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## Leapfrogging into hydrogen technology: China's 1990-2000 energy balance

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Ying Zhu

**Leapfrogging into Hydrogen Technology:  
China's 1990-2000 Energy Balance**

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## **Abstract**

As a country beginning its motorization process, China must confront the problems attached to an oil-based car society. In adopting conventional automobile technology, the country would aggravate an already unstable oil balance while pushing up carbon dioxide levels. Not only would domestic problems emerge, but international concerns regarding oil shortage, global pollution, and the energy security balance would also result from erecting a traditional automotive infrastructure. One viable alternative the country can consider is a leapfrog towards hydrogen technology. By using hydrogen as the fuel source and investing in a hydrogen-based car society, China could overstep the problems created by an oil-based infrastructure. When examining China's potential for undertaking this technology leapfrog, China's energy past and future must be considered. China's energy balance and energy resources play a crucial role in determining the country's leapfrogging possibility. This paper analyzes one facet in China's energy balance by scrutinizing energy expenditures between 1990-2000. By looking at data compiled from major international and academic sources, an overview of China's past energy consumption and production activities is presented. Patterns and discrepancies in Chinese coal, oil, natural gas, and nuclear production are unveiled and the trends considered in relation to the country's energy balance. Each energy sector is analyzed separately for consumption and production trends. Because implementation of hydrogen technology is governed by energy resource availability and energy use patterns, such an energy analysis provides an appropriate background from which China's leapfrogging potential can be evaluated.

## **Zusammenfassung**

Der in China beginnende Motorisierungsprozess führt zwangsläufig zu einer Konfrontation mit den Umwelt- und Ressourcenkonflikten, die mit der erdölbasierten Automobiltechnologie des vergangenen Jahrhunderts Hand in Hand gehen. Dadurch würde sich zum einen die gegenwärtig problematische Erdölenergiebilanz des Landes durch erhöhten CO<sub>2</sub> Ausstoß verschärfen. Zum Anderen würde der Aufbau einer chinesischen automobilen Infrastruktur auf Erdölbasis, die Ressourcenknappheit in diesem Sektor, die globalen Umweltprobleme und die Sicherung der weltweiten Energiebilanz negativ beeinflussen.

Eine realistische Alternative für China ist ein Quantensprung auf dem Gebiet der Automobiltechnologie zu vollziehen und in Wasserstoffmotoren zu investieren. China kann mit einer Automobilwirtschaft auf der Basis einer Wasserstofftechnologie die durch Erdölverbrennung geschaffenen Umweltprobleme umgehen. Dieser Artikel untersucht das Potential Chinas zu einem solchen Quantensprung in der Automobiltechnologie. Ein wesentlicher Aspekt ist die Prüfung der Energiebilanz Chinas in den Jahren 1990-2000, die es ermöglicht den Energieverbrauch und die Produktion auf Quellenbasis internationaler Organisationen und wissenschaftlicher Arbeiten, zueinander in ein Verhältnis zu setzen. Die Energiebilanz der einzelnen Sektoren Atomkraft, Kohle, Erdöl und Erdgas wird analysiert und vergleichend werden die zukünftigen Trends prognostiziert. Für die Implementation von Wasserstofftechnologie ist die Verfügbarkeit und Nutzung von Energieressourcen von zentraler Bedeutung. Eine Analyse der Energiebilanz ist daher die Grundlage für eine wissenschaftlich fundierte Einschätzung des Potentials Chinas zu einem solchen technologischen Quantensprung.



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## 1. Introduction

Technological changes exist in two basic forms. The first and most common involves incrementally improved technology. In this process, adjustments are made to increase the performance and reduce the costs of pre-existing technologies. But change can also emerge abruptly, when a new technology rather than a new adjustment is unveiled. Traditional technological advancement is a time-consuming development process, whereas a leapfrog strategy oversteps the current technological model, entailing implementation of a revolutionary paradigm.

While technology changes occur on many levels, its impacts are particularly prominent on a national plane. Country-wide technology changes affect not only the nation, but also influence private citizens and the international community. The intensity of the technology change determines the level of social change. Incremental changes to a technology infrastructure result in minor country-wide improvements, while innovative changes via leapfrogging produces sweeping, national consequences. Countries adopting new technology can accelerate development and bypass undesirable effects connected with current technology paradigms. More significantly, leapfrogging propels a country lagging in technological advancements into a technological leader. By undertaking a new technological paradigm, such a country could serve as a technological model for the world and gain a competitive edge in related technologies. Nations without technology infrastructures are not entangled in old systems and more easily adjust to the leapfrogging process. Such countries can erect next generation's technology without the burden of demolishing last generation's technology infrastructure.

Because traditional technology satisfies most countries' needs, technology is usually slowly refined rather than radically overhauled. Only heightened necessity and pressure compels countries to undergo a drastic technology change. Strain from rising global energy demand, connected with widespread auto sales in developing countries, serves as an impetus towards a national or international leapfrog. The country experiencing the most environment and automobile tension is China. While China remains one of the world's largest untouched car markets, the population's demand for mobility via the private car pushes for an automobile infrastructure. China's growing car count reveals the population's desire for automotive freedom. Car sales in China increase more than 10 percent every year and may account for 15 percent of the world's automotive growth within the next five years (Gao 2002). China is a prime candidate for an automotive leapfrog, since the country's 1.3 billion residents will inevitably aggravate global problems when the country is fully motorized through traditional automotive technology. Currently, most Chinese cars rely on the internal combustion engine powered by gasoline or diesel fuel, so the rising number of gasoline-powered cars will impact the country's energy resources, environmental problems, and political security. Already, China stands behind the United States as the second largest primary energy consumer with transportation as the country's fastest growing energy sector (International Energy Agency [IEA ] 2000). According to Greenpeace<sup>1</sup>, China ranks second in the world for greenhouse gas

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<sup>1</sup> Greenpeace is not alone in ranking China second in carbon dioxide emissions. Zhong Xiang Zhang, in his book, *The Economics of Energy Policy in China* places China second behind the United States in carbon dioxide emissions. "China at the Crossroads," a report examining China's future transportation options gives the country a second place ranking. The International Energy Agency also ranks China second, in the



emissions. The country produces over 800 million tonnes of carbon dioxide or 9.6% of the world's total.<sup>2</sup> Were each household in China to own a private car, the country could easily become the largest global energy consumer as well as the world's biggest green house gas emitter<sup>3</sup>. By erecting a traditional car society, China would drain the world's diminishing fuel supply, while adding to the pre-existing carbon dioxide crisis. Both scenarios would incite tension within the international political arena. Consequently, a traditional approach to Chinese auto mobility generates a multidimensional problem affecting domestic and global planes. By circumventing tradition and leapfrogging to new technological models, China could avoid negative consequences associated with a gasoline-based car infrastructure.

One viable leapfrogging option for China, and the option related to this paper, puts emphasis on hydrogen technology. This technology transformation would replace gasoline with hydrogen as the fuel source. While the world contains a finite amount of oil, hydrogen is a ubiquitous element, present throughout the environment. The element is accessible through most natural resources such as wind, sun, and water. As a result, a country using hydrogen-based fuel will not face a supply shortage, since the element is contained in most renewable resources. Little emissions are emitted when hydrogen fuel is burned, so, in a country structured around hydrogen, the environment can be spared further pollution. From a technological perspective, the rate of research and development on hydrogen fuel makes the element a viable leapfrogging option. Finally, by modifying a gasoline-powered internal combustion system, hydrogen can be substituted for gas as the dominant fuel.

China is structurally suited to undertake a technological leapfrog. Most countries are heavily invested in the dominant gasoline economy, so lack incentives for taking political risks of such radical reform. As a consequence, these countries are bound to incremental change over long periods of time. Only a country with fairly small investments in the gasoline economy and with strong decision-making power could embark on the vision of a hydrogen society. Currently, China is poised at the initial stages of developing an automotive infrastructure. Such a provisional state allows an uncomplicated transition into a hydrogen-dominated fuel culture. Domestic pressure also pushes China towards assuming leapfrog technology. Within the last decade, China began importing more crude petroleum as the country's domestic supply failed to sustain its increasing oil dependence. Were China to erect a gasoline powered, automotive infrastructure, the country's oil supply would be inexorably drained. As a consequence China would become entirely reliant on imported oil. Such a scenario would economically drain the country and heighten China's political vulnerability to oil-rich countries. The country's incapacity to sustain itself also damages political security, resulting in weaker political decision-making power. On an international level, China's massive oil imports would deplete an already diminishing fossil fuel supply, enhancing international tensions caused by the energy crisis.

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world, for carbon dioxide emissions, with Nielsen and McElroy editors of *Energizing China* reaffirming this status.

<sup>2</sup> This figure was derived from a 1999 Greenpeace publication. Figures for China's carbon dioxide emissions range between 10 to 14%. Earlier publications, such as "China at the Crossroads" place this figure at 11% while the World Energy Outlook 2000, compiled by the International Energy Agency, claims China to emit 14% of the world's carbon dioxide emissions.

<sup>3</sup> This assumption is supported by the International Energy Agency's book *China's Quest for Worldwide Energy Security*. In evaluating China's energy consumption, the IEA predicts China to produce the most greenhouse gases by 2020.

China's natural resources and technological capabilities can support a technology leapfrog. Being richly endowed with solar, wind, and natural gas resources, China can choose to extract hydrogen from different mediums. The country recently established Transrapid as a new rail-based mode of ground transportation and jumped straight into the cellular age by developing wireless telecommunication infrastructures instead of adding millions of miles of copper to its telephone system. These advances already prove the country's willingness to exploit leapfrogging technology. More importantly, China's human capital fuels its leapfrogging potential. Private-car owners will push China into a fully mobile car society. Sufficient domestic researchers, scientists, and knowledge are present for China to realize hydrogen-technology.

Two crucial elements govern technological leapfrogging: revolutionary technology and new infrastructure. Only by scrutinizing the country's past infrastructure and technology, can China's capacity to undergo a technological leapfrog be realized. Because energy resources are crucial to building a hydrogen-based automotive infrastructure, China's former energy expenditures must be examined. This paper centers upon China's suitability for taking an auto-related leapfrog from an energy vantage. By evaluating China's past energy production and consumption, one can chart an overview of the country's energy strategy, revealing the limitations or potential for traditional or new, radical technology. The period of China's energy history examined ranges from 1990 to 2000. Investigating China's energy history also sets the basis for building leapfrogging scenarios and paves the way for more detailed investigations into China's leapfrogging options in the future.

## **2. Methodology**

The paper analyzes China's energy production and consumption with data gathered from available English-language sources. Focus is placed on energy expenditures from the last decade: 1990-2000. Not only are production and consumption independently scrutinized, but the relationship between energy production and consumption is also investigated. By compiling data from government, corporate, and academic sources, an overview of China's past energy activities will be presented. Consumption and production of oil, natural gas, coal, and nuclear energy are separately analyzed. It is not the goal of this paper to determine the most legitimate data source for Chinese energy development, but rather, the study considers different data sets in relation to each other. In order to examine China's potential for leapfrogging into a hydrogen-based car society, past energy trends and discrepancies must be evaluated. Do patterns and trends exist from the different data sources documenting the same information? Do separate sources contradict each other or contain matching trends? By examining energy development patterns, the basis for leapfrogging possibilities can be revealed: whether the country possesses enough suitable resources for leapfrogging, what energies are available for leapfrogging, and whether traditional automotive technology can be supported by China's energy spending patterns.

For this paper, the research problem determines methodological practice. Since the research question calls for data comparison between different sources in connection with China's leapfrogging potential, this analysis does not fall into one traditional methodological

structure. Instead, various approaches are combined to fulfill the study's dimensions<sup>4</sup>. On one level this energy question requires a quantitative look at data in relation to each other, but an examination of the structural and geographic details related to the country's energy activities is also required in a general overview of China's energy past. So, research locating energy production sights, energy production sectors, and energy policies also help answer the main question.

Data collection is a key aspect of quantitative analysis. Traditional data retrieval approaches via academic publications such as books and journals were utilized, but data from international organizations, government, and corporate data sources were also accessed. Many organizations post statistical information in paper form and online, so the Internet and digital data in CD-ROM form served as prime data receptacles. Data reliability and accuracy are vital in data analysis, so only sources using clear methodological practices were chosen for the comparison. Data were collected from international organizations, official government statistics, and academic studies<sup>5</sup>.

Data compilation and organization play a crucial role in data analysis. To effectively compare data, all related statistical collections must share the same unit of measurement. So, all data were converted into a single, scientifically acceptable unit. Because the metric system is used as a means for data comparison in the scientific community, this system was also chosen for this study. Data were converted into the common metric measurement for each specific sector. For example, the most common metric unit used to measure oil is million metric tonnes (Mt), so all oil-related data were converted into Mt. Conversion accuracy was ensured by using online metric conversion systems and then manually crosschecked by using the International System of Units conversion equivalents. But not all data shared convertible units. For instance, data from the same sector were often measured in different units such as mass or energy. Because energy units are not adaptable to mass equivalents, data within the same sector were occasionally separated into two sub-sections, due to differences in units.

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<sup>4</sup> Abbas Tashikkori and Charles Teddlie, editors of the *Handbook of Mixed Methods in Social and Behavioral Research*, place importance and validity in mixed method research. They write "the ultimate goal of any research project is to answer the questions that were set forth at the project's beginning. Mixed methods are useful if they provide better opportunities for answering our research questions." They also point out "a major advantage of mixed methodology research is that it enables the researcher to simultaneously answer confirmatory and exploratory questions, and therefore verify and generate theory in the same study." Tashikkori and Teddlie note three areas where mixed method research advances beyond single approach designs. Mixed method research can answer questions that other methodologies cannot, offers stronger inferences, and gives an opportunity to present a "greater diversity of divergent views." In combining quantitative and qualitative methodology, research can confirm and complement results. Many social phenomena cannot be understood by one perspective alone, a combination of different data sources and analysis clarifies the situation. Engaging in mix method research more clearly illuminates a multifaceted question. By not ascribing to one accepted research approach, this study explores China's energy expenditure from a quantitative dimension and uses foremost texts, examining China's energy condition from a structural perspective.

<sup>5</sup> Data from the United Nations Energy Statistics Yearbook and the Energy Information Administration (EIA) were compiled from a series of annual yearbooks. Because each UN Energy Statistics Yearbook only publishes data from the latest four years, compiling data for a 1990-2000 time period required several yearbooks. Since methodology, units, and energy definitions remained consistent and unchanged in all UN energy yearbooks, a ten year data set compiled from three yearbooks remains scientifically valid. Because data from the EIA International Energy Annual were also divided into two yearbooks, methodology, units, and energy definitions for this yearbook were also examined for consistency. Like the UN yearbooks, energy yearbooks from the EIA employed a consistent structure in data collection methodology, so a data series compiled from two EIA yearbooks remains scientifically acceptable.

This divergence in units does not affect data analysis, as only overall trends were examined and trends from separate units were comparable. All data were converted to three significant figures, allowing clear data analysis while eliminating the complications connected to numbers exceeding three significant figures.

Data were finally examined through both a numerical and structural perspective. To effectively examine trends and discrepancies between data sources, data were visually presented in two methods: numerical chart form and graphs. All data sharing the same unit and falling in the same sector were plotted on the same line graph as well as presented in the same data chart. Finally, charts and graphs were analyzed for trends and differences within data sources, unveiling an overview to China's energy use. The trend in each energy sector was determined by an average of all data sources. Not all sources contained a complete ten-year series, so the average was taken by available data. Because the study only presents an energy overview, missing data pieces did not detract from plotting a general pattern. Data was finally examined in relation to energy activities in China's energy history. And this history linked with the gathered data presents a synopsis of energy policy and goals within China.

### 3. Source Descriptions

Data from ten sources are used to analyze China's energy patterns. Not all ten sources contain data for each energy sector, but every source covers, at minimum, complete data for one energy group. In order to maintain scientific legitimacy, sources must use clear and valid data compilation methodologies. So, only data from valid academic, government, or global organizations are collected. Data from these sources appear in three major forms: in print, included in books or journal articles; electronically, connected with an organization's official website, or as an electronic database such as a data series stored on CD-ROM. When collecting energy statistics, along with complete time series, many single data pieces were also located in books, journal articles, newspapers, and related websites. Since this paper measures China's energy situation from 1990-2000, only complete data series were included in the examination. Single figures were not exploitable in this context. The sources used in this energy analysis are described below.

*Asian Pacific Economic Cooperation (APEC) Database:* Twenty-one economic jurisdictions comprise this organization that "facilitates economic growth, trade, and investment in the Asia-Pacific region." The database contains statistics from 21 countries in all energy sectors. The Expert Group on Energy Data and Analysis (EGEDA) is responsible for data collection and dissemination for all APEC countries.

*Asian Development Bank (ADB):* Owned by 61 members, ADB is a multi-lateral, non-profit finance institution aimed at reducing poverty in Asia and the Pacific. ADB specializes in public sector lending for its developing member countries, of which China is one. ADB also assists its member countries in collecting and disseminating improved statistical data. Its Chinese energy data is derived from official communication with the central energy divisions and the Chinese Statistical Yearbook.

*British Petroleum (BP):* A London-based, multi-national petroleum exploration and production company. The firm produces an annual energy review, documenting the

consumption and production of five energy sectors. Energy data is gathered through government and other published sources.

*Energy Information Administration (EIA)*: This organization functions as the United States Energy Department's statistical agency. The EIA provides independent data, forecasts, and analysis of domestic and international energy production and consumption. The agency uses data resources from China's various departments, supplementing Chinese information with APEC and ADB databases.

*International Energy Agency (IEA)*: An autonomous division within the Organization for Economic Co-operation and Development (OECD). The agency implements an international energy program. IEA maintains an energy cooperation with 24 of its 29 member countries. The organization also collects and analyzes energy data from countries outside the OECD collective. IEA statistics about Chinese energy rely primarily on the Chinese Statistical Bureau, energy divisions in Beijing, and published Chinese energy journals.

*Lawrence Berkeley National Laboratory (LBNL)*: This research institute compiles the foremost comprehensive Chinese energy data collection in the form of the China Energy Data Book. The Data Book is incrementally updated and stored on CD-Rom. The energy database is compiled by combining statistical information from China's National Bureau of Statistics with data sources from China's industrial, environmental, and public sectors.

*United Nations (UN)*: The United Nations prepares an annual international yearbook documenting worldwide energy statistics. This publication is organized by the UN Statistical Division. Data are gathered primarily from the annual energy questionnaire distributed by the United Nations Statistics Division and supplemented by official national statistical publications. When official data are unavailable or inconsistent, the UN Statistics Division then makes estimates based on governmental, professional, or commercial data sources.

All data sources share a common reference point by relying on official data from the China Statistical Yearbook, compiled by China's National Bureau of Statistics (NBS). While a few data sources only use NBS figures, most data sources combined information from NBS, specific Chinese energy ministries, and external, western sources. A few data sources, from prominent international organizations, lack clear references sections, citing vague reference details. Asian Pacific Economic Cooperation Database (APEC) and the ADB depended solely on numbers from the China Statistical Yearbook. While the two sources showed similar energy trends in most charts, some discrepancies remain. This may result from conversion inconsistencies. Because Chinese statistics are measured in standard coal equivalent (SCE), western data sources must convert SCE into scientifically acceptable units (China Statistical Yearbook, 2001). While the APEC database and the ADB yearbook compile energy data from the same source, the conversion process may result in disparate figures, leading to dissimilar chart patterns. Data from the APEC database wavered most in pattern and number consistencies, often diverting from the average data curve. The UN Energy Statistics Yearbook relied primarily on a specialized UN questionnaire. The UN annually submits an extensive questionnaire to the Chinese government, requesting data relevant for the energy yearbook. Unspecified government sources also supplemented the questionnaire. The BP energy yearbook lacks clear citations in the yearbook's reference section, vaguely

referring to use of government and known published sources. Despite the source ambiguity, BP's energy graphs all followed the overall trends in every energy sector, suggesting that BP accessed sources used by the other data sources. The majority of data sources not only relies on figures from official Chinese publications, but also from western sources. Most data sources draw on each other as external references. The International Energy Agency (IEA), the Energy Information Administration (EIA), and Lawrence Berkeley National Laboratory (NBNL), used each other as supplementary sources. This connection between sources may also explain the consistency in graph similarities between the three data sources. Almost all energy curves from the EIA, IEA, and NBNL reflect the general energy consumption or production pattern. With rare exceptions from IEA graphs, the three data sources follow the energy trends in all energy sectors. Although all three data sources cite one another as references, the three organizations also employ many domestic and foreign sources when compiling energy figures. The IEA, EIA, and NBNL use Chinese energy ministry figures, international and Chinese energy journals, domestic and western energy newsletters, and direct contact with government experts when compiling Chinese energy data. Because such diverse resources are accessed, the possibility for data inconsistencies grows, but instead, this resource diversity only serves to clarify the similarities in energy data among the three data sources. And compared to data sources such as the ADB or the UN energy yearbook, that fail to use such extensive outside sources, the differences in energy curves are relatively minor, suggesting that official Chinese figures serve as a main anchor in data compilation, as the China Statistical Yearbook is the only common reference used by all data sources.

#### **4. Data Analysis**

China's energy consumption and production are investigated through four energy sectors: coal, oil, natural gas, and nuclear. Data analysis will proceed along this order. All energy sections open with a synopsis putting the energy in context to China's general energy development. Production and consumption are initially examined separately, but the connection between production and consumption will also be considered. Coal and oil sections contain energy import statistics. Import data are also evaluated with coal and oil production and consumption. All production and consumption trends, patterns, and discrepancies between data sets are explained.

##### **4.1 Coal**

Coal is China's most abundant and well-used resource, accounting for over 70% of the country's primary energy consumption.<sup>6</sup> According to the IEA, China possesses 110 billion tonnes of proven recoverable coal, roughly 11% of the world total<sup>7</sup> (2000). China's coal reserves contain three major coal categories: bituminous, anthracite, and lignite. Bituminous coal is the country's most common coal type, making up roughly 70% of the country's

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<sup>6</sup> Most sources calculate China's coal consumption between 65 and 70%, but all sources differ in specific percentage numbers. Sinton and Fridley in their article "What Goes Up: Recent Trends in China's Energy Consumption" estimate China's coal consumption in 1998 and 1999 as 68% of the country's total entire consumption. Weidou and Sze measure China's coal consumption at 76% in the past decades. The U.S. department of energy assesses coal use at 76% of China's total.

<sup>7</sup> China's coal reserve is another figure that varies between sources. While the IEA points to a 110 billion tonnes coal reserve, Weidou and Sze calculate a more conservative figure at 960 billion tonnes.

reserves (IEA 2000). China's enormous coal supply is primarily located in northern China, where 80% of total reserves are mined. Northern Chinese coal mines contain high grade coal, while China's southern coal mines contain low-grade, high sulfur content coal. The northern coal mines pose as a geographic problem since coal is primarily needed in the economically developed regions situated in the south and along the eastern seaboard (Zhang 1998). According to Weidou and Sze, "the average railway transportation distance for coal is 500 kilometers." So, coal transport pressures the railroad system, creating traffic congestion between northern and southern China (1998).

Coal is China's most abundant resource and reliance on this resource is evident in many sectors. The Chinese industry sector leads in coal usage. Industry relies heavily on coal for power generation (Lin 1996; Sinton & Fridley 2000). While coal production rose in the early 1990's, by 1996, the country's coal production peaked (Sinton & Fridley 2000). After 1996, coal output steadily decreased. This decline follows a government decree in the mid-1990's, limiting production in state-owned mines and closing down low-cost, non state-owned mines. The state controls a little less than half the coal production areas, so any decrease in all state-controlled mines would result in an evident decrease in consumption. In 1998, the Chinese government closed 25,000 small, non-state owned mines and 40 state-controlled mines, diminishing coal output by 250 million tonnes (Sinton & Fridley 2000). Preliminary statistics in 1999 reveal decreases in coal production deriving from the decline in small mine production while output from state-owned mines increased (Sinton & Fridley 2000). Along with the decrease in output, coal consumption also slowed down. As previously mentioned, coal consumption is heaviest in China's industry sector, suggesting cutbacks in industry activities, but Sinton and Fridley point out only casual and minor statistical data support such an assumption (2000). Coal used within private households also dropped since 1990 (Zhang 1996; Sinton and Fridley 2000).

## Coal Production

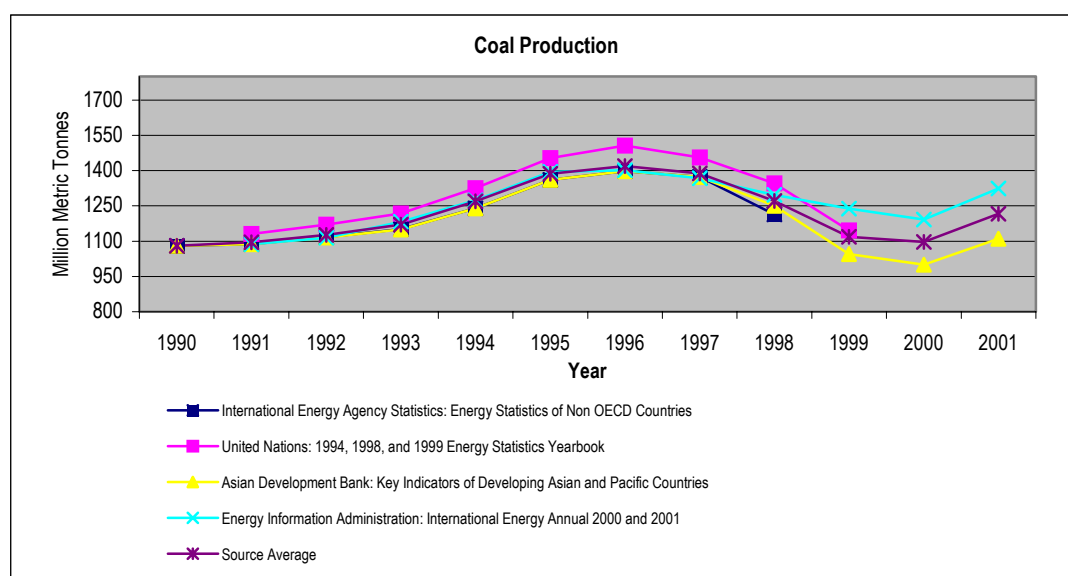


Figure 1

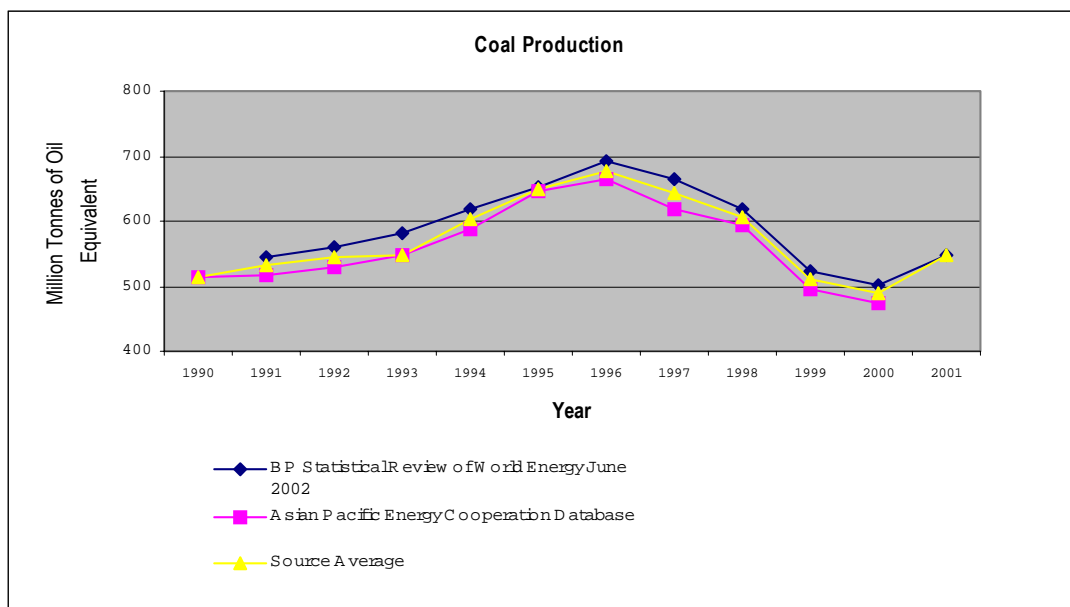


Figure 2

Without any exceptions, data in figures 1 and 2 follow the same overall trend. Coal production rose incrementally until 1996, when the production level peaked. Between 1997 and 2000, coal production steadily fell. The curve reaches its lowest point in 2000, but immediately rises in 2001. The curves from every data source follow this pattern. All data sets cluster closely around the average curve in figures 1 and 2, with greatest differences at single points of 100 Mt. Considering that all data sources consistently reflect the same coal production patterns, the average curve can appropriately represent the overall trend to China's coal production.

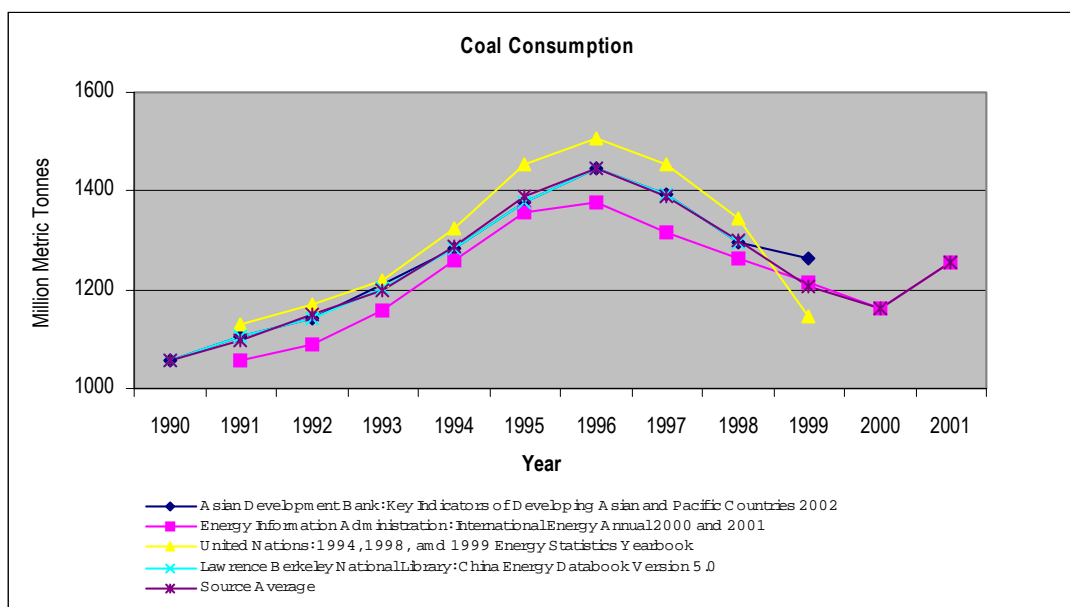


Figure 3



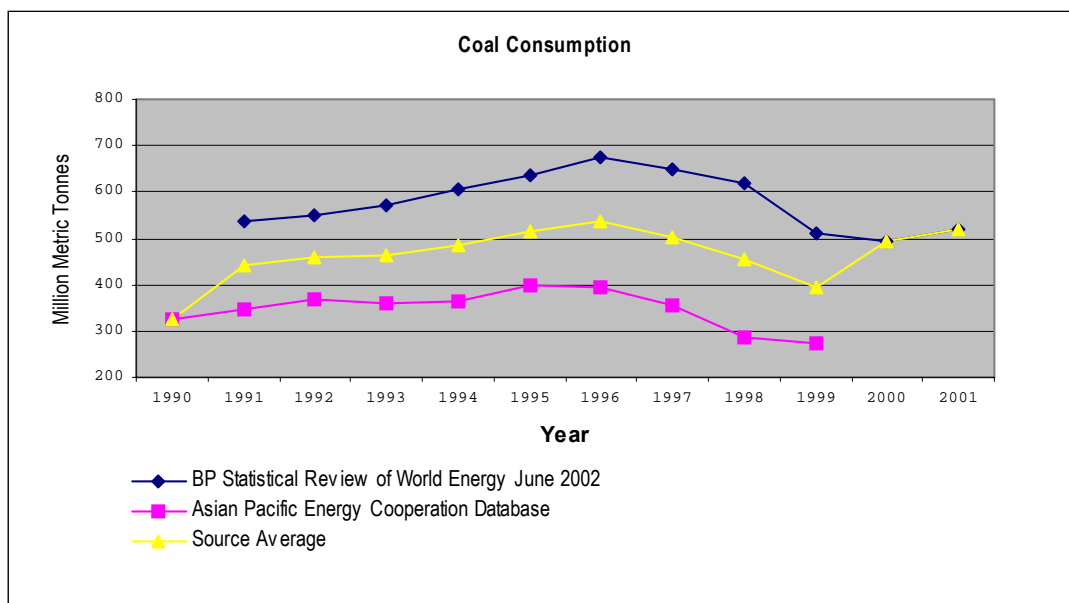


Figure 4

Like coal production curves, figure 3 and 4 data curves share the same consumption trends. Until 1996, coal production grew, reaching a high point in 1996. Following 1996, coal consumption gradually fell over four years. The curve reaches its lowest level in 2000, but promptly rises in the next year. Each data set reflects the same peak and trough pattern. All curves in figures 3 follow the same pattern and fall in a close vicinity to the average curve. While curves in figure 4 also share the same consumption patterns, a greater disparity exists between the average curve and the curves from data sources. This difference exceeds 150 Mtoe, but a main trend exists. Because the average curve in figure 3 and 4 follows along the same consumption trend, both curves suitably represent China's coal consumption.

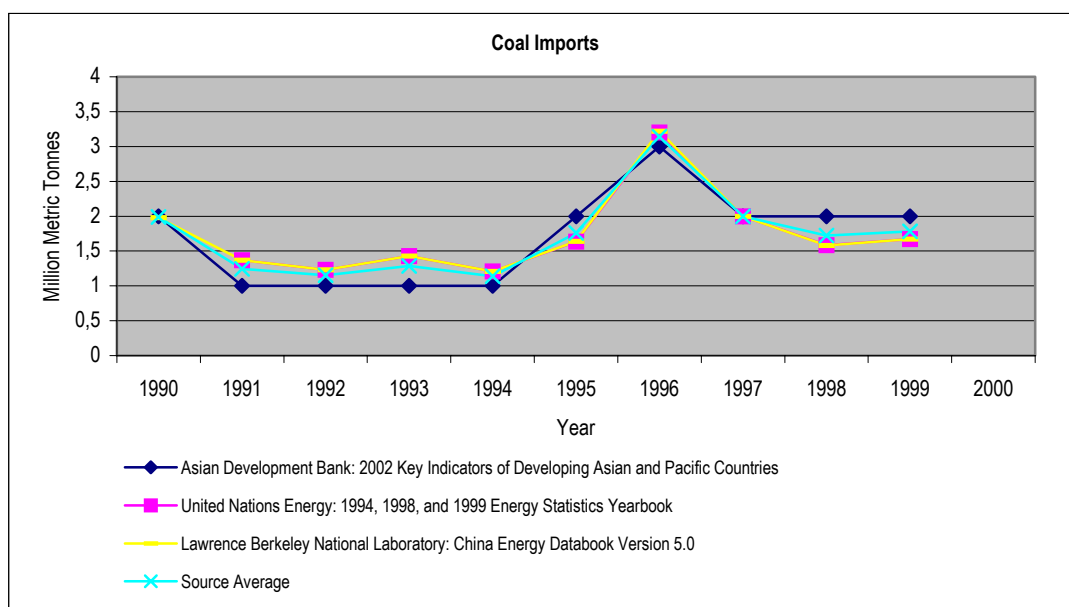


Figure 5

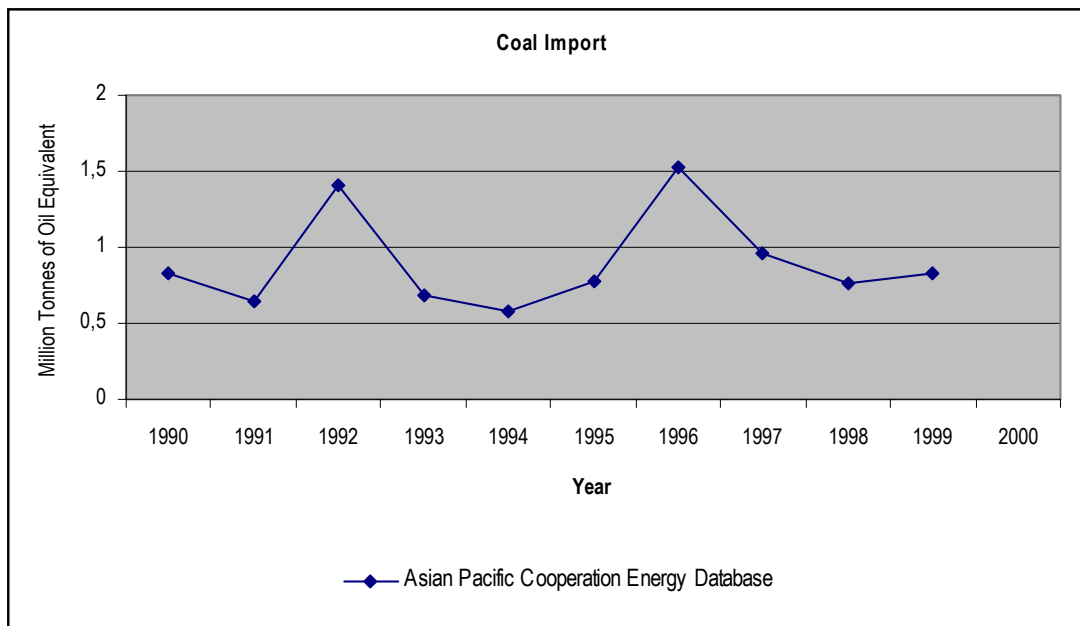


Figure 6

Coal import statistics during this period are noticeably erratic. Between 1990 and 1991, imports into China dropped dramatically, reaching a trough in 1992. The curve's rise/fall pattern continues until 1996, when import numbers peak. Following this 1996 high, import figures drop and rise slightly in 1999. This rocky up and down pattern is reflected in all sources except data from the Asian Development Bank (ADB). Data from the ADB suggest a smoother pattern in Chinese coal imports. Between 1991 and 1994, import levels remained consistently unchanged. Coherent with the remaining data sources, ADB data show a sharp import hike in 1996. For most data sets, numbers in the period between 1997-2000 returned to a rise/fall trend, but ADB data indicate stagnancy. According to data from the ADB, coal imports in this three-year period remained steady. The average import curve falls between ADB data and the other data sources. The divergence between the average curve and the source curves is small, with the biggest difference in 1993 and 1998 from ADB data. Otherwise, the average curve reflects the general trend in coal imports. With one exception, coal import data from figure 6 resembles import curves from figure 5. While data from figure 5 display a rise in coal imports in 1993, the curve in figure 6 depicts such a rise one year earlier. Along with this difference, the rise in coal imports in 1992 is steeper in figure 6 than the 1993 import growth in figure 5. Aside from this difference, the average data curve from figure 5 appropriately represents the import patterns in figure 6 and suitably reflects the import trends from all other data curves.

China maintains an unequal import/export balance. According ADB data, China's coal exports far outweigh the country's import figures. In 1990, China imported 2 million metric tonnes of coal (Mt), but exported 17 Mt. Because the country is endowed with a coal surplus, it is no surprise exports exceed import figures. This discrepancy between export and import expands toward the end of the last decade. In 2000, China failed to import any coal, but in the same year, the country exported 55 Mt of coal (Asian Development Bank [ADB] 2003)

## Analysis of Coal Data

China upholds a domestic coal balance. And this balance will remain stable since the Chinese government looks to move the country away from its heavy coal reliance by maximizing other energies such as oil or natural gas. According to the consumption and production rates between 1990 and 2000, the country effectively satisfied its coal demand independent of foreign assistance. Production and consumption rates show only marginal differences, suggesting a domestically contained coal demand. Even import and export figures reflect the country's wealth in coal. Yanrui Wu, author of "Deregulation and Growth in China's Energy Sector: A Review of Recent Development," points to China's coal exporting status (2003). Relevant export and import data support his claim. According to energy data from the Asian Development Bank, in 1995, China exported 29 million metric tonnes (Mt) of coal, but only imported 2 Mt (ADB, 2003). While China consistently imported 2Mt of coal between 1995 and 2000, the country's coal exports grew annually from 29 Mt in 1995 to 55 Mt in 2000. The country's coal exports outweigh such minor coal import figures, suggesting little urgency for external coal supplements. China's coal demand remains a domestic situation. Coal production and consumption began declining in 1996, but such decline was minimal. Coal remains China's most exploited energy source. This reduction was partially stemmed by improved efficiencies such as coal washing and more effective coal-related technologies. The government mandated coal mine closures shaped coal production losses (Wu 2003; Sinton & Fridley 2000). Concerns regarding pollution, also pushed down coal expenditures since the late 1990's (Sinton & Fridley 2001).

## 4.2 Oil

In 1960, China emerged as a major oil producer upon discovering Daqing oil fields, located in the northeast (IEA 2000). Previous to Daqing, China was considered an oil-barren country, producing insignificant amounts of oil. Since this breakthrough, the country has created roughly 22 large and medium-sized oil bases located in northern and northeastern China, areas with high oil density. Even now, Daqing produces one-third of China's oil supply and in the last twenty years, has provided China with 50 millions tonnes of oil annually. China also possesses offshore oil fields, situated in Bohai Bay, along the Yellow Sea's eastern arm, east of Tianjin, and west of Dalian (IEA 2000).

Through exploiting its consistently rich oil-fields, China served as a major oil exporter between early 1970 and 1990. But in 1993, the country's oil consumption exceeded its domestic production, forcing China take an oil-importing role.<sup>8</sup> By the mid-90's China's oil exports nearly tripled from the country's first export period.<sup>9</sup> And demand for transport fuels pushed the gap between domestic production and consumption even wider. As a consequence, China's oil exports grew. Currently, oil is mainly used as transportation fuel or as feedstock for the petrochemical industry with oil positioned behind coal as the second-most used energy source (Cannon 1998). Along with an expanding transportation structure, falling

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<sup>8</sup> This date remains consistent throughout all sources. The journal articles reporting on Chinese oil expenditure also cite this date as China's oil importing year and the OECD/IEA reaffirms this period.

<sup>9</sup> The year China began drastically increasing oil imports is a slight contention point. The International Energy Agency dates China's main oil export year as 1996, Andrews-Speed, Liao, and Dannreuther point to 1995 as the significant year for China's oil exports.

oil production levels also exacerbate the discrepancy between oil production and consumption. China's major oil fields such as Daqing and Shengli are mature oil fields, sustaining China's oil needs for nearly four decades, but capacity in the old fields are dwindling. Although rising output from offshore oil fields compensates for declining oil fields in the north and northeast, China's oil demand is only appeased by increasing imports since the production growth rate measures around 1.5% per year.<sup>10</sup>

Beginning in 1990, Chinese oil demand has grown 7% per year, but international agencies forecast increased oil consumption when an expanding transport sector places pressure on petroleum resources (IEA, 2000). In 2001, China produced 165 million metric tonnes of crude oil, but the country imported another 82 million tonnes (Wu 2003). Almost one-third of China's oil demand was satisfied by foreign oil shipments. According to Andrews-Speed, Liao, and Dannreuther, road transport heightens China's growing oil demand and will remain a large impact for at least 10 to 15 years (2002). Understanding its potentially dire oil future, the country has placed great hopes on the Tarim Basin, situated in western China. This area is expected to yield 3.6 billion barrels of oil, but Chinese geologists believe the Tarim Basin holds small and medium-sized oil pockets rather than large reservoirs (IEA 2000). In 1994, China opened certain sections in the Tarim Basin for foreign investment, expecting foreign technology and a financial injection to increase exploration rates, thereby enhancing domestic potential for new oil resources.

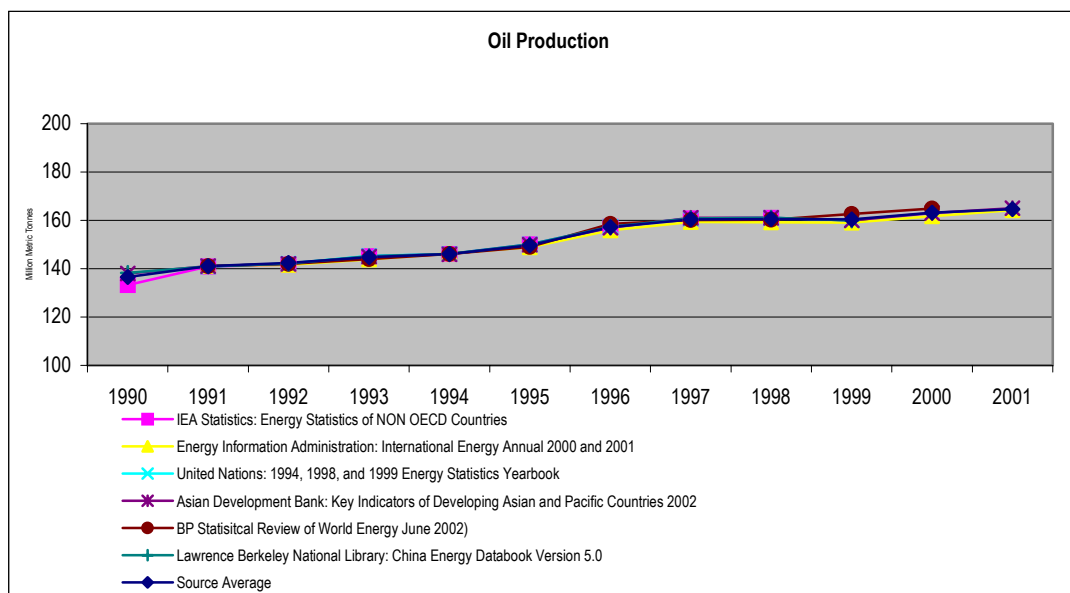


Figure 7

<sup>10</sup> The increase rate of oil varies between sources, but all sources hover around 1.5%. Weidou and Sze place growth at 1.67%, the U.S. Department of Energy measure the Chinese growth rate in oil at 1.4%

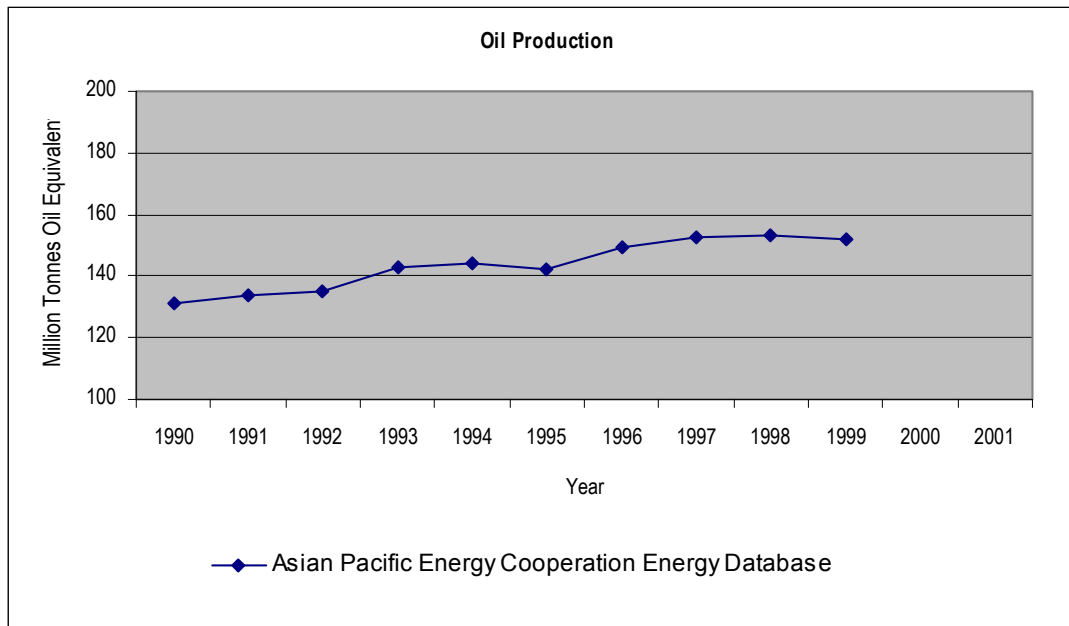


Figure 8

All figure 7 curves consistently follow the same production pattern. Oil production distinctly increased between 1990 and 1991. From the early 90's, production steadily grew until 1995. In 1996, production rose sharply, but remained level between 1997 and 1999. Oil production increased again in 2000. While data in figure 7 suggest smoother growth in oil production, the APEC data in figure 8 suggest a rocky rise in oil production. The curve rises erratically for the first five years, but falls in 1995. According to figure 8, oil production grows in 1996 at a less irregular pace. The 1995 production drop in figure 8 remains the main difference between data from figures 7 and 8. Figure 7 displays no drops in production rates. All data sets reflect a rise in oil production, but growth remains less extreme in figure 7. The data average in figure 7 exactly fits the trend present in every curve, with all data sets falling closely around the average curve. While the average curve appropriately represents the overall production pattern for figure 7, the curve only moderately represents the trends in figure 8 data. Because the majority of production curves, including the average curve, follow along the same trend, the average curve is a suitable representative for oil production trends.

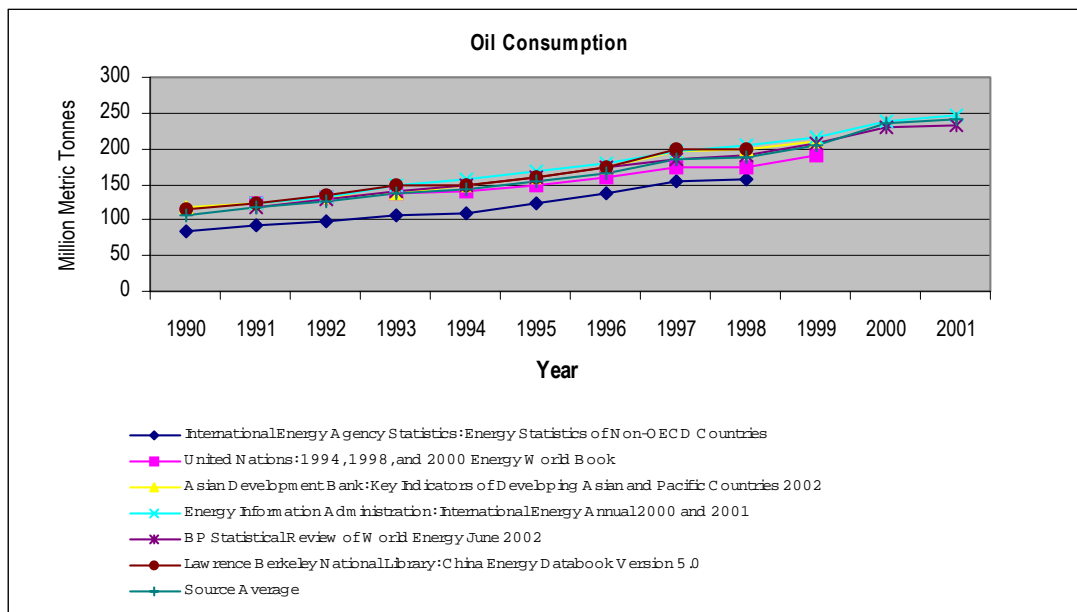


Figure 9

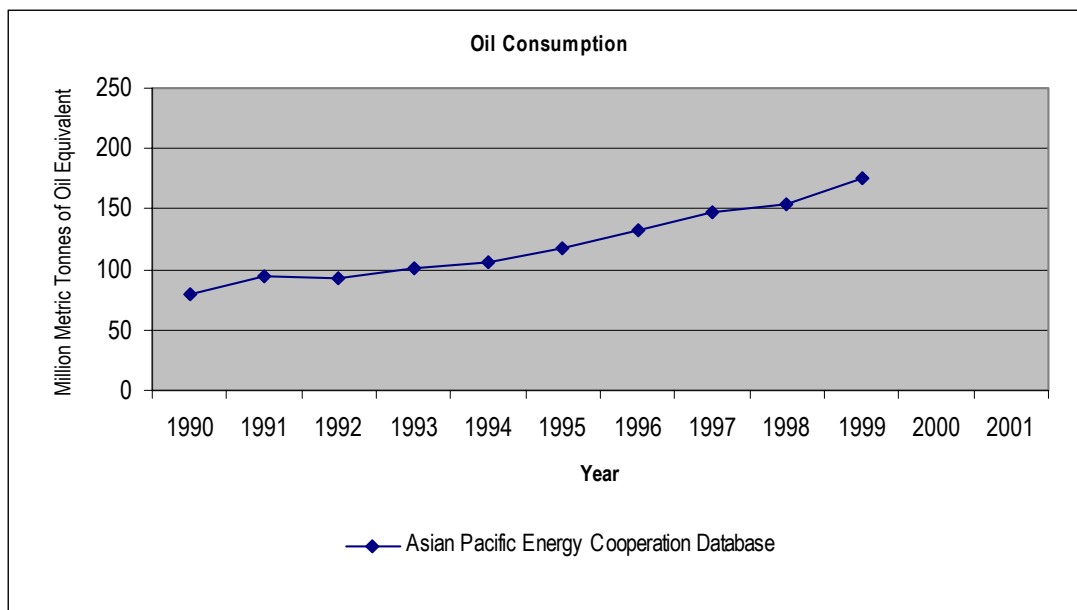


Figure 10

Data in figure 9 reflect an almost linear growth in oil consumption. This unswerving rise in oil consumption shows one stagnant period in 1998. Growth in consumption between 1997 and 1998 was barely perceptible, with growth ranging from 1 to 2 Mt's. Data in figure 10, from the APEC database, also reveal a near-linear pattern, but this curve is unlike figure 9 data. According to APEC, growth is continuous and the almost stagnant period from 1997 to 1998 from figure 9, is not present in figure 10. Another difference between the data from figures 9 and 10 emerges from 1992 data. While the APEC curve shows a dip in oil consumption, all curves in figure 9 reflect steady growth. With the exception of APEC, the average consumption curve appropriately reflects the overall trend in China's oil consumption. All data curves cluster closely around the average curve with the IEA curve falling most out

of range. IEA data, in its greatest distance from the average data set measures 50 Mt less, yet the IEA curve reflects the same consumption trend.

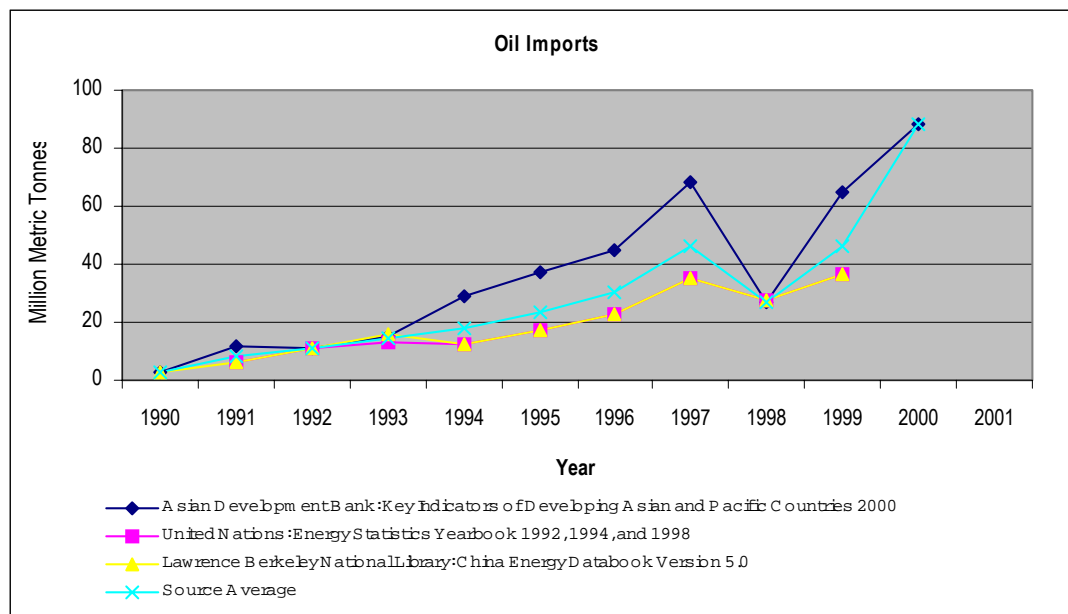


Figure 11

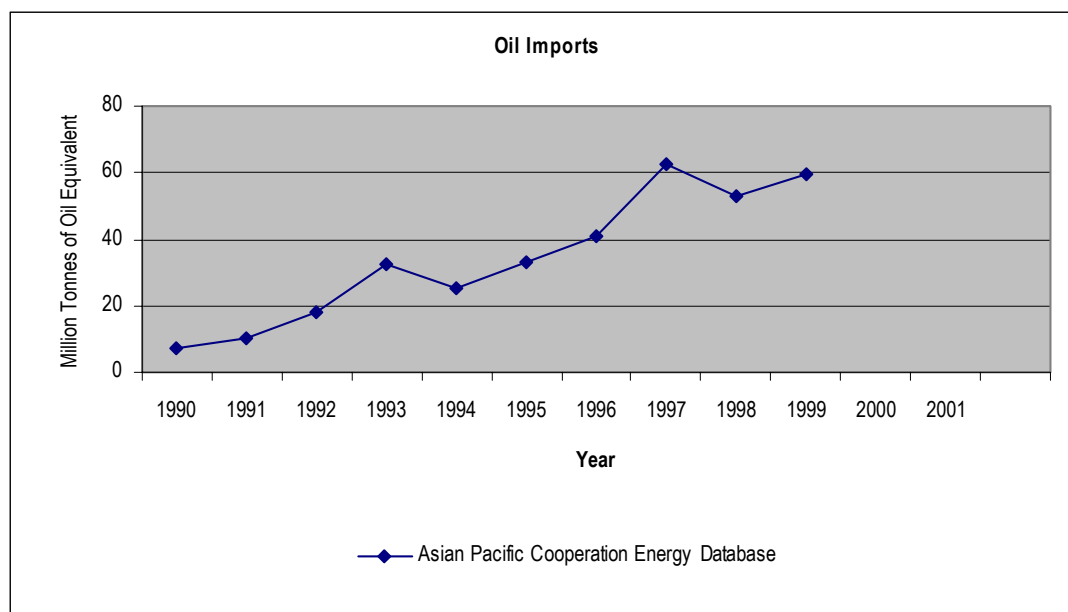


Figure 12

Unlike oil consumption and production, oil import figures are less consistent and unpredictable in growth and decline. While an overall oil import trend is present, not all data sets perfectly follow this average curve. Data in figures 11 and 12 depict growth in imports until 1994. Between 1993 and 1994, the import level fell, but quickly rose again in 1995. Except ADB figures, all data reflect this import pattern. According to ADB data, the drop in oil imports occurred not between 1993 and 1994, but rather between 1992 and 1993. Another drop in oil imports occurred in 1998, but this decline is present in all data sets including data from ADB. Unlike other data sources that suggest a more modest decline in 1998 oil imports,

ADB data show a particularly extreme drop in 1998. Oil imports rose following the fall in 1998. The average curve represents the overall trend present in all data sets. The average curve falls in between three data sets in figure 11 with ADB falling furthest away from the average curve. Despite this discrepancy, the ADB curve follows the same general pattern as the average curve. While data from figure 12 is measured in million tonnes of oil equivalent instead of metric tonnes, data from figure 12 also mirrors figure 11 import trends, reflecting the same import decrease in 1994 and 1998.

China's import/export oil balance is uneven. But unlike the coal balance, the disproportion is tilted towards a higher import rate. In the early 1990's China's import/export balance resembled the current coal situation. The country possessed an oil surplus, so oil exports surpassed oil imports. But from 1993 onwards, export levels decreased and import figures dramatically rose, pushing the oil imbalance into another direction. In 1990, China imported 3 Mt of oil, but exported 24 Mt. Such numbers were clearly different in 1994, when China imported 29 Mt of oil, but exported 18 Mt. The gap between exports and imports widened towards the end of the decade when in 2000, 88 Mt of oil were imported, but only 13 Mt of oil were exported (ADB 2003).

#### Analysis of Oil Data

China's oil balance cannot be domestically contained. The country's oil demands can only be satisfied through foreign supplements. This oil shortage is reflected in production and consumption figures from the last decade. China's self-sufficiency in oil expenditures began deteriorating in 1993, when oil consumption surpassed oil production. The data sets correctly reflect this imbalance as production figures fell short of meeting consumption numbers. The divergence between oil demand and oil production grew even wider after 1995 when the difference increased from 20 Mt to 40 Mt. While oil production after 1995 leveled off around 160 Mt, consumption data reflect steady growth above 200 Mt. Import and export figures from the Asian Development Bank also verify this problem. From 1995, the amount of imported oil exceeded oil exports. In 1995, the difference between export and import measured 12 Mt, but this discrepancy grew significantly every year. By 2000, China was importing 97 Mt, but exporting only 20 Mt (ADB 2003). Such large imports resulted from the country's growing oil consumption connected to a dwindling internal production capacity. As a consequence, China's oil balance is no longer self-contained. According to Yanrui Wu's oil data, imports support almost one-third of China's oil consumption. In 2001, China produced 165 Mt crude oil, but imported another 82 Mt (Wu 2003). Data tables from the ADB point to an even larger foreign oil dependence with imports documented at 91 Mt (2003). Few opportunities can right China's uneven oil balance. Unless new oil-rich areas are discovered, China's dwindling oil fields cannot support the country's oil demand beyond four more decades (Weidou & Sze 1998). With China's emerging motorization and economic growth, transportation and residential sectors are predicted to heavily raise China's energy consumption (Wu 2003). Because oil plays a major role in transportation mobility, future motorization activities may push China deeper into foreign, oil-producing hands.



### 4.3 Natural Gas

Because China prioritized oil exploration, the country has placed minimal attention and effort in developing its natural gas resources (IEA 2000). Although natural gas is marginally developed, China possesses enormous resource potential. According to many international sources, China harbors large natural gas fields. Currently, proven reserves measure between 1.4 and 1.7 trillion cubic meters.<sup>11</sup> China primarily uses natural gas as fuel in industrial factories and as raw material for manufacturing chemicals and fertilizer. When considering China's natural gas resources and environmental benefits, this resource is finally recognized as a suitable coal and oil substitute (Weidou & Sze 1998; Zhang 1998). Despite the country's potential for developing natural gas into a major energy resource, production growth remains stunted. In the mid-nineties, production of natural gas increased between 2 to 3% every year, but accounted for less than 2% of China's total energy production<sup>12</sup>. And according to Sinton and Fridley, this figure remains largely unchanged since 1980 (2000). In 2001, natural gas filled 3.4% of China's total energy demand (Wu 2003). Future forecasts support a China relying more on natural gas along with a China fully exploring its natural gas areas. Many international agencies and experts in the academic arena predict China to use 90 to 100 billion cubic meters of natural gas every year, compared to roughly 20 billion cubic meters per year in the last ten years.

China's natural gas production is contained in three areas. The Sichuan province dominates natural gas production, producing and using the most natural gas. While distribution pipelines service major cities in the province, Sichuan lacks a country-wide pipeline system, so gas transportation is contained to Sichuan. (Cannon 1998). In 1983, the Atlantic Richfield Company discovered China's largest offshore field at Yachieng (U.S. Department of Energy [DOE] 1998). This gas field was momentous in increasing gas production in the mid-nineties. China's second largest gas field, in Shanxi province, supplies fuel to Beijing and Xian via China's first long distance natural gas pipeline, erected in 1997. China possesses other potentially natural gas-rich areas, mainly in located in Xinjiang province. And areas like the Tarim Basin, are currently surveyed not only for oil, but also for natural gas.

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<sup>11</sup> The IEA points to a 1.5 trillion cubic meter figure while the U.S. department of energy estimate this figure at 1.7 trillion cubic meters.

<sup>12</sup> Growth in natural gas production ranged between 2 and 3% depending on the source consulted. According to Sinton and Fridley of Lawrence Berkeley National Library, China presented 3% growth in natural gas, while Weidou and Sze suggest 2.8% annual increase. IEA estimates this figure at little more than 2%.

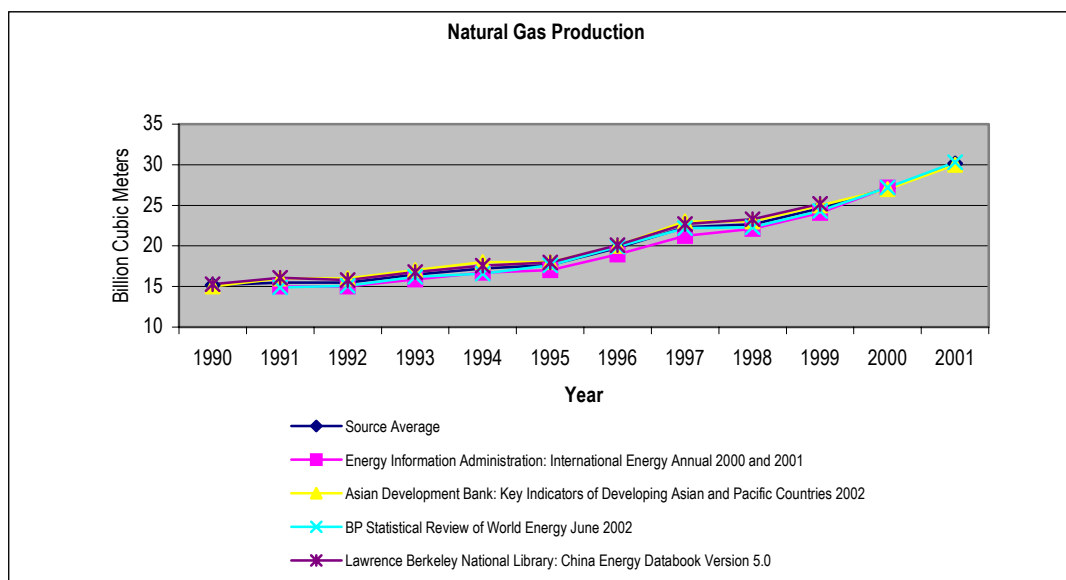


Figure 13

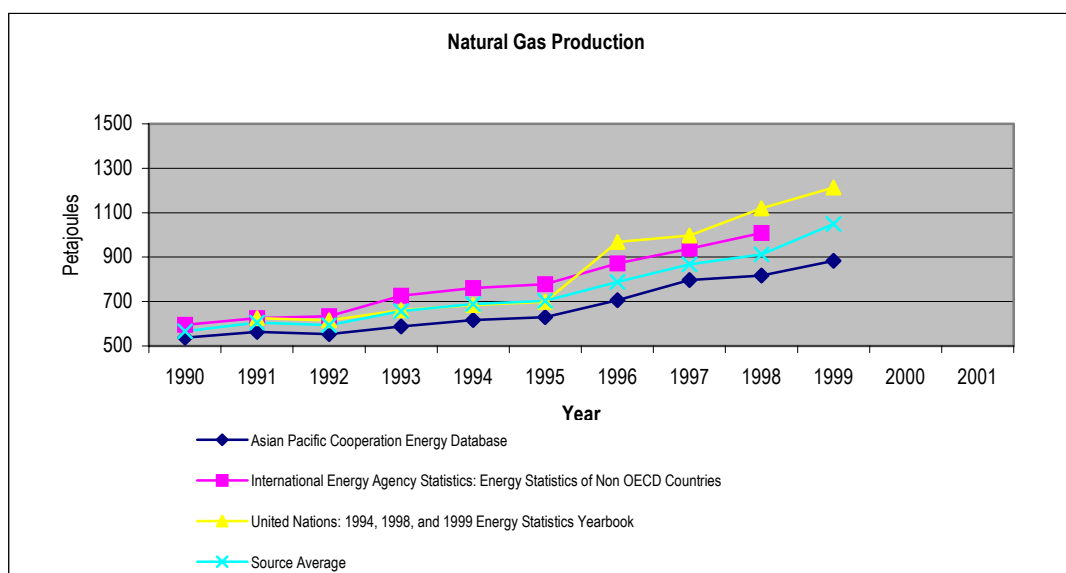


Figure 14

Production levels in figures 13 and 14 show a persistent, but slow growth in gas production. All data sets reflect a low-rising, upward curve, suggesting constant increase in natural gas production. Only data from the UN Energy Statistics Yearbook deviate from this general pattern. While UN data also show progress in natural gas production, this growth is pointedly steeper between 1995 and 1996, as compared to other data curves. Following this sharp increase in production, the curve returns to a slow progression in production. The average curves from figures 13 and 14 appropriately represents an overall pattern. Both average curves depict a line moving slowly in an upward direction. All graphs from figure 13 cluster tightly around the average curves. While the average curve in figure 14 reflects the same trends as the average curve in figure 13, the separate graphs in figure 14 do not settle as closely to the average as those curves in figure 13. Despite this difference, the average in figure 14, along with the separate data curves also acceptably characterize China's overall natural gas production.

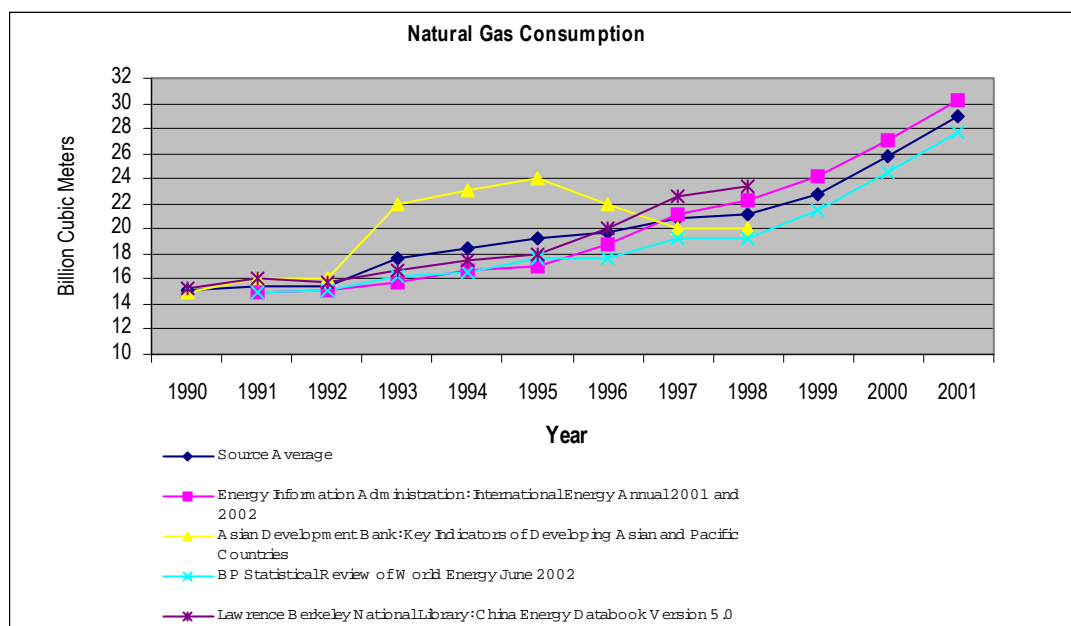


Figure 15

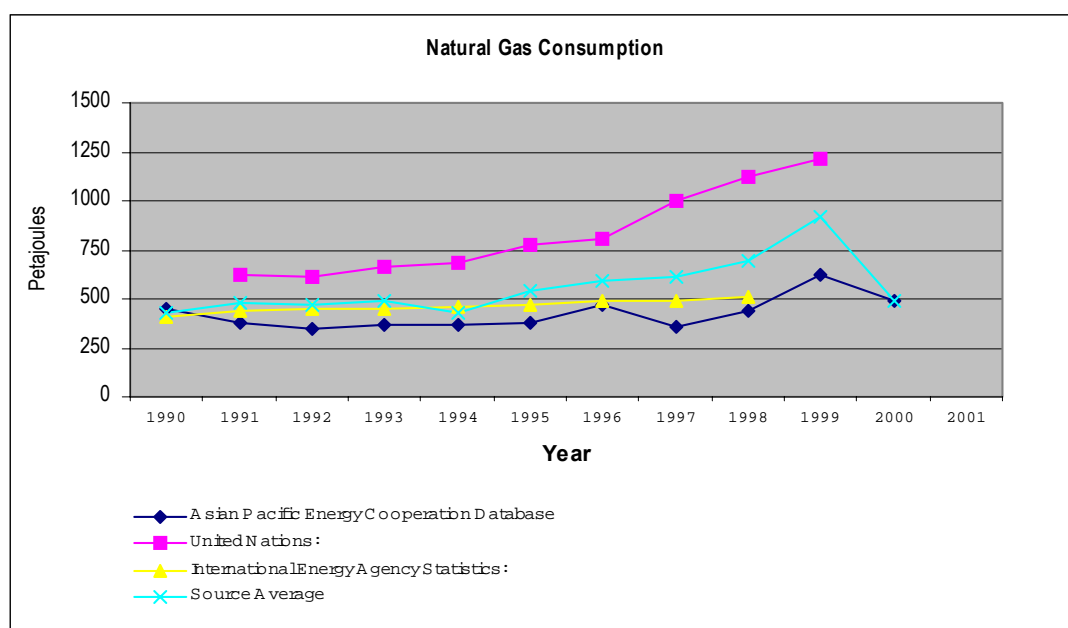


Figure 16

Unlike natural gas production, data curves depicting China's natural gas consumption are inconsistent and dissimilar. Most data sets in figure 15 depict natural consumption increasing on a yearly basis. Only one data source, ADB, detracts from this general pattern. ADB data point to a steep rise in gas consumption in 1993. Between 1993 and 1995 consumption grew at a linear pace, but steeply dropped after 1995. This pattern veers away from the overall consumption trend in figure 15. Figure 16 shows varying trends in China's natural gas consumption and lacks a general consumption pattern. Data from the UN suggests an upward growth in gas consumption, while IEA statistics show almost no growth. APEC figures fall furthest from a growing consumption pattern, revealing instead, growth and

decline in consumption rates. The source average in figure 15 feasibly reflects the general consumption trends from most data sources. Aside from ADB data, all curves fall closely within the average curve's sphere. Because the curves in data 16 lack a harmonizing structure, the average curve cannot reflect general patterns in China's gas consumption, suggesting differences in the data gathering process or contention within the natural gas sector regarding China's consumption levels.

China has only recently developed a natural gas infrastructure, so the country has yet to develop an import/export exchange. Consumption and production are domestically fulfilled.

#### Analysis of Natural Gas Data

Because dependency on natural gas is minimal compared to the country's coal and oil demands, China currently maintains a natural gas balance. Only in the last decade has China placed priority in exploiting this resource. Data from natural gas production and consumption show domestic self-reliance. Enough natural gas was produced internally to support the country's consumption rate. Production figures minutely exceed consumption figures, suggesting possibilities for further natural gas usage. Despite this domestic balance, Yanrui Wu points to natural gas as the fastest growing energy sector (2003). As residential and power generation sectors increase natural gas consumption, Wu suggests China to surrender its natural gas self-containment: "the two largest users of natural gas will be the residential and power generation sectors. Demand in these sectors is projected to grow at a rate greater than 20 percent during the period 2000-2010. This growth can only become possible with overseas supplies" (Wu 2003). Between 1990 – 2000, China did not export or import natural gas, so no data exists to refute or support Wu's forecast. Consumption and production data suggest continued domestic control over natural gas demands. While natural gas consumption steadily grew between 1990-2000, a growth rate between 2 and 4 billion cubic meters or between 50 or 200 petajoules is the annual increase (see figures 15 & 16). Such rises in consumption level are minor compared to the escalation in oil consumption. Also, Yanrui Wu does not take into account China's natural gas deposits. Considering its wide energy base, natural gas is an underutilized resource. Fully established natural gas fields will offset much of the need to import natural gas from foreign firms.

#### 4.4 Nuclear

China recently began developing nuclear energy, erecting its first nuclear plant in 1991<sup>13</sup>. Located in the Zhejiang province, along the south Shanghai coastline, the Qinshan plant is a domestically designed 300 MW pressurized water reactor (DOE, 1996). The second nuclear plant, operating in Daya Bay, is situated in the Guangdong Province near Hong Kong. This plant houses two 900 MW pressurized water reactors constructed by French expertise in 1994. During China's 9<sup>th</sup> Five-Year Plan (1996-2000), four more nuclear power plants with eight reactors were constructed (Cannon 1998). These plants were located in the same area as China's first two nuclear plants. Such a strategy allows more districts access to electricity.

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<sup>13</sup> All sources used in this paper date China's first nuclear plant construction as 1991 except James Cannon in "China at the Crossroads." His article dates China's first nuclear plant as erected in 1992.

The Daya Bay plant now services Hong Kong, the Guangdong province, and China proper. The French company, Framatome, along with Russian firms, offers technology improvements to the Daya Bay plant while a South Korean firm is contracted to equip the Qinshan plant with new vessels (DOE 1996). In early 2003, China completed construction for another nuclear power plant located in Shenzhen, a city in China's Guangdong Province. Construction for the new Ling'ao Nuclear Power Plant began in 1997 and contains two generating units, each possessing a one million kilowatt installed capacity (China Daily 2003).

Currently, China maintains 2.1 GW of nuclear capacity, but long-term official plans push this figure forward exponentially to 20 GW capacity in 2010 and 40 GW<sup>14</sup> in 2020 (IEA 2000). Because plant construction requires a lengthy planning and building period, such forecasts for the future exceed reality. Considering the high capital costs connected to plant development, the IEA predicts China's potential nuclear capacity in lower figures: 11 GW in 2010 and 20 GW in 2020 (IEA 2000). China's high, nuclear energy estimates stem from necessity. Since the country's energy expenditures annually increase, China must offset such demand without relying on coal or oil. By moving away from its coal reliance, China must create a diversified energy mix. Since China's domestic oil supplies do not cover the country's energy demands, another energy alternative is required. Nuclear power, for China, appears as a suitable alternative (Dazhong & Yingyun 2002). Nuclear power is especially attractive considering China's energy distribution problems. Geographic unevenness problematizes energy distribution since coal and oil are not only unevenly distributed, but energy distribution also strains an already stressed transportation system. Nuclear power expansion reduces energy distribution problems. (Dazhong & Yingyun 2002). The country has designed an infrastructure for carrying out its aggressive nuclear plans. China maintains a large scientific community, many of which are competent in nuclear technology from the atomic bomb program. The health physics program, a subset of the atomic bomb program, is also retained for China's energy possibilities. A fuel fabrication facility is placed in Sichuan, servicing the Daya Bay and Qinshuan. Lastly, a heavy water plant from the atomic bomb effort exists, supplementing China's nuclear power expansion (Dong, Lew, Ping, Kammen, & Wilson 1998). Despite Chinese interest in expanding its nuclear production, several factors obstruct continued development. Costs for plant construction, maintenance, and plant equipment are reportedly five times higher for nuclear power plants compared to conventional power plants (Dong, Lew, Ping, Kammen, & Wilson 1998). When using China's past experiences in power plant construction to determine future plant projects, the expansion process will be predictably tedious. The domestically constructed Qinshuan power plant began operation in 1991, resulting from two decades of delays and technical difficulties. The plant was conceived in 1972, but controversy over the optimal reactor type mired initial production. The project was pushed off in 1980, yet required seven years for completion. This lengthy construction period resulted from incompatibility between foreign parts and equipment. While the country upholds personnel competency in nuclear technology, China lacks sufficient manufacturing capacity for producing nuclear reactor equipment (Dong, Lew, Ping, Kammen,

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<sup>14</sup> *World Energy Outlook* and *China's Worldwide Quest for Energy Security* (both books are associated with the IEA), and the U.S. Department of Energy predict China's nuclear capacity for 2010 and 2020 to be half of the official Chinese figures.

& Wilson 1998; DOE 1996). Such problems may force China to search for other energy alternatives to satisfy its energy demands.

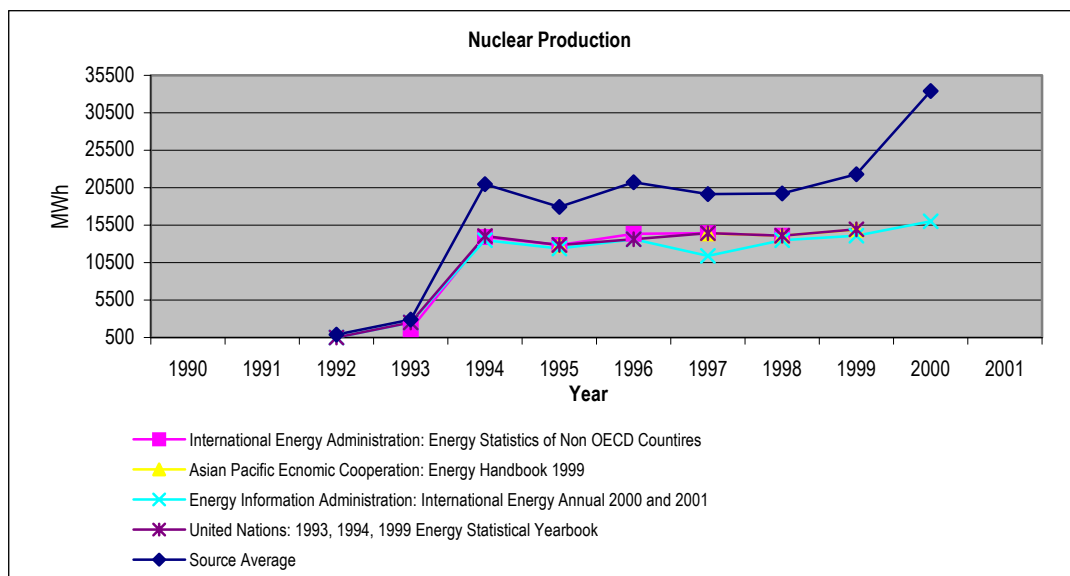


Figure 17

While minor discrepancies between data sources exist, in general, the data curves for nuclear production match. Production figures appear negligible between 1992 and 1993, with all data showing a production jump in 1994. Production decreased the following year, only to rise again in 1996. Figures in 1997 grew marginally, but remained stagnant in 1998. Nuclear power finally grew between 1999 and 2000, but this growth is also barely discernable and linear. The main statistical difference rests in data from the EIA's *International Energy Annual*. While data from the other sources suggest a slight production growth in 1997, the EIA curve shows a drop in nuclear production. Despite this small disparity, the average data curve reflects nuclear production trends. While the average rests above all data curves, containing higher statistical figures, the trend remains consistent with all data sources.

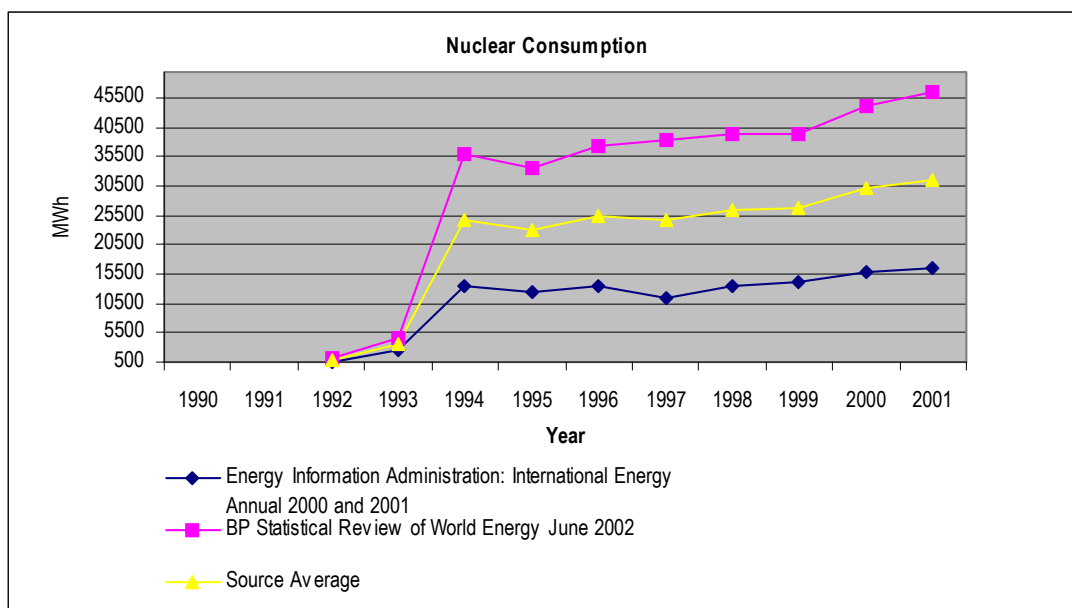


Figure 18

While consumption numbers between the two data sources clearly diverge, the overall trend for nuclear consumption remains consistent between the two data sets. Nuclear energy consumption between 1992 and 1993 remained low, but quickly jumped in 1993. Consumption rates dropped slightly in 1995, but increased between 1996 and 1999, but growth was fairly minimal until 2000, when consumption levels grew distinctly. One obvious difference lies in the consumption drop in 1997 reflected in EIA and BP data. Unlike EIA data, the BP curve suggests a slight rise in consumption. The source average falls between the two data curves and despite the trend difference in 1997, the average curve serves as a passable overall representation of nuclear consumption.

Like natural gas, China's nuclear power history is short. Instead of importing nuclear power, the country imports nuclear technology. This is primarily due to insufficient nuclear power technology and knowledge. The country consumes all domestically produced nuclear energy and no import/export structure is set up for nuclear energy.

### Analysis of Nuclear Data

While nuclear power is only a fledgling power industry in China's energy sector, it remains a significant energy in China's energy development plans. While it is too early to forecast China's ultimate nuclear development, nuclear data suggests growth in the sector. Energy data follow this slow, but steady growth pattern as production figures from 1992 rose yearly. While an upwards curve is present in production trends, this growth is minimal, showing an almost linear growth line. The country is responding to nuclear energy since consumption figures, albeit small, nearly match production numbers. This suggests not only an internal, nuclear energy balance, but also implies a demand for nuclear energy. China strives to maintain this internal nuclear balance through a "self reliance and international cooperation" policy, promoting localized nuclear technology development and maintenance

(Dazhong & Yingyun 2002). One concern lies in nuclear expansion. Although the Chinese government plans to develop production output, the lack of construction funding and technology inconsistencies obstructs nuclear development.

#### 4.5 Other Energy Resources

China primarily relies on nonrenewable energy sources such as coal or oil, but the country is also endowed with renewable energies. In the renewable energy sector, biomass energy is the most often used resource, particularly in rural China (Ping 2001; Chang, Leung, Wu, and Yuan 2003). Biomass consists of stalks, firewood, and other organic waste, with biogas serving as China's main biomass resource (DOE 1996). Biogas is mainly produced in the south central regions, an area dominated by agriculture. The availability of agricultural byproducts along with the warm temperature make the degasification process possible. According to Zhou Jia Ping, in the last decade, biomass accounted for 70% of the energy consumed in rural China, but this heavy reliance may decrease in the future (2001). This predicted drop in biomass consumption partially stems from the urbanization of rural areas (DOE 1996). But a more effective alternative resource has yet to be located for rural China, so biomass will remain prominent in the agricultural sector.

China possesses abundant solar resources, mainly along northwest and southeast regions. The most concentrated solar radiation falls over Xizang-Qinghai grasslands, or eastern Tibet, while China's most densely populated centers such as the Sichuan province measure in the lowest solar radiation levels (DOE 1996). Despite China's rich solar energy, the sun's contribution to energy consumption is minimal. China's photovoltaic research and development began in 1958 and commercialized in the 1980's. But technology costs, time dependency, and low energy densities prevent solar technology from entering the energy mainstream. Continued exploration into solar technology may heighten China's energy use in the far future (Chang, et al. 2003).

For centuries, China harnessed wind power, initially using windmills for pumping water and grinding grain. Modern China employs the wind turbine, generating electricity from the wind's power (Chang et al. 2003). Similar to solar radiation, the areas richest in wind are located away from China's most populated districts. China's wind zones are essentially divided into coastal wind zones, situated along central coastal areas and the northern wind zone found in Inner Mongolia (Ping 2001; DOE 1996). The strongest wind zone is a 200,000 km<sup>2</sup> funnel created by the Altay, Kunlun, and Tianshan ranges along northwestern Xinjiang, but China's main focus for wind power is pointed towards the Nei Mongol grasslands. Because most wind power remains in unpopulated areas, wind development in many of China's strongest zones is not likely. China lacks technology expertise in wind power and must import all wind generators, so development cost serves as a barrier in developing wind energy (Ping 2001).

China is perched along the eastern end of the Eurasian tectonic plate, an area fueled with activity by the Indian and Philippine plate. Such movement creates a large geothermal store along southern Tibet (DOE 1996). China's 2,500<sup>15</sup> hot springs are strong indicators of

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<sup>15</sup> China's hot spring count is not consistent between sources. While Zhou Jia Ping, author of "China's New and Renewable Energy Situation" counts 2,500 springs, the U.S. Department of Energy points to a collection of 2,412 hot springs. But as an overview, the numbers roughly match.



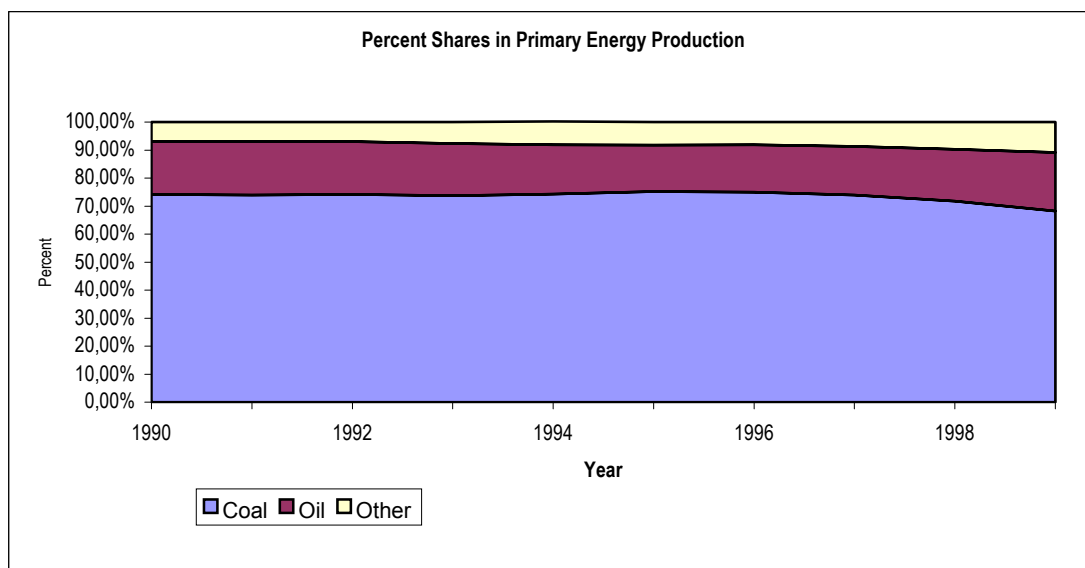
the country's heavy geothermal energy activity (Ping 2001). Geothermal resources are mainly exploited as hot water sources for greenhouses, aqua-culture pools, health care, and the textile industry (DOE 1996). And geothermal uses are spread across areas such as Tinajin, Beijing, Hebei, Jiangsu, and Jianxi (Ping 2001). Despite proven geothermal potential, China has yet to fully utilize this resource.

China's 32,000 km of coastline provides sufficient ocean energy. Tidal energy in the Zhejiang and Fujian provinces provide economical, energy potential. A technology exploration of tidal energy began in the 1950's when tidal power stations were erected in the Fujian and Guangdong province for pumping water into irrigation systems. Currently, seven tidal power stations exist with 6 MW of total installed capacity (Ping 2001; Chang, et al. 2003). China has prepared special conditions for further ocean energy development: ocean energy installations must be placed in areas lacking in conventional energy; designs of ocean energy conversion systems must be diversified to reach different uses and demands; and future ocean energy systems must be small or medium in scale and positioned in coastal areas where the electricity grid does not reach (Change et al. 2003).

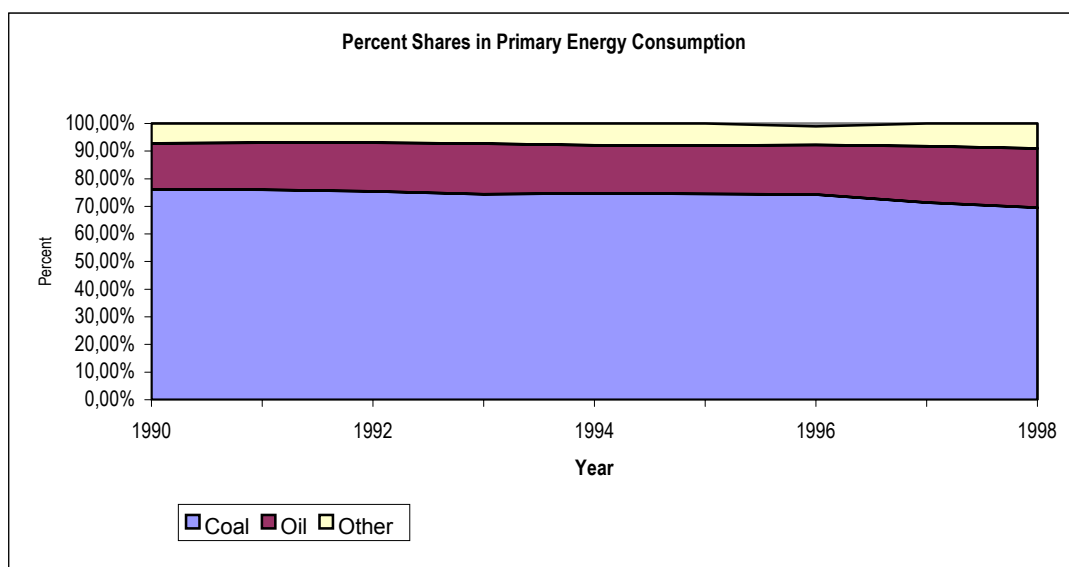
Although China can potentially supply much of its energy demands through renewable energies, between 1990-2000, the country placed little emphasis on expanding its alternative energy base. Instead, such energies remained along the margins of China's energy mix. And as a consequence, few sources document China's renewable energy history through data sets. Very few statistics were located for renewable energy. Available data were single data points, rather than entire time periods. Because this paper investigates a ten-year period in China's energy history, only ten-year data series were relevant for inclusion. Since China's energy interests lie in the coal, oil, natural gas, and nuclear sectors, focus was placed on the more prominent energy sectors.

#### 4.6 Energy Data Overview

In order to fully understand China's energy balance, the impact each energy type makes in the production and consumption mix is as equally important as understanding the trends and patterns in China's energy expenditures. Determining which energy sector played large or small roles in China's energy demand is crucial to understanding China's present and future energy patterns and is also vital to realizing the logistics behind China's energy infrastructure. In creating an energy distribution chart, it is necessary that all data share the same unit. Because most data sources use different units to measure specific energies, the majority of data sources could not be used in compiling a distribution chart. But the China Energy Data Book (LBNL) contains both relevant data and distribution statistics. Since other data sources lacked distribution data and because LBNL data curves consistently followed average curve patterns in all energy sectors, the LBNL distribution figures suitably offer an overview of China's energy make-up.



China Energy Data Book: Lawrence Berkeley National Laboratories, 2001



China Energy Data Book: Lawrence Berkeley National Laboratories, 2001

From 1990-2000, coal dominated China's energy mix. The energy distribution charts reveal coal's major role in production and consumption sectors. In the last decade, oil fell behind coal as the second primary energy source. Natural gas and nuclear energies contributed so minimally to the energy balance that the two resources, along with other energies such as hydro and biomass, can be slated into one section. Of the energy produced and consumed, natural gas only contributed 1 to 3% (LBNL 2001). Within the energy balance, nuclear energy made-up an even smaller percentage. In electricity production and consumption, nuclear energy measured between 0.7% and 1% (LBNL 2001). This energy balance in which coal and oil served as the primary energy resources changed little in the last decade. While coal levels dropped, partially resulting from improved coal usage and government attempts at reducing coal reliance, increases in oil and other energy expenditures were not dramatic.

Even with a decline in coal production and consumption, the distribution between coal, oil, and other energy sources remains virtually unchanged. In 1990, coal was the most consumed energy resource with oil falling second and other energy alternatives ranking last. With the exception of a slight decrease in coal consumption and small increases oil and alternative energies consumption, this make-up remained the same at the end of the decade. China's production distribution at the end of the decade also closely resembled the country's production levels in the beginning of the 90's, in which coal served as the dominant energy. This trend in the energy balance foretells China's future energy balance into the next several decades. Unless the Chinese government institutes radical energy policies for other energy sources, coal will remain the largest energy source, with oil falling behind as a close second. Resources such as natural gas, nuclear, and biomass will undoubtedly expand in the future energy mix. Yet, due to coal's overwhelming presence, such energy sources will maintain a marginalized status. Because energy production and consumption is concentrated in the coal sector, to relieve China from a heavier reliance on foreign oil, the country must factor in coal when building an automobile infrastructure from China's growing transportation sector.

## **5. Conclusion**

China's impending motorization is unavoidable. As domestic and international companies vie for shares in the country's sizeable car market and as the Chinese population reveals increasing desire for accessible, private mobility, additional pressure will be placed on China's energy supply. Such a strain extends beyond the energy sector. An oil imbalance would also threaten the country's political security. So, preserving China's energy security seems most feasible through a technology leapfrog into hydrogen fuel. By investigating past energy expenditures, one can more effectively examine the country's future energy balance in connection with China's growing automobile society. The overview of China's past energy consumption and production not only outlines energy spending habits, but also forecasts Chinese energy potential. More importantly, the overview points to country-wide consumption patterns and reveals the resources available for leapfrogging.

The period between 1990 and 2000 leaves China in a multi-dimensional energy balance. The consumption patterns in the last ten years suggest the country can always satisfy the country-wide coal demand. In the last decade, coal was the primary energy source and this energy mix is not likely to change in the future. Oil consumption was also high, falling second to coal in energy production and consumption. Natural gas and nuclear energies also figured in the energy balance, but their contribution in the energy mix was minimal. Although China's coal reserves can sustain the country's consumption habits, the country seeks to reduce its coal dependency. Such intentions are reflected in production and consumption figures in the mid 90's. Between 1997 and 2000, production and consumption levels for coal diminished. Yet, coal consumption rates, even between 1997-2000, exceeded consumption figures of other energy resources. So, China can reduce coal use, but coal will inevitably remain the major energy source in China's energy balance. The International Energy Agency forecasts coal consumption rates to grow between 1995 and 2020, though the growth level will remain minimal (IEA 1999). Due to planned deceleration in coal consumption, China must emphasize alternative energies. With interest in marginal energies such as natural gas or nuclear energy mounting, consumption rates for natural gas and nuclear ener-

gies may increase. The energy trends from 1990-2000 reflect such possibilities since natural gas and nuclear consumption and production figures grew over the last decade. Forecasts for natural gas and nuclear consumption also predict further development and consumption of both energy sectors. Because hydrogen can be produced from both energies, increased progress in natural gas and nuclear production would complement a technology transfer into hydrogen power automobiles. China's energy balance appears suitably prepared for a hydrogen-based automobile society with the country's oil supplies further supporting the situation. In the last decade, internal coal, natural gas, and nuclear production fulfilled domestic energy demands, but China was less self-contained in the oil sector. Since 2000 almost one-third of the country's oil demand is supplied through foreign means. Because reliance on oil is growing, China's oil balance may swerve further from equilibrium. Such a scenario obstructs China's emergence into a traditional automobile society. If China reaches full-scale motorization, the country risks relying more heavily on outside oil sources to satisfy an internal oil consumption. Not only would complete motorization pressure domestic oil supplies, but escalating oil consumption would also diminish already shrinking global oil supplies.

Between 1999-2000 China's carbon dioxide emissions were aggravated by coal consumption, but oil consumption places an additional burden on China's pollution situation. James Cannon points out that air pollution in China's urban centers is deeply affected by automotive emissions<sup>16</sup> (1998). Many elements transform automotive growth into an environmental concern. With more of China's population owning cars, more of China's population is driving, leading to increased CO<sub>2</sub> levels. China also lacks national vehicle emissions standards, so tailpipe emissions of Chinese cars are higher than its Western counterparts. Chinese bus and truck engines lack fuel efficiency, another factor aggravating the carbon dioxide problem. Since China's motorization exploded only in the beginning of the last decade, the country possesses few well-paved or well-maintained roads, increasing automobile fuel expenditures, thereby negatively distressing the environment. Automobile related emissions will not subside in the future as China's private car fleet augments in the future. Only by considering fuel economy technology or by reverting to alternative, environmentally friendly fuels, can the country decrease a dangerously rising CO<sub>2</sub> level. So, widespread oil consumption, in conjunction with pollution consequences destabilizes China's energy balance, endangering China's energy security and exponentially heightening the global carbon dioxide problem.

Having relied on coal and oil for many decades, China cannot immediately restructure its consumption patterns. By integrating alternative energies into the energy mix, China can support a technology leapfrog. This means opening wider access to marginalized, hydrogen-friendly resources and redistributing China's energy balance to include more alternative energies. Energy expenditures from the last decade already reflect slow, but well-intentioned efforts to exploit alternative resources. China's past energy activities reflect sufficient infrastructure for undertaking a technology leapfrog with the country's emerging oil concern paving the road toward radical, automotive technology. Adopting leapfrog technology to the

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<sup>16</sup> This is a common point noticed by authors discussing carbon dioxide emissions and transportation. Zhong Xian Zhang, author of *The Economics of Energy Policy in China*, Xiannuan Lin of China's Energy Strategy, and Lin and Polenske who wrote "Energy Use and Air Pollution Impacts of China's Transportation Growth" all point to China's transportation growth in relation to the CO<sub>2</sub> problem.

country's infant automobile infrastructure can mitigate the country's current reliance on non-renewable energy. But coal will continue to play large a role in China's energy expenditures, so the country must take into account coal's dominance when considering hydrogen technology. China must find a way to exploit coal and renewable energies when erecting a hydrogen-based automobile society. Since hydrogen can be produced from renewable and nonrenewable energies, all of China's resources, especially its vast collection of renewable energies and coal surplus, serve as an appropriate backdrop against which to adopt hydrogen technology. So, China's developing natural gas and nuclear energy sectors ensure potential leapfrogging possibilities. While China uses minimal amounts of renewable energy, suggested by the lack of appropriate energy data, the country is nonetheless endowed with valuable resources. And enough infrastructure exists in biomass, solar, geothermal, hydro, and wind sectors to extend technology and resource development.

Past energy expenditures offer one perspective into leapfrog technology, but other outlooks are needed to fully determine whether China's energy balance can support hydrogen technology. China's energy history can only outline the country's energy infrastructure and past energy patterns. While both elements factor into determining China's leapfrogging viability, forecasted energy activities and decisions also influence the direction the country takes toward motorization. China's present energy situation and recently established energy infrastructure are also dimensions crucial to determining China's leapfrogging potential. In order to effectively understand China's energy balance and to effectively assess the country's viability for erecting a hydrogen-based automobile society, we must next examine China's recent energy trends as well as investigate data sets forecasting China's future energy demands.

## 6. Measurement Units

bbl	Barrel
Gf <sup>3</sup>	One Billion Cubic Feet
Gm <sup>3</sup>	One Billion Cubic Meters
GWh	One Billion Watt Hours
Mt	Million Metric Tonnes
Mtoe	Million Tonnes of Oil Equivalent
PJ	Petajoule; One Quadrillion Joules
TJ	Terajoule; One Trillion Joules

## 7. Appendix

### Coal Consumption

Source	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Asian Pacific Energy Cooperation Database	Mtoe	325.182	345.92	368.891	360.038	364.664	398.754	393.076	356.389	288.446	272.239		
BP Statistical Review of World Energy June 2002	Mtoe		534.9	549.5	570.3	606.4	635.7	676.9	649.3	616.8	512.7	493.7	520.6
Source Average	Mtoe	325.182	440.41	459.196	465.169	485.532	517.227	534.988	502.845	452.623	392.47	493.7	520.6
Asian Development Bank: Key Indicators of Developing Asian and Pacific Countries 2002	Mt	1055	1104	1141	1209	1285	1377	1447	1392	1295	1264		
Energy Information Administration: International Energy Annual 2000 and 2001	Mt		1056.76	1088.15	1157.2	1260.84	1358.52	1375.89	1315.81	1262.81	1216.23	1163.24	1254.3
United Nations: 1994, 1998, and 1999 Energy Statistics Yearbook	Mt		1130.27	1169.81	1217.58	1325.31	1452.58	1505.49	1455.26	1345.44	1145.47		
Lawrence Berkeley National Library: China Energy Databook Version 5.0	Mt	1055.23	1104.32	1140.85	1204.02	1285.32	1376.76	1447.34	1392.43	1294.92			
Source Average	Mt	1055.12	1098.84	1150.55	1196.95	1289.12	1391.22	1443.93	1388.87	1299.54	1208.56	1163.24	1254.3

# Coal Production

Source	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Asian Pacific Energy Cooperation Database	Mtoe	512.995	516.528	530.291	546.58	588.965	646.36	663.446	619.497	593.762	496.385	474.059	
BP Statistical Review of World Energy June 2002	Mtoe		545.1	559.9	580.7	619.4	650.9	691.5	665.5	619.7	523.9	501.8	548.5
Source Average	Mtoe	512.995	530.814	545.0955	546.58	604.1825	648.63	677.473	642.4985	606.731	510.1425	487.9295	548.5
International Energy Agency: Energy Statistics of Non OECD Countries	Mt	1079.883	1087.406	1116.38	1150.741	1239.902	1360.731	1396.699	1372.82	1213.312			
United Nations: 1994, 1998, and 1999 Energy Statistics Yearbook	Mt		1130.269	1169.808	1217.582	1325.312	1452.582	1505.491	1455.259	1345.441	1145.467		
Asian Development Bank: Key Indicators of Developing Asian and Pacific Countries 2002	Mt	1080	1087	1116	1150	1240	1361	1397	1373	1250	1045	1000	1110
Energy Information Administration: International Energy Annual 2000 and 2001	Mt		1087.406	1114.55	1182.54	1273.234	1394.316	1401.827	1367.245	1296.358	1238.253	1192.43	1323.601
Lawrence Berkeley National Library: China Energy Databook Version 5.0	Mt	1079.88	1087.41	1116.38	1150.67	1239.9	1360.73	1396.7	1372.82	1250	1045		
Source Average	Mt	1079.942	1095.898	1126.624	1170.307	1269.612	1385.872	1419.543	1388.229	1271.022	1118.43	1096.215	1216.801



# Coal Imports

Source	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Asian Development Bank Key Indicators of Developing Asian and Pacific Countries 2002											
	Mt	2	1	1	1	1	2	3	2	2	2
United Nations: 1994, 1998, and 1999 Energy Statistics Yearbook											
	Mt		1.368	1.23	1.43	1.209	1.635	3.2	2	1.586	1.673
China Energy Databook Version 5.0											
	Mt	1.98	1.37	1.23	1.43	1.21	1.64	3.22	2	1.58	1.67
Source Average	Mt	1.99	1.246	1.153333	1.286667	1.139667	1.758333	3.14	2	1.722	1.781
Asian Pacific Cooperation Energy Database											
	Mtoe	0.833	0.65	1.402	0.678	0.574	0.777	1.528	0.956	0.766	0.829

# Oil Consumption

Source	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Asian Pacific Energy Cooperation Database	Mtoe	79.798	94.565	92.454	100.436	105.982	117.463	132.711	146.585	154.097	174.683		
International Energy Agency Statistics: Energy Statistics of Non-OECD Countries	Mt	84.459	91.282	97.811	105.219	109.799	122.62	137.994	155.558	158.075			
United Nations: 1994, 1998, and 2000 Energy Statistics Yearbook	Mt		123.649	131.565	138.307	139.942	147.326	159.208	174.995	173.169	189.473		
Asian Development Bank: Key Indicators of Developing Asian and Pacific Countries 2002	Mt	118	124	132	138	149	160	174	197	198	210		
Energy Information Administration: International Energy Annual 2000 and 2001	Kbbl/day		2499	2662	2959	3161	3363	3610	3916	4106	4364	4796	4975
BP Statistical Review of World Energy June 2002	Mt		124.415	132.53	147.317	157.374	167.43	179.727	194.962	204.421	217.266	238.774	247.685
Lawrence Berkeley National Library: China Energy Databook Version 5.0	Kbbl/day		2411	2662	2913	3145	3390	3672	3935	4047	4416	4985	5041
Source Average	Mt	105.773	117.5143	126.0743	136.0938	142.5292	153.121	166.6148	184.4925	187.2125	205.9848	234.437	239.7925

1 barrel to 0,1364 Metric Tonnes

# Oil Production

Source	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Asian Pacific Energy Cooperation Database	Mtoe	131.393	133.945	134.995	142.623	143.848	142.265	149.47	152.707	152.953	152.003		
International Energy Agency Statistics: Energy Statistics of NON OECD Countries	Mt	133.306	140.992	141.747	145.174	146.082	150.044	157.334	160.741	161			
Energy Information Administration: International Energy Annual 2000 and 2001	Kbbl/day		2835	2845	2890	2939	2990	3131	3200	3198	3195	3249	3300
	Mt		141.143	141.641	143.882	146.321	148.86	155.88	159.315	159.217	159.066	161.755	164.294
United Nations: 1994, 1998, and 1999 Energy Statistics Yearbook	Mt		140.992	142.097	145.237	146.082	150.044	157.334	160.741	161	160		
Asian Development Bank: Key Indicators of Developing Asian and Pacific Countries 2002	Mt	138	141	142	145	146	150	157	161	161	160	163	165
BP Statistical Review of World Energy (June 2002)	Mt		141	142	144	146.1	149	158.5	160.1	160.2	162.6	164.9	
Lawrence Berkeley National Laboratory: China Energy Databook Version 5.0	Mt	138.31	140.99	142.1	145.17	146.08	150.04	157.33	160.74	161	160		
Source Average	Mt	136.5387	141.0195	142.4425	144.7438	146.1108	149.6647	157.2297	160.4395	160.5695	160.3332	163.2183	164.647

1 barrel to 0,1364 Metric Tonnes

# Oil Imports

Source	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Asian Pacific Cooperation Energy Database	Mtoe	7.179	10.208	17.849	32.391	25.164	32.815	40.646	52.558	52.745	59.33	
Asian Development Bank: Key Indicators of Developing Asian and Pacific Countries 2002	Mt	3	12	11	15	29	37	45	68	27	65	88
United Nations: 1992, 1994, and 1998 Energy Statistics Yearbook	Mt		5.973	11.36	13	12.346	17.09	22.617	35.47	27.32	36.614	
Lawrence Berkeley National Laboratory: China Energy Databook Version 5.0	Mt	2.92	5.97	11.36	15.67	12.35	17.09	22.62	35.47	27.32	36.61	
Source Average	Mt	3	7.981	11.24	14.55667	17.89867	23.72667	30.079	46.31333	27.21333	46.07467	88

# Natural Gas Consumption

Source	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Asian Pacific Energy Cooperation Database	PJ	452	375	351	363	368	375	468	361	435	620	493	
United Nations: 1994, 1998, and 1999 Energy Statistics Yearbook	PJ		625.621	614.72	660.733	684.435	776.35	802.848	997.494	1120.237	1212.584		
International Energy Agency Statistics: Energy Statistics of Non OECD Countries	PJ	404.103	434.761	447.356	447.782	455.84	469.003	489.71	486.114	512.453			
Source Average	PJ	428.0515	478.4607	471.0253	490.505	428.0515	540.1177	586.8527	614.8693	689.23	916.292	493	
Energy Information Administration: International Energy Annual 2001 and 2002	Gm³		14.89	15.09	15.8	16.68	17.02	18.77	21.21	22.2	24.18	27.1	30.3
	Gf³		526	533	558	589	601	663	749	784	854	967	1070
Asian Development Bank: Key Indicators of Developing Asian and Pacific Countries 2002	Gm³	15	16	16	22	23	24	22	20	20			
	Gf³	530	565	565	777	812	848	777	706	706			
BP Statistical Review of World Energy June 2002	Gm³		14.9	15.1	16.2	16.6	17.7	17.7	19.3	19.3	21.4	24.5	27.7
	Gf³		526.189	533.251	572.098	586.223	625.07	625.07	681.573	681.573	755.734	865.209	978.216
Lawrence Berkeley National Library: China Energy Databook Version 5.0	Gm³	15.3	16.07	15.79	16.77	17.56	17.95	20.11	22.67	23.33			
	Gf³	540.314	567.507	557.617	592.227	620.126	633.898	710.178	800.583	823.891			
Source Average	Gf³	15.15	15.465	15.495	17.6925	18.46	19.1675	19.645	20.795	21.1575	22.79	25.8	29

# Natural Gas Production

Source	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Asian Pacific Cooperation Energy Database	PJ	537	564	554	588	616	630	706	797	817	884		
International Energy Agency Statistics: Energy Statistics of Non OECD Countries	PJ	595.644	625.621	634.012	726.278	760.63	777.436	871.307	938.449	1008.4			
United Nations: 1994, 1998, and 1999 Energy Statistics Yearbook	PJ		625.621	614.72	660.733	684.435	699.137	967.93	997.494	1120.237	1212.584		
Source Average	PJ	566.322	605.0807	594.006	657.,139	688.315	703.718	788.6535	867.7245	912.7	1048.292		
Asian Development Bank: Key Indicators of Developing Asian and Pacific Countries 2002	Gm³	15	16	16	17	18	18	20	23	23	25	27	30
	Gf³	529.72	565.035	565.035	600.35	635.664	636.664	706.293	812.237	812.237	882.867	953.496	1059
Energy Information Administration: International Energy Annual 2000 and 2001	Gm³		15.01	15.01	15.86	16.71	17	18.97	21.24	22.09	24.07	27.18	
	Gf³		530	530	560	590	600	670	750	780	850	960	
BP Statistical Review of World Energy June 2002	Gm³		14.9	15.1	16.2	16.6	17.6	19.9	22.2	22.3	24.3	27.2	30.3
	Gf³		526.189	533.251	572.098	586.223	621.538	702.761	783.986	787.517	858.146	960.559	1070.034
	Gm³	15.3	16.07	15.79	16.77	17.56	17.95	20.11	22.7	23.28	25.2		
Lawrence Berkeley National Library: China Energy Databook Version 5.0	Gf³	540.314	567.507	557.619	592.227	620.126	633.898	710.178	800.583	823.891	889.93		
	TJ	600000	630000	620000	650000	680000	700000	780000	890000	910000	980000		
Source Average	Gf³	15.15	15.475	15.475	16.4575	17.2175	17.6375	19.745	22.285	22.6675	24.6425	27.12667	30.15

Billion Cubic Meters: 1 Cubic Feet is 0.0283168 Cubic Meters

Billion Cubic Feet: 1 Cubic Meter is 35,3146667 Cubic Feet

### Nuclear Consumption

Source	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Energy Information Administration: International Energy Annual 2000 and 2001	GWh			500	2500	13500	12400	13600	11400	13500	14100	16000	16700
BP Statistical Review of World Energy June 2002	Mtoe			0.1	0.4	3.1	2.9	3.2	3.3	3.4	3.4	3.8	4
	GWh			1163	4652	36053	33727	37216	38379	39542	39542	44194	46520
Source Average	GWh			831.5	3576	24776.5	23063.5	25408	24889.5	26521	26821	30097	31610

1 Tonne of Oil Equivalent: 11.36MWh

### Nuclear Production

Source	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Asian Pacific Energy Cooperation Database	PJ			6	18	153	140	156	157	154	163	183
	GWh			1666.667	5000	42500	38888.89	43333.33	43561.11	42777.78	45277.78	50833.33
International Energy Administration: Energy Statistics of Non OECD Countries	GWh				1604	13906	12833	14339	14418	14100		
Asian Pacific Economic Cooperation: Energy Handbook 1999	GWh						12800		14400	14100	14900	
Energy Information Administration: International Energy Annual 2000 and 2001	GWh			500	2500	13500	12400	13600	11400	13500	14100	16000
United Nations: 1993, 1994, 1999 Energy Statistical Yearbook	GWh			500	2500	14043	12833	13620	14420	14100	14950	
Source Average	GWh			888.889	2901	20987.25	17950.98	21223.08	19639.82	19715.56	22306.94	33416.67

1 Petajoule: 277777.778 MWh

Percent Shares of Primary Energy Production

Energy	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Coal	74.12%	73.96	74.17	73.77	74.33	75.20	74.95	73.97	71.79	68.22
Oil	19.00	19.19	18.89	18.63	17.53	16.60	16.90	17.33	18.51	20.91
Other	6.88	6.85	6.93	7.60	8.41	8.21	8.15	8.69	9.71	10.87

Percent Shares of Primary Energy Consumption

Energy	1990	1991	1992	1993	1994	1995	1996	1997	1998
Coal	76.16%	76.00	75.42	74.44	74.70	74.54	74.28	71.34	69.50
Oil	16.60	17.07	17.68	18.23	17.41	17.42	17.92	20.40	21.42
Other	7.23	6.93	6.90	7.33	7.89	8.04	6.79	8.26	9.07



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