one such system on a generating unit suggests that environmental officials are achieving some regulatory traction. Recent national figures reveal a similarly encouraging story. By the end of 2007, according to some Chinese estimates, over 270 GW of generating capacity had been installed with some form of FGD equipment.¹³ In particular, state regulations demand that all new power plants as of January 1, 2004, must be equipped with FGD systems, and a series of programs have been initiated to insure retrofitting of FGD systems on older plants by the end of the decade.¹⁴ The rules are now on the books, and they seem to be having some effect, but as will be discussed later, regulatory traction is partial at best. The shortfalls appear particularly serious on the operational side of power plants. That is, the systems are increasingly in place, but whether they are actually operated is another question.

The broader message of this section is that many Chinese power plants are investing in a range of modern systems. The phenomenon is clearest with regard to coal combustion technologies across a variety of scales and steam conditions. Modern technology acquisition is also apparent to some degree on the environmental cleanup side. The bottom line is that it is

¹³ China Electricity Council, "Guojia Fagaiwei Fabu 2007 Nian Huodianchang Yanqi Tuoliu Chanye Xinxi," March 19, 2008 (<http://www.cec.org.cn/news/deptnews.asp?id=2871>).

¹⁴ Andrew Minchener, "Coal Supply Challenges for China, IEA Clean Coal Centre, 2007, p. 16.

not generally correct to say that China today is building a second-rate, technologically obsolete electric power infrastructure.

V. Coal Supply: The Power Plant Perspective on Fuel Sourcing and Pricing

Technology and capital equipment constitute one major piece of the puzzle for how power systems impact the environment. Power plant operation constitutes the other. Coal access, pricing, and quality are obviously central to a host of operational issues. Indeed, because fuel costs are the single largest operating expense of a coal-fired power plant, they can under certain circumstances also exert major influence on long-term technology acquisition and investment decisions.

State and Market Channels of Allocation

Over the last five to six years, Chinese power plants have faced rapidly changing conditions for fuel supply. Coal is generally available through two main channels: a national allocation system managed by the state, and an ad hoc system of direct, market-like transactions between mines and power plants. Until at least 2002, the state managed system, involving annual delivery contracts at state-set prices, accounted for the bulk of coal delivered to power plants. Since 2002, when coal demand began to surge in China, the market channel has become far more important. Much of the new coal demand in China has been met by smaller, locally-owned mines, which were never part of the state coal allocation system. Moreover, the larger, more state-oriented mines anchoring the state allocation system proved increasingly unwilling to move output through state channels in such a tight market. With demand soaring and no risk of being saddled with excess inventory, why sell at a low state-set price when one could instead contract directly with major consumers at a higher market price? The upshot in recent years has been two-fold. First, market transactions – direct interactions between producers and consumers at variable prices – have come to account for an increasing share of all coal delivered in China. Second and concomitantly, Chinese domestic coal prices have been rising, effectively converging toward world market levels.

Just over half the plants in the survey sample (44 of 85 plants) responded to questions about coal allocation and pricing. Of the plants that responded, 55 percent (24 plants) reported that none of their fuel supply was subsidized, while 45 percent (20 plants) reported that at least some fraction of their supply came through state channels at subsidized prices. Interestingly, as indicated by Chart 5.1, only six plants reported receiving all of their fuel through subsidized channels. For many of the other plants accessing subsidized coal, these lower-priced fuels accounted for only a fraction – and sometimes a very small fraction – of the plant’s total fuel supply.

For coal coming in through market channels, one-year contracts between mine and power plant appear to be the norm, but spot market transactions also take place. As indicated by Chart 5.2, of the 25 plants that provided contracting information, 17 (68 percent) reported the use of one-year contracts. Four plants reported contracts of less than one year in duration, and three plants reported that they were accessing fuel via “temporary” contracts – that is, on spot markets.

In visits to power plants and mines in the past year, members of our team witnessed the operation of these spot markets. Under the strained supply conditions of the present, consumers entering these markets have to take what coal they can get, often without any clear information or assurances about the type and quality of the coal being offered. If the consumer delays by taking time to test the coal, the mine will likely just sell to someone else in the interim.

Pricing in the Chinese Coal Market

Power plants are essentially price takers in what amounts to a complex and chaotic seller’s market for coal. As illustrated by Chart 5.3, plants across the sample reported a wide range of maximum prices for delivered coal paid in 2007. Spot contracts (red bars) can be found across the price spectrum running from roughly 250 RMB per ton to just over 600 RMB per ton. For comparison purposes, the average price for delivered coal paid by U.S. power plants is included at the far right of the chart (black bar).

In addition to coal prices varying across plants, individual plants themselves source coal at multiple price points through the year. The survey responses permit us to measure that differential for each plant in the sample. Chart 5.4 categorizes these differentials according to the magnitude of the price range, and then shows how many plants in the sample fall into each category. Chart 5.5 shows similar information, but controls for the size of the plant, effectively showing how much generating capacity of the sample's total falls into each of the price differential categories. What is clear is that a substantial portion of plants, particularly if one controls for size, are experiencing considerable price differentials, ranging anywhere from RMB 200 to RMB 349 per ton of coal.

A possible explanation for these price differentials between and within plants is that they simply reflect the different types and qualities of coal available on the market. This may be true, but it is also true that coal quality standards are loosely specified and poorly enforced in China. Thus, information asymmetries exist between coal suppliers and buyers in this market. Prices technically may differ across coal types, but buyers are often either uncertain of what they are getting or facing situations of scarcity in which they have to take whatever they can get, regardless of preferred type. Hence, we witness the situation of single firms paying a variety of prices – i.e., experiencing substantial price volatility -- in their coal sourcing operations. Given the volatility of the current coal market and the fact that fuel costs are the single greatest operational expense in power generation, plants are disinclined to maintain large coal inventories. Furthermore, given that electricity prices are set by the state and do not move fluidly upward with rising coal prices, plants have to find ways to reduce operational costs in the face of escalating fuel expenses. One response is to purchase cheaper, lower grade coal, particularly on the margins to fill out narrow inventories. Mines too may substitute lower grade coal to round out a shipment of ostensibly higher-grade material.

In either case, plants end up burning a wide variety of coal types, sometimes to the detriment of their installed technology. This is a particularly serious problem for firms employing more advanced PCC and FGD technologies, systems that have low tolerances for fluctuations in coal ash and sulfur content. Here, we can see how rising coal prices can limit FGD use in two ways. First, with rising fuel expenses, plants may be inclined to cut costs by simply not operating their FGD systems. Second, rising fuel expenses encourage plants to

source lower quality, cheaper coal, just as soaring demand encourages mines to round out shipments with lower quality material. As this substandard coal runs through the plant that actually is running FGD, the cleanup system gets overtaxed and degraded.

Indeed, these factors help to explain why fluidized bed combustion systems have an important market in China. Such systems can burn virtually any type of coal with no ill effect. It is not surprising therefore that so many of these systems are being installed in smaller scale units, and that the Chinese state has been encouraging research into FBC applications at the high end of the size spectrum as well.

Coal Transport

Because the prices reported in the survey are for delivered coal, some of the price variation experienced across firms may be due to transport costs. Nonetheless, the survey uncovered a somewhat different picture of coal market geography from what the conventional wisdom usually asserts. The conventional view is that coal in China moves long distances, via rail, from major suppliers – mines in Central and Northwest China – to major consumers, the power plants along the East and Southeast Coast. The picture emerging from the survey, however, is that a substantial amount of steam coal – coal burned by power plants – is still sourced locally, trucked in from relatively nearby mines. This result was found despite the overrepresentation in the sample of power plants in Shandong, a province that is not a major mining center. In contrast to issues surrounding pricing, most of the plants in the sample – 79 of 85 -- were able and willing to provide information about fuel transport. As illustrated by Chart 5.6, 28 plants (37 percent of all that responded), reported that all of their fuel came in via truck. Slightly fewer plants, 23, reported that all their fuel arrived via train. The remainder utilized a mix of train and truck, as well as oceangoing collier barge.

Three interesting points emerge from these data. First, as noted previously, a considerable portion of power plant fuel seems to be sourced locally, thus reinforcing the idea that at least in the current market, plants on the margin take what they can get, as opposed to relying exclusively on the larger state mines and higher grade fuels found in the Northwest. Second, while it may be true that the Chinese national railway system is overburdened by long-distance

coal transport, the road system is also playing a key role in fuel transport. That may have important ramifications for everything from diesel markets to environmental controls for vehicles. Third, there is an environmental ramification. That so much coal is being sourced locally suggests that Chinese power plants burn very little washed coal. It has long been asserted in the literature that Chinese power plants do not wash their coal, a practice that matters since washing is a primary means of lowering sulfur and ash levels prior to combustion. The MIT survey confirmed that plants themselves are certainly not washing -- none of the plants in the sample reported doing so. However, in recent years, the Chinese central government, as part of its environmental agenda, has pushed major investments in steam coal washing facilities in large state-owned mines, particularly in the Northwest.¹⁵ In addition to environmental concerns, the government policy was motivated by the desire to lessen the amount of mineral material that would have to be shipped along the national railway system. For the large mines themselves, washing facilities may be appealing to the degree that they increase the attractiveness of China's steam coal in global export markets. The key point, though, is that smaller, local coal mines have neither the resources nor incentive to invest in washing facilities. That local mines are supplying such a large portion of power plant fuel suggests that while some washed coal may be reaching Chinese power plants, much of the coal burned is unwashed.

Coal Quality: Sulfur Content

Coal on the Chinese market comes in a variety of types and quality grades. Coal quality in general is a complicated issue involving multiple dimensions. The MIT survey collected data along several of these dimensions, but for the sake of brevity, this section will focus on sulfur content, an important parameter both for plant-level pollutant emissions and for the integrity of sensitive boiler and cleanup systems.

Roughly 90 percent of all coal currently mined in China falls into the low to medium sulfur content classification (sulfur concentrations at or below 2 percent).¹⁶ As indicated by Chart 5.7, most of the plants in the survey sample reported using coal at or below the 2 percent level. Six

¹⁵ Minchener, p. 23.

¹⁶ Minchener, p. 11.

plants of the 80 that responded in total (8 percent) reported using coal of considerably higher sulfur content, one as high as seven percent. Nonetheless, the general point is that most Chinese power plants, at least in self-reported data, seem to be accessing low-sulfur coal. Indeed, some recent observers have commented that their tendency to do so – basically in response to governmental pressures on the environmental front – has squeezed out other non-power-related industrial consumers of coal from the low-sulfur market. In theory, at least, this could be a worst-of-all-worlds policy outcome. Power plants, in part because they are better monitored by the state, and in part because they seek to lower operating costs by avoiding the overtaxing of their FGD systems, conceivably are willing to keep paying slightly higher prices for low-sulfur coal. Meanwhile, other industrial consumers, poorly monitored by the state and devoid of any cleanup systems, migrate over to the higher sulfur content end of the coal market.

The broader point is that while plants are burning a variety of coal types, there appears to be enough regulatory traction in the system to push them under most conditions to continue sourcing low-sulfur coal. Of course, another possible explanation is that plants are misreporting the quality of their fuel. We return to this subject below.

The Cross-Cutting Effects of Coal Marketization

For Chinese power plants, the marketization of coal creates a jumbled mix of new incentives, many of which are cross-cutting and difficult to untangle. This is an important subject requiring more research; however, we can already speculate about some of the incentive effects, several of which are borne out in the survey results.

First, the price increases and volatility associated with marketization make understandable the finding that many plants have invested in advanced coal combustion technologies. More efficient combustion translates into better fuel economy and lower operating costs over the life of the plant, a good way over the long run to cope with rising fuel expenses.

Second, to the extent they have been forced through regulatory pressure to install post-combustion cleanup systems, plants may attempt to counter rising fuel costs by operating

those cleanup systems less frequently, if at all. Flue-gas desulfurization systems are very expensive to operate. Under certain conditions they may account for upwards of a third of a power plant's operating expenses.

Third, particularly given the low fuel inventories maintained in a volatile price environment, power plants face pressures to access coal from a variety of different suppliers at a variety of different price points. As the number of suppliers increases – particularly when smaller, more locally-controlled mines get involved – coal quality becomes less certain. It is highly probable that many power producers today are running a wide variety of coal types through their boilers, whether knowingly or not. As noted previously, this can have not only environmental ramifications, but also consequences for the integrity of the physical plant.

Fourth, power plants, in an effort to reduce overall costs by saving on transport, may increasingly be sourcing coal from local suppliers. Again, this can lead to a fuel supply of lower, or at least more variable quality actually reaching the power plant.

In the end, what does this all mean for the environment? The development of markets for coal – like the development of markets for any commodity – solves certain problems and creates others. The unleashing of fuel prices to reflect real market demand appears to be having a positive impact on long-term technology choice and infrastructure quality. Yet, as will be discussed in the following section, the impact on plant-level environmental practice appears far more ambiguous, and in some cases, even negative.

VI. Power Plant Environmental Performance

Power plant environmental performance is obviously a multi-dimensional issue involving a number of pollutants. Measuring the quantity of emissions of each type of pollutant is extremely challenging. Determining whether emissions levels for a given plant are within regulatory limits is also challenging, given all the regulatory changes that have occurred in China in recent years. The rules are complex, and have changed repeatedly, thus affecting in all sorts of ways the manner and accuracy by which plants report emissions data. As noted previously, continuous emissions monitoring systems have become more prevalent in China,

but even so, available emissions data are frequently dismissed as unreliable by industry insiders and government regulators alike. That said, the MIT survey did collect information – self-reported by power plant respondents – on environmental performance. With all appropriate caveats in mind, we present results for one of the pollutants most emphasized in recent regulatory efforts, sulfur dioxide.

Forty-seven of 85 plants in the sample provided information about SO₂ emissions, as shown in Chart 6.1. These data refer to average annual pollutant concentrations in the smokestack gas. As with the figures presented earlier on FGD installation, the data here were unfortunately reported at the plant rather than generating unit level. Emissions concentrations depend upon the particular boiler and cleanup technologies in use, as well as the manner by which those technologies are operated. These are all factors pertinent to the unit rather than the plant. Nonetheless, the plant-level data that we have can provide a general sense of the overall emissions story.

To clarify how these levels relate to regulatory compliance, a word is in order about the Chinese government's current emissions standards for SO₂. The standards, adopted in 2003, delineate a range of emissions limits depending primarily on power plant age.¹⁷ For the first category of plants -- plants that came on-line prior to January 1, 1997 -- average annual stack SO₂ emissions are currently not permitted to exceed 2100 mg/m³. On January 1, 2010, the limit will drop to 1200 mg/m³. For the second category of plants -- those that came on line from the beginning of 1997 through the end of 2003 -- the limits are 2100 mg/m³ through the end of 2009, and then 400 mg/m³ from there on out. Exempted from this category are plants whose environmental impact assessment report was approved prior to the promulgation of the rules in 2003. Also exempted is a particular set of mine-mouth power plants in Western China -- located outside the two special restriction zones for acid rain control -- that burn low-sulfur (<0.5%) coal. Their emissions limits are set at 1200 mg/m³, a level that will be maintained after 2009. A third category of plants -- those that have come on line since the beginning of 2004 -- must abide by limits of 400 mg/m³, a restriction set to continue indefinitely.

Exceptions exist in this category as well, however. Certain power plants burning coal waste are

¹⁷ Zhonghua Renmin Gongheguo Guojia Biaojun, GB 13223-2003, "Emission Standard of Air Pollutants for Thermal Power Plants," 12/30/2003.

permitted to emit up to 800 mg/m³. Also, like their older counterparts, new mine-mouth plants in Western China are also permitted to emit up to 1200 mg/m³.

Chart 6.1 codes the respondent plants by color according to the regulatory category in which they belong. Blue pertains to plants that came on line prior to 1997, yellow to plants that came on line between 1997 and 2003, and green to plants that came on line after 2003. We are fairly certain that none of the exceptions noted in the regulations apply to any of the Category Two and Category Three plants. We cannot say the same for the older Category One plants. We have left unclassified those plants whose regulatory category is indeterminate. These, colored red in the chart, are primarily older plants that happen to have new units that came on-line after 2003. Presumably for such plants, some of the units fall under one regulatory category while other units fall under another. The chart also demarcates the legal emissions limits for each category. For comparative reference purposes, emissions limits in the United States and European Union are included as well.

Several things are noteworthy about this chart. First, relative to EU and US standards, SO₂ emissions levels in Chinese plants appear to be very high, far beyond the compliance limits that exist outside China. Second, a number of plants in the sample – even with self-reported data – appear to be out of compliance with China's own domestic limits. At least one of the pre-1997 plants and three of the unclassified plants reported emissions beyond China's legal limits. Perhaps most interesting, four out of the six plants falling under the strictest regulatory category reported non-compliant emissions levels. These are China's newest plants, required by law to be equipped with environmental cleanup systems, and held to emissions limits that while relatively lax by European or American standards are strict relative to what older plants in China face. Most of these new plants, however, seem unable to meet the standards, often by a large margin.

In some respects this is an extraordinary finding, not least because it is based on data reported by plants themselves. It is well known that aggregate Chinese emissions have consistently exceeded, often by a large margin, the annual SO₂ emissions targets established by the government. The data presented in Chart 6.1 suggest why, in part. It is also usually assumed that Chinese power plants are massive emitters of SO₂. This too is confirmed by the

survey results. Yet what is striking is the contrast between these bleak performance data and the relatively positive data about technology modernization presented earlier. The basic story seems to be that on the investment side, Chinese power plants are pumping money into massive technology modernization and upgrading efforts. They are in many cases installing state-of-the-art equipment. This is even true to some extent on the environmental cleanup side. Yet they do not appear to be operating that equipment. The FGD systems are going in, but they are not, it would appear, being turned on. An alternative possibility, as indicated earlier, is that plants may be burning sub-standard coal types that are overwhelming these systems even when they are operated. In either case, the basic story is that while market pressures seem to be driving substantial upgrading on the combustion technology side, and regulatory pressures seem to be bringing about widespread installation of environmental cleanup systems, neither of these forces appears to be driving sound environmental practice at the plant level. Indeed, day-to-day environmental performance appears grim.

VII. Conclusion

This study has attempted to add systematic data to an increasingly public, vociferous, and global debate about China's energy future. Many people now understand that China's energy sector build-out has global ramifications, involving long term environmental impacts, geopolitics, worldwide resource availability, and global commodity pricing. Many constituencies around the world are now voicing opinions about that build-out. These opinions often inform policy decisions in other countries. This is unquestionably the case in the United States as the American government -- and American society more broadly -- consider how, whether, and how aggressively to address global warming. Our aim in this study has been to inject real data into this growing public debate. We have sought to test the emergent conventional wisdom about China against empirical findings from the field.

The data we have collected are by no means foolproof or complete. The findings presented in this paper represent the first step in what we expect to be an ongoing, long-term program of data collection and analysis. Moreover, in this overview paper we have been able to present only a fraction of our survey results, leaving out, for example, important findings about ownership diversification and investment sources in China's energy sector. We also

acknowledge that our tentative conclusions are based on a relatively small sample of power plants. At the same time, it must be emphasized that supposedly more comprehensive official analyses of the “entire” sector are based on samples of similar size. In this initial survey effort, we have effectively duplicated the scale and scope of official data collection efforts. It is interesting to note how even in the most straightforward areas – such as in the size distribution of Chinese power plants – our results differ from official estimates. We also note the differences in more sensitive areas such as environmental compliance.

What we have found, perhaps not surprisingly, is that Chinese coal-fired power generation – the heart of the nation’s energy sector – is far more complex than most observers understand, and more complex than we ourselves anticipated when embarking on this study. Several changes – almost revolutions in some cases – are occurring simultaneously. New energy infrastructure is being added at a torrid rate. Fuel allocation is shifting rapidly toward a market footing, with prices responding accordingly, if chaotically. Myriad new transactions are taking place between coal suppliers and consumers, often in the context of imperfect information and ambiguous product standards. Power plants, like mines, have increasingly come to be treated as commercial entities, autonomously pursuing and financing a range of long-term investment and day-to-day operational strategies. Meanwhile, as the central state has increasingly removed itself from direct control over production – whether for mines or power plants – it has become ever more focused on regulation, particularly in new areas like environmental management. As a result, all manner of new rules have been put into play, even as the state scrambles to build the capacity needed to ensure that those rules get enforced. Given the scope of change in the contemporary energy sector, regulators are scrambling simply to figure out what is unfolding on the ground.

Meanwhile, Chinese policy makers, like many concerned outsiders, are looking for points of leverage to achieve desired change. The MIT study, focusing on levers for influencing near- and long-term environmental practice, demonstrated the complex combination of positive and negative outcomes produced by reform and marketization. On the environmental front, policies designed to achieve change in one dimension frequently lead to undesired changes in others. Also worth remembering is that Chinese policy makers are seeking levers over a far broader array of issues, including energy security concerns, political concerns, national

economic competitiveness concerns, economic growth and stability concerns. Most of these involve the energy sector, and many operate in contradictory directions. Energy security concerns, for example, push China toward greater use of coal, but concerns – and doubts – about the magnitude and quality of national coal reserves push toward more efficient use of coal. Efficiency concerns motivate national efforts at technological upgrading, as well as efforts to marketize fuel supply. Yet, the price hikes associated with marketization in some respects discourage sustainable environmental practice at the plant level, thus countering another major concern of policy makers, clean air and a sound ecosystem. Environmental demands emerging from across society – demands that of course have political implications -- may encourage switching to alternative fuels such as gas, but those fuels must be imported from abroad, thus exacerbating energy security concerns. Meanwhile, Chinese policy makers seek to ensure and expand the flow of energy to a citizenry that by global standards – at least in per capita terms – consumes at very low levels. China may conserve, but it is inconceivable that in overall consumption terms it will solve its own – or the world’s – energy problems by scaling back. Chinese energy consumption, and by extension, Chinese coal-fired electric power generation will continue to expand rapidly.

From this perspective, the issues explored in MIT’s China Energy Survey will become only more consequential over time. Our study suggest grounds for hope in certain areas – such as long-term infrastructural choice – and pessimism in others, such as present-day power plant environmental practice. More than anything else, the study, in touching upon just a fraction of the complex reality on the ground, provides an indication of how far we collectively – whether in our capacity as observers, regulators, overseas governmental counterparts, or global commercial players – still have to go in developing a solid understanding of China’s energy sector and how it might be influenced to move in a preferred direction.

Building upon the survey data presented in this initial descriptive paper, follow-on papers will explore a range of questions about causation. How are technology choice and day-to-day operational practice influenced by ownership patterns? How is ownership related to modes of finance? How does financing, in turn, affect technology choice and operations? How does the presence of foreign commercial suppliers and foreign technologies influence power plant performance and strategy? What factors account for environmental compliance in some plants

rather than others? How exactly does fuel price influence plant operations? This paper has provided an initial descriptive overview. Deeper, more focused analyses will follow.

Charts and Tables

Table 2.1 Distribution of Power Plants by Province in 2007 MIT China Energy Survey

Province	# of Plants
Shandong	33
Heilongjiang	12
Jiangsu	7
Hebei	8
Henan	4
Hubei	4
Anhui	3
Guangdong	3
Inner Mongolia	3
Tianjin	2
Shaanxi	2
Yunnan	2
Shanxi	1
<u>Beijing</u>	<u>1</u>
Total	85

Chart 2.1 Location of Power Plants in 2007 MIT China Energy Survey



Table 2.2 MIT Survey Sample as Percent of National Coal-Fired Total (Units)

	<u>Sample</u>	<u>National Total</u>	<u>% of Total</u>
Under 100MW	161	4508	3.57%
100-199	26	480	5.42%
200-299	20	245	8.16%
300-399	30	534	5.62%
500	0	8	0.00%
600-699	12	213	5.63%
700-800	0	8	0.00%
900-1000	1	8	12.50%
Total	250	6004	4.16%

Sources: NBS, Electricity Yearbook, 2007; CEC Draft Estimates 2008; Authors' calculations.

Chart 3.1 Average Size of Generating Units Added By Period

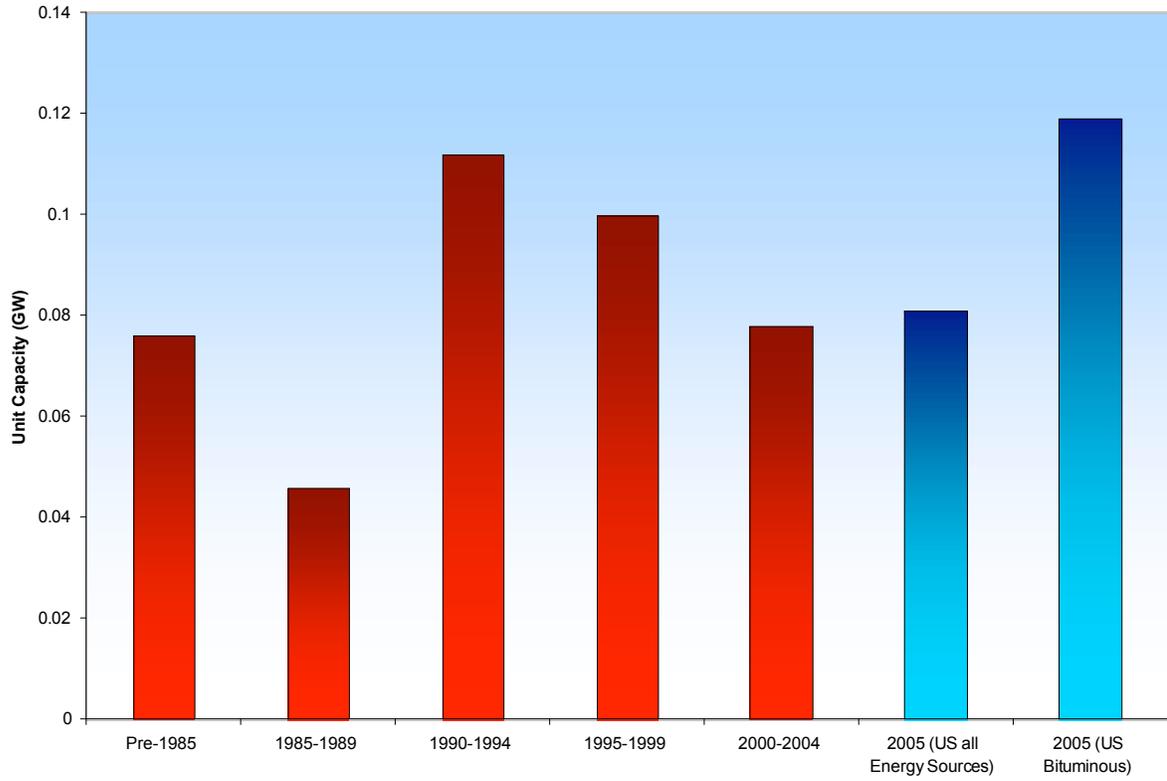
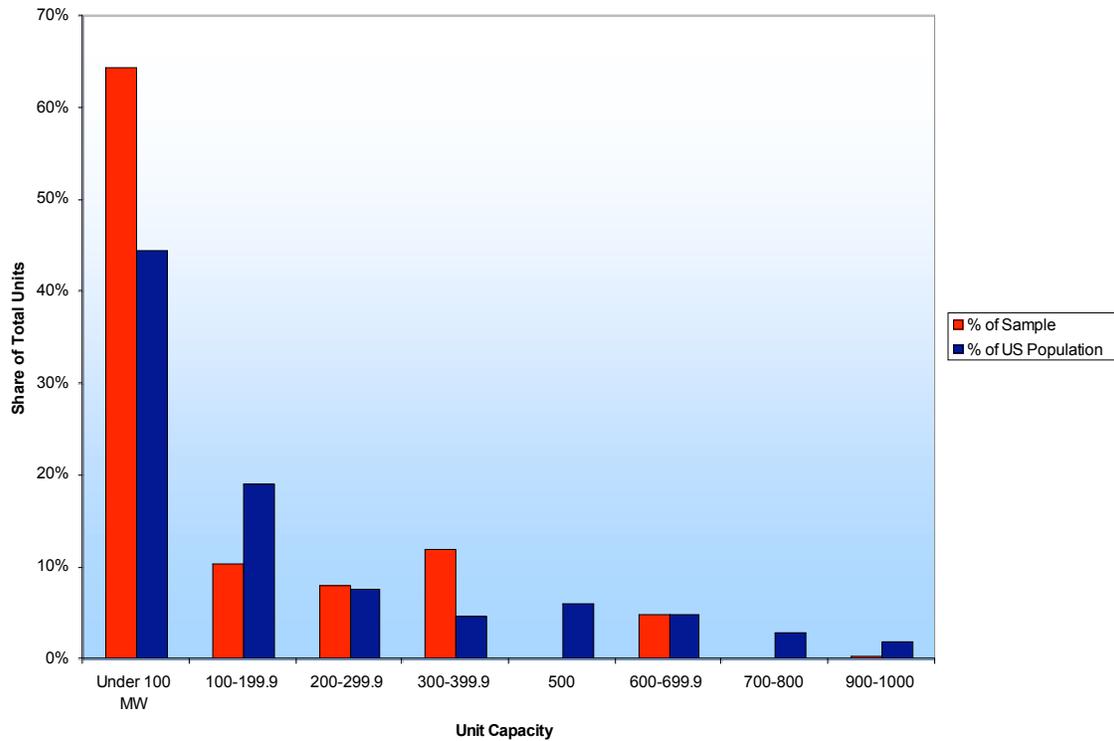
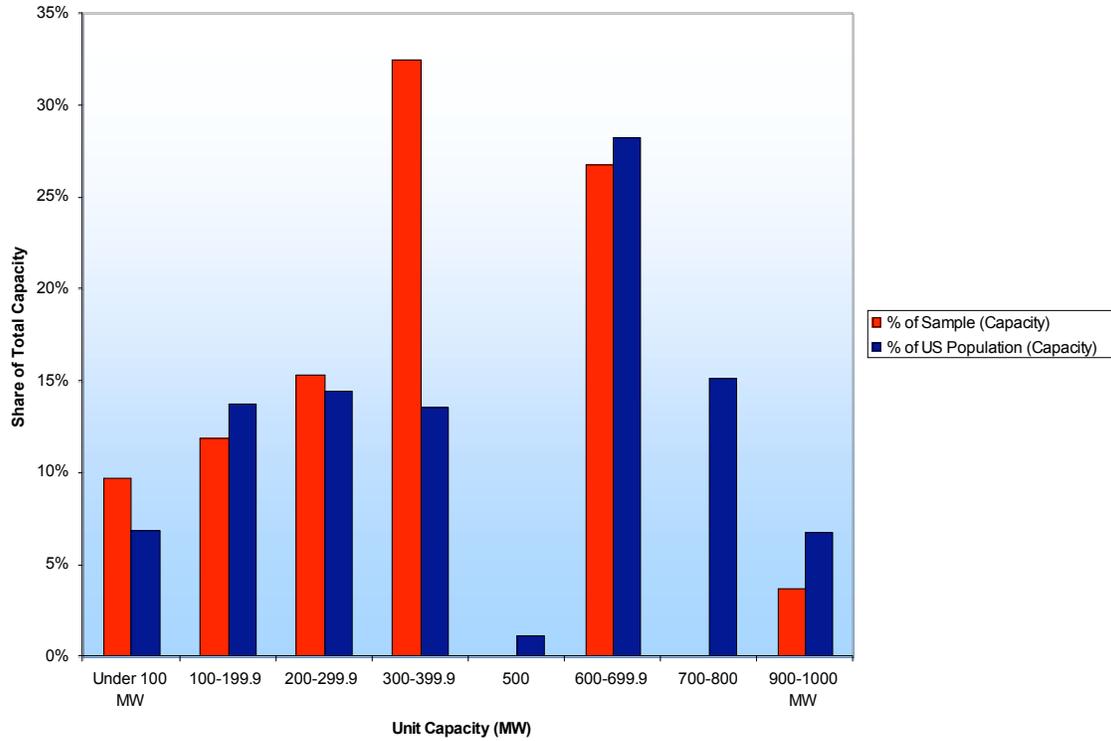


Chart 3.2 Size Distribution of MIT Survey Sample vs Size Distribution of American Coal-Fired Power Plants, 1956-2007



Note: U.S. figures do not include 2007

Chart 3.3 Capacity-Weighted Size Distribution of MIT Survey Sample vs. Size Distribution of American Power Plants, 1956-2007



Note: U.S. figures do not include 2007.

Chart 4.1 Steam Conditions in MIT Survey Sample Plants

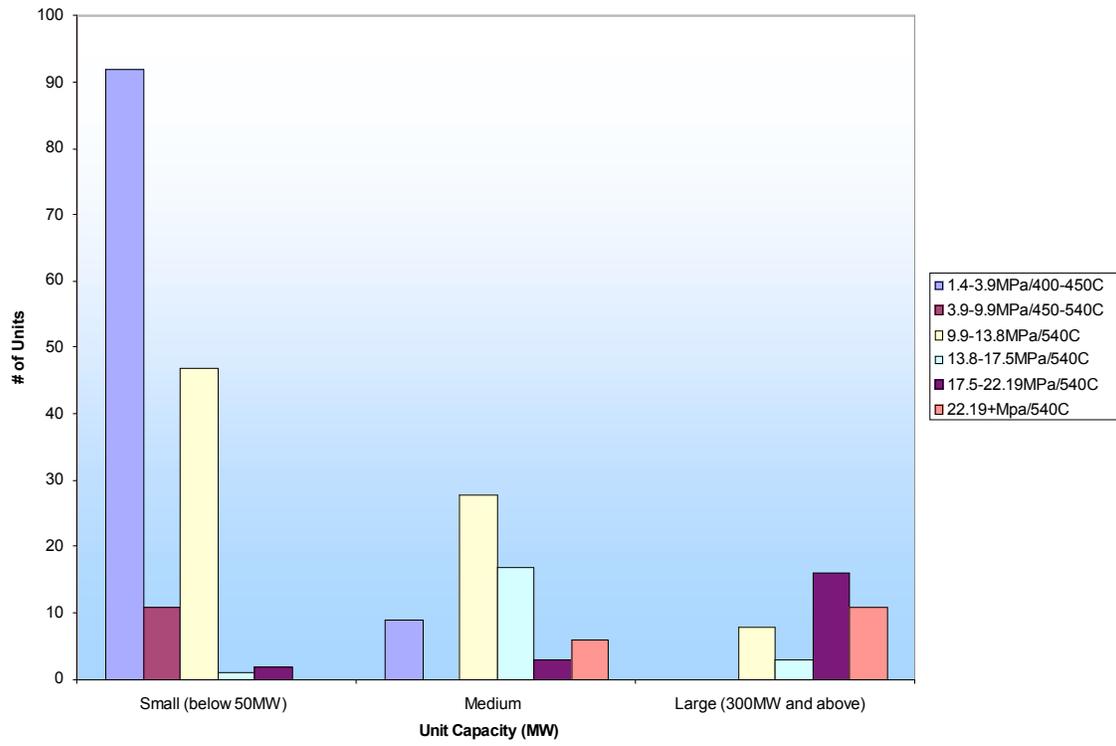


Chart 4.2 The Evolution of Boiler Efficiency Over Time

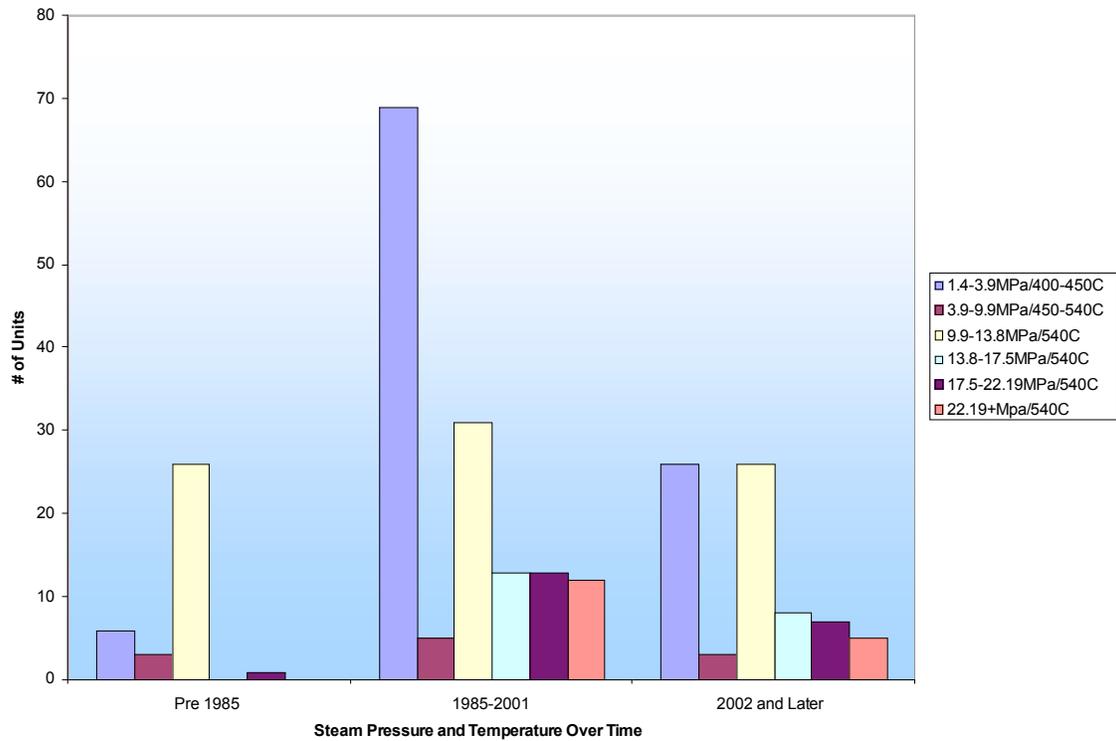


Chart 4.3 Distribution of Steam Conditions in Total MIT Survey Sample

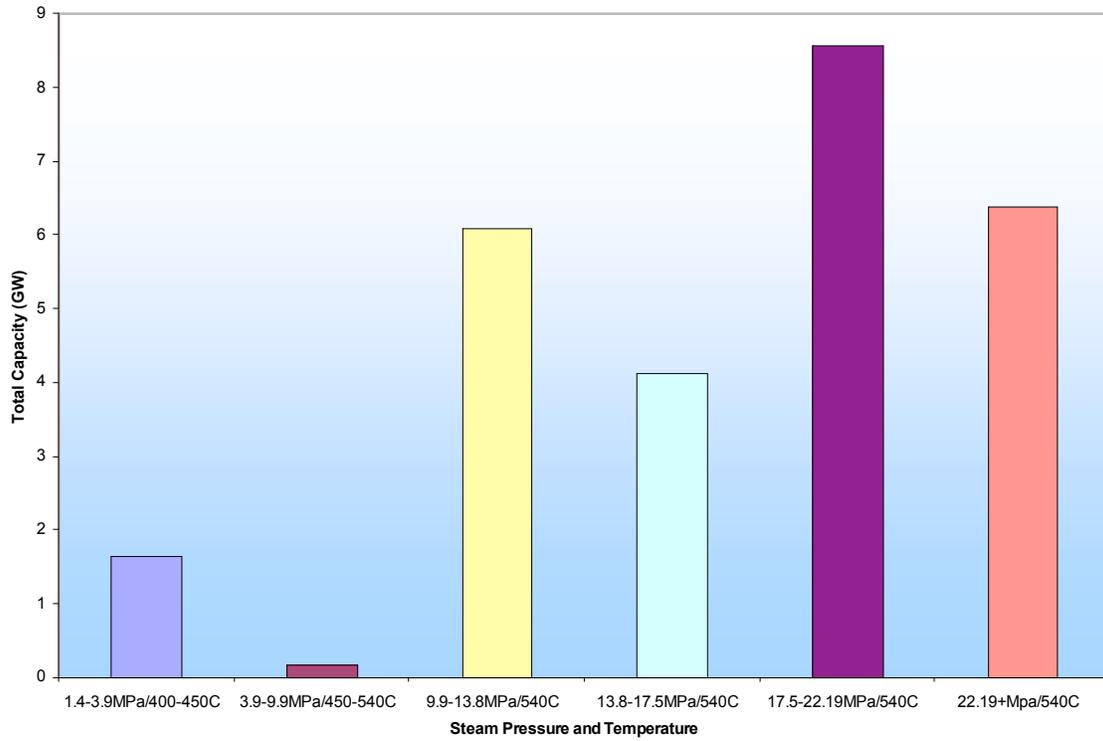


Chart 4.4 Distribution of Technology Types by Unit Size in MIT Survey Sample

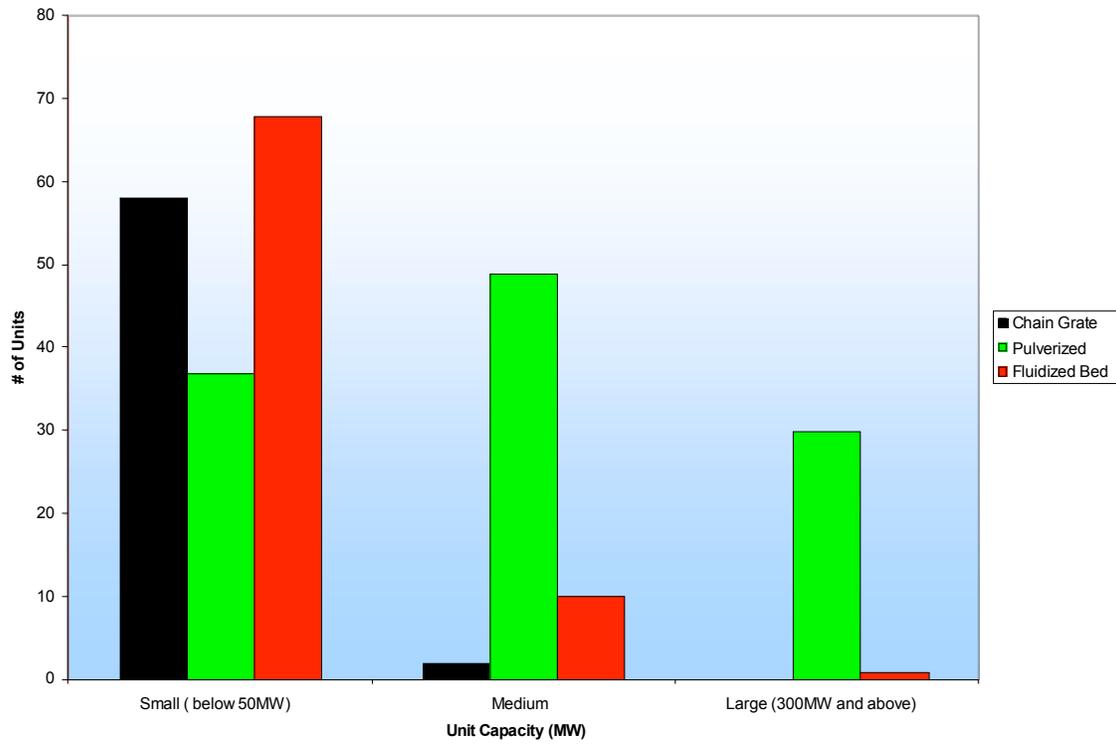


Chart 4.5 Distribution of Technology Types Over Time

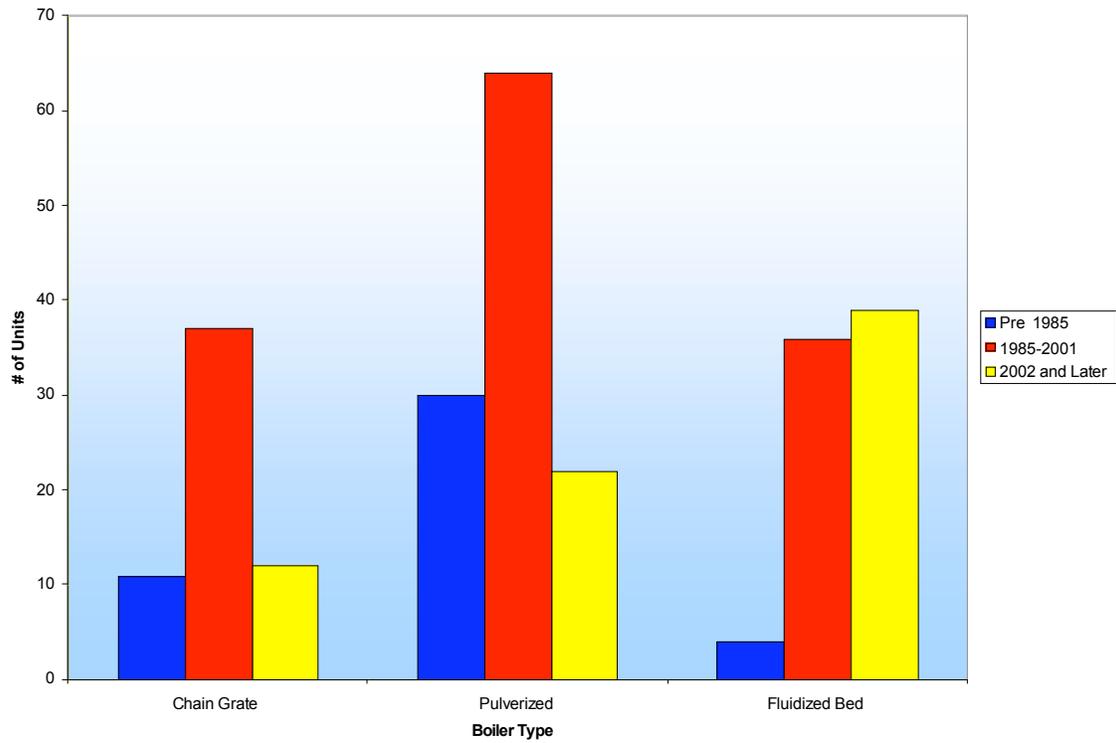


Chart 4.6 Distribution of Sample's Total Generating Capacity Across Boiler Types

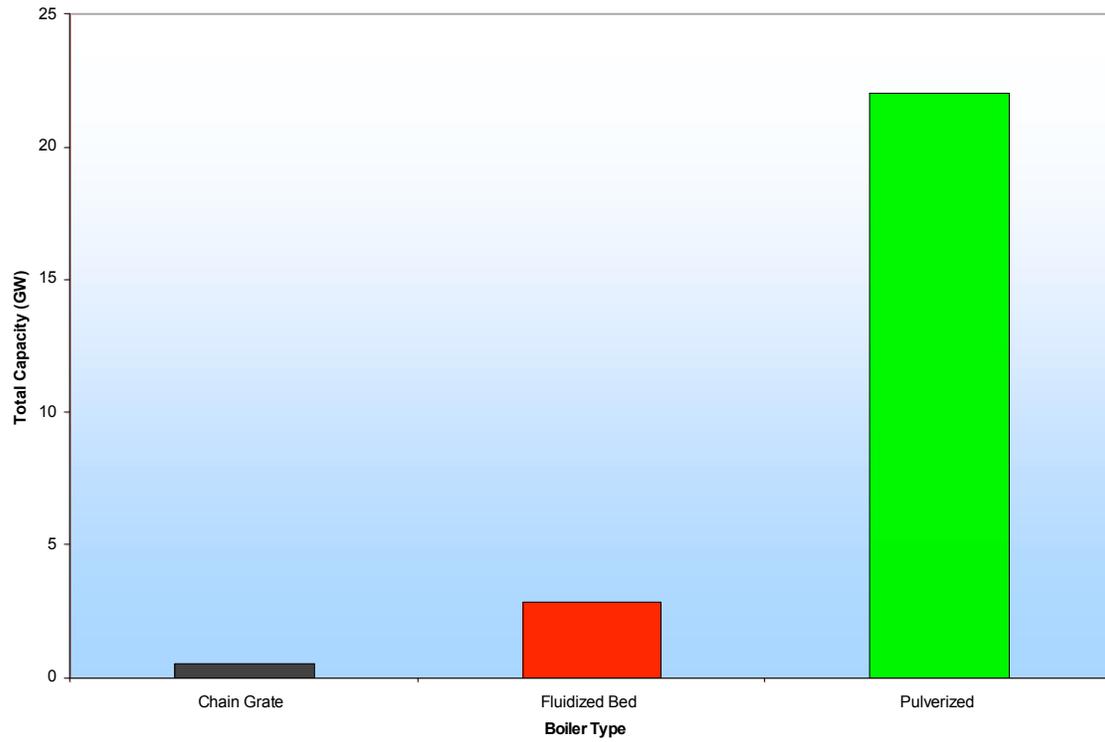


Chart 4.7 Occurrence of FGD Systems in Survey Sample

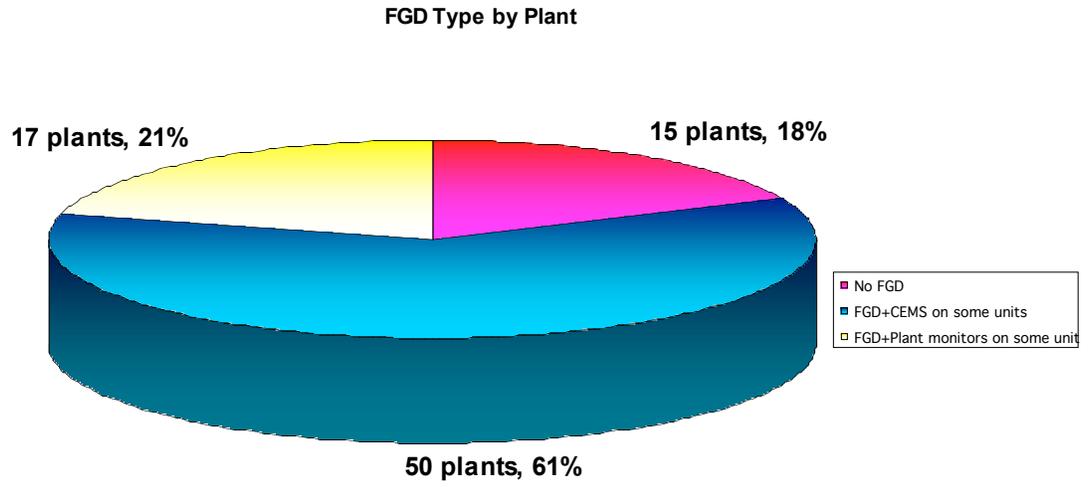


Chart 5.1 Power Plant Access to Subsidized Coal

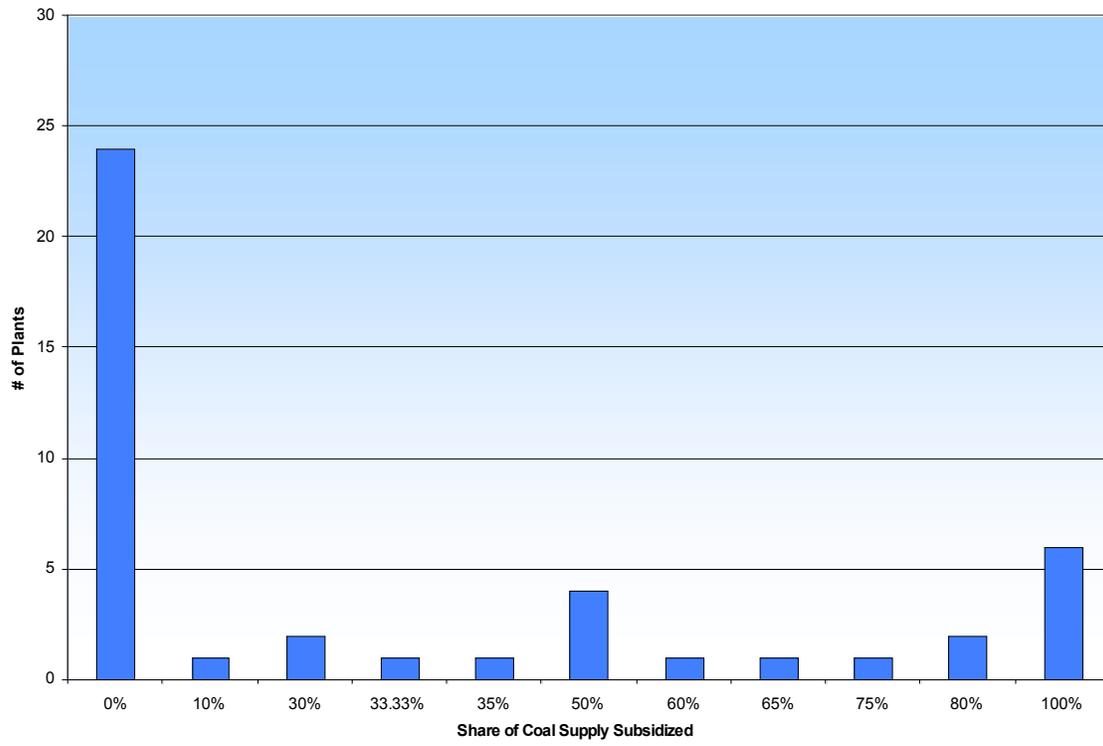


Chart 5.2 Contract Types for Coal Accessed Through Market Channels

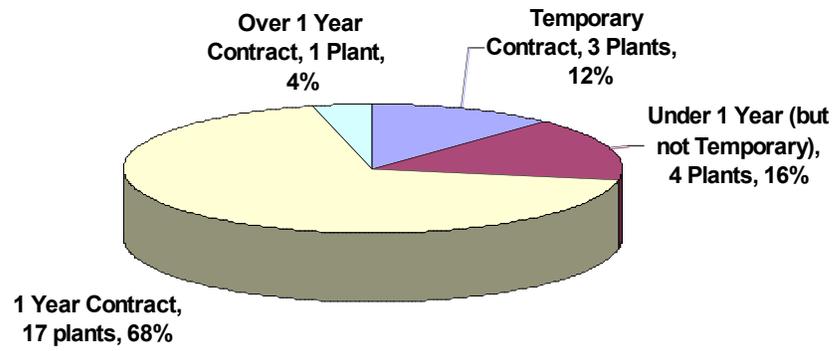
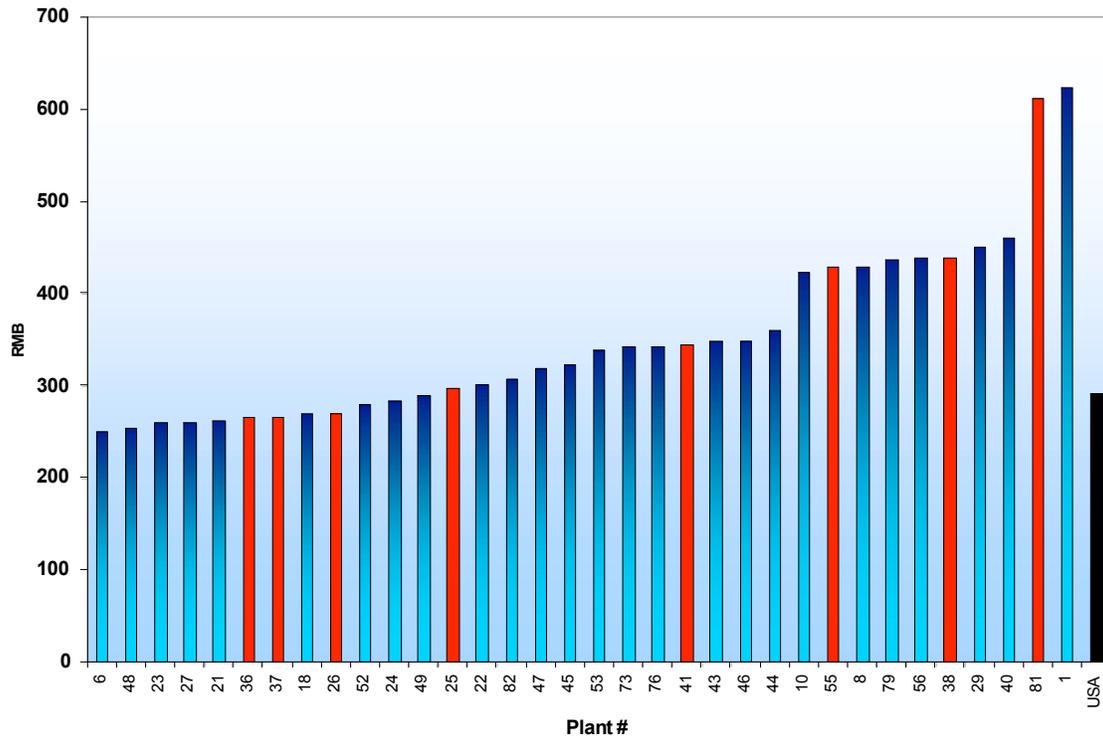


Chart 5.3 Most Expensive Coal Price Reported by Power Plants (RMB/MT), 2007



Note: Source for U.S. 2007 delivered coal prices is Fred Freme, “US Coal Supply and Demand: 2007 Review”, Energy Information Agency, U.S. D.O.E. (<http://tonto.eia.doe.gov/FTP/ROOT/features/feature07.pdf>). For Chart 5.3, data from Freme were then converted from short tons to metric tons, and from US Dollars to RMB at the December 31, 2007 interbank lending rate.

Chart 5.4 Coal Price Differentials Experienced by Individual Plants

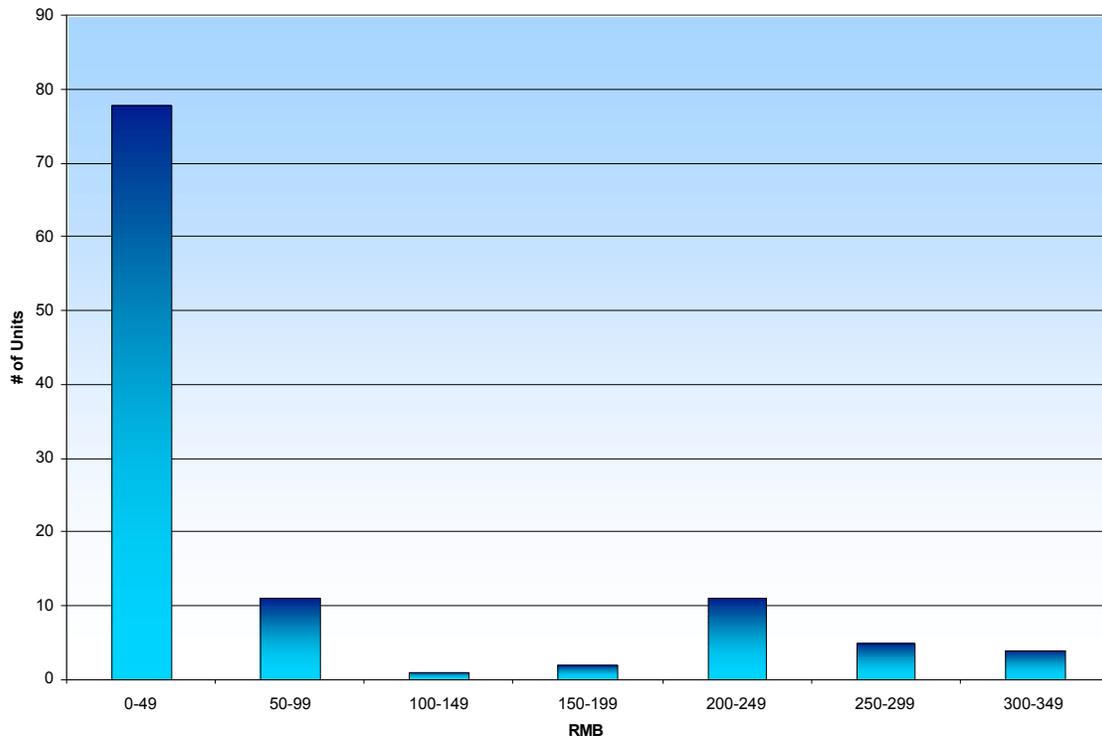


Chart 5.5 Coal Price Differentials as Distributed Across Total Generating Capacity of Sample

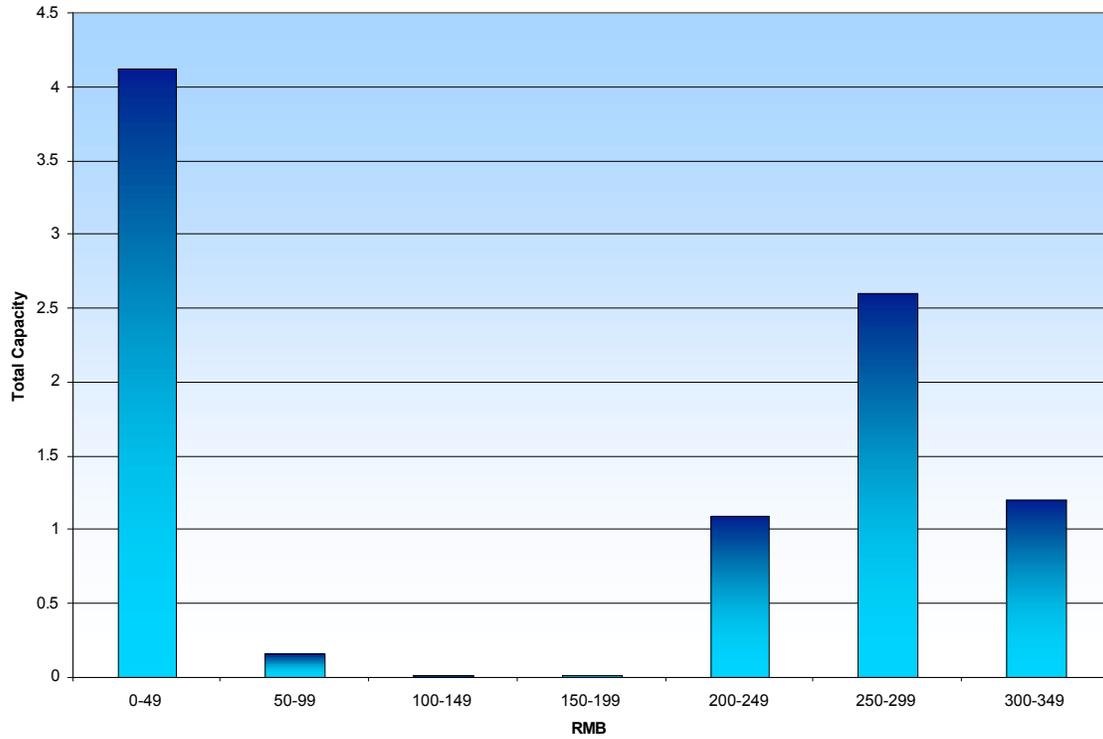


Chart 5.6 Modes of Coal Transport for Plants in the the Survey Sample

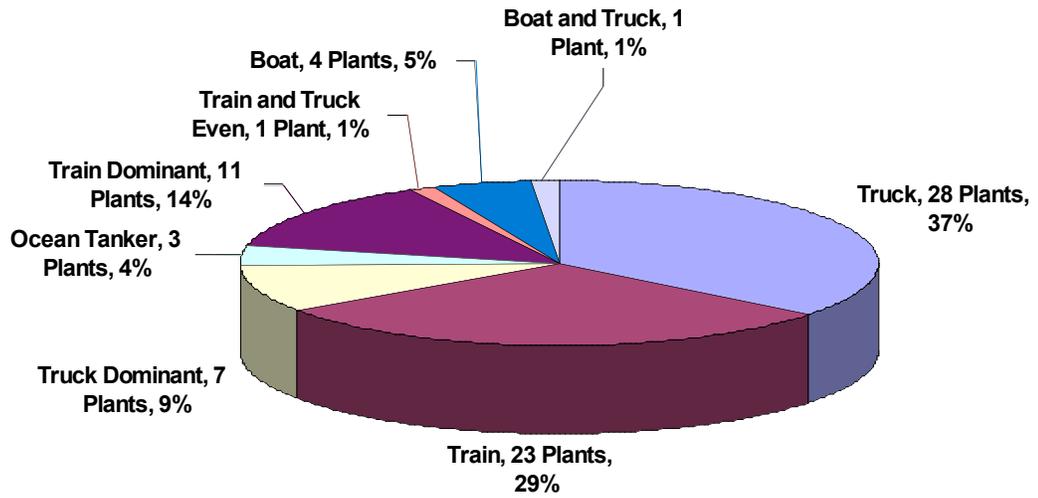


Chart. 5.7 Sulfur Content of Power Plant Fuel (weight percent)

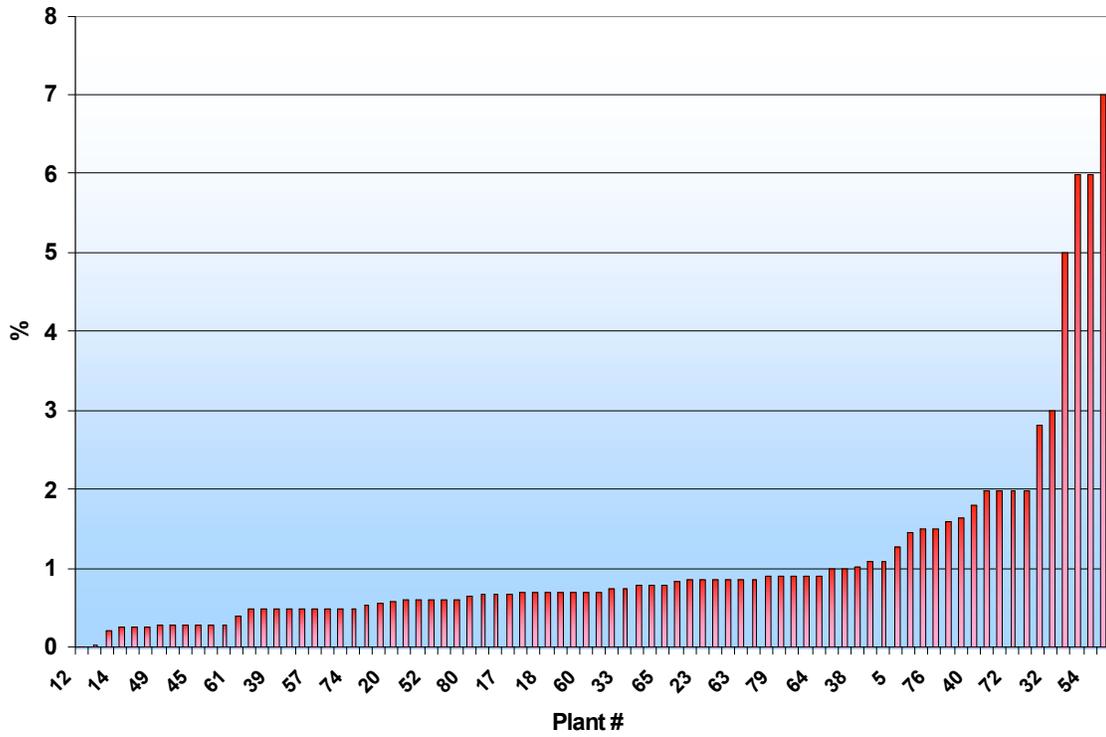
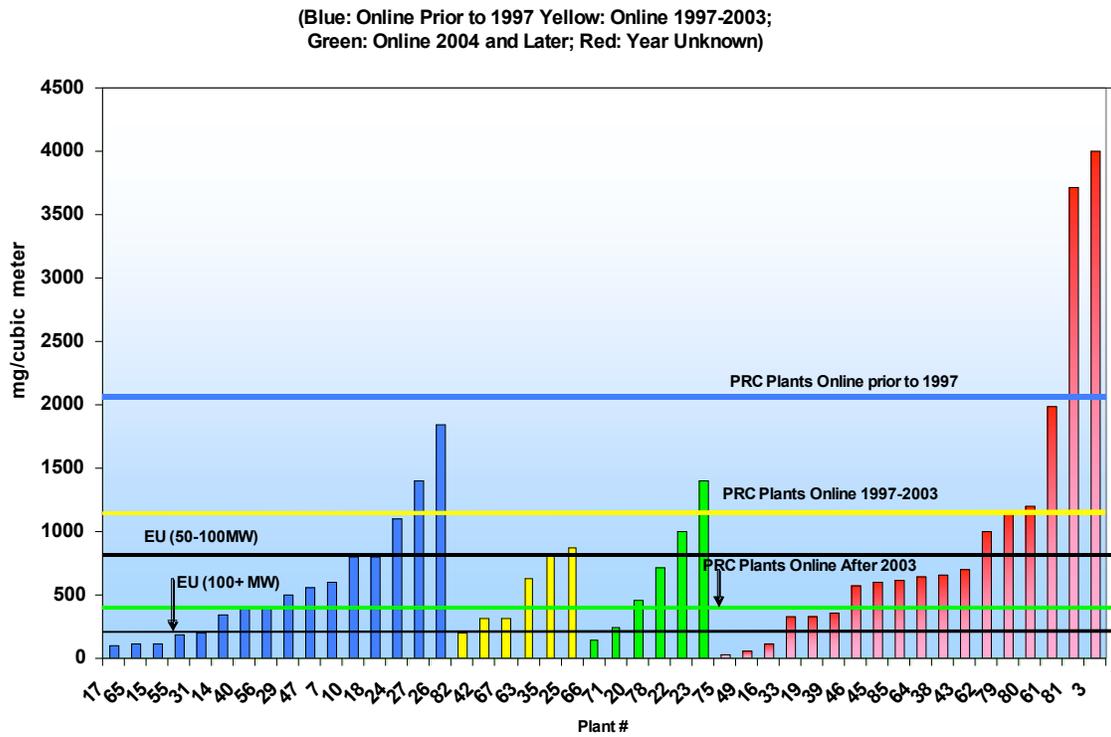


Chart 6.1 Plant Level Sulfur Dioxide Emissions



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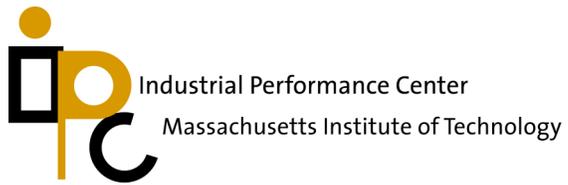
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