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The Future of the Chemical Industry

EDITED BY
Roger F. Jones

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Roger F. Jones, Editor
Franklin International LLC

Sponsored by the
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Foreword

The ACS Symposium Series was first published in 1974 to provide a mechanism for publishing symposia quickly in book form. The purpose of the series is to publish timely, comprehensive books developed from the ACS sponsored symposia based on current scientific research. Occasionally, books are developed from symposia sponsored by other organizations when the topic is of keen interest to the chemistry audience.

Before agreeing to publish a book, the proposed table of contents is reviewed for appropriate and comprehensive coverage and for interest to the audience. Some papers may be excluded to better focus the book; others may be added to provide comprehensiveness. When appropriate, overview or introductory chapters are added. Drafts of chapters are peer-reviewed prior to final acceptance or rejection, and manuscripts are prepared in camera-ready format.

As a rule, only original research papers and original review papers are included in the volumes. Verbatim reproductions of previous published papers are not accepted.

ACS Books Department

Preface

This book continues, updates, and expands the discussions and papers presented at the symposium, "The Future of the Chemical Industry," held at the 236th National Meeting of the American Chemical Society in Philadelphia, Pennsylvania, August 18, 2008. This symposium was cosponsored by the Business Development and Management Division and the Committee for Economic and Professional Affairs. The symposium's theme was the future of an increasingly globalized chemical industry under highly volatile cost pressures, geographically divergent environmental measures, and broadening competition. While some of this information enlarges upon themes in our earlier book, "The Chemical Industry and Globalization," published by ACS in 2006, there is a great deal of new material, plus an brief assessment on the impact of the global recession that began to hit harder in the second half of 2008..

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The speed of change in our industry seems only to continue accelerating. The most noticeable event was the unprecedented rapid escalation of the cost of oil during 2007-2008, plus growing US and EU government demands (but essentially nowhere else) to reduce carbon dioxide emissions. The abrupt run-up in oil prices was widely attributed to surging demand throughout the industrialized world, particularly in China and India. Also intensifying the rise in oil prices was an increased "security premium," reflecting a number of supply interruptions experienced in the past several years, including the delivery suspensions of Russian natural gas during the winters of 2007 and 2008, and oil pipeline sabotage in Nigeria. In the US, and to a lesser extent, Europe, leading chemical industry companies have been reacting to these challenges by moving petrochemical production operations to offshore sites that are integrated back to the wellhead, most notably in the Persian Gulf. The 2008 elections have resulted in a new direction of the US government, with immense implications for the future of the chemical industry.

An analysis of chemical industry employment vs. university graduations is presented that indicates job opportunities for new graduates with degrees in chemistry has been in steady decline for over two decades. New graduates with degrees in chemical engineering, however, appear to have been in steady demand over this same period.

Pharmaceutical companies are seeking new ways to reduce the cost of bringing new drugs to market in the face of lengthening approval processes, which is effectively halving the time a new product has patent protection. They are also continuing to seek the most cost- and time-effective venues in which to do research.

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The EU chemical industry looks to China as the principal future market for its products, seeing that its dramatic growth will require imports to supplement domestic production for many years to come. Western European countries are finding that their domestic demand for chemicals has steadily slowed, influenced by the lack of population growth; this puts emphasis on export and outsourcing to sustain the existing European-based chemical industry.

China is constantly changing and the speed of this change is a challenge to western companies who participate in the enormous marketplace. An important part of this change is a rapid upgrading of the abilities of domestic industries to make increasingly sophisticated products. Despite the recession, China's domestic market continues to grow – just less rapidly than before. In the meantime, demand for China's exports has dropped sharply and is causing substantial turmoil in manufacturing, with the less advanced manufacturers suffering the most.

Finally, alternative sources of energy continue to be the subject of intense development efforts to overcome their inability to compete with conventional sources on an unsubsidized basis. Fuel cells have been held out as having significant potential for replacing motor fuel, the largest single end use for petroleum, although commercialization is at least five years away, even with subsidies. Other, more modest scale, fuel cell power applications may have more immediate promise.

Without question, portions of this book will be dated by the time of publication. The authors have tried their hands at predicting trends that may – or may not – seem prescient to the reader. It is typical of the popular news media to deal in sensationalism and we have tried hard to avoid such extreme views. The reader is encouraged to check the references provided at the end of each chapter, as this basic information constitutes the authors' sources of data and analyses for their views of how the industry is changing.

It was apparent that a large percentage of the attendees at the symposium were recent university graduates and postgraduate students, looking for information on which to base their career decisions. We hope that they find our views and assessments useful.

The editor and authors are deeply grateful to the symposium sponsors for providing a forum to explore this important subject and to the American Chemical Society Publications Division for publishing our work. We also owe special thanks to the manuscript reviewers, Patrick Barron, Ernest C. Coleman, William Dunkelburg, Kenneth R. Dargis, Rex Luzader, and Susan Wollowitz who helped us to make this book a more accurate, useful, and readable work.

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About the Editor

Roger F. Jones is president of Franklin International LLC, a management consulting firm offering services to the chemicals and plastics industries. He is also the non-executive board chairman of PlastiComp LLC, an advanced composites technology and products firm, based in Winona, Minnesota. In his 50-year industrial career, he has also been president of Franklin Polymers, Inolex Chemical, LNP Engineering Plastics, managing director of BASF Engineering Plastics, and a group executive with Beatrice Chemical. He has held managerial/professional positions in R&D, manufacturing, and marketing with DuPont, Avisun, and ARCO Chemical (both of the latter have become parts of BP Chemical).

He is a graduate of Haverford College, holding a BS with Honors in Chemistry. He is a Fellow of both the Society of Plastics Engineers and the American Institute of Chemists. He is a 50-Year Member of the American Chemical Society.

His publications include over 100 papers/patents, and two SPE-endorsed books: *Guide to Short Fiber Reinforced Plastics* (Hanser 1998) and *Strategic Management for the Plastics Industry* (CRC Press 2002). The American Chemical Society previously published his book *The Chemical Industry and Globalization* (ACS 2006), now in its second printing.

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Chapter 1

The Future of the US Chemical Industry

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Introduction

During 2007-2008, the US chemical industry was roiled by rapidly escalating raw material costs. While this at first appeared to be simply part of the familiar sine-wave pattern experienced in the past several decades, the leading US chemical companies have been signaling that they believe a new paradigm has come into being, with a permanent loss of US competitive advantage taking place, particularly in petrochemicals and downstream products manufacturing. The underlying reason was not simply the rapid rise of oil prices but more compellingly, the enormous increase in price volatility experienced in 2007-2008. The 75% drop in oil prices in the last half of 2008 almost amounted to free-fall and left many companies with expensive inventories but with little demand for them in the face of the mounting recession. Chemical company executives have reacted to these developments by closing a number of US plants, forming joint ventures with offshore partners in the Middle East, divesting businesses that are sensitive to petrochemical feedstock costs, and attempting to acquire businesses that are less cost sensitive.

The rapid decline of the "Big Three" (GM-Ford-Chrysler) US-label automobile manufacturers' sales and a deep, extended slump in the housing industry has meant a major contraction in the two largest markets for US chemical producers, with no clear resolution in sight, despite (or, more likely, because of) inconsistent and vacillating government intervention. This deterioration of US housing and automotive markets in early-to-mid 2008 proved to be early warning signals of a global economic downturn, which became widespread and obvious in the third quarter of 2008.

At this point, the US government publicly acknowledged the deepening recession when the subprime mortgage market collapsed and threatened to cause the bankruptcy of many major banks and other lending financial institutions, as well as drying up credit for virtually all borrowers. In the fourth quarter of 2008, the US government injected nearly $400 billion by into financial

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institutions via a partial nationalization and made loans to GM and Chrysler. Despite these moves, the recession grew deeper and broader, with similar economic turmoil overseas. Consumer confidence declined, and 2008 holiday sales (the period between Thanksgiving and Christmas), which normally account for nearly 40% of the year's revenues, were the lowest in decades. Companies began layoffs and initial unemployment estimates indicated a level of nearly 8% by late January; final figures are likely to be higher. While this level is not significantly higher than that experienced in such previous post-WW II recessions as in 1980-1982, it has been reached more quickly and may well grow higher.

At the time of writing, the new administration and Congress have hurried through an unprecedented and far-reaching eight hundred billion dollar "economic stimulus" package. Exactly what are the full details of this enormous and complex package have yet to be fully disclosed and analyzed, months following its passage into law. From the time the stimulus bill was introduced, separate versions passed by the House and Senate, reconciled, passed again, and signed into law, a period of only ten days elapsed, and that without any meaningful public disclosure or debate ever taking place.

Many of the details that have become visible so far reveal that the package contains a massive amount of "pork" – spending targeted to benefit favored groups but without significant economic benefits to the general public. US stock market indices showed investors' worries over the massive deficits that such legislation will produce by hitting successive lows that are around half of the 2008 high. It was revealing to learn that substantially less than 15% of the "stimulus" will be spent in the first year, suggesting that the extraordinary urgency associated with the passage of this bill had much more to do with minimizing debate and keeping the details from being aired publicly than with promoting immediate economic recovery.

Some of the money was specifically targeted at General Motors (GM) and Chrysler to keep them from sliding into bankruptcy, although many in the industry believe that a "prepackaged bankruptcy" without government involvement would have been a far more efficient, timely, and less intrusive way to resolve these companies' financial problems. Since then, GM and Chrysler have missed several government-set deadlines to put their houses in order, and President Obama has taken the extraordinary step of dismissing GM's CEO, Rick Waggoner, as well as virtually demanding that Chrysler merge with Italy's Fiat or liquidate.

Why should these matters be of more than general interest to chemists and the chemical industry? Because they demonstrate that the new president and Congress have an agenda that is not particularly concerned with the state of US manufacturing other than the specific situations of General Motors and Chrysler. This agenda does include bolstering US R&D spending but only at US government laboratories, primarily those involved in specific environmental issues. Judging from the ineffectiveness of the several anti-recession measures taken since September 2008, it strains credulity that this unfocused increase in federal spending will have any measurable, beneficial effect on the overall economy, and that the current economic downturn is likely to be longer and possibly more severe than any since the 1930s. These emergency spending bills

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are not coupled with any spending reduction or even tax increases. At some point in the future, the government will be obliged to either raise taxes or borrow the money – or it may simply print money, which will result in monetary inflation greater even than that seen during the Carter administration. Still to come are carbon dioxide emission tax proposals that will hugely increase energy costs (and provide a stunning amount of new tax revenue to support the new government spending). In the months and years to come, the industrial sector of the US economy will be undergoing greater stress and change than any seen since World War II. This chapter will attempt to identify which factors will affect the US chemical industry the most and how its components may react.

The Chemical Industry and Financing

One of the problems besetting the chemical industry in this recession is the strain on its finances. Mergers and acquisitions in the last five or more years have largely been financed with debt and companies that have used this have balance sheets with far more leverage than is comfortable or prudent during a recession. Chemtura, one such company, has had to declare bankruptcy and it will likely have to break up into more manageable, smaller pieces – effectively "demerging" – in order to continue in business; Tronox, divested by Kerr-McGee and saddled with debt, has also filed for protection under bankruptcy laws. *(1)* LyondellBasell is another example of an overleveraged product of a merger; its US subsidiary is in bankruptcy and its European operation missed an interest payment on its debt early in 2009, raising questions about the future of the company overall. In the meantime, LyondellBasell also announced that it is closing a number of US plants, due to lack of demand. *(2)* As described later in this chapter, many of these closings are likely to be permanent because of looming Persian Gulf competition.

Several companies were in the midst of acquisitions when the recession and the accompanying credit contraction hit, notably, Dow Chemical and Rohm and Haas. Dow intended to finance the R&H acquisition with cash it would receive from a joint venture it planned in Kuwait, but the Kuwaitis refused to complete the deal at the last moment. Dow then tried to renegotiate or back out of the acquisition, but R&H sued; eventually, the suit was settled by a modest reduction in price accompanied by an equity injection by major R&H shareholders, so that the transaction could be completed. *(3)*

Huntsman was another company caught in the midst of an acquisition when the "double whammy" of credit contraction and recession made the transaction unattractive to its suitor, Hexion Specialty Chemicals. Huntsman sued – and won – but Hexion eventually settled by paying Huntsman $1 billion for canceling the transaction, which it claimed would otherwise result in both companies becoming unviable. *(4)*

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Oil, Natural Gas, and Energy

The US chemical industry is heavily dependent on oil and natural gas, which represent an estimated 90% of its feedstocks. *(5)* In addition, it is an energy intensive industry, but its efficiency has been improving steadily – 46% since 1974. *(6)* Nevertheless the industry is dependent on access to competitive power costs, costs that are strongly affected by federal and state energy and environmental policies. These policies have had the effect of barring the construction of any new nuclear power plants or major hydroelectric projects over the past thirty years, and while US power generation plants built in earlier years have been designed to use coal, those built in the past two decades have been designed to use natural gas, as strongly "encouraged" by federal government environmental policies as well as those of some states, e.g., California. As a result, the US and its chemical industry have become increasingly dependent on imported oil and natural gas for both petrochemical feedstocks and energy production. The industry has also had to deal with increasingly volatile oil price movements.

Shale oil deposits in the northern Rocky Mountain states constitute a huge, new potential source of hydrocarbons but exploration and development of this area is explicitly banned by federal legislation. The presence of very large quantities of both natural gas and crude oil beneath these shale oil deposits has also been detected. Known as the Bakken Formation, these reserves are estimated by the Energy Information Administration as holding 503 billion barrels of oil, greater than the existing oil fields of Saudi Arabia. *(7)*

US coal reserves are estimated to be large enough to last over 300 years at the present rate of consumption, which has been declining. *(8)* However, the stated policy of the new administration has been to work with Congress to forbid the construction of any new coal power plants, even those based on "clean coal" technology, citing environmental concerns.

Overall, federal government policies and laws have banned the development of virtually any significant new domestic oil and gas fields for more than the past twenty years, as well as severely restricting the construction of new pipelines or additional liquefied natural gas (LNG) terminals. The predictable result has been that the US has grown heavily dependent on offshore suppliers for its oil and gas, as demand outgrows current domestic production from existing fields. Improved production technologies have kept US oil and gas production from actually declining but at some point, this will no longer be effective. In 1970, the US imported 30% of its oil requirements; in 2008, this number peaked at 70% before the recession-induced drop in demand brought this back down to 60%. *(9)*

According to the US Department of Energy, the US is the world's third largest producer of crude oil, as well as the most energy-efficient country in the world. Nevertheless, the US imported nearly 50% of its oil and gas needs from Western Hemisphere countries in 2007, but only 24% in 2008. This dramatic change is due to a substantial and continuing decrease in Mexican oil and gas production. Mexican extraction and exploration technology dates from the 1930s but state-owned Pemex has been unable to find sources for new technology without paying for it out of profits, which is constitutionally

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forbidden. Pemex must meet domestic needs first, but to do so means offsetting the decline in production with a corresponding drop in exports. If these conditions do not change, Mexico will effectively cease to export any crude oil within the next four to five years. *(10)*

Canada is the US' largest source of crude oil and refined product imports, accounting for a relatively constant 18-19% of all such imports in 2007-2008. While conventional sources of oil and gas continue to be developed in Canada, the Alberta tar sands deposits represent nearly half of its oil exports to the US. *(10)* Canada is also an essential route for pipelines from Alaska to the "lower forty-eight" states, although contentious regulatory and legal battles over rights-of-way within the US have prevented any significant additions to existing pipelines.

Saudi Arabia has now replaced Mexico as the second largest supplier to the US, with Venezuela third and Nigeria fourth. These top five suppliers accounted for over 60% of US imports in the first ten months of 2008; Canada's share, as described above, is greater than any of the others – Saudi Arabia accounted for 7.9% with none of the others exceeding 6%. *(11)*

Surprisingly, the Department of Energy projects that US dependence on oil and gas imports will remain constant at 60% of the country's needs for the next two decades. *(12)* However, this forecast relies upon increased production from fields in the Gulf of Mexico and elsewhere, plus growing production of biofuels and coal-to-liquids (CTL). This forecast is questionable at best, since it evidently ignores three important trouble spots:

a) exploration and development of coastal oil fields will need to be resumed within the currently banned 200-mile limit in order to begin production sooner than 10-12 years from now,

b) corn-to-ethanol output is already consuming 30% of US corn production and is projected to peak not later than 2012,

c) the existing US stock of cars cannot use a blend of more than 10% ethanol,

d) CTL technology requires oil prices to exceed $80/bbl. on a sustained basis to be competitive, not to mention that no CTL plants exist in the US or are even in the planning stages, plus requiring eight to twelve years to build and begin production.

On the last point, the US undertook to develop its own CTL technology in 1980 by establishing the Synthetic Fuels Corporation. This project spent $ 8 billion but proved unsuccessful and was dissolved in 1985. Only SASOL in South Africa presently has a commercially viable process, which has been in operation since 1955 and expanded in the 1980s. This technology has been licensed in Qatar and Nigeria within the current decade; curiously, the US has never shown interest in obtaining a license. *(12)*

Other "green" energy initiatives, such as solar panels, wind and tidal turbines, are very far from cost competitive with unsubsidized conventional sources and there are no realistic prospects they will be for at least a decade or more. In addition, the land footprint for solar and wind energy units is very substantial and any important growth in this sector will almost certainly be subject to extended delays due to environmental impact litigation. These

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sources only generate energy intermittently, requiring standby generators to "fill in" the times when the wind is not blowing between design limits, or the sun is not shining, or the tides are between low and high, which is an additional large cost and subtracts significantly from the environmental desirability of these "alternative energy" sources. While the US will surely need multiple energy sources, conventional ones will necessarily be predominant for some decades to come.

In the meantime, a number of countries with carbonaceous resources located within their borders are building plants to produce their own chemical feedstocks and to supply local downstream manufacturing on an integrated basis. In virtually every one of these cases, corporations that control oil, coal, and gas production are owned and operated by the state and can set transfer prices as they please. Examples include the Persian Gulf countries, China, Russia, and Brazil. It is understandable that US chemical manufacturers view this competitive prospect with great concern.

Almost immediately upon taking office, President Obama revoked the Bush administration executive orders allowing expanded exploration for oil and gas deposits inside areas that were previously off-limits. While the new Congress has yet to conduct hearings on these matters, it seems highly unlikely that any loosening of exploration limits will be enacted into law (and presumably over a presidential veto). So far, both the Obama administration and Congressional majority leadership have been concerned only with boosting alternative energy sources. Unless there is more flexibility in this policy than has been announced, the US chemical industry's global cost competitiveness will be sharply impaired.

The "elephant in the room", as concerns this situation, is the prospective legislation to reduce US generation of carbon dioxide, along the lines of the Kyoto Protocol. It is worth noting that the European Union (EU) member countries, particularly Germany and France, have failed to meet the targets they agreed to, while the US – which did not agree to be bound by these goals – has significantly surpassed the EU in lowering its rate of increase in carbon dioxide generation. *(13)* Nevertheless, the new political leadership in the US has said that it is very much committed to enacting carbon taxes, "cap-and-trade" policies, and other methods of cutting back CO2 generation on a much greater scale. The McCain-Lieberman bill of 2008 called for a CO2 generation rollback to 1920 levels over a 30 year period; despite its bipartisan appeal, this bill failed to gain any traction, largely because of Republican opposition. In the new Congress, that opposition is considerably shrunken. It is notable that EU chemical companies have already told their governments that they are in danger of becoming globally noncompetitive if they are forced to pay increasingly higher "green taxes." *(14)*

In the meantime, China, India, Brazil, ("CIB") and other emerging countries, which never agreed to be bound by the Kyoto Protocol, have made it very clear that they believe any onus concerning CO2 reduction is on the developed countries. Each of the CIB countries have been steadily adding power generating stations (most of which utilize fossil fuels), without worrying about CO2 generation. China in particular has such substantial energy needs as it industrializes, that it is in the process of building both nuclear and coal-fueled

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generating plants (it has substantial coal deposits, thought to be second only to the US).

The developed nations are being increasingly confronted with impossibility of their situation: if they impose strong measures on their own manufacturing to reduce CO2, they will effectively see their manufacturing moved offshore to the developing countries – but without having achieved any meaningful overall global CO2 reduction. Furthermore, if they give up their manufacturing base, they will effectively no longer control their own economies and will become increasingly impotent in the international political area.

Nuclear power generation should a promising source to expand from its present level of 20% of US electricity supply. It also meets EPA's need for minimal carbon dioxide generation. The only piece missing in an expanded US nuclear power scenario is recycling used fuel, currently barred by Federal laws although successfully utilized for many decades in France, the UK, Canada, and Russia. However, US regulatory policies have also stopped any construction of new nuclear power plants for nearly 30 years, despite an outstanding record of reliability and safety. The Three Mile Island (TMI) accident in 1979 is the only one in the history of US use of nuclear power, including over 80 nuclear-powered US Navy ships in service since 1955. No one was harmed at TMI; the plant was restored to normal operations in 1982 and has run normally ever since. The vigorous expansion of nuclear power would go far to meet the needs of a growing economy without consuming more fossil fuels and creating CO2. It would also make the US chemical industry more competitive by keeping energy costs down and conserving fossil fuels for use in their highest value, chemical feedstocks.

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Chemical Feedstocks and Fuels

The modern global chemical industry has become largely based on petrochemical feedstocks, an evolution during the past century from plant materials and coal. This evolution took place because petrochemicals offered significant cost advantages in terms of extraction, processing, storage, and transportation over the previously used feedstocks. In addition, extracting useful feedstocks from plant materials and coal typically generates significant amounts of ash and other waste byproducts (only some of which can be incinerated for heat content), whereas there is no directly comparable waste generation from the production of petrochemicals from oil and gas.

As noted earlier, there is a strong movement toward downstream integration in those countries with sovereign ownership of mineral resources, primarily in the Persian Gulf. Saudi Arabia has been in the lead, but other countries with significant oil and gas resources, e.g., Kuwait and Iran, are not far behind. For some years now, a number of polyolefin plants in the Persian Gulf states have been under construction, but various problems have delayed completion until late 2009. The timing, of course, could hardly be worse; worldwide polyolefin demand has dropped up to 20% during the last half of 2008 vs. the prior six months. US polyolefin producers began shutting down substantial amounts of US polyolefin capacity in mid-2008, as demand dropped sharply. Now that projections of the length of this recession are reaching out beyond 2010, many of these closings are being made permanent, inasmuch as they will not only be uncompetitive with the new Persian Gulf plants, but China is building its own polyolefin plants and a worldwide glut of polypropylene and polyethylene is expected to ensue as they come onstream.

"Green chemistry" initiatives have been hailed in some quarters as the way to bypass US dependence on imported oil and gas, but there has been little commercially significant progress so far. The largest initiative so far has been the production of ethanol from corn, which is then blended (10%) with gasoline. However, the ethanol program has many questionable elements. First, ethanol is much more expensive to make and transport than gasoline, so it requires significant government subsidies to make it appear to be comparable in cost. Tellingly, a special tariff was enacted on imported ethanol to make it impractical to use imports (the primary source would have been Brazil, where cane sugar-based ethanol is less expensive to manufacture, compared to corn-based). Thus it is obvious that domestic political considerations (protection of US corn-to-ethanol manufacturers from competition) were even more important than green energy policy. Second, ethanol has less specific heat content than gasoline, so there is a loss in engine efficiency when ethanol is added to gasoline – approximately 4%. Third, the program has resulted in 30% of corn production previously used for food being diverted to provide only 4% of US motor fuel, with an accompanying significant escalation in food prices. Fourth, there is a very credible case made that the total carbon footprint of using corn-based ethanol to replace gasoline creates more CO2 than it saves – a net negative balance. *(15)* This is a "poster case" for showing how government interference with price mechanism of free markets creates more problems than it claims to solve.

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Biopolymers

Biopolymers are held out as an alternative to conventional oil and gas-based polymers, but upon close examination, they appear to have serious flaws that undercut any realistic probability of such claims coming to pass. Such polymers as polylactic acid (PLA) and polyhydroxalkanoates (PHA), are made from heavily subsidized US-grown corn, and have low service temperatures that limit the applications in which they can be used. Of course, any agriculture-based product is also subject to the typical swings in production and accompanying price changes that are caused by unfavorable weather – droughts, floods, windstorms, etc. Government subsidies themselves are notoriously for abrupt changes, thus further undermining biopolymers' long-term competitiveness in uses other than those where they offer unique service properties, rather than simple substitution.

Biopolymers, despite current marketing hype, are hardly new. The first plastic material to be recognized as such was natural rubber, described by French explorer and natural scientist Charles Marie de La Condamine in a paper he presented to the Académie Royale des Sciences of France in 1736. Natural rubber is a thermoplastic but can also be vulcanized to become a thermoset; current usage is estimated to be nearly nine million metric tons per year. The next oldest thermoplastic material was cellulose nitrate, used to cover billiard balls, beginning in 1870. In the 20th century, additional cellulose-based polymers were (and continue to be) used to make film ("cellophane"), fiber ("rayon"), and molding compounds (cellulose acetate and cellulose acetate butyrate); consumption of this family of products is estimated at close to 3.8 million metric tons per year.

The next tier of biopolymers includes nylon (polyamide) 11 and 6/10, which date back to the 1930's; current consumption is roughly 50 thousand metric tons per year. The basic raw material for producing nylon 11 and the "10" portion of nylon 6/10, is castor oil. Over one million metric tons per year of castor oil are produced from castor beans, 93% of which are grown and processed in India, China, and Brazil; the US stopped producing commercial quantities in the early 1970's. *(16)* This would mean that any significant increase in castor oil consumption would either require the US to resume farming castor beans or to depend on imports – much as it presently does for petroleum. The author's first professional employment in the chemical industry was at a DuPont plant in Niagara Falls, NY, where furfural, extracted from corn cobs, was the starting material in a four-step process used to make nylon 66 intermediates. This process had diminishing commercial success for about a decade before production was discontinued.

Polylactic acid (PLA) has had the most publicity among green polymers, but this material has also been around a long time and has yet to offer a convincing cost-performance benefit vs. conventional polymers. The largest producer of PLA, NatureWorks, has an annual production capacity for PLA of 140,000 metric tons per year, making PLA a relatively tiny biopolymer among those others already in use as described above. *(17)*

The only green-based polymer that appears to be cost-competitive with oil or gas-based polymers to date is scheduled to be produced in Brazil, not the US. However, the initial starting material is sugar cane and therefore at least partially dependent on government support: Brazilian sugar cane is processed to extract the high sucrose content for conversion to ethanol, which is best known for being used as vehicle fuel, but this same ethanol can be converted to ethylene for making polyethylene. Braskem has announced that it has begun construction on a 200 M TPA HDPE plant, scheduled to be completed in 2010. *(18)* Dow Chemical has a joint venture in Brazil to also make HDPE from sugar cane, but this project has recently been put on hold, a step that seems more rooted in Dow's investment capital problems than in any new doubts about the commercial potential for green-HDPE.

Sustainability

Much of the preceding concerns stem from a prevalent concept of dubious heritage, called "sustainability." This term has come to mean finding ways to avoid using mineral resources, such as oil, natural gas, coal, or even uranium (for nuclear power), based on the idea that the world is running out of these

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materials. The problem with this line of thinking is that it lacks any sound foundation in basic economic theory. The latter teaches that *all* resources are scarce, because they require time and effort to obtain and use. We quantify that amount of time and effort as monetary *costs.* These costs represent the total energy expended in connection with any resource. Concealing part of or distorting these costs via government mandates, subsidies, or taxes does not change the underlying economic facts, but does lead to erroneous economic decisions. There is nothing wrong with using materials that come from biological rather than mineral origins but to do so without regard to the economic implications is substituting emotional considerations for scientific ones.

As mentioned earlier, sustainability theory is based on the assumption that oil, gas, and coal will all be consumed within our lifetimes, and are therefore are "unsustainable" resources that must be replaced by "renewable," plant-based ones, but this concept is defective because it fails to consider full cost differentials, accessibility, efficiency improvements, and the substitution of alternatives according to economic principles.

The history of predictions on the general subject of running out of resources is lengthy. In 1865, the British government warned that the country's coal mines would very shortly be exhausted and Great Britain would have no more coal. The US Bureau of Mines/Department of the Interior predicted in 1914, and again in 1951, that the US would run out of oil within a decade. *(19)* In 1968, Stanford University Professor Paul Erhlich predicted mass starvation would take place worldwide within 20 years, and in 1980, Ehrlich wagered with U. of Maryland Professor Julian Simon that the inflation-adjusted price of a "basket" of tin, tungsten, nickel, chromium, and copper would rise within ten years – Ehrlich lost the bet. *(20)* In summary, none of these predictions came true, and while each of them received widespread favorable publicity when they were made, almost nothing was said when they failed to come about. Those making these faulty prophesies never conceded their reasoning might be wrong, only that their timing was off. Consequently, it is not surprising to note that these doomsday scenarios have a way of reappearing several decades later – after the earlier prognostications have been forgotten – and the cycle repeats itself.

There are three important flaws in the reasoning underlying such forecasts which cause them to fail so consistently. First, the predictions deny both the validity of the laws of supply and demand as well as the probability of substitution. They simply extrapolate current uses and behaviors and assume that people are not capable of changing their economic behavior of their own free will, often stating that government intervention and coercion is essential. Second, they assume that current estimates of coal, oil, and other mineral reserves are exact and unchanging – which is not true and never has been. These estimates rise almost every year as new reserves are discovered, ways are developed to increase extraction from existing reserves and access reserves previously thought to be uneconomic. Third, the marketplace reacts to a general rise in cost of *any* commodity by finding ways to use less of it and has done so since the beginning of commerce.

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Predicting that oil, gas, and coal will be completely used up and no longer be available as chemical feedstocks by the middle or even the end of this century is simply repeating the previous flawed thinking that characterized such forecasts. These resources may well cost more, but that will not end their consumption, simply change their pattern of use to the highest value – which may or may not include using fossil fuels for transportation and power generation on any widespread scale. The Saudi Arabian Oil Minister, Sheikh Zaki Yamani put it most succinctly in 2003: "the Stone Age did not end for lack of stones, and the Oil Age will end long before we run out of oil."

We need to understand that the run-up in oil prices in 2007-2008 was a major anomaly when viewed over the period since 1945, using inflation-adjusted dollars per barrel (Table QQ). The outlook for worldwide oil prices for the next decade or more is on average around $60/bbl, but this assumes no wars in producing regions or widespread government intervention that would cause prices to rise above this level.

While it is conceivable that some developed countries might effectively ban the production and use of oil, gas, and coal within their borders, this would simply present a great gift to other countries' chemical companies to become world leaders by increasing their production and use of these very same materials. Consumers and industry have long been responding to market price signals by conservation and changing energy sources, in accordance with the laws of economics. There is no convincing reason to believe that the normal functioning of these laws would be insufficient or ineffective.

In summary, the US chemical industry's future is largely going to be determined by the political actions of the US government in the near future, as normal economic considerations will be overwhelmed by the consequences of these decisions. For many years, the federal government has appeared to strongly favor an "all-service economy," where manufacturing would be drawn down to a minimum because of environmental concerns. However, accepted economic theory treats such a concept as unworkable because wealth is created by resource extraction and manufacturing (which includes food production) – services merely rearrange this created wealth. While intellectual creations, e.g., such inventions and innovations as computer software, also can be potential sources of wealth, they become globalized almost immediately by their very nature. Intellectual property rights are not observed equally overseas, but, in any event, others can make changes and improvements that may leave such concepts of fleeting value to the originators. It is not enough to create something new – it must be reduced to practice to have value and, more often than not, this means manufacturing is an essential part of wealth creation.

US Chemical Industry R&D and Employment

There have been disturbing signs that chemical employment in the US has been stagnating for a long time before the current recession began, although this has not been widely recognized. The American Chemical Society has conducted annual salary and employment surveys for many years; the most recent available one is from 2007. *(22)* The first statistic in this survey that catches the eye is

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that there has been effectively no growth in starting salaries (inflation-adjusted) for chemists with bachelors through doctoral degrees for at least the past ten years (Figure 1). This suggests that there has been no significant increase in available jobs during the same time frame. However, we find that this deduction significantly understates the problem, if one examines unemployment numbers, beginning 25 years ago:

During the 1982 recession, only 2.4% of those ACS members who responded to the survey said they were unemployed. *(23)*

In 1992 (not a recession year), this group had risen to 5.6%. *(24)*

In 2002 (another recession year), the unemployed has grown to 7.0%. *(25)*

In 2007, a non-recession year, unemployed chemists represented 10% of those responding to the same question. *(26)*

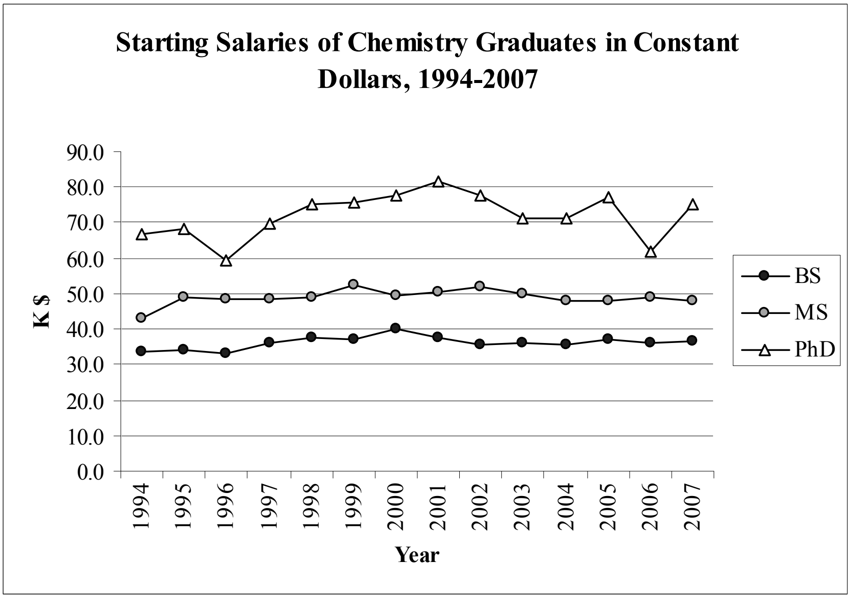

Figure 1. Source: C&EN April 2, 2008

Thus, a steady rise in unemployment *for new graduates* has been taking place in the course of the past 25 years, regardless of whether the economy is in recession or not. This has also happened during a period of a relatively static number of university graduations in chemistry – approximately 12,000 per year at all degree levels between 1979 through 2004, except for a 10% contraction in bachelor degree graduates during 1988-1991. Bachelor degree graduation rates have grown significantly, 2005-2007 (Figure 2), but this has had no discernable

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effect of either starting salaries or employment levels. The number of institutions offering chemistry degrees has grown 5%, 1979-2007 (see Figure 3), but the graduation rate has remained nearly constant, 12 graduates/institution. The conclusion is inescapable that the job market for chemistry graduates has been steadily contracting since 1997. It should be noted that the 2007 data in the ACS survey were obtained from only 3000 individuals whereas the 1997 survey was based on responses from 7400 (the number responding has been falling during the intervening years); therefore, drawing comparisons between 2007 and earlier years must be treated with some degree of caution because outliers will have a greater impact on the smaller data field. Nevertheless, the trends are consistent, unmistakable, and troubling for members of the chemistry profession.

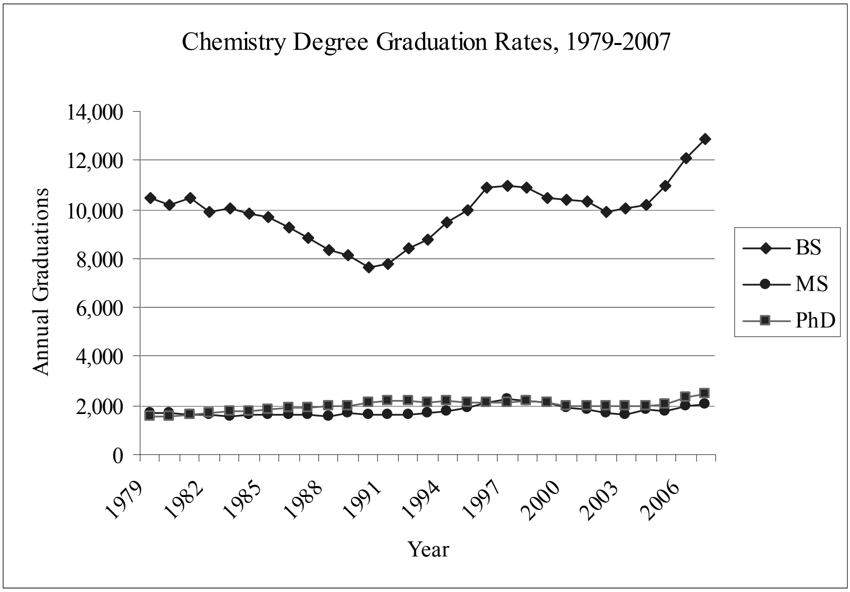

Figure 2. Source: C&EN, 1980-2008

During the past decade, one can observe from industry press releases and, in a few cases, corporate annual reports, that large, non-pharma, chemical company US-based corporate R&D employment is effectively static. While total large chemical company R&D expenditures have remained relatively stable as a percentage of sales (about 2.5%, excluding pharmaceutical firms), the only way this proportion has been maintained is by expanding R&D employment in overseas corporate sites, not in US ones. US universities and independent research institutions also do not appear to be creating any significant number of additional positions. In line with these trends, the data show that nearly half of all Ph.D.s in chemistry awarded at US universities are to non-US citizens. Of this latter group, 80% have only temporary study visas, indicating that they will return home after graduation. Put another way, less than two-thirds of newly

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minted US Ph.D.s in chemistry stay in the US and less than half of this remaining group are able to find full-time employment.

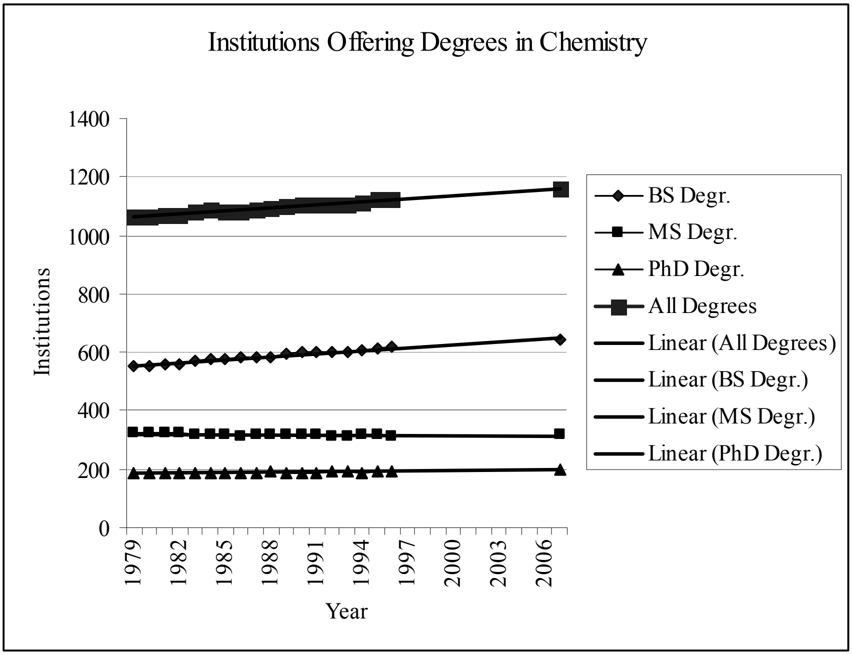

Figure 3. Source: C&EN, 1980-2008

The increasing unemployment facing new chemistry graduates is a troubling sign, even if industry and academia positions are estimated to be more or less static. The first wave of "Baby-boomers" are now hitting retirement age. Either a significant percentage of the "Boomers" are choosing not to retire just now or their positions are being eliminated when they do. Either way, new Ph.D.s in chemistry face a 50-50 chance that they will not be able to find work in their chosen career upon graduation, a circumstance that is likely to lead to reduced future enrollment in graduate programs, which, in turn, could easily lead a decrease in the number of full-time faculty required.

Chemical engineers are quite another matter: while annual salary surveys do not always show steady growth in starting salaries, these have been consistently and significantly higher than those for chemists (a 60-20% premium, depending on degree attained), as shown in Figure 4 (note that this figure is shown in current, rather than constant, dollars). In addition, the differential has widened – the premium was only 48-12% in 1999. ACS's salary data for chemical engineers appear to match reasonably well with that published by the American Institute of Chemical Engineers. *(27)* All of these indicators show that the US demand for qualified chemical engineers, compared to chemists, has been and continues to be much stronger at all degree levels and continuing to grow. This is confirmed by the much higher employment levels of chemical engineers vs.

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chemists, particularly Ph.D. chemical engineers (nearly double that of chemist Ph.D.s).

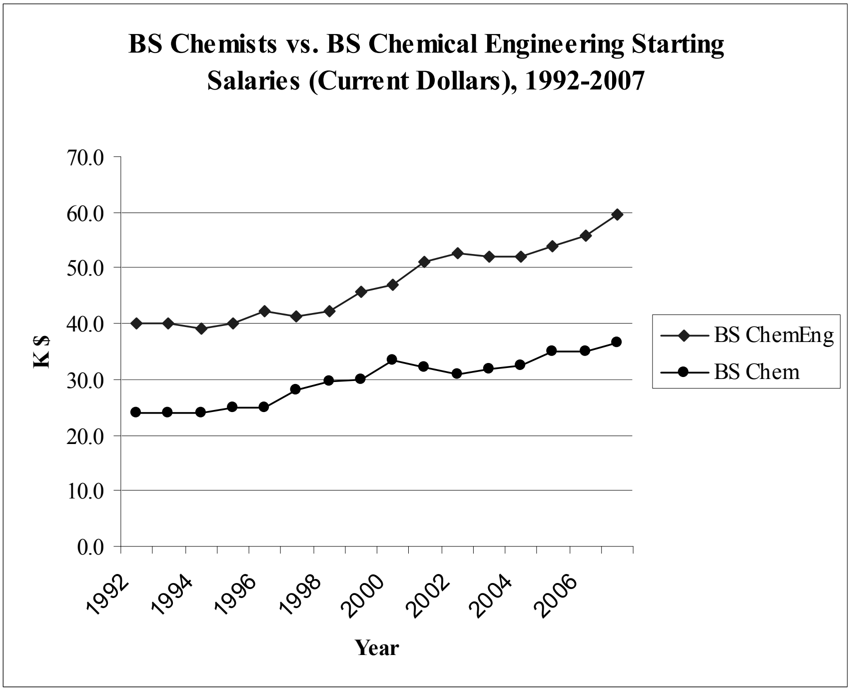

Figure 4. Source: C&EN, 1993-2008

Analysis of the type of employment found by recent chemistry graduates in 2007 shows that largest segment, one-fourth (in each degree level), is employed in academia. This proportion does not appear to have changed in the past decade. Seven to eight percent are employed by government and the balance in industry. About half of the industrial chemists work in "other manufacturing," meaning somewhere other in than pharma or traditional chemical companies.

Conclusions

The US chemical industry is facing a very troubling future without a significant change in federal government policies. These policies have been making it increasingly difficult for US firms to be globally competitive and the outlook is even more precarious. US chemical manufacturing output has already slipped to second in the world, behind the European Union group of manufacturers. These adverse policies include a refusal to develop domestic petroleum and natural gas deposits, a commitment to raise energy prices, the second highest corporate tax rate among industrialized countries, and economic

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policies that history has consistently shown will prolong rather than shorten the current economic recession.

While there is widespread interest in developing "green" chemical processes, this is largely indistinguishable from good, old-fashioned cost-reduction and safety concerns, valuable motives no matter what the label applied. The emergence of biological based chemical products is as much a 'dusting off" of old technology from the early 20th century as it is the creation of new materials from plant sources. So far, most of these products evidently require government subsidies in order to compete with unsubsidized conventional products, with no assurance that they will able to survive without subsidies for the foreseeable future. It is troubling to see that some of these products offered as an answer to reducing CO2 generation cannot demonstrate that they actually do so without resorting to "green credits" by purchasing wind energy certificates. Of course, anyone could do this for any product, so that the "green" claim is reduced to nothing more than marketing hype.

Concurrently, non-pharma chemical research and development funding is slowing in the US. This is in addition to staff reductions made by companies in reaction to greatly reduced demand. These trends will make it even more difficult to find employment for new graduates in chemistry at all degree levels. Despite relatively static graduation rates, inflation-adjusted starting salaries have not really changed for over a decade now, but unemployment for new graduates has grown four-fold in the past twenty five years, even before the current recession began. Only newly minted chemical engineers have seen any growth in starting salaries and their unemployment rates are only one-fourth that of chemists.

The implication is clear that employment opportunities for recent graduates in chemistry within the US have been growing steadily weaker for a long time. Half of all new graduates are taking jobs outside academia/government or traditional chemical companies. The prospect for newly graduated PhD chemists is even grimmer: only half of those who are US citizens (about 60% of those receiving degrees) are currently finding employment. It appears that the long-heralded boom in employment because of "baby-boomer" retirements is not happening, either because this generational group is deciding to work longer or their jobs are being eliminated when they retire.

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Chapter 2

R&D in the Global Pharmaceutical Markets

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The global pharmaceutical industry continues to increase its investment in R&D. However, the performance of the sector varies considerably in different regions. When analyzed through reported industry association data, the US environment remains more conducive for innovation, with European and Japanese companies still having to deal with stifling cost containment measures imposed by their regional governments and other pricing pressures. Global economic trends are influencing pharmaceutical companies to shift many R&D operations to emerging areas such as Asia. In particular, clinical development is accounting for a growing portion of R&D investment and companies believe that shifting investment to these other regions may offer cost benefits.

Pharmaceutical Innovation

Pharmaceuticals remain an essential part of healthcare and the advances of modern medicine would have been impossible without the contribution of the many companies that pursue R&D. The media and public often forget the role of the industry in developing new drugs - as the attention shifts to the high prices of its products. Between 1970 and 2000, pharmaceutical companies have been responsible for the majority of the 1,400 new molecular entities (NMEs) launched as human therapeutics (1), which have made major contributions to improvement in healthcare The Pharmaceutical Research and Manufacturers of America (PhRMA) notes that eight of the current top ten worldwide prescription pharmaceutical products have their origins in US R&D and that

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since 1990, the US pharmaceutical industry has grown twice as fast as the overall national economy. Across the industrialized world, the pharmaceutical industry is still considered to be one of the most highly R&D-intensive technology sectors. A Canadian study of top corporate R&D spenders ranked the biopharmaceutical sector as second only to the information, communications, and technology sector in terms of expenditures *(2).* The survey indicated that the biopharmaceutical sector also had the highest research investment of any industry with R&D representing 17.7% of sales *(2).*

At present however, there is an internal debate within the industry concerning its productivity and whether innovation has declined. In 2007, Food and Drug Administration (FDA) approvals were at their lowest level for five years, with only 17 new molecular entities (NMEs) gaining approval in the US (3). Furthermore, the FDA approved 65 original new drug applications (NDAs) in 2007, which was the fewest since 1999 *(3)*. Internationally, companies have fared little better, with the total global 2006 output of 26 NMEs being well below the 47 NME output of 1997. *(4)*

As far back as 2001, it was suggested that for the industry to maintain even a modest growth rate, companies would need to triple the number of NMEs launched annually *(5)*. Yet year-by-year new drug output has continued to decline, despite continuing unmet medical need in a number of disease areas.

Simultaneously with the decline in approved NMEs, the cost of new drug development has been rising steadily since the 1970s. In 2001, the Tufts Center for the Study of Drug Development (CSDD) estimated the cost of successfully getting a drug to market at around $802 million and raised this figure to $897 million in 2003 *(6).* However, the consulting firm, Bain & Company, has recently suggested a figure of $1.7 billion as the actual cost of successfully launching a new drug *(7).* A major difference between these two published analyses is that the Bain & Company estimate factors in the expense of commercializing a new drug whereas the CSDD figure focuses solely on R&D expense. Financial analyses show that the global pharmaceutical industry is currently investing twice as much in R&D as it was ten years ago, to generate two-fifths of the drugs it previously produced. In 1977, the US pharmaceutical industry invested around $1.3 billion in R&D, but in 2006 this figure had risen to $43 billion *(4, 8).* (Table I). The global pharmaceutical industry continues to increase its investment in R&D, with an estimated spend exceeding $60 billion in 2008 (Table 2).

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Table I: Pharmaceutical R&D for major companies (Source: Annual Reports, Company Press Releases, 2008)

Company	Pharmaceutical R&D ($ Billion)
Pfizer	8.1
Johnson & Johnson	7.7
Roche	7.0
GSK	6.7
Novartis	6.3
Sanofi-Aventis	6.2
AstraZeneca	5. 2
Merck	4.9
Eli Lilly & Co.	3.5
BMS	3.3
Wyeth	3.3

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Clearly, the performance of the sector in translating this investment into innovative new products remains questionable.

Like all areas of the economy, innovation is funded primarily with an expectation that a profit will be derived from it. The changing landscape of the industry, payers, consumers and the public health status of various regions have resulted in a continuing reanalysis of what sectors will be profitable enough, or otherwise important, such that it is worth investing in them. Likewise, as returns have become more restricted in recent years, the sector has looked at ways to focus and control the investments themselves. Below we will provide an overview of the current investment and returns of the industry. Second it will discuss how the policies of payers and the public sentiment within different global regions affect the returns that can be obtained in those regions and for what innovations. Third, it will discuss current trends in defining pipelines and managing the costs of innovation.

It has been assumed that companies with high R&D expenditures will be the most innovative and productive, but given the poor relationship between global investment and NMEs launched, it is not surprising that the situation is far more complex. Obtaining a benefit from R&D investment requires long-term planning and a consideration of how the commercial and technological environment in which industry operates is changing. For example, as drug development times lie between the 10 and 12-year range, predictions must be made about the future healthcare environment and how these fit in with the company's objectives.

Pharmaceuticals as Part of the Overall Healthcare Dollar

Sales growth in the pharmaceutical industry has been impressive through the 1990s. While a portion of this has been through expansion of markets to new regions, the majority has been through increased sales within the current US, EU, and Japanese markets. This has certainly not gone unnoticed by payers in these regions in which healthcare dollars has become an increasing portion of the GDPs and nor for that matter by competitors.

Although affordability of pharmaceuticals has become a much talked about issue with the public and within government departments, several studies show that when effective medicines are used properly, early intervention in treating diseases can counteract some of the draining effect disease has on the economy. For example, chronic illnesses such as heart disease, cancer, and diabetes account for 83% of the expenditure on health care each year in the US *(9).* A US study found that pharmaceuticals accounted for only 9.4% of the total \$1.3 trillion spent on healthcare in 2000 *(10).* Since many new treatments aim to modify the diseases being targeted rather than treating only the symptoms, they should remove the need for expensive, lengthy stays in hospital.

The International Federation of Pharmaceutical Manufacturers and Associations (IFPMA) cite a 2002 study by the National Bureau of Economic Research in the USA that showed that when an older medicine was replaced with one 15 years newer costs were increased by an average of \$18, but this reduced hospital and other non-medicine costs by \$129 *(11, 12).* The study suggested that for each additional \$1 spent on newer pharmaceuticals, \$6.17 was saved in total health spending.

The US pharmaceutical market remains the dominant world market for manufacturers, representing over 40% of the global market *(13).* A major attraction for pharmaceutical companies has been the reluctance of the US government to directly intervene in the market. Although other forces have the effect of regulating prices, pharmaceutical companies are able to charge higher prices in the US than they can in the other key markets of Europe and Japan.

The US healthcare system is the most fragmented, the most complex, and the most rapidly changing in the industrialized world. It continues to grow tremendously in size and was valued at \$2.4 trillion in 2007 *(14).* When averaged over the past 10 years, the US market grew at an average of 15% (*15*). In comparison, Europe has grown at an average of 5% and the Japanese market has only grown by 1.6% annually. With respect to Europe and Japan, the biggest surge in growth for the US pharmaceutical market occurred between 2001 and 2004. According to IMS Health data, 66% of sales of new drugs marketed since 2002 are generated on the US market, compared with 24% on the European market. Recently, the US market growth has slowed considerably. For example, while growth exceeded 8% in 2006, in 2007 this dropped to only 3.8%.

The slowdown in the pharmaceutical market has been linked to a number of blockbuster drugs coming off patent, pressure from payers to curb costs, a more cautious attitude from regulators in approving new drugs and for the US, the impact of the introduction of Medicare Part D *(16).* We will talk about each of these in more detail though it is difficult to separate some of them.

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Generics

The rise of the generics market in the US is due to a variety of factors, most notable of which is the increasingly competitive business strategies of the generic manufacturers themselves, aligned perfectly with the need by payers for reducing healthcare costs. By aggressively challenging patents, and effectively marketing to payers, the generics industry has grown more rapidly than the research pharmaceuticals industry in recent years. In 2004, about half the prescriptions filled in the US were for generics. Since generic drugs are typically sold for about 1/3 the price of the innovator drug, this has helped to control drug costs for payers, but has lead to essentially a complete shutdown in sales of the innovator drug once the patent has expired. A commonly cited study, by those supporting the increased use of generics, is one by the US Congressional Budget Office (CBO) which estimated that in 1994, purchasers saved between US$8 billion and $10 billion by substituting generic drugs in place of brand name products *(17)*.

It should be added here that this enormous shift in sales forces one to re-evaluate the generally held description of the pharmaceutical industry and must acknowledge that it has bifurcated into the companies represented by the Pharmaceutical Research Manufacturers of America (PhRMA) and the Biotechnology Industry Organization (BIO)' and those represented by the Generic Pharmaceutical Association (GPhA). Interestingly while generic versions of drugs sell for considerably less than their innovator counterparts, the generic industry is as profitable as the research pharmaceutical industry. According to one study, while generics companies spent a lower proportion of their sales on R&D compared to the R&D-based pharmaceutical companies, their average operating margin was 21.3%, only slightly below the figure of 23.6% for the R&D-based pharmaceutical companies cohort *(18)*.

However, PhRMA members are responsible for around 80% of the total R&D efforts of the pharmaceutical industry *(19)* and we therefore mean that group when we talk about innovation challenges.

As regards, investment in innovation, this means that less than half of US prescriptions are providing returns that feed back into further investment in development and the (research) pharma industry must find a way to achieve financial success in this continuously shrinking market.

Generic Impact on Biologics

Biologics have enjoyed a choice position in the pharmaceutical industry. Slight differences in manufacturing processes can create subtle chemical differences that are difficult to detect and yet may have a significant impact on efficacy or safety, particularly immunogenicity. Thus each biologic, or even process change to a current product, required clinical studies to demonstrate the safety and/or efficacy of the new product. Generics were in effect, impossible and biologics manufacturers could be assured of little competition and market dominance for a long time, well beyond their patent lifetime. Thus there is a huge return allowed for investment within a higher risk environment – basic

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research, discovery tools, bioengineering advances, molecular characterization and mechanisms of disease cascades that could be controlled by biological products – particularly for oncology and inflammatory diseases

Nothing lasts forever though. New means have been developed to characterize proteins, there is a better understanding of the impact of specific manufacturing changes on the compounds, and non-clinical means of assessing immunogenicity potential have been developed. As bioengineering became routine, it was natural that pressure would arise for the approval of bio-generics. Biogenerics do exist in some countries, but their widespread introduction into the major pharmaceutical markets of the US, Europe or Japan remains some way off. However, a number of biotech products are due to come off patent in the next few years and generic companies have been lobbying in the US and Europe for changes to regulatory legislation. If biogeneric products were to have the same impact as generic versions of mainstream pharmaceuticals have had, analysts have suggested that the potential market for biogenerics could exceed $2 billion *(20)*.

The first biologics to go are the well characterized, relatively small molecules with limited ability to have variable sections (no glycosylation) such as human growth hormone and insulin. In January 2006, the European Medicines Agency (EMEA) adopted a positive opinion for Sandoz's generic growth hormone product Omnitrope *(21)*. The Sandoz product was described as having demonstrated comparable quality, safety, and efficacy to Genotropin, a reference medicinal product already authorized for use in the EU. Although the EMEA's decision concerning Omnitrope was considered a positive move by the generics industry, it has not resulted in any dramatic changes to the regulatory processes being applied to other applications. For example, the FDA followed a similar line in approving Omnitrope, but it indicated that it would evaluate follow-on biopharmaceuticals on a case-by-case basis *(22)*. Nevertheless, the impact of biogenerics will be substantial when assessing the 10-year horizon risk-reward relationship.

Tiered formularies

While the US doesn't believe in the government negotiating prices with the pharmaceutical industry, the rise of formularies by Medicaid and by private insurers has played a similar role in cost containment and has dramatically transformed the potential returns on research investment. The principle of tiered formularies is theoretically simple – insurers cover the cost of basic drugs for an indication and the consumer then makes choices about how much additional value they want, and accepts the additional costs. Most formularies have three tiers, possibly four as shown in Table II. Managed care formularies vary considerably in the co-payments expected for each tier, and the tiers assigned to a given drug.

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Table II. Typical Tiered Formulary for Managed Care Providers

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Tier	Drug types
1	Generics and other highly preferred drugs
2	Branded drugs with no therapeutic equivalent in Tier 1
3	Drugs for which there are generic or therapeutic equivalents in Tier 1
4	Non-preferred drugs, some biologics

Certainly this type of system has shifted some of the decision making, and financial burden on to the consumer and not surprisingly has resulted in patients reducing their purchases of drugs though the jury is out on whether this will have any health impact or not. From the pharmaceutical industry perspective, such tiered systems affect the decisions on what type of new products to invest in. The "therapeutically equivalent" definition for Tier 3 can mean the branded version of a generic drug, an alternate formulation of the same drug, such as a once-daily form of a twice-daily generic or a combination drug. More importantly on the question of innovation, this can also mean drugs which have a similar mode of action. Since a drug that is placed at Tier 3 in the formulary will be much more challenged to gain market share, me-too drugs, even if they can provide additional benefits such as reduced side effects, become less attractive to develop. The ability to sell them in the face of older generics depends on the ability to convince the consumers through DTC that they should choose that newer product. Given the restrictions on what is allowed by the FDA in promotional material, this can be an uphill battle. That means that innovators want each new drug to have a different mode of action, or be able to make different claims to efficacy than the currently available drugs. In the past there were typically several drugs developed with similar mode of action, each (hopefully) with reduced side effects or more patient acceptability that made them sequentially more attractive, however development of these follow-on drugs provides less returns and therefore there is less development of them today, which is likely one of the causes in the reduced number of NMEs being launched today. Conversely, as discovery and validation of new targets for drugs screening is one of the big chunks of the R&D costs for a new drug, this drives up costs for drug development for those that are developed.

The Complexities of Healthcare – Drugs vs. Other Costs

The Medicaid Part D benefits which is a public-private collaboration to provide prescription drugs to seniors at controlled costs has certainly lowered costs for many patients. However, aside from the obvious compromise on potential profits for the pharmaceutical industry, two additional issues should be noted that impact the value and direction of innovation. First, the Part D budget is completely separate from that of Parts A through C which cover all in-patient care and much of the out-patient care except for pharmaceuticals (Table III). By

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separating these out, the value of judicious use of drugs as a means to reduce hospital stays cannot be readily assessed and a motive for balancing these is removed from both the government and the payer/user.

Table III: The four parts of Medicare

Medicare part	Details
Part A	Hospital insurance that helps pay for inpatient care in a hospital or skilled nursing facility (following a hospital stay), some home health care and hospice care
Part B	Medical insurance (Part B) that helps pay for doctors' services and many other medical services and supplies that are not covered by hospital insurance
Part C	Medicare Advantage (Part C) plans are available in many areas. People with Medicare Parts A and B can choose to receive all of their health care services through one of these provider organizations under Part C
Part D	Prescription drug coverage (Part D) that helps pay for medications doctors prescribe for treatment

Additionally, the infamous "donut hole" of the Part D plan requires patients who have incurred a certain amount of costs to then pay 100% of the costs of drugs as a deterrent for overuse of medication. If the costs become too great however, a catastrophic support kicks in and Part D again supports the costs of medication. Costs of chronic treatments become much more of a challenge to patients.

Label claims and Off-label use

Innovation should of course be directed towards improving the health outcomes and overall quality of life of patients. For therapies in areas with a number of other drugs, this is a challenging task. The FDA only allows companies to promote drugs on the specific efficacy and safety results of the FDA-approved clinical studies. The specific markers, results, and interpretation must be carefully selected to allow for the best clarification to physicians and patients on the benefits of the new drug over currently available drugs. From an innovation perspective, being able only to make claims that are essentially those of their competitors provides little benefit. Again, the selection of drugs to move through development is based on what new claims for greater efficacy, reduced side effects, ability to be effective against symptoms that might not be controlled by available drugs, or effect the disorder earlier in the disease cycle. If insufficient added value is seen, the drug won't be developed.

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The off-label use of drugs has been a significant market for the pharmaceutical industry (both innovator and generic). Off-label use entails physician's prescribing drugs for indications that the FDA has not approved the drug for. This allows use of drugs for indications that a company might not want to carry out a clinical study for due to value of the sub-market size or difficulty in enrolling patients. Likewise if the market is identified late in the patent life of the product or after patent expiry, no one company wants to take on the burden of the study when they will only receive a limited amount of the sales. However, without rigorous clinical studies, the efficacy and safety for the indicated use remains unproven and is speculative only, though investigator sponsored trial. Issues of off-label use have arisen of late *(2377)* due to more aggressive FDA enforcement of laws forbidding promotion of products for off-label use, and reluctance of payers to approve re-imbursements for unapproved indications. The industry has countered this by seeking more promotable claims of efficacy during clinical studies, certainly of benefit to physicians and patients. More controversial is the practice of promoting the definition of new disorders or diseases for the purpose of getting claims particularly associated with those "new" diseases.

Ex-US pricing

Today, no matter where the corporate offices of a global pharmaceutical company are, the value of the US, European and Japanese markets must be considered in the overall valuation, though the pressures on revenues differ in each region.

Continuing gaps in regulatory harmonization in Europe drive up the cost of product launches requiring multiple regulatory engagements to allow use in the overall market. Although in principle, the pharmaceutical market in Europe has grown as the EU has expanded, the different regulations and regulatory authorities ultimately make progress to approval slow.

Table IV: Average prices of 150 of the world's best-selling prescription medicines *(24)*

Country	Percent of US Price
UK	59
France	59
Germany	62
Spain	50
Italy	50
Japan	76

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It is widely discussed that the selling price of pharmaceuticals in the EU is substantially below that of the same drugs in the US due to the ability of each country to directly negotiate prices with the seller. For example, in a 2005 survey of the 150 best selling pharmaceuticals, the prices of these drugs varied considerably in Europe; in Spain and Italy they were around half of US prices *(24*, Table IV*)*. The study also revealed that the situation was different when the prices of biologics were considered. Whereas European prices averaged 88% of US prices, the prices in Japan were almost the same.

The US pricing environment has allowed the US to remain the first and sometimes only place for launch of new products *(25)*. This can be shown through comparisons with foreign pharmaceutical sectors. The US launched 259 drugs in the 1990s, compared with 151 launches in Japan. Furthermore, the US launched 78 FDA priority-review drugs, compared to 36 by the UK in second place *(26)*.

The funding of expensive, new biotech treatments has become a contentious issue in many European countries. For example, in the late 1990s patients with multiple sclerosis (MS) took court action to gain access to the new treatments as some governments proved reluctant to fund an area of healthcare that had previously cost them very little. As a result of patient pressure, many European governments began to draw up guidelines for the reimbursement of such therapies. Despite this precedent, as newer biotech therapies have reached the market, this situation has recurred.

Pharmaceutical companies certainly have other reasons why Europe is a harder sell than the US. DTC advertising is not allowed, mail-order prescription drugs are restricted, and parallel trade allows repackagers to move drugs purchased in lower priced Member States to higher priced Member States outside of the control of the manufacturers themselves. As regards parallel trade in the EU, there is a system of regional exhaustion, which means that the manufacturers' intellectual property rights are exhausted on first sale of the product in any EU Member State *(27)* and thus they derive no remuneration from the resale. Several EU countries, including the UK, parallel trade accounts for over 10% of sales within the country, which has a substantial impact on profits. Pharmaceutical companies see this as 'parasitic competition' and frequently focus on how it affects the research efforts of the pharmaceutical industry. EFPIA have stated that loss caused to European pharmaceutical R&D by parallel trade is around €1 billion.

In the US, importation from Canada has a similar impact though the products are technically different products. Since the drugs in the two countries are reviewed and approved by different regulatory bodies, they may have different quality (unlikely, if they are actually made by the same companies and distributed legally), different label claims, and different warnings.

Japan also sets pharmaceutical pricing and has institutes biannual price cuts aimed at products which significantly exceeded original (official) sales projections. The losses to the Japanese pharmaceutical industry due to these price cuts has been estimated at nearly $4 billion per year, which has compromised the industry's profitability and ability to invest in R&D *(28)*.

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Cost Containment Strategies – Pharmacoeconomics and Comparator Assessment

In 1999, a new pharmacoeconomic body, the National Institute for Clinical Excellence (NICE) was set up in the UK as a Special Health Authority *(29)*. It is part of the UK's National Health Service (NHS), and its stated role is to provide patients, health professionals and the public with authoritative, robust, and reliable guidance on current "best practice." NICE's guidance is defined as covering both individual health technologies (including medicines, medical devices, diagnostic techniques, and procedures) and the clinical management of specific conditions. NICE carries out technology appraisals on the use of new and existing medicines and other treatments within the NHS in England and Wales, based on a review of clinical and economic evidence. NICE has been instrumental in evaluating and publicly reporting the benefits of drugs for general use and for specific indications based on the estimated effect on Quality of Life Years with respect to other treatments.

Not surprisingly, the assessments of NICE have not been popular with the pharmaceutical industry especially since they are issued prospectively before a full understanding of how the products may fit in with other healthcare options. Many companies believes that a full economic review of a drug cannot be carried out until it has been in use over a period of time in a wider population than clinical trials can involve. NICE is aware of the controversial nature of its recommendations as there is a fear in the pharmaceutical industry and among patient groups that NICE's decisions will lead to rationing of important drugs for major diseases simply because they happen to be expensive. The pharmaceutical industry has also carried out analyses emphasizing the economic and quality of life value of pharmaceuticals *(30).*

There has been speculation that an EU equivalent of NICE could be set up. This is often referred to in the press as "Euro-NICE." Such a move faces a number of political challenges that make it unlikely in the near future. Even if this highly controversial step took place, there would be numerous problems in ensuring that the EU-wide analyses yielded comparative data, as approaches to diagnosing and treating disease vary widely across the EU. However, other countries are doing their own analyses.

Regulatory agencies, both in the US and in Europe are not delegated to address the market value of a product, only its efficacy, safety (risk/benefit) and quality. However, the EMEA is at the forefront of the philosophy that risk/benefit is not a standalone consideration, but must be weighed against other therapeutic options available. In addition, the use of placebo controlled studies for diseases in which denial of therapy would be considered unethical, has encouraged a move to more comparator studies. The interpretation of the outcomes of such studies can be ambiguous however and increase the risks of regulatory delays or denials for unexpected reasons.

These same issues of understanding the relative cost, safety, and efficacy of available therapies are being discussed in the US as well. For both care providers and payers, these issues are being increasingly recognized as valuable, but if implemented, will certainly add another factor in the new product return on investment equation.

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Globalization - Changing Populations and Changing Diseases

There is no question that the changing population profile has had an impact on the relative value of therapeutic areas of potential value. For the developed world, the largest changes have been the increased average lifespan and the concomitant increase in diseases of the elderly - Alzheimer's Disease, Parkinson's Disease, chronic pain, respiratory disorders and oncology to name a few. Likewise, sedentary behavior and availability of high-caloric food has led to increases in diabetes and metabolic disorders which are now even being seen in developing regions of the world with a previous history of limited food accessibility and less automation. Therapies for oncology and chronic diseases are increasing in demand in India, China and other emerging markets.

Neuro-psychiatric disorders have become increasingly of interest as they are more diagnosed, rightly or wrongly, such as depression, attention deficit disorder, fibromyalgia, and restless leg syndrome.

Additionally, there is new interest in therapeutic areas in which un-met needs are being re-defined. For examples, antibiotics, antipsychotics, and chronic pain medication are areas in which a wealth of drugs were developed that seemly met the therapeutic needs. In the case of antibiotics, multi-drug resistant strains of bacteria are now challenging even the powerhouse drugs available. Expansive studies of antipsychotics for schizophrenia have underscored the many insufficiencies of current therapies to safely and chronically control this unfortunate disorder. This has generated new efforts in understanding the disease and how to control its diverse manifestations. And the post-market identification of safety issues with Cox-2 inhibitors for chronic pain, which were specifically developed to avoid GI side effects of prior drugs, has led to an interest in new ways to control pain. Vaccines have also re-emerged as an area of growing interest due to their potential for control of global epidemic diseases and the significant investments of international and philanthropic organizations. Relegated to the periphery in the past, large pharmaceutical companies are embracing vaccines as another opportunity to stabilize their portfolios.

From a market perspective, globalization has been beneficial to the industry. The increasing middle class in India and China demand higher standards of care and the use of more pharmaceuticals. Between 2007 and 2012, pharmaceutical sales in Brazil, Russia, India, China, Mexico, Turkey and Indonesia are expected to grow twice as fast as in the US, Europe and Japan, with China, India and Turkey being the biggest leaders *(31)*. Changes to the patent laws in these countries have allowed the US and European pharmaceutical industry to consider launching products in these countries with less fear of immediate generic and/or fraudulent competition. Globalization has not been without issues however. The development of sophisticated illegal manufacturing, trade, and mail-order organizations that bring false or adulterated products into the markets, sometimes put at significant risk the unwitting patients, but always result in financial loss to the legal pharma industry.

Globalization has had other impacts. The understanding of epidemics and localized diseases in developing and undeveloped regions has increased the

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demand for healthcare solutions, including new therapies and vaccines for neglected or potentially emerging diseases. *(32,33)*

The Investment in Innovation

We have discussed some of the constraints on the value of innovation in the pharmaceutical industry, and some of the opportunities. The industry has responded by focusing their activities and exploring ways to control the risk and cost of new product development to better balance the ROI equation.

Innovation Tools

The industry, academic, and government groups continually seek to make the discovery and development of new drugs more efficient. Such efforts attack the issue from many fronts. From the discovery side, there are increased efforts to identify new mechanisms of action, faster identification of active molecules; and inclusion of screening for potential safety problems, as part of candidate selection. And in development, the goals are faster and cheaper clinical studies; faster development of suitable chemistry and manufacturing information to allow rapid commercialization, and most importantly, identification of safety or poor efficacy problems as early as possible in the development cycle.

These demands are at the forefront of the industry's fragmentation by role in R&D with small and emerging entrepreneurial pharmaceutical companies ("biotechs") playing a key role in the discovery of drugs and contract research organizations (CROs) dominating the development space providing cheap and flexible locales and personnel.

In recent years, pharmaceutical innovation has become closely linked to the use of biotechnology. Over 30% of drugs developed today are developed or in-licensed from small and emerging companies *(83)*. Since 2005, biologicals, often discovered and developed by biotech organizations have represented 22% of the NME output of the industry (launched drugs), and now account for a quarter of total R&D investment *(34)*. Current annual worldwide recombinant product sales are of the order of $70 billion *(35)*. In 2007, biotech drug sales grew by 12.5% - twice as fast as the pharmaceutical market *(36)*.

The number of biotech compounds has been increasing steadily over the last twenty years, but rather than just concentrating on absolute drug output, the emphasis must also be on the quality of the drugs being produced. A 2006 industry-wide analysis of pipelines revealed that 50-90% of the projects in development in the leading therapeutic areas were considered to have a novel mode of action *(37)*. In this regard, there is no denying the innovation that biotechnology has brought to the field of drug development since its adoption in the 1970s *(38)*.

In 2008, the Pharmaceutical Research and Manufacturers of America (PhRMA) reported that there were more than 630 biotech drug products and vaccines in clinical trials, targeting more than 200 diseases, including various

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cancers, Alzheimer's disease, cardiovascular disease, diabetes, multiple sclerosis (MS), AIDS, and arthritis *(39).*

From a general perspective, the US biotech industry is the most successful in the world and it is likely to maintain this leading position for the foreseeable future. This is because the US has been much more proactive than other countries in encouraging its biotech sector. For example, in 2003, the US House of Representatives introduced the Biotechnology Future Investment Expansion (BIOFIX) Act (H.R. 2968), a piece of legislation designed to change the US tax code in order to encourage further investment and innovation in the biotech industry *(40).* In Europe, the sector is much further behind in getting such recognition at a regional level. Some believe that the political set-up of the EU is not always conducive for effective biotech legislation and that individual European countries may do better by implementing national policies *(41).* Multinational pharmaceutical companies have responded by slanting their R&D investment to the US rather than the EU or Japan. In 2002, Novartis set up the Novartis Institute for Biomedical Research in Cambridge, Massachusetts rather than selecting a European location. Similarly, in 2004, Daiichi (now Daiichi Sankyo) announced that it would use New Jersey as its global clinical drug development operations, indicating an R&D shift away from Japan.

For example, the European Commission is still carrying out an assessment of the sector and how it adds value in terms of economic, social, and environmental aspects *(42).* The Bio4EU Task 2 report was released in 2007, but it has not yet resulted in mainstream government support for the sector as appears to be the case in the US. While Europe still attempts to find a suitable strategy, many emerging economies have identified the biotech sector as a key area for investment and are aiming to mirror the success achieved in the US. Policies designed to foster biotech innovation are being implemented in India, China, South Korea, Brazil, and South Africa.

Interestingly, in the US, the major pharmaceutical companies now account for nearly 25% of all biotech investment, which is three times greater than the entire venture capital investment *(43).* The biotech industry generates about half of its revenue from licensing to major pharmaceutical companies. Collaborations between small biotech companies and larger drug development organizations, such as pharmaceutical companies, can be mutually beneficial. Under such agreements, smaller companies can gain financing to carry on with their R&D programs, while the bigger company will supplement its new drug pipeline with an innovative product. The future is likely to see a continuation of this symbiotic

R&D investment in the EU

When analyzed through reported industry association data, the US environment remains more attractive for innovation than other regions. For example, while R&D spending for large US pharmaceutical companies rose from $39.9 billion in 2005 to $43.0 billion in 2006, the increase in European R&D spending was more modest *(39,441).* In 2005, European companies invested $28.7 billion in R&D and this only rose to $29.7 billion in 2006 *(44).* In fact, between 1990 and 2006, R&D investment in the US grew 5 times while in

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Europe it only grew 2.9 times *(39,44)*. This investment includes both internal and external investment in both discovery and development including investing in small and emerging pharma (biotech) organizations to build pipelines. Biotech companies have relied on this investment more heavily since the collapse of the IPO market in 2001.

Despite its problems, the biopharmaceutical industry remains one of the most R&D-intensive industries in European countries, with an estimated 12.5% of sales invested in R&D (EFPIA 2007). Many in the industry believe that there should no reason why Europe cannot keep pace with the US given the existence of high quality research resources available in different European countries. Interestingly, the IPO climate in the EU has improved significantly and in recent years, more IPOs activity has occurred in Europe than in the US, partially offsetting the lower investment by large pharma.

However, recognizing the continued challenge to the smaller commercial enterprises in Europe, and the emerging biotech industry, national governments have established plans to encourage incubators, investments and update business strategies *(45)*. One of the problems for Europe is how a regional effort to improve innovation fits with national measures. There is a possibility that gains in one EU member state could equate to losses in another, thereby resulting in no overall R&D gain for the region. For example, in 2003, Pfizer reacted to new government health care reforms in Germany by deciding to institute a hiring freeze in Germany and relocate certain staff members to its UK operation.

The European Commission issues multi-year plans for research investment, the current one being the Seventh Framework Program for Research and Technical, 2007-2013 Development *(46)*. A 2004 analysis of the European Commission framework programs estimated that a €1 increase in public R&D investment induced €0.93 of additional private sector investment *(47)*. The framework programs focus on improving the competitiveness of Europe's biotechnology industry by developing new diagnostic, disease prevention, and therapeutic tools. The Sixth Framework Program (FP6) has funded 608 health-related projects. The Framework programs have been concluded to provide considerable added value, as they expand the funds available to national researchers over and above those that they would receive from national sources. Furthermore, for groups based in different European countries, the program allows them access to foreign researchers and research outputs that a national program cannot provide. In effect, the pooling of financial resources enhances regional efforts.

European authorities have decided to take steps beyond these programs and develop a system to coordinate developments in individual fields and combine private sector investment and national and European public funding. Therefore the Innovative Medicines Initiative (IMI) is a new Public-Private Partnership (PPP) that is being developed by EFPIA and the European Commission and. The initiative, with a total budget of two billion Euros, will address a number of the factors that are considered to be hampering European pharmaceutical innovation, including the fragmentary approach to R&D. It will also take into account the increasing use of biotech technologies in drug development. IMI's goal is to reinvigorate the European biopharmaceutical sector in view of a growing research gap relative to the US. What is different from previous

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European efforts is that industry-matching funds will be made available for public funding.

R&D in Asia

Given the commercial pressures that pharmaceutical companies are facing within the major markets, they are looking further afield for cost-cutting opportunities. Global economic trends are influencing companies to shift many R&D operations to areas such as Asia. In particular, clinical development is accounting for a growing portion of R&D investment and companies believe that shifting clinical activities to these other regions may offer cost benefits. This suggests that the future success of the pharmaceutical industry will depend to an increasing extent on these foreign initiatives and less on domestic initiatives. Table V lists major foreign operations in China including research activities.

Initially, international pharmaceutical companies had been somewhat reluctant to place R&D efforts in emerging economies due to worries about their intellectual property environments. A 2005 survey by Ernst and Young of 348 senior industry executives found that respondents did not believe their companies' levels of investment would reach $150 million or more by 2010 in China or India *(48).* At the time, 70% of the surveyed pharmaceutical executives stated that threats to intellectual property posed a business risk in China, with 62% considering patent protection in India an issue.

Clearly, conditions for intellectual property protection and the regulatory environments have much improved as evidenced by the presence of virtually every major Western and Japanese company in China and India. *(49,50)* A 2006 report suggested that the CRO market in India for pre-clinical and clinical studies would exceed $1B by 2010 *(51).*

The investment in bringing innovations to market is more and more driven by the late stage development costs and not in the innovation itself. Clinical development is accounting for a growing portion of total R&D investment. It has been estimated that around 40% of total R&D costs are accounted for by clinical trials *(39)* In a 2002 survey of its US-based member companies, PhRMA noted that the inflation-adjusted increases in clinical R&D costs were more than five times greater than the costs for preclinical work *(52).* CSDD estimate that between the 1970s and 1990s, whilst total average (preclinical plus clinical) costs increased 5.8 times, the corresponding clinical costs increased 8.6 times *(53).* The cost increases are related to increased collection of safety data and biomarker information, and increased competition for clinical sites in the US, EU and globally. In addition, because of patent expiration concerns for innovative products, one wants to compress the development time as much as possible, so that there is willingness to trade money for time efficiency.

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Table V: Pharmaceutical R&D Investment in China by Major Foreign Companies

Company	Major locations	Main focus
Pfizer	Dalian, Suzhou and Wuxi	Manufacturing facilities
GSK	Beijing, Chongqing, Tianjin, Suzhou and Pudong	Manufacturing facilities and joint ventures.
AstraZeneca	Shanghai and Wuxi	Clinical development and manufacturing facilities.
Merck & Co	Beijing, Shanghai, Hangzhou, Guangzhou	Manufacturing and possible joint development projects
Novartis	Beijing	R&D and manufacturing facilities
Roche	Shanghai and Wuxi	R&D and manufacturing facilities
Sanofi-Aventis	Shenzhen and Beijing	Manufacturing and joint ventures importation and distribution
Lilly	Suzhou, Shanghai	
	Hong Kong	Joint venture manufacturing, sales and marketing and R&D
Wyeth	Wu County Economic Developing Zone, Suzhou, Shanghai	Manufacturing facilities and joint ventures.
BMS	Minghang (Shanghai)	Joint venture manufacturing facilities.

The attractiveness of China and India is primarily due to their lower operational costs relative to the US, Europe or Japan – especially for clinical trials, though there is increasing awareness that these are potential markets for the future. Clinical studies help raise the awareness and demand for an improved standard of care with both physicians and patients. The general costs for clinical trials in China are much lower than those in the major pharmaceutical markets *(49)*. Current thinking suggests that in terms of general running costs, clinical

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trials can be conducted in China for around 10% of the equivalent cost in a Western country *(54)*. More specific domestic estimates suggest that Phase I clinical trials in China are 15% of the price in the west, while Phase II trials in China cost 20% of the price in the west *(54)*. These estimates are in line with comments from the former CEO of AstraZeneca, Sir Tom McKillop, who was cited in a 2006 edition of the Wall Street Journal as stating that a major post-marketing clinical trial for two cardiovascular drugs (involving 46,000 patients in 1,250 hospitals in China) cost $3 million *(55)*. Such a trial would be impossible to run in the West or Japan, to the required standards, for such a low cost. In India, estimates suggest that the general running costs for clinical trials are between 30% and 50 % of those in the West *(50)*.

In India, many global pharmaceutical players (Pfizer, Novartis, AstraZeneca, Eli Lilly, GSK, Aventis, Novo Nordisk, Bristol-Myers Squibb, Roche and Amgen - to name but a few) have expanded their existing clinical research investment and infrastructure Table VI). According to estimates from Chiltern International, in 2005, outsourced clinical trials generated an estimated $71 million in revenues for Indian companies in this sector, and were predicted to grow to $318 million by 2010.

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Table VI: Growth of the Indian Clinical Trials Market *(63)*.

Year	Market Value of Clinical Trials
1999	$7 million
2000	$10 million
2001	$17 million
2002	$21 million
2005	$71 million
2010	$318 million

However, it is not just cost that has seen international pharmaceutical companies use emerging markets for their R&D. Foreign companies are showing growing confidence in using Chinese and Indian clinical data to support their global clinical programs. In 2003, Pfizer opened a clinical trial center in Shanghai and stated that not only would this be concerned with developing drugs for local approval, but would also form part of the company's global R&D network *(56)*. Similarly, since 1996, AstraZeneca has undertaken nine international multi-center clinical trials in the respiratory area in China with the involvement of more than 130 hospitals and institutions. The company recently conducted clinical trials for its asthma product, TurbuHaler, in China and used the data to support the drug application overseas *(57)*. The company described the clinical data as acceptable to the US FDA. The Chinese clinical work involved collaboration with professors who had worked on SARS and had valuable experience in the respiratory field. Novartis has been conducting a global chronic hepatitis B Phase III clinical trial, which relies considerably on data from Chinese centers *(54)*.

India's regulatory reputation has been strengthened by the fact that FDA will most likely establish a formal presence in the country (Times of India 2008, Barnes K 2008). A decade ago, India had little in the way of clear-cut regulatory guidelines for clinical trials, but it slowly progressed towards internationally recognized Good Clinical Practices as clinical trial standards *(50)*. Due to pressure from the industry and proactive initiatives of the regulators, the Central Ethics Committee on Human Research (CECHR) of the Indian Council of Medical Research (ICMR), New Delhi issued "Ethical Guidelines for Biomedical Research on Human Subjects" in 2000. Subsequently in 2001, a central expert committee was set up by the Central Drugs Standard Control Organization (CDSCO) to develop Indian GCP Guidelines in line with the latest WHO, ICH, USFDA, and MHRA guidelines.

Eisai has been building links with Chinese academics in the neurology field and in 2003 it supported the World Senile Dementia Day Conference *(58)*. Featuring local medical experts the conference discussed how providing early treatment might prevent dementia and public perceptions of the condition. The conference also recommended hospitals to which patients could go to seek further information.

In 2005, the company decided to set up a subsidiary in India called Eisai Pharmaceuticals India Pvt. Ltd *(59)*. Eisai India also signed a co-promotion agreement with GlaxoSmithKline Pharmaceuticals, India to market Parit, its Proton Pump inhibitor for gastric disorders and is collaborating with Wockhardt. Eisai's collaboration with Wockhardt covers Methycobal for peripheral neuropathy therapy and Aricept (which is marketed as Aricept in India) for treating Alzheimer's disease.

Given its role in representing the Japanese pharmaceutical industry, the JPMA has been studying the internationalization of its member companies. Since 1989 it has been running annual surveys to determine where its members are investing in foreign operations. In 2001, it found that over half its members were intending to expand in Asia, with China being of particular interest. However, there have been alternative views expressed suggesting that Japanese companies are now showing a preference to invest in India. One Indian newspaper cited Japan's Consulate-General in India as saying that certain Japanese pharmaceutical firms were withdrawing from China *(60)*. Supporters of this view in the Indian media have linked this to the intellectual property environment in India being better than that in China *(61)*.

Political Dimensions

No one can be sure exactly how the US political environment will unfold with respect to healthcare over the next few years, but it is likely to feature continuing support for generics and for formularies that impact the profits of innovator companies. However, according to an October 2008 Boston Consulting Group (BCG) analysis, the Obama administration may cause the US industry a number of difficulties *(62)*.

One of President Obama's main proposals during the presidential campaign was to let the US Federal government negotiate Medicare drug prices. This

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would overturn the elements of the 2003 Medicare Prescription Drug Improvement and Modernization Act, which actually banned the government from negotiating down the prices of prescription drugs *(63)*. It was suggested that this change in policy could result in healthcare savings of up to $30 billion, but would obviously limit the profits of the industry.

Additionally, the world economic downturn starting in late 2007 and dropping disastrously the following year will surely have an impact directly or indirectly on the research pharmaceutical industry. Not only will profits be constricted due to the increasing ranks of the un- insured and under-insured. The pressure this group puts on the government will coincide with government initiatives for more equitable healthcare.

The economic collapse has also had a significant effect on biotechs that depend on venture capital to keep them going until large pharma or other investments kick in. Private investors have had a significant reduction in wealth which has limited their interest in high risk investments, and encouraged them to sell currently held shares and stock that retains value. The pull-out of investors will results in a down-sizing of the biotech field for the near term, reducing the number of new companies starting up, and starving companies that are not in progressive mode during this period. Similar to the pre- and post-2001 collapse, it is likely that one will see changes and new trends in business models, funding sources, risk valuation, and even R&D focus of biotechs emerging from this down cycle.

Conclusion

As outlined above, the R&D efforts of the modern pharmaceutical industry are affected by myriad factors including the political, social, and financial climates of the developed and developing world. Given that drug development cycles are frequently of the order of ten years, it is difficult to predict which of these issues may have an impact on future performance and how to react to them. In addition, the pharmaceutical market is truly international and so company management must monitor developments in numerous countries where they operate. However, it is clear that a few factors will be significant in the next decade.

Internationally, both consumers and governments have become increasingly price conscious and the value of pharmaceuticals with respect to health benefits will be assessed more carefully in the future. More cost containment will surely come to the US and its impact will be re-assessed in Europe.

Industry will become much more focused on those therapies that have an expanding demand globally, both in changing demographics in traditional markets, and the new markets in Asia. Annual sales will also be determined by how new drugs can be positioned against older drugs in the face of generics and controlled formularies. Innovation will be targeted largely to those areas with strong financial justification.

Companies will continue to outsource development activities with more rapid expansion into Asia both for development cost control and to get a foot into the growing markets. Biotechs are expected to be especially challenged by

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the current economic condition, but will continue to be key innovators feeding the overall drug development pipeline.

If they are to survive, pharmaceutical companies will need to continue to invest in innovative R&D. Companies are well aware that despite all the operational difficulties they now face, the rewards for bringing an innovative medicine to market remain substantial. History has shown that a focus on innovation creates long-term benefits and so necessitates continued ambition for the modern pharmaceutical company.

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Chapter 3

EU vs. China - Challenges and Opportunities for European Companies

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Summary

The chemical industry is one of the largest and most diversified in the world. The total demand for chemicals (including pharmaceuticals) in 2007 was valued at €2, 4 trillion. The EU-27 accounted for 28.9% of this, the United States for 21.3%, Japan for 6.5% and China for 14,8%. This can be contrasted sharply with 12 years ago, when China's share of global chemicals turnover was only 3.5%. With a chemicals turnover of €329bn in 2007, China has become the world's second largest manufacturer of chemicals, just after the US (€522bn) and before Japan (€179bn) and Germany (€178bn).

The structure of the global chemicals industry is changing, largely because China is becoming an increasingly important consumer and supplier of chemical products. The reasons for this are China's cost advantages over industrialised countries in the production of chemical products and strong demand conditions due to key customer industries building up production capacities in China. This has meant consumption of chemicals has increased by around 15% p.a. over the past ten years.

Although China is now the world's second-largest manufacturer of chemicals products, domestic production is unable to cover demand in all segments. In 2007, China's chemicals imports (including pharmaceuticals) were valued at about €74,8bn, equivalent to an import: demand ratio of 19%. This provides an opportunity for European commodity chemicals producers in upstream segments to invest in China, as well as specialty and fine Chemicals producers to export to China. The European chemical sector is the world leader in terms of energy efficiency, environmental management and the development of renewable materials. European chemical companies would therefore clearly gain a competitive edge if Chinese authorities would increase stringency of enforcement to comply with environmental standards in order to avoid pollution and wasting of resources as outlined in the 11th Five Year Program (FYP).

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ACS Symposium Series; American Chemical Society: Washington, DC, 2009.

Moreover, a higher degree of environmental regulation in China would create business opportunities for the European chemical companies.

In addition, Chinese companies still lack the technological proficiency that many European companies have attained in the manufacturing of petrochemicals such as propionic acid or acrylic esters. This is one of the reasons China's oil and petrochemical companies are likely to continue to seek foreign partners and European companies are best-placed to facilitate this.

The customer base of the specialty chemical industry has experienced consolidation and globalization. This is a competitive advantage for the big-size European specialty giants, since chemical companies with a global reach are preferred global partners of their multinational customers. They are focusing less on their products and increasingly on the services supporting them, by concentrating more on niche markets and building exclusive relations with customers, especially with the help of e-business. Since China has focused mostly on developing basic feedstock industries in the past, the growth potential for specialty chemicals is especially high. China is a particularly attractive destination for chemical specialties to invest, as their production tends to be relatively labor-intensive, while the increasing availability of a well educated academic workforce also makes establishing local and regional service centers an attractive proposition.

European specialty chemicals are in an advantageous position since their products are usually not made to specification. In other words they offer tailor-made solutions for customers. Products like specialty chemicals, which contain a strong service component, are not as prone to local competition, since local companies tend to lack prerequisites. Given that domestic manufacturers in many cases do not fully satisfy the quality standards required for exports, European companies have good opportunities in this market.

Introduction

Today, the chemical industry is one of the largest and most diversified in the world. The total value of chemicals demand (including pharmaceuticals) in 2007 was about €2.4 trillion, with the EU-27 accounting for 28.9% of this figure, the United States for 21.3%, Japan for 6.5% and China for 14.8% [1]. Among OECD member states, chemicals and petroleum products make a larger contribution to GDP than any other manufacturing industry. The chemical industry's contribution in 2007 to the EU gross domestic product amounts to 1.2%. When pharmaceuticals are added, this figure rises to 1.9% 2004 [2].

Market Segmentation and the Value Chain

The chemical industry is a broad, complex, industry that produces over 70,000 different products. These products range from the chemicals first derived from the initial processing of organic or inorganic raw materials - such as benzene, toluene, and chlorine that are vital to other production - to finished consumer products such as medicines, soap, and toothpaste that are seldom

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associated with the chemical industry. In volume terms, however, most of the industry's outputs are basic chemicals little known to consumers. For the most part, its products are used by other chemical producers to make other chemicals or by other industries to make or grow things that serve society. Nevertheless, much of the public is unaware of the vital role of the chemical industry in everyday life and modern products.

These diverse product lines are manufactured by more than 1,000 large and medium-sized companies, plus countless very small ones. The many different products and processes of the chemical industry make a concise but meaningful description difficult. In essence, however, at the base of the chemical industry are companies that combine organic and inorganic materials from the earth with heat, air, and water to make chemicals that, in turn, are essential to products used in everyday life in modern economies. Figure 1 displays – based on a representative example – the value chain of the German chemical industry (in 2004) [3].

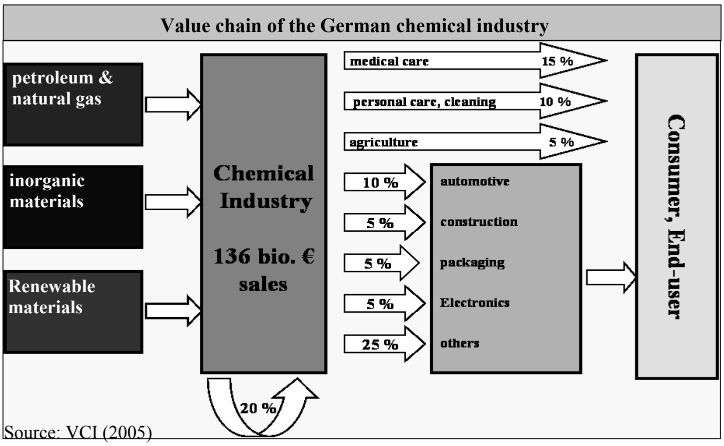

Figure 1: Value Chain of the German Chemical Industry

One way the "Chemicals Industry" can be roughly segmented is into product-use categories such as basic chemicals, specialty chemicals, fine chemicals, consumer chemicals, and agrochemicals. Figure 2 displays – again as a representative example – the global chemical output in 2004 by sub-sector based on product-oriented categories:

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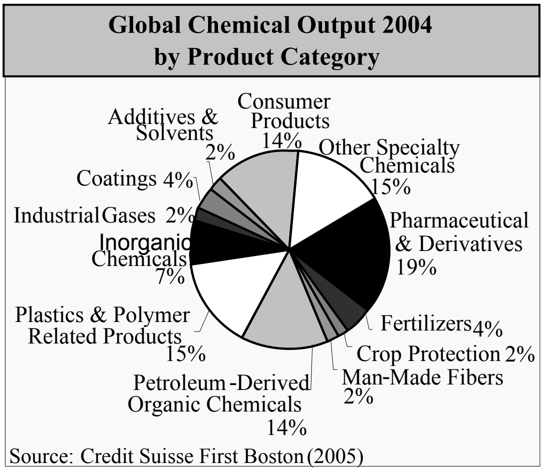

Figure 2: Global Chemical Output by Sub-Sector (Product-Oriented)

Alternatively, the chemical industry can be characterized as consisting of many "mini-industries" of varying sizes, and it counts virtually every other industry among its customers - from agriculture to construction and electronics. The huge range of products also means that the chemical industry's returns and financial condition are heavily reliant on the overall health of the economy. As a result, the sector is cyclical, and one of the key bellwethers of its fortunes is GDP trends. Figure 3 displays – as a representative example - how the output can be categorized by market-segments.

Chemical products can therefore also be roughly segmented into sectors according to their related markets. However, for the purposes of this study, chemicals are classified along product lines according to their position in the value chain due to their differences in strategic considerations(Figure 4) [3, 5]:

a) Commodity Chemicals: Comprised of chemicals produced upstream intended for generic use, such as basic chemicals and petrochemicals as primary building blocks, and industrial chemicals such as polymers or man-made fibers

b) Specialty Chemicals: Produced further downstream then commodity chemicals and are intended for a specific application and include many electronic and construction materials chemicals. From a strategic perspective, the category specialty chemicals includes "consumer chemicals" since the consumer chemicals business follows the same strategies and key success factors as the specialty chemicals business

c) Fine Chemicals: Represents the highest value end of the chemicals industry. This industry segment consists of products sold based on performance characteristics rather than price per weight unit and includes a large number of fine organics and life science products.

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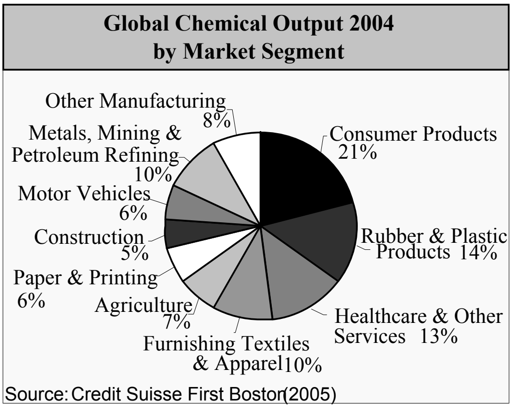

Figure 3: Global Chemical Output 2004(Categorized by Market-Segments)

Fragmentation of Chemical Markets

An interesting aspect of the chemical sector is that the industry as a whole is highly fragmented. The top ten companies in chemicals (excluding pharmaceuticals) account for only 16% of the total market, well below other industries, such as automobiles, where the top ten companies account for 83% sales, or semiconductors, where the top companies account for more than half of all sales [6]. However, at the product segment level, the top ten manufacturers of acrylic acid, for instance, account for 82% of their market. The top ten manufacturers of organic pigments account for 77% of their market, and the top ten in flavors and fragrances for 68% [6].

The level of concentration in the industry also varies by region, with North America in general showing the highest concentration, and Asia the lowest. For acrylic acid, for example, the top four manufacturers in the United States account for the whole market. In Western Europe they account for 98% but in Asia (excluding Japan) they account for only 76% of the market. The comparable figures for the top four producers of PVC in the United States, Western Europe, and Asia (excluding Japan) are 78%, 58%, and 45% respectively [6]. There are plenty of other examples (e.g. polypropylene and polystyrene) where the Herfindahl Index, a measure of industry concentration frequently used by antitrust authorities, is rather high in North America and Western Europe. This necessarily limits the opportunities for Western players to grow by means of mergers and acquisitions in their own domestic markets. Given this structure, it is not surprising that Western players are becoming increasingly interested in acquiring Asian companies. In Asia, and China in particular, the large degree of industry fragmentation often results in sub-scale plants with fairly inefficient operations where the benefits of consolidation could be substantial.

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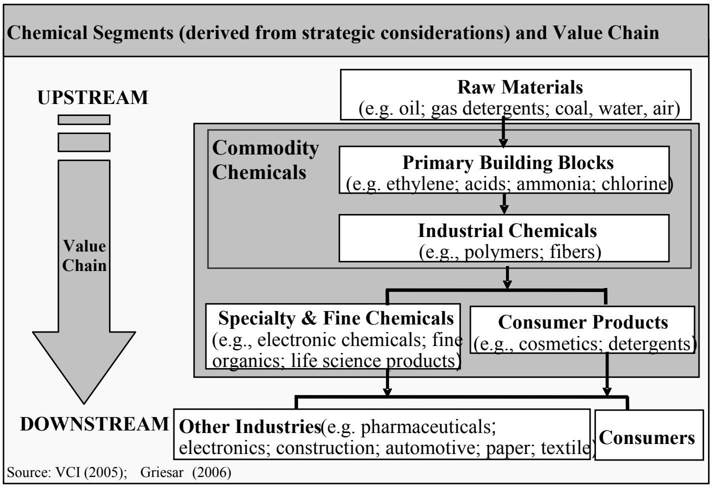

Figure 4: Chemical Segment (Derived from Strategic Considerations) and Value Chain

The EU and Chinese Chemicals Market in Comparative Perspective

Market Output and Demand. In 2007, the EU-27 was the largest global market for chemicals with 29%, followed by the United States with a 21% share, Japan with 7% and China with 15%. World chemicals production (including pharmaceuticals) was estimated at €2,4bn in 2007, and the EU-27 accounts for 31% of the total. The EU is therefore also the largest chemicals producing area in the world and the only region where output outstrips demand (see Figure 5).

In China, chemicals consumption has increased by about 15% p.a. over the past ten years, while the EU-27 and the USA posted figures of only 4% apiece and Germany merely 2% [7]. Table I shows the development of chemicals consumption and output (including pharmaceuticals) over the last years. (For chemicals demand in the period 1991-2001, no consistent set of statistical data is available)

With chemicals turnover (including pharmaceuticals) of €329bn in 2007, China has become the world's second largest chemicals producer. Only in the USA (€522bn) more chemicals were produced. In 1991, China's share of global chemicals turnover was only 3.4% [1]. In 2007, it reached 13.7%.

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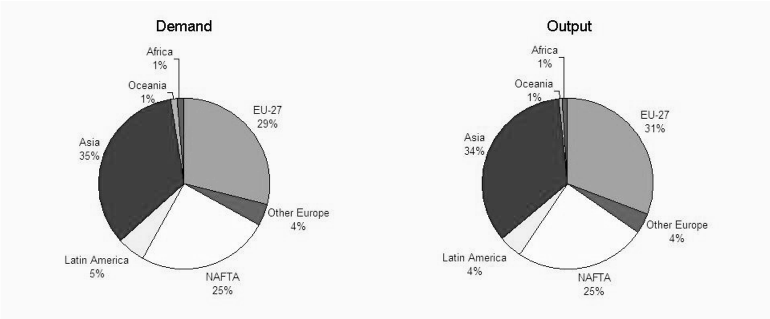

Figure 5: Chemicals Demand and Output (including Pharmaceuticals) 2007 [1]

Table I: Chemicals Demand and Turnover (including pharmaceuticals) 1991 – 2007 in EU-27, China, and Worldwide [1]

Year	Chemicals demand [€ MM]			Chemicals turnover [€ MM]		
	EU-27	China	World	EU-27	China	World
1991	–	–	–	372.019	35.627	1.024.898
1992	–	–	–	371.313	39.067	1.038.869
1993	–	–	–	366.785	51.697	1.137.504
1994	–	–	–	399.560	45.608	1.207.347
1995	–	–	–	431.763	51.179	1.269.080
1996	–	–	–	443.032	60.884	1.302.517
1997	–	–	–	481.289	72.834	1.475.459
1998	–	–	–	487.759	73.598	1.437.963
1999	–	–	–	505.973	83.768	1.550.023
2000	–	–	–	578.361	114.749	1.893.550
2001	–	–	–	589.332	126.353	1.897.532
2002	578.821	158.720	1.936.363	600.887	131.620	1.880.801
2003	574.874	173.160	1.861.764	603.333	145.119	1.814.121
2004	604.209	199.598	1.956.237	629.370	165.983	1.904.858
2005	626.197	263.459	2.182.671	655.910	227.589	2.124.917
2006	668.082	323.041	2.380.107	705.151	286.501	2.330.483
2007	709.276	363.437	2.454.327	739.672	329.318	2.402.181

International Trade. In 2007, the global total of chemicals exports was estimated at €1033bn. The EU-27 accounts for 59% of this trade, making it the biggest global player [1] (see Figure 6 and Table II). By comparison, China's low share of global exports (3.9%) reflects its minnow status in the global chemicals business and to some extent its inability to fulfil the quality requirements of global customers. However, China's relatively low share of global exports is also explained by China's increasing industrial expansion which fuels domestic demand for chemical inputs. China's already significant

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share of global imports already stands at almost 7% [1], with China's growth in imports rapidly outpacing its growth of exports in the last decade.

Table II: Chemicals turnover (excluding pharmaceuticals) 2007 [1]

Countries and regions	Industry Turnover (2007)		Trade Balance (2007)	
	Total [€ bn]	Market share	Exports [€ bn]	Imports [€ bn]
EU – 27	739,7	30.8%	612.9 (59.4%)	500 (47.1%)
NAFTA	592.2	24.7%	141.2 (13.7%)	161.2 (15.5%)
Japan	179.9	7.5%	50.7 (4.3%)	31.4 (4.0%)
China	329.3	13.7%	40.7 (3.9%)	74.8 (7.1%)
World	**2402**	**100%**	**1033**	**1061**

DB Research suggests two main reasons for China's continued inability to fulfil its domestic demand. Firstly, chemicals consumption is rising enormously as a result of rapidly expanding industrial capacity, fuelled by double-digit economic growth. Secondly, the market is demanding increasingly high-quality products that China will not be able to produce in sufficient quantities in the foreseeable future [7]

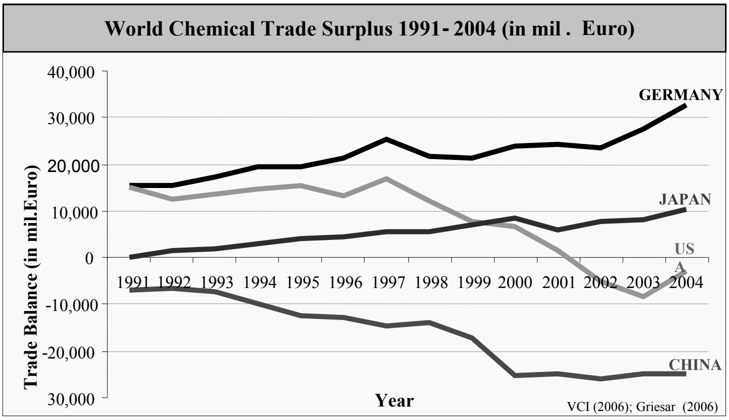

Figure 6: World Chemicals Trade Surplus for Selected Countries(1991-2004) [5, 8]

Intra-Regional Trade. Unfortunately, China's thirst for chemical inputs does not necessarily mean that China will become an attractive export destination for Europe. For commodity chemicals producers in particular, whose logistics costs such as freight and tariffs can often account for up to 30% of total costs [9], the global chemicals industry has a distinctly regional character. Even between the world's three main manufacturing regions (USA, Europe, and Japan) only limited trade flows take place relative to overall output.

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In 2003, only 10.6% of total output was shipped between these three regions (see Figure 7). Accordingly, EU-25 chemical exports to China (including pharmaceuticals) in 2005 only amounted to $5.9bn or only 1.1% of total EU chemicals output, and only 7.6% of China's total chemicals imports [8]. (Please note that the data presented in Figure 7 are based on a slightly different set of statistical data in comparison to the previously used data). To fully tap into the potential of the Chinese market, European chemicals producers will therefore have to localize production within China. Not surprisingly, inter-regional trade is particularly limited for volume products, which are relatively expensive to transport. Nevertheless, even this limited amount of inter-regional trade is sufficient to couple prices and industry cycles in the different regions worldwide. The price of basic commodity plastics, for example, has been moving in remarkable close harmony in all three regions for the last two decades of the twentieth century.

Chemical companies in the rest of Asia are becoming increasingly dependent on sales to the Chinese market. 50-80% of chemical exports from other Asian countries end up in China. As a result, China is the biggest driver of profitability for Asian chemical companies. China's influence on industry profitability in Asia will continue to grow, with the key drivers being China's self-sufficiency, trade flows, and buying patterns of Chinese plastics converters. Roughly one-third of China's oil products are imported. Around 75% of imports come from neighbouring countries like Singapore and the Republic of Korea (ROK). For example, the ROK, Japan and Taiwan together account for 66% of general-purpose resin imports to China every year. Japan, ROK, Singapore, Malaysia and Taiwan also contribute 80% of China's polyester imports. About 90% of China's styrene butadiene rubber imports came from Japan, ROK, Russia and Taiwan [10].

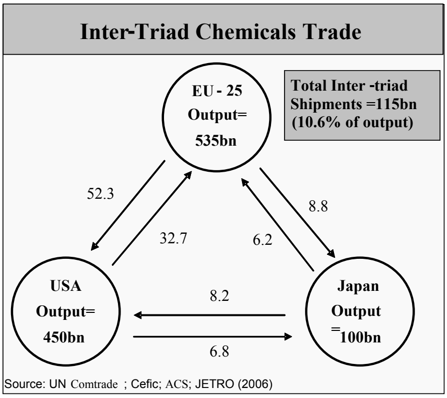

Figure 7: Inter-Triad Chemical Trade 2003 [8]

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The Chinese Chemicals Market

Chinese Market Growth and Potential. Due to the importance of geographical proximity in the chemicals industry, multinational companies are increasingly shifting chemicals activities to China, following their main clients – the automobile, electronics, communications, and textiles industries – that were attracted by Chinese sales prospects and cost advantages. This increase in demand from both foreign as well as local customer companies means that the market is estimated to grow 10% over the next decade, more than three times the growth rate of demand in markets such as the USA (3.5%) and Germany (3%). Despite increasing local production capacity from foreign as well as Chinese companies, European company BASF predicts that at least some of the increased demand will have to be made up from increased imports (see Table III) [11].

Table III: China's Chemical Production Capacity Shortfall

	2004 [$ bn]	2015 [$ bn]	CARG [%]
Local Production	**120**	**220**	**5.6**
Imports	40	120	10.5
Export	30	100	11.6
Demand	**130**	**240**	**5.7**

Chinese Market Segmentation. With basic chemicals accounting for 58% of the demand in the Chinese chemicals market, commodity chemicals are still by far the largest market segment in China with demand for fine chemicals (15%) and specialty chemicals (11%) trailing behind substantially in importance. However, DB Research predicts that over the next five years, the importance of basic chemicals relative to specialty and fine chemicals will decline substantially (a drop from 58% to 40% share of the market). Specialty chemicals in particular will grow in importance, almost doubling its current share (from 11% up to 20%). Consumer chemicals and fine chemicals will also become substantially more important (and increase 5 and 3 percentage points vis-à-vis other market segments). Figure 8 shows an overview of the Chinese chemicals market segmentation in 2003 and a 2010 estimate [7, 12].

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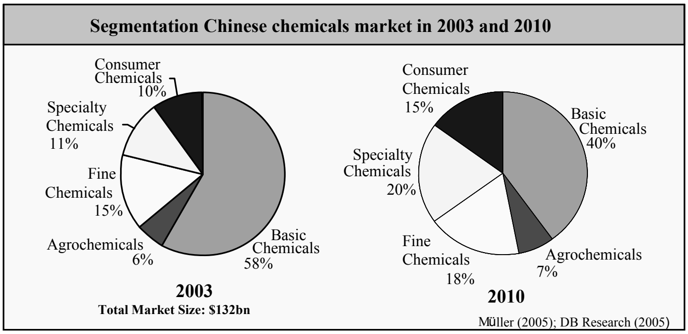

Figure 8: Segmentation of Chinese chemicals market in 2003 and 2010 [7,12]

Commodity Chemicals: Basic Chemicals, Petrochemicals & Plastics. Despite the aforementioned relative decline in the importance of commodity chemicals vis-à-vis other chemicals, commodity chemicals will continue to be by far the biggest market in China. China is changing from being a net exporter of primary materials into becoming a net importer (e.g. crude oil). Due to China's enormous economic growth, the same thing is happening in petrochemical products and starter chemicals - the raw materials for chemical products.

Basic commodity chemicals are produced in so-called cracker plants that require an investment of billions of euros. Since China is determined to establish a presence in this segment, it is assured of very high priority status. Projects of this kind have been mostly built and operated on a joint venture (JV) basis involving a foreign and a Chinese company. A production facility can take years to build, especially if one counts the planning phase and the time it takes to get the necessary licenses. The BASF, Shell and BP crackers (construction of these plants has been finalized in 2005-2006) on average have a ten-year planning phase behind them. Since no other similar production plants are in the pipeline in China apart from these three crackers, they are likely to be a very important source for supplying China's chemical industry with starter chemicals over the next ten years. With these three crackers now online, the Chinese chemical industry passed a landmark in 2005 with the start-up of three multi-billion dollar petrochemical joint ventures. BP and BASF commissioned separate JV's with Sinopec at Shanghai and Nanjing respectively, becoming the first foreign invested entities in China to produce olefins and derivatives. A third petrochemical JV, involving Shell Chemical and China National Offshore Oil Corp. (CNOOC), was also started in 2005. These three crackers added a combined 2.3 million m.t./year of ethylene capacity, increasing China's total by 37%, to 8.5 million m.t./year. This is a compound growth rate of (CAGR) 19%, versus a growth rate in domestic ethylene, one of the basic chemicals used as feedstock in the petrochemical and chemical industries, consumption of almost 11% (see Table IV).

Nevertheless, the required actual imports into China will continue to grow, albeit at a more modest level. By 2010, BASF forecasts China will import some 12.5m tons of ethylene and equivalents, up from 9.9m in 2004. At

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the same time, Chinese ethylene capacity is forecast by BASF to increase to 16m tons by 2010 (compare also Figure 9, displaying a similar prediction [14]).

Similarly most products in the petrochemical chain are likely to remain in domestic deficit well past 2010 [13] as illustrated in Table V:

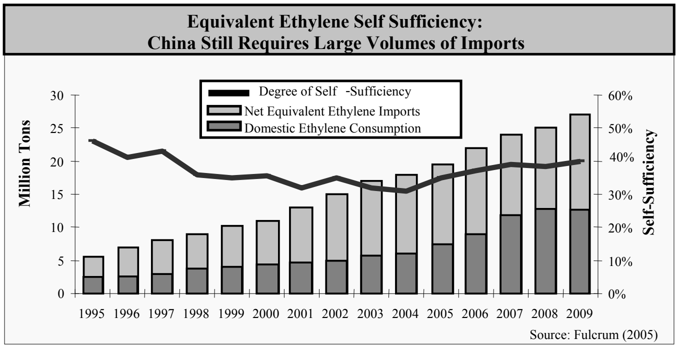

Figure 9: Ethylene Self Sufficiency in China, 1995–2009e [14]

Table IV: Chinese ethylene capacity vs. demand [13]

	2004 [m tons]	2010 [m tons]	CAGR [%]
Total Local Capacity	5,600	16,000	19.1%
Total Ethylene Demand	15,500	28,500	10.7%
Chinese Shortfall	9,900	12,500	4.0%

Plastics (Polymers). While China is the world's workshop and the major exporter for products from toys to motorcycles, it will continue to be a net importer of plastics products. The net trade deficit of China's polymers increased from $13.5bn in 1997 to $33.4bn in 2002. Because Chinese companies can take advantage of tax-breaks for polymer imports, essentially all polymers used to produce fabricated products or simple plastic products are imported. Currently, China is the world's largest polymer and chemical (monomer) importer. China accounts for approximately 45% of total Asian polymer demand, a number that is expected to exceed 50% by the end of the decade [14]. As with most chemicals, imports for polymers are mainly related with intra-regional rather than inter-regional trade. In 2004, approximately 20% of China's polymer imports came from the ROK, the largest supplier of polymers to China [14]. However, by the end of the decade the Middle East will become China's largest global supplier of polymers (Figure 10).

Plastic supply in China is expanding. In addition, domestic companies continue to expand and add capacity. In future, China should continue to drive

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polymer demand. Industry experts expect double-digit demand growth for polymers over the next few years but believe that production will not be sufficient to meet projected demand. Therefore, China should continue to be the world's largest importer of plastics.

Table V: Chinese chemical supply/demand balance basic chemicals [13]

Chemical	2005	2010
Acrylic acid	Imports	Imports
Superabsorbant Polymers	Imports	Oversupply
Butanediol	Oversupply	Oversupply
TDI	Imports	Imports
MDI	Imports	Imports
Styrene	Imports	Imports
ABS	Imports	Imports
PS	Imports	Imports
EPS	Oversupply	Oversupply
Caprolactam	Imports	Imports
PE	Imports	Imports
PP	Imports	Imports
Methylethyl Glycol	Imports	Imports

China has become the dominant world player in the process export business (products produced for the export market that use imported resins). China has been able to gain such a strong hold on the process export market because of its favorable cost position relative to other players in the global market. The perceived unfairness of this cost differential contributed to the U.S., in 2003, to enact an anti-dumping action against China targeting carrier bag imports. As an example, in order to produce a ton of HDPE bags, a Chinese converter would need to invest $103/tonne, whereas a U.S. producer would have to invest $1,740/tonne, almost 17 times more. Such low capital expenditure requirements in China promote a fragmented conversion industry that has little indebtedness and high production flexibility.

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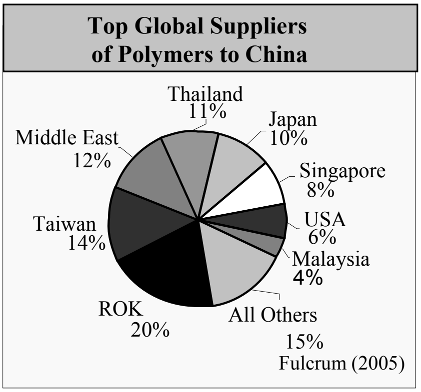

Figure 10: Top global suppliers of polymers to China, 2004(market share in %) [14]

Specialty and Consumer Chemicals. The recent years of chemical market growth in China have been dominated by meeting the demand for basic chemicals. However, as customer needs change, change in the market structure is bound to follow in the long term. Many multi-national customers such as the automotive, construction, electrical and electronics industries are investing billions to build their own production plants in China. This means that chemical companies will increasingly have to offer these customers higher-value products from further down the value chain. Major specialty chemicals sub-segments are expected to double their volume vis-à-vis other chemicals segments in the period 2003-2010 [15]. These include special chemicals needed for a large number of products like coatings, additives, adhesives, flavors, scents and pharmaceutical feedstock, all of which will continue to expand in China.

Moreover, constant optimization and upgrading in various fields of the national economy have promoted the development of a group of new industries such as environmental protection, new energy, and new materials. Table VI exhibits the future predicted Chinese demand for various specialty chemical segments. As shown in this table, all major Specialty chemicals sub-segments are expected to double their volume from 2003 to 2010 [15].

Fine Chemicals. In 2005, the Chinese fine chemicals industry had an estimated output worth around $12 billion, already representing a significant part of the world's fine chemicals industry. Total market volume is about $120m. In 2004, approximately 60% of this market was devoted to Active Pharmaceutical Ingredients (APIs) [16]. In 2004 Chinese companies already accounted for 13.1% of global market share in the merchant market for APIs, compared to a 44% share for European companies. Chinese companies are especially strong in the field of generic APIs. In this segment, in 2005, Chinese producers account for 30% of merchant trade in generic APIs, while European companies at 36% account for only a slightly higher proportion of total world trade. China is also the world's largest producer of dyes, the second-largest producer of pesticides, and the second-largest producer of composite feedstuffs [16, 17].

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Table VI: Demand of Major Fine and Specialty Chemicals for China in 2010 in 1000 tonnes) [15]

Segment	Demand In 2003 ['000 t]	Demand in 2010 ['000 t]
Coatings	2,500	4,000
Food additives	2,200	2,800 – 3,000
Feed additives	1,800	2,600 – 2,800
Paper making chemicals	n/a.	1,000 – 1,200
Adhesives	3,350	4,800 – 5,000
Plastics additives	n/a.	1,800 – 2,000
Water treatment agents	n/a.	200 - 250
Surfactants	n/a.	1,500 – 1,700

High growth rate is one obvious characteristic of the Chinese fine chemicals industry with the industry growing at an annual rate of more than 10% over the past ten years (see Figure 11). Due to China's generally strong economic growth, production relocation of multinational chemical companies, and the increasing trend among downstream manufacturers like the pharmaceuticals and agrochemicals industries to source from China (see Figure 12), it is likely that this growth rate will be maintained for the next five years.

However, China lacks the capability to produce certain fine chemicals that are required only in small amounts but are nonetheless vital to the national economy. Examples are methionine, lysine, pantothenic acid, calcium, vitamins E, A and D, L-lactic acid, behenic acid, nucleic acid, artificial sweeteners, new types of enzyme, biodegradable polymers, long-chain fatty acids and new biotech-based pesticides. Most of China's fine chemicals are currently produced in small quantities, and in relative technical and geographical isolation. This sector can only be developed if China's scientific and technological base is upgraded, especially in chemical engineering.

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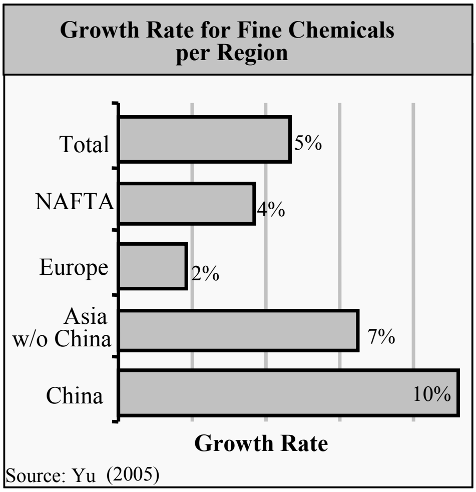

Figure 11: Growth Rate for Fine Chemicals per Region [17]

Competitive Trends in the Chemical Industry

Brief Evaluation of Global Competition. As mentioned above, the global chemical sector as a whole is traditionally very fragmented something which is beginning to change. In order to understand the broader strategic motivation of European chemical companies, this section describes the restructuring and consolidation process that has taken place during the last two decades.

In the 1990s, the chemical industry split into three parts in a bid to improve financial performance. The oil industry took over most of the petrochemicals and plastics industry elements, the pharmaceutical industry went its own way, leaving the centre ground to a core chemicals-business that are now often called specialty and fine chemicals.

In this global process of consolidation the chemical industry experienced many mergers, acquisitions and divestitures. Increasing shareholder pressure forced large broad-portfolio pharmaceutical and chemical conglomerates to re-focus their activities. As a result of this break-up process, multi-billion dollar specialty chemical companies were formed - especially in Western Europe. These structural changes in the chemical industry signalled the abandonment of business models with vertical integration and a regional focus in favour of new models that are built around core competencies with a global orientation.

Consequently, well-known names including Hoechst, Hüls, Rhộne-Poulenc, Sandoz, American Cyanamid, and Union Carbide have disappeared and their assets and organizations have been merged into other entities. Mergers created new names like Novartis, AstraZeneca, and Aventis (disappearing after being merged with Sanofi) while other parts were spun-off into new companies such as Clariant, SynQenta, Avecia, and Cognis.

Life Sciences. The life sciences concept in the mid-1990s that created Novartis and Sanofi tried to capture synergies among pharmaceuticals, pesticides, and

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agrochemicals. The strategy favored today is mergers among purely pharmaceutical companies.

Specialty Chemicals. The specialty chemicals sector, especially in Western Europe, is still going through a period of reorganization and streamlining of portfolios. Restructuring of the specialty chemicals sector has resulted in a three-tiered industry: a) mainly European mega-specialty companies, b) medium-sized diversified companies and c) focused niche players. The medium sized companies are especially challenged because they can not compete in cost with larger companies and are vulnerable from inroads by smaller, highly focused companies. Over the coming years the industry is likely to see more consolidation of medium-sized specialty chemical companies or their absorption by mega-specialty companies.

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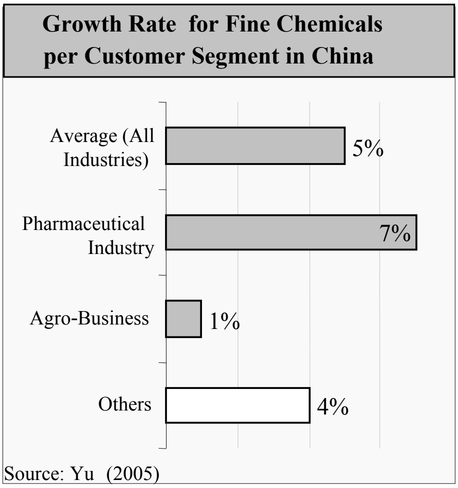

Figure 12: Growth for Fine Chemicals per Customers Segment in China [17]

Key Success Factors in Commodity Chemicals

The profitability of a typical commodity business is mainly influenced by the following factors:

- lowest cost of production (economy of scale and economy of scope)
- capacity utilization (plant and site)
- number of competitors
- oil price and price of derivatives (naphtha etc.)
- long-term access to technology
- long-term access to feedstock (petrol and gas)

After the restructuring of the chemicals industry described in the previous section, oil and gas companies, as well as chemical companies, have undertaken the manufacturing of first-generation commodity organic chemicals. The former group has gained some market share, as it often possesses a number of cost advantages that lead to greater production efficiency. Foremost among these are: security of feedstock, or the ability to integrate the chemical production into a refinery, and consequently, gain significant CAPEX advantages; and location in a deep-sea port enabling ease of transport of the end product.

Oil, gas, and chemical producers located in the Middle East and other oil-rich zones are expanding their market positions fairly rapidly, taking advantage of stranded natural gas in their locales and exporting the derived chemical products. Some Western producers have entered into joint ventures with local partners to access reserves, owned by local (state-owned) partners. Elsewhere in Asia, backward integration by Reliance and Formosa groups from chemicals to refining and exploration, as well as creation of vertically integrated oil and chemical giants in China, stand testimony to this latest trend in which organic chemical production is becoming a forte of oil companies. In response to these global trends Chinese petrochemicals companies in this sector have already made initial moves to acquire overseas capacities.

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Key Success Factors in Specialties and Consumer Chemicals

Specialty chemical companies have traditionally been viewed as small-volume, high-growth, high-margin businesses that generated high levels of predictable earnings and shareholder value. By the early 1990s, however, several factors contributed to a significant slowdown in growth of earnings, such as:

- the dependence of the specialty chemicals industry on the underlying growth of its relatively mature end-use markets such as automotive, appliances/consumer products and electronics;
- the growing competitive intensity in the specialty chemicals industry and the increasing globalization and buying power of its end-use customers;
- the commoditization of certain specialty chemicals, with low-cost manufacturers, mainly from outside Europe and North America, selling products on price rather than on performance,
- the maturity and saturation of key markets such as dyes and pigments, plastics additives, surfactants, mining and oil field chemicals, coatings, and colorants during the 1990s.
- During the last decade, the customer base of specialty chemical companies has consolidated. From their increased position of strength, the automotive, petroleum, paper, and electronic industries reduced the number of vendors serving their facilities and put extreme pricing pressure on suppliers.

Typically, competition within the specialty chemical industry is based upon product differentiation and innovation, and certain logistical issues such as distribution capacity. Specialty chemical producers often supply not just a product, but also a much broader range of services to their customers, including research, problem solving, bespoke product development, and storage solutions.

The biggest challenge of the specialty chemical giants is keeping a small-business mentality by retaining customer focus in day-to-day operations and speed of innovation, while at the same time, leveraging the advantages of greater size such as:

- greater financial muscle and greater visibility in the financial markets;
- the ability to take bigger risks when entering new markets and technologies;
- the opportunity to diversify risks and spread central costs across a range of businesses.

Increasingly, specialty chemical companies are trying to raise barriers to entry into their markets by becoming more service-oriented. They are focusing less on their products and more on the services supporting them by concentrating more on niche markets and on building exclusive relations with customers, especially with the help of e-business. As more sectors wrestle with slowing growth rates and encroaching commoditization, more specialty chemical companies increase their service portfolio to be able to offer customers more than just the chemicals needed. Service offerings include customized product development, on-site technical support, training, and supply chain management with the aim of working more closely with key customers to help improve customers' performance and reduce their costs. It is generally accepted that Chinese competitors are still weak in this area.

Key Success Factors in Fine Chemicals

While the United States represents the biggest fine chemicals market, for historic reasons the leading producers (Degussa, Lonza, DSM, etc.) are based in Europe. The merchant fine chemicals market is still a highly fragmented one with the top ten producers having a combined market share of less than 20% [17].

The following are considered the most important key success factors for the fine chemicals business:

- Customer intimacy, service-oriented approach;
- Technology tool box;
- Reputation and size;
- Development and scale-up capability;
- Efficient use of R&D, sales force, etc.

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Chinese companies have only established their international business operation for one decade, yet they already reached a 13.1% market share in the Active Pharmaceutical Ingredient Market in 2004 [16].

Competing in China

To remain competitive, direct contact between European chemicals producers and their customer companies in China are often of pivotal importance. The big chemicals companies mainly want to profit from high demand in the country and lower wage costs. Average labor costs in the Chinese chemicals sector are lower than €1 per hour, compared with about €5 in Poland and more than €20 in Germany. Furthermore, construction costs are relatively low and licensing procedures have become shorter than in Europe. Following labor-intensive sectors, the capital and knowledge intensive chemicals industry is now also increasingly investing in China. European chemicals manufacturers are currently not only establishing sites for simple production processes, but increasingly also for high-value-added products that incorporate the latest technology and R&D activities.

Market Entry. The most appropriate entry vehicles for market entry to China have changed significantly over the last 25 years, dictated both by fashion and by government legislation. Originally, foreign companies went into joint ventures with local companies, as required by law. During the 1990s, these strict requirements for foreign entry were relaxed with the introduction of the WFOE implementation regulations. A period followed during which most foreign companies tried to avoid joint ventures at all cost. With the introduction of the holding company law this allowed further options for foreign investors to consolidate their Chinese activities. Nowadays, joint-ventures are making a comeback, as more attractive private joint-venture partners appear in the market.

These trends largely hold true in the case of the chemicals industry although ownership restrictions in strategic upstream segments remain firmly in place. Another concern for industry representatives is indications in the 11th Five Year Program (FYP) that investment caps in the adjacent energy and environment sectors will remain and local content requirements for the construction of new plants will be introduced

Competing for the Chinese Market: European vs. Chinese Companies. Despite some of the obvious strengths of Chinese chemicals producers such as a lower cost base and cheap access to government funded research, there are a large number of challenges local companies must overcome if they are to compete with foreign competitors within the Chinese market, or indeed, on the world stage:

- Management is an obvious weakness of Chinese enterprises and reform efforts with the introduction of sound corporate governance systems have only just begun. It will take time to catch up with international standards in

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this regard and the volume of redundant staff remains serious despite massive lay-offs.

- In addition, the large number of Chinese players in several industry segments often results in sub-scale plants with inefficient operations. The average plant size of an acrylic acid manufacturer in China, for instance, is less than one-seventh of the average size of corresponding plants in advanced markets.
- With the notable exception of the petrochemical industry, China's chemical industry is very fragmented. The lack of critical mass of many companies makes it hard for them to compete with European or US-based multi-nationals. China has over 14,000 chemical companies of which 10,000 are privately owned and the remainder state owned [13]. However, consolidation is already underway which should increase the competitiveness of Chinese chemicals producers in the long term.

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Competition in Commodity Chemicals Sector. Domestic players in the Commodity Chemicals sector are not as competitive as North American or European players, particularly in the more complex downstream intermediates. The biggest players in the commodity chemicals market in China are the three main oil and gas companies, China National Petroleum Corporation (CNPC), China National Petrochemical Corporation (Sinopec) and China National Offshore Oil Corporation (CNOOC), all of which are still primarily owned by the Chinese government.

Multinational companies in the petrochemicals, basic chemicals, and plastics sectors compete with local counterparts on the basis of their significant ownership advantages in access to capital, technological R&D, human resources, service, distribution skills, and brands. However, the extent to which foreign companies can fully exploit their ownership advantages is limited because most foreign companies wishing to operate in these sectors have to establish a joint venture with a local partner.

The real competitive challenge for local players therefore will be to cope with higher pressure from overseas imports. Estimates show that compared with the average prices of ethylene products from neighboring countries such as Japan and ROK, domestic prices are 20 to 30% higher in China. The difference in prices is 8 to 12 percentage points down to higher manufacturing costs, 3 to 5 points to financial costs, 1 to 2 points to management costs, and 3 to 8 points in tax costs. However, most fundamentally these problems are related to the inferior size of Chinese companies' domestic facilities, most of which are sub-scale: In 2005, out of 18 ethylene plants, only seven produce more than 300,000 tons per year, compared with the world average of 750,000 tons per year [10]. Only the aforementioned recently established domestic facilitates by foreign companies such as BASF, Shell and BP can compete with imports from neighboring countries.

These companies investing in Chinese chemical capacity will have a significant advantage over companies importing into the region and will be able to displace imports, meaning that new plants should run flat-out soon after start-up. A good example is polyurethanes and polycarbonate where domestic capacity is virtually non-existent. Industry experts see no reason that this should change in the near future and it therefore leaves room for foreign companies such as Bayer and BASF to fill the supply-shortfalls in the local market. The domestic shortage of material should also mean that these plants should remain fully loaded into a downturn. The speed at which Chinese chemical producers can enhance their competitiveness, compared not only to imports, but now also with this new threat taken into account, is critical to their survival. Chinese companies will need to invest substantially to adopt the latest technology and operating practice required to operate large-scale plants. At the same time, local Chinese producers will have to leverage their natural advantages better, such as comparatively small tariffs for imports, lower transportation costs, and proximity to customers. While new Chinese ethylene plants cannot compete on costs with Middle Eastern producers, leveraging local advantages could mean they are able to compete with US, other Asian and local producers on the following basis:

1. Lower investment costs: Plants built in China cost typically 20-30% less than an equivalent plant in the US or Europe. The reason the cost savings are not higher is that much of the plant is still imported, although pumps, pipes, and valves can now be sourced locally, saving VAT and transportation costs. Construction costs are lower than in Europe and local constructors are able to finish projects on time and on budget.
2. Favorable tax treatment for investments in China. Tax regimes vary across China. However, in Jiangsu province (includes Nanjing and Caojing), foreign investors pay no tax in the first two years and thereafter half the rate for the following three years.
3. Lower personnel costs: Although these account for only a small percentage of running costs, personnel costs are significantly lower to make a difference. The annual salary for plant operators is in the region of RMB 40,000-50,000 per annum ($5,000-$6,250) compared with the $40,000 or more in the US and Europe [13]

It will be critical for China's long term competitiveness in the global marketplace to ensure that these new plants are large-scale, world-class, and able to compete with the best competitor facilities. At the same time Chinese Commodities Chemicals producers will need to take the following tough measures:

- Close small and inefficient plants;
- Cut operating costs;
- Reduce redundant staff;
- Restructure institutional inefficiencies such as corporate governance and accounting systems;
- Upgrade technologies and equipment;
- Integrate refineries and petrochemical plants with sales and distribution companies;

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- Expand sales network;
- Strengthen international cooperation.

Only a few Chinese companies such as Shanghai Petrochemical (SPC), the subsidiary of China's top refiner Sinopec, have already achieved the critical mass needed to compete against western companies. SPC, as one of the largest petrochemical companies in the PRC, follows a strategy based on its competitive advantages in economy of scale and scope.

Competition in Specialties and Consumer Chemicals. The customer base of the specialty chemical industry has experienced consolidation and globalisation. This is a competitive advantage for the big-size European specialty giants, since chemical companies with a global reach are preferred global partners of their multinational customers. As mentioned earlier, multinational specialty chemical companies are trying to raise barriers to entry into their markets by becoming more service oriented. They are focusing less on their products and more on the services supporting them by concentrating on niche markets and on building exclusive relations with customers, especially with the help of e-business.

Since China has focused mostly on developing basic feedstock industries in the past, the growth potential for specialty chemicals is especially high. This is why most players in the specialty chemicals field (mainly European companies) have moved aggressively in the last few years to establish themselves in China. China is a particularly attractive destination for chemical specialties to invest, as their production tends to be relatively labor-intensive, while the increasing availability of a well-educated academic workforce also makes establishing local and regional service centers an attractive proposition.

European specialty chemicals are in an advantageous position since their products are usually not made to specification. In other words they offer tailor-made solutions for customers. Products like specialty chemicals, which contain a strong service component, are not as prone to local competition, since local companies tend to lack prerequisites. Since domestic manufacturers in many cases do not fully satisfy the quality standards required for exports, foreign companies have good opportunities in this market although Chinese competitors will try to improve their competitive position by increasing their:

- End-user experience;
- international R&D backup and an R&D pipeline;
- Experience with value selling;
- International sales networks and leverage thereof.

A possible strategy in achieving these capabilities is the acquisition of foreign companies. In January 2006, for example, ChemChina's subsidiary, China National BlueStar Group Corporation took over Franco-Belgian Adisseo Group, the largest animal nutrition supplement producer in the world. It is the first case of a Chinese enterprise acquiring an overseas company in the field.

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Competition in Fine Chemicals. There are as many as 20,000 producers in China capable of manufacturing fine chemicals. However, most of them have very poor technological competence and production capabilities by European standards, with only some 500 possessing GMP-certified production plants. Chinese fine chemicals producers typically concentrate on producing basic intermediates and active ingredients for pharmaceutical and agrochemical industries in China. The technology and equipment used in China's fine chemical industry is 15–20 years behind that of advanced economies. Hydrogenation, continuous nitration, cold nitration and sulfonation using liquid sulfur trioxide have not been adopted on a large scale. The use of automation and distributed control also falls far short of that in developed countries. Many products in the newer fields of technology - such as functional polymers, fine ceramics, liquid crystals, information chemistry and nanomaterials - are very weak in China.

In the last five years numerous investments have been made and new companies have been established and built up. The average company has sales of less than $10 million and under 1,000 employees, although some companies have a turnover exceeding $50 million with focus on the more attractive European and U.S. markets. Nevertheless these companies struggle to be competitive due to a lack of scientific research and pollution management. The Chinese local fine chemicals market is extremely price-driven and this situation will remain in the future. Consequently strategies targeted to achieve product differentiation, which play a key role when entering into foreign markets (e.g. improving marketing and sales competence or boosting the exchange in information) will not be important even for the next ten years.

As in the case of specialty chemicals, fine chemical multinationals with a global reach are likely to become partners of choice for their multinational customers. However, in selected market segments, European custom synthesis or building blocks suppliers face aggressive competition from China as their Chinese competitors are in a superior cost position for the following reasons:

- Access to low-cost research at universities and institutes;
- Low labour costs, which are especially important in labour-intensive custom synthesis/ building;
- Blocks, where production runs are usually small and labor intensive;
- access to low-cost engineering;
- Low capital requirements.

Even in their home markets, European custom synthesis or building blocks suppliers, face aggressive competition from China. The situation in the Chinese market is even worse and European Fine Chemical manufacturers particularly in the area of (Generic) Active Pharmaceutical Ingredients are already loosing significant market share against Chinese competitors.

Today the fine chemicals market in general still offers attractive margins. It is important to emphasize that the variable costs (raw materials and utilities) for Chinese players are often more or less comparable to those of producers in advanced countries. However, European players in particular suffer from very

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high fixed costs as their plants' operation rates are currently low and wages are significantly higher than in China. Many European companies maintain a significant marketing staff and R&D capacity as additional services to defend their market position. These cost positions are justified by relatively higher margins, although it is questionable to what extent the market will continue to pay for these higher prices. Due to the aforementioned “free research” that Chinese competitors obtain from local educational institutions, they usually do not have to bear these costs, or the relevant costs are significantly lower compared with their European peers.

These lower costs compensate in many cases the cost advantages derived from the advanced technologies of Western companies. However, low investment, low-cost and often low-tech production also result in very low entry barriers for other new emerging competitors in China. Very often, as soon as the margin for one specific product becomes attractive enough, too much new investment is initiated. This can lead to a dramatic overcapacity and fierce price competition for this specific product. Many of these new Chinese companies manage to have quite attractive margins at first, but the companies often have a very weak cash position as the investments have been financed to a large extent by bank loans with high financing costs. In the event of possible price erosion or other market turbulence, a company will face real financial problems. Furthermore, in the fine chemicals segment which has a large service element, newcomers lack the business relationships and customer knowledge essential to raise entry barriers for potential competitors.

Detailed Strengths-Weaknesses-Opportunities-Threats (SWOT) analyses comparing the position of European and Chinese chemical companies are presented in Chart I.

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Chart I

Strengths	**Weaknesses**
• Growth in chemicals demand in recent years: CAGR 10+ percent • China No. 2 chemical market worldwide behind the US • Main clients of chemical shifted business activities to China - attracted by the Chinese sales prospects and cost advantages • High competitiveness of domestic capacity: 1) Lower investment costs in China; 2) Lower personnel costs; 3) Favorable tax treatment	• Commodity-type chemicals dominate: Basic chemicals (including plastics & polymers) share about 60% • Environment problems • Poor logistics: Insufficient freight capacity and poor road and rail infrastructure • Power shortage; especially electricity-intensive sectors such as chlor-alkali and PVC are affected
Opportunities	**Threats**
• Chinese demand will grow at 5.5%, almost twice the growth rate of global chemical demand • Import growth 10%, since domestic capacity build-up not fast enough to keep up with the growth in local demand • Markets for specialty chemicals, consumer chemicals and fine chemicals will show strong growth • Chinese domestic production base will benefit from governmental decision to crack down on certain chemical products (in order to avoid overheating of economy)	• Legislation regarding manufacture and import of new chemical substances does not provide for intermediate notification requirements → data requirements for low volume chemicals are extremely restrictive (even for sending samples) → restricted introduction of new technologies & new substances • Labor shortage for chemical companies in some costal areas

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Chart I (Continued)

Strengths	**Weaknesses**
• Technology • Global customer base • International sales & marketing network • Economy-of-scale • Locations in areas of good logistics (Caojing and Nanjing sites)	• Unfavorable labor cost position • Costs due to high environmental standards in Europe
Opportunities in the Chinese market	**Threats in the Chinese market**
• Participating from domestic growth (see "The Chinese chemicals markets/ strengths") • Acquisition opportunities due to consolidation in Chinese chemical industry • Growing imports into China (CAGR 10%) • Reduced obstacles for chemicals imports since 2001. Import tariffs reduced from 15% to about 4-7%. (Nevertheless, given the huge size of China's chemical market and the high competitiveness of Chinas local production, import tariffs are considered as still relatively high) • Local governments in China competing fiercely to attract foreign investment • Favorable tax treatment for investments in China: No tax in the first 2 years in Jiangsu province (includes Nanjing and Caojing); half the rate for the following three years) • Timing for approvals might no longer be a major issue: More authority for local authorities to approve foreign investment projects. Time will show, however, whether this will really lead to a speed-up in project approvals. • Expansion of higher environmental standards would favor European chemical makers in China	• Chinese companies will become larger and more competitive • Long delays to chemical investment projects by overseas companies in China, caused by government bureaucracy and inefficiency • Very strict environmental standards for foreign investments; whereas provincial and local governments still try to help local industries • Divergence of regulatory schemes used to assure the protection of safety, health and environment • Poor IPR compliance of Chinese competitors **Threats in international markets from Chinese competitors** • Poor IPR compliance of Chinese competitors • As regards anti-dumping measures taken by the EU, chemicals are one of the most affected sectors (22% of total cases); as regards the main targeted countries, China is at the top of the place-list of countries affected by Cefic complaints • Threats due to increased competitiveness of Chinese competitors: for fine chemicals already existing; for specialty chemicals: threats in the mid-term; for basic chemicals companies: threats in the long term

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Chart I (Continued)

<table>
<tr><th>Strengths</th><th>Weaknesses</th></tr>
<tr><td>• Advantage labor costs
• Access to low-cost technology and low cost R&D</td><td>• Most Chinese companies have sub-scale plants with fairly inefficient operations
• Management is often a weakness</td></tr>
<tr><th>Opportunities in the Chinese market</th><th>Threats in the Chinese market</th></tr>
<tr><td>• Participating from domestic growth (see “The Chinese chemicals markets / Strengths”)</td><td rowspan="3">• Increased operational costs for Chinese companies due to recently introduced safety requirements; some poorer performing companies forced to reduce certain economic activities
• Chinese competitors forced to invest in expensive environmental abatement equipment (result of increased government control)
• Government decided to crack down on certain chemical products (hazardous) and investment in less efficient and smaller-sized chemical plants (in order to avoid overheating of economy)</td></tr>
<tr><th>Opportunities in international markets</th></tr>
<tr><td>• Opportunities exist especially for Chinese companies from fine chemicals sub-sector, in the mid-term also for companies from the specialty chemicals sub-sector</td></tr>
</table>

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Chart I (Continued)

Strengths	**Weaknesses**
• Huge demand for polymers, driven by domestic consumption and Chinas process export business • Huge demand for basic chemicals	• Overcapacity for selected polymers such as polyethylene terephthalate (PET)
Opportunities	**Threats**
• China will continue to be a net importer for polymers and basic chemicals	• See under "Chemical industry – general aspects"
Strengths	**Weaknesses**
• Consolidation led to 3 strong Chinese petrochemical players • Major petrochemical players such as Sinopec progressed considerably in the past few years	• Lack of economy-of-scale • World-scale plants of Chinese basic chemical manufactures are based on JVs with Western Partners. • Even technology leader Shanghai Petrochemical, has only 5% of its revenues from exports • Domestic prices are 20 to 30 percent higher compared with the average prices of ethylene products from neighboring countries like Japan and ROK (no valid for the new JVs) • No substantial domestic players in TDI, MDI or polycarbonate - despite strong domestic demand
Opportunities in the Chinese market	**Threats in the Chinese market**
• Consolidation of Chinese basic chemical industry (efficiency and profitability up to international standards): Cost cutting, M&A deals • Chinese basic chemical manufactures will be able to set-up world-scale plants on their own	• Higher pressure from overseas companies which have recently invested in China. Chinese companies as domestic facilities are mostly sub-scale. • Chinese electricity-intensive sectors such as chlor-alkali and PVC affected from power shortages

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Chart I (Continued)

Strengths	**Weaknesses**
• Annual growth rate of Chinese fine chemicals market 10%	• Low entry barriers for new emerging competitors due to low investment, low-cost and often low-tech production • Dramatic overcapacity and fierce price competition • Highly fragmented industry
Opportunities	**Threats**
• Growth rate of 10% will continue	• See under "Chemical industry – general aspects • Market will continue to be extremely price-driven. Strategies targeted to achieve product differentiation not be important even for the next ten years
Strengths	**Weaknesses**
• European companies are global leaders (Degussa, Lonza, DSM etc.) • Technology competence	• See under "Chemical industry – general aspects" • Unfavorable Labor cost position (R&D, marketing)
Opportunities in the Chinese market	**Threats in the Chinese market**
• Acquisition opportunities for European fine Chemical companies due to industry consolidation	• Increased competitiveness of Chinese competitors **Threats in international markets from Chinese competitors** • Even in their home markets, European custom synthesis or building blocks suppliers, face aggressive competition from China

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Chart I (Continued)

Strengths	**Weaknesses**
• Superior cost position for the following reasons: access to low-cost research at universities and institutes; low labor costs, (especially important in custom synthesis/ building blocks, where production runs are usually small and labor intensive); access to low-cost engineering; low capital requirements. • Recent competitiveness improvements: improving marketing, implementing an IT platform, upgrading technology competence) • Knowledge of local niche markets	• Lack of track record • Barriers to build business relationships (different business and cultural practices) • Reliability of supply is still low
Opportunities in the Chinese market	**Threats in the Chinese market**
• Benefit from 10% growth in domestic market	• See under "Chemical industry – general aspects"
Opportunities in international markets	**Threats in international markets**
• improve competitive position by acquisitions	• None identified

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Conclusion: Changes, Challenges, and Choices

This paper has attempted to identify the key determinants and larger global trends, as well as indigenous factors which will affect the development of the Chinese chemicals industry and opportunities for European players. As the Chinese chemicals industry gains importance it will increasingly affect global trends as well. The development of China's chemicals industry will be mainly driven by China's drive for self-sufficiency, as well as the importance of geographical proximity, which requires the European chemicals industry to locate close to their customers.

The future competitiveness of China's chemicals producers will depend on China's ability to reform its industrial structure through privatization and consolidation. In some segments, the specialty and fine chemicals industry in particular, companies will have to go through an industrial reformation process similar to that experienced in Europe during the 1990s. A focus on core competencies and raising entry barriers by locking in customer networks are key areas which need to be developed by Chinese players. Provided a more secure institutional framework is established which is flexible and adequately protects investor's rights, exciting new opportunities for cooperation between established European players, and emerging local companies might come to the fore. Future cooperation between European and local companies would help to achieve

China's desire for increased self-sufficiency in key commodity chemicals and higher value added activities in downstream segments.

The European chemical sector is the world leader in terms of energy efficiency, environmental management and the development of renewable materials. European chemical companies would therefore clearly gain a competitive edge if Chinese authorities would increase stringency of enforcement to comply with environmental standards in order to avoid pollution and wasting of resources. Moreover, a higher degree of environmental regulation in China would create business opportunities for the European chemical companies. In this context however, a primary obstacle to the introduction to the latest technology is down to a lack of IP protection.

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Chapter 4

China's Rapid Progress Up the Value Chain

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In this essay we describe how China is moving deliberately and rapidly from a low value-added to a high value-added industrial base. In broad terms, we examine two critical threads of development which support this trend - the role of central planning as manifested in the 'Five Year Plans', and the profound shift to the private sector. In this context we look at key drivers including Special Economic Zones and the contribution of foreign investment. We are especially interested in China's emphasis on innovation and the corresponding rise of entrepreneurship. The use of tax incentives and revaluation of the Yuan are also addressed. Finally, we review the rising strength of R&D and education in China. The concluding comments focus on the increasing interdependence of China and the US and contend that this relationship will increasingly become the most important in the world.

"So in 30 years we have gone from 'sold in China' to 'made in China' to 'designed in China' to 'dreamed up in China.' "

- Thomas Friedman, *The World is Flat*

By now nearly everyone is familiar with China's unbelievable economic growth since the great "Opening Up" in 1979. What is less well known is how China is rapidly building a high value-added industrial base while it maintains its global manufacturing dominance. This combination of both high

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tech and traditional manufacturing gives China a powerful and, so far, unique position in the global marketplace.

The Special Role of "Special Economic Zones" (SEZs)

For most of the 1980s, China's infrastructure was very weak, although growing fast. There was little to offer foreign investors, and those foreign investors who sallied forth in those days did so based on the huge market potential and a belief that there was no turning back for China, but little else. When you spoke to Chinese managers in those days, the first words from their mouths were almost always "joint venture," and the formulas for the proposed JVs were monotonously similar: the Chinese side offered in-kind contributions of workshops and cheap labor in return for investment, know-how, and markets from the foreign company.

To this formula the Chinese government added what turned out to be brilliant strategic and financial support. Beginning in Shenzhen, opposite Hong Kong, which was the traditional access point to the mainland, the central government set up Special Economic Zones (SEZs) where foreign investment could be focused, supported, and used as learning tool. These SEZs became the backbone of growth and technical development for China. They rapidly diversified to include science and technology parks, university science parks, technology business incubators, etc. The major SEZs included a central administrative staff to work with investors on everything from establishing legal entities to dealing with customs and the tax bureaus. Frankly, the management staff was primitive at the beginning. But they gained rapidly in sophistication to the point that, today, SEZs like the Tianjin Economic & Technical Development Area (TEDA) and the Suzhou Industrial Park (SIP) are world class organizations. Staffs go through a rigorous screening process; they tend to be young, very bright, and very proud of their region's accomplishments and their role in that development.

What really made the SEZs effective, however, were favorable tax policies. In general, *any* - repeat *any* - foreign investor in a manufacturing concern paid no taxes for its first two profitable years, and then was taxed at half the normal rate, or 15%, for the next three years. There was no distinction made between GE turbines or a badly polluting electroplater. They were not so concerned about "good corporate citizens." Moreover, if you were classified as "high tech," you could obtain additional years of favorable tax breaks, and SEZs used this liberally to compete.

Provincial governments and municipalities followed the central government's initiatives and began to set up their own SEZs as well, and often these local and regional SEZs offered additional tax and other incentives to investors. So you ended up with a matrix of national, provincial, and local SEZs vying for the attention of foreign investors.

It worked extremely well. Today Shenzhen – which was a sleepy country town of around 20,000 people – is the size of New York City. By 2005, China had well over a half million resident foreign invested enterprises (FIEs), up from basically none under Mao in the 1970s. Around 2006, China became

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the world's #1 target for foreign direct investment (FDI), attracting over $1 billion *per week***.** In addition, FIEs accounted for

- 35% of industrial output, up from 2.3% in 1991
- Controlling assets of 21 of 28 leading industrial sectors
- Over 20% of China's tax revenues
- 25 million employees (10% of urban workforce)
- Some 750 foreign R&D Centers in 2005
- *60%-plus of exports out of China*

The export data are shown in Figure 1 and illustrate clearly the contribution of FIEs. (They also sound a note of caution for those who fear "China exports", since some 60% of such exports are from our own companies which have established operations there in order to bring down costs and increase shareholder value.)

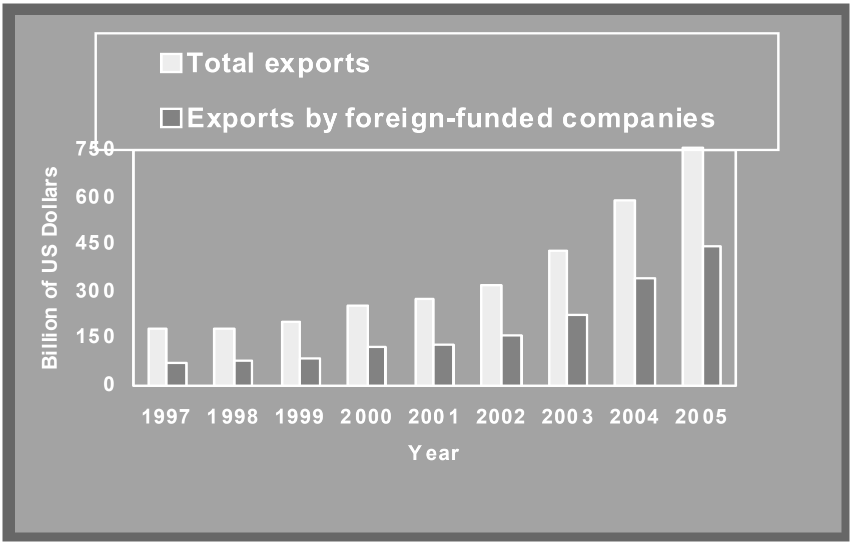

Figure 1: Export Ratio of FIEs in China[1]

To be sure, there were many macroeconomic forces at work that made this investment migration feasible, but the SEZs were the great facilitators. China simply did its best to make it "easy" to invest, and it paid off big time.

Figure 2 gives us another view of the export picture. It shows both the dramatic growth of high-tech exports and the ratio to all exports. It is clear that while China remains the world's major producer and exported of shoes, clothes, toys, etc., it is also rapidly becoming the world's largest technology exporter. Much of this export is by foreign firms in terms of both volume and ratio, as is shown in Figure 1 and 2. Note especially the bottom of figure 2, where wholly foreign owned enterprises and JVs account for over 90% of all technology exports. Nevertheless, increasing amounts are coming from Chinese firms like Lenovo, Haier, Huawei, TCL and others.

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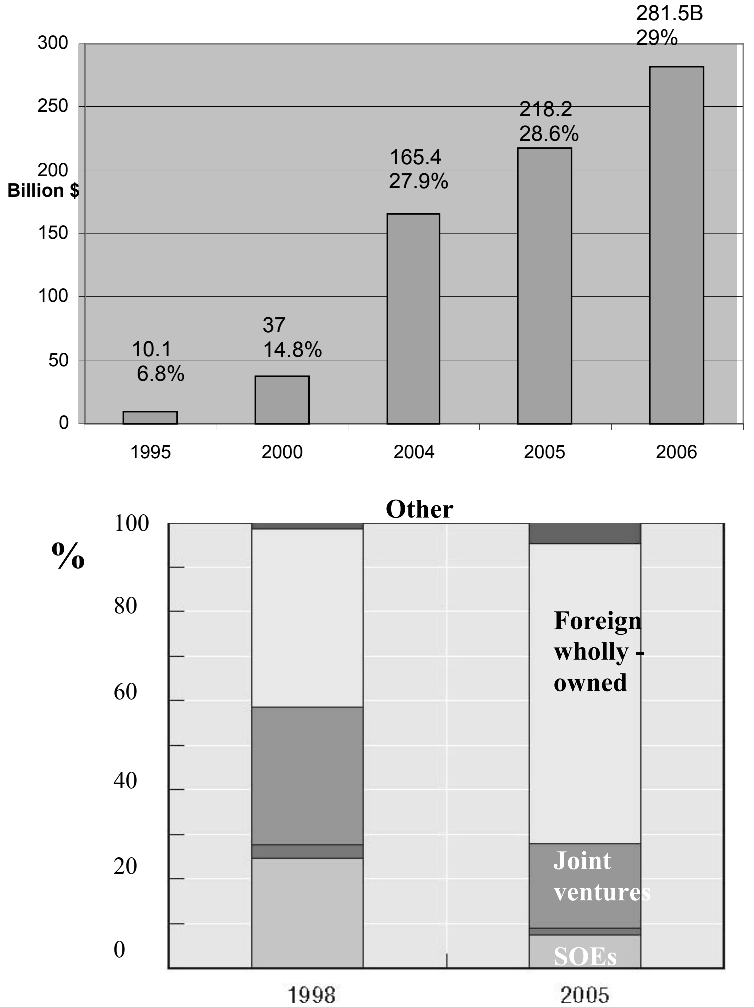

Figure 2. Export Growth of High Tech Products (top) and Ratio (%) of Exports by Source (bottom)[2]

One of the first places to look for the move up the value chain is obviously, therefore, the SEZs. But let us first view the evolution of the SEZs in the larger context of China's critically important 'Five Year Plans'.

China's Five Year Plans

China is a strange hybrid of both a planned and a market economy and it is not easy to understand. Suffice it to say here that China has moved significantly toward a free market, but guides that development to help protect

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its strategic interests and growth. This guidance is both macroeconomic and, to a degree, microeconomic, for it backs policy goals with financial support to help companies implement changes.

Every five years, the government debates, prepares and adopts a development plan for the next five years, the so-called "five-year plan." It covers the whole economy and generally includes goals, broad support policies, investment policies, and a great number of indexes by which to measure progress. Further, based on this macroeconomic plan, the National Development and Reform Commission (NDRC) prepares related five-year plans for every single industry. The central state-owned enterprises (SOEs), banks, funds, etc. invest in projects according to these plans. As China shifts to a market economy, the five-year plans are not as important as they used to be in many industries. Market forces increasingly tend to be greater drivers than "planning." But in some industries, they are still the key drivers. These include fundamental industries such as energy, power, and communication. Heavy investment is usually required in order to achieve the goals of the plans. So while the government requires companies to invest in new projects, the companies also enjoy favorable policies such as low tax rates, inexpensive money from policy banks, etc. and even co-investment.

This powerful planning tool was behind China's rise as a manufacturing powerhouse, setting policy, investment targets, production goals, support mechanisms, etc. In this context, the '11th Five Year Plan', the most recent one for 2006-2010, clearly illustrates China's intention to move up the value chain. Its goals and programs are not secret and are plainly stated in the Plan. Mr. Ma Kai, Minister of NDRC made the plan's intent clear when he said, "We regard the enhancement of independent innovation capability as the central link and will promote market-oriented & enterprise-led innovation" Here are some key examples noted by Mr. Kai:

- Shift the dominant feature of foreign trade from "quantitative to qualitative growth"
- Key policy focus: Develop technology-led sectors and high-value capabilities, while maintaining the manufacturing base:
  - Increase R&D spending from 1.3% of GDP in 2005 to 2% by 2010 and 2.5% by 2020
  - Targets include biotechnology, nanotechnology, renewable energy, etc.
    - IC research – nano circuits and smaller
    - Biomedicine - major biotech centers in Beijing and Tianjin, etc.
    - Civil aircraft
    - Satellite applications
    - New materials
  - Tax equalization between FIEs and domestic firms
  - 150% deduction for qualified R&D expenditures
  - Spend 4% of GDP on education
- Emphasize support for science and technology education, entrepreneurship:

We will look at a number of these items in more detail. But we first return to the SEZs. As of 2007, the tax incentive structure for foreign investors was terminated by the central government and a uniform tax of 25% was

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adopted for both foreign and domestic companies. The across-the-board tax breaks are gone. However, in support of the Plan, the tax incentives were kept alive but shifted to support high value added companies – software development, business process outsourcing, R&D centers, financial services, and high tech.[3] In other words, if you just want to set up another manufacturing operation to take advantage of cheap labor, you are welcome to do so, but there are no longer any government incentives to do so. The incentives have gone to upstream industries.

Here's how the Tianjin Economic Development Area (TEDA) and the Suzhou Industrial Park (SIP) have adjusted to accommodate the 11th Five Year Plan. We'll start with some summary bullets for TEDA:

- 4% of TEDA income will be set aside for development of research institutes and high-tech enterprises.
- High tech businesses will be exempt from value-added tax (VAT), business tax, and income tax for three years and then pay half of the normal 25% tax for the next five years.
- Software enterprises will be exempt from VAT, business tax and income tax for five years and then pay half for another five years.
- Industrialized patents in TEDA can be reimbursed at a rate of 50% of patent application and annual fees.
- Projects supported by the National Innovation Fund for Medium and Small Size Enterprises will receive matching funds from a special TEDA fund
- A one million Yuan (about $150,000) seed fund has been established for high-tech startup companies
- 300,000 RMB per company is available to support IPOs
- Favorable rents and energy allowances

Similarly, a medium sized medical software company recently approached SIP about setting up its first China operation, and here is what SIP offered:

- 200,000 RMB start-up subsidy
- 15% corporate tax rate
- 100% tax exemption on revenue from offshore outsourcing
- Qualified key technical personnel may receive salary subsidies ranging from RMB1000 to 3000/month/person
- Key technical personnel get priority access to lease government subsidized apartments - about 70% of the market price.
- Training subsidy for employees of RMB 4500/person.
- Rent exemption for certain space. 2nd year rent at half price.
- 400,000 to 1 million RMB for getting CMM/CMMI certification
- RMB 0.20 for every USD of export value for pure software products

You can also see this shift in the new *Catalog Guiding Foreign Investment in Industry*. This catalog is issued by the central government every few years and lists three investment categories: encouraged, restricted and prohibited. Zero2IPO Research Center did a simple but revealing comparison of

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selected investment categories in the 2004 and 2007 catalog, as shown in Figure 3.

Table 1 Comparison of the entries of the old and new versions "Catalogue for the Guidance of Foreign Investment Industries"						
Entries Involved	The 2007 Amended Version			The 2004 Amended Version		
	Encouraged	Restricted	Prohibited	Encouraged	Restricted	Prohibited
Mining industry	9	8	3	11	6	2
Pharmaceutical manufacturing	16	6	2	16	6	2
Non-metal mineral manufacturing	20	--	--	9	--	--
General machinery manufacturing	19			7	3	--
Special equipment manufacturing	71	3	1	42	3	--
Traffic & transport equipment manufacturing	26	1	--	17	--	--
Chemical materials and chemical products manufacturing	26	10	--	25	7	--
Communication equipment, computer and other electronic equipment manufacturing	35	2	--	30	1	--
Manufacturing of instruments & meters, culture and machinery for office purpose	18	--	--	8	--	--
…	…	…	…	…	…	…
Total	**351**	**87**	**40**	**257**	**78**	**35**

Source: Zero2IPO Research Center

Figure 3. Comparative Catalogs for Guiding Foreign Investment in China

The number of 'encouraged' investment categories jumped from 257 to 351, or 37%, while the number of 'restricted' and 'prohibited' categories changed little. More important, most of the encouraged categories relate to high-end manufacturing, not toys, clothing or Christmas tree ornaments.

Pressure from VAT Rebate Policy and Yuan Revaluation

There is a price to be paid for this policy shift away from basic manufacturing. Throughout the '90s and in the first half of this decade, domestic Chinese exporters became a formidable challenge in certain areas of the global market. The government provided strong export incentives to companies, especially though the VAT rebate program. The value added tax is 17% in China. But if you exported your final product, you received a 100% VAT rebate for most product categories. This rebate was so significant that many companies exported *below cost*, and then counted on their profit from the rebate.

Our company worked with many US companies that were trying to develop an 'engagement strategy' to deal with the flood of imports, many of very high quality, during this time. One, for example, was a producer of cast iron soil pipe. The company had seen imported product coming into the US from China at prices 20% to 30% lower than domestic prices. It seemed there was no way to stop this market and price erosion. Yet when China began to reverse the

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VAT rebate program the whole landscape changed very quickly. Kurt Winter, the then CEO of the company, summed the situation up aptly:

"The low-margin, low labor commodity game is over. Since our visit [in 2006], Chinese market share of soil pipe and fittings has been halved in the US. The Chinese manufacturers have lost most/if not all of their rebates and the net effect is a pretty level playing field for us, which we are confident in the fact we can kick ass. The commodity game is over"[4]

The scenario was similar in other industries. Conversely, however, the impact in China has been heavy. Margins in the domestic market are a fraction of what they are for exports, so domestic producers get squeezed. Moreover, as a result of the huge balance of trade surpluses, China's trading partners have pressured it to, among other things, revalue the Yuan. China responded positively, if not as dramatically as the US would have liked, and as of 2008 the Yuan had appreciated some 18%, from 8.3 to about 6.8 to the dollar. This greatly stimulated imports and added to the pressures on Chinese companies.

We can be sure that these pressures – elimination of VAT rebates and Yuan revaluation – were very carefully considered by Chinese authorities, as the effects of contracting exports can have serious economic and social results, unemployment being one of the most fearful. In fact, many low tech companies, such as toy companies, have been forced to close their doors because of the elimination of the rebates and declining export demand due to both the Yuan revaluation and the larger, global financial crisis. The government has even brought back some rebates to try to stem the growing unemployment. It is a difficult balancing act. But these pressures have a positive side as well. They pressure Chinese companies to move into the higher value-added businesses – just as intended by the government.

Shift to the Private Sector

When the great "opening up" began, the environment was essentially hostile to private enterprise. Under Mao, there was basically no private enterprise of any importance, and active hostility to the idea of private ownership and wealth. This makes all the more amazing the transformation to an economy driven by the private sector and strongly supportive of entrepreneurial innovation. We begin with an overview of this trend, and then drill down a bit into entrepreneurial development and support and education and training.

The trend toward private enterprise in China, as shown in Table I, is key to understanding China. We have taken just three years of data for comparison, available from China's statistical yearbooks and include the most recent data of 2006. We have done the best we can to compare apples and apples, but this cannot be guaranteed 100%, as qualifying footnotes in the Statistical Yearbooks are not always the best. In this case we are comparing only what is referred to as "Industrial Enterprises." Still, the trends are strong and clear and the same patterns can be seen in other sources.

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Table I. Trends in State-owned & Private Enterprise in China[5]

Year	# State-Owned & Holding Co's (% Change)	# Private Enterprises (% Change)	State-Owned Output Value (% Change)	Private Output Value (% Change)	State-Owned Employment (% Change)	Private Employment (% Change)
1998	64,737	10,667	33,621	2,083	37,477,800	1,608,000
2002	41,125 (-36%)	49,176 (+360%)	45,179 (+35%)	12,951 (+500%)	24,236,300 (-35%)	7,329,000 (+356%)
2006	24,961 (-39%)	149,736 (+204%)	98,910 (+119%)	67,240 (+419%)	18,040,000 (-25%)	19,710,100 (+170%)

There are many observations to be made about these data. To begin, note the time frame - just eight years, from 1998 to 2006. This is a very short period of time, which only amplifies the underlying trends.

First, the sheer number of state-owned companies (SOEs) fell by over 60% during this period, from 64,737 to 24,961. This was a direct result of government policy aimed at unloading unproductive SOEs and consolidating others. State asset management companies were formed to manage this daunting divestiture. Many SOEs had become complete social systems in themselves. They had their own dormitories, day care centers, schools and even hospitals. And once you were on the payroll, you never got off. So payrolls were crowded with people long retired, making it difficult to attract any new talent. Equipment and processes were obsolete and there was little or no incentive to upgrade. And there was the famous “triangle debt”: a company borrowed from the bank, received credit from suppliers, and extended credit to buyers – and on and on it went. Although there was great worry about social unrest and rising unemployment that would result, the government saw no other path of escape from the crushing burden created by so many of these SOEs. They bit the bullet and started calling buyers, packaging and selling these debt burdened assets as best they could.

As a result, employment in SOEs fell in half during this period, from about 37 million to about 18 million – a huge loss. But we also see the remarkable fact that SOE output value actually went *up dramatically*, not down as one might suspect. This was a result of consolidation, strategic investments in upgrading certain backbone industries (energy, power generation, communications, etc.), and increased productivity learned in part at least from the West. In power equipment, for example, all of the major turbine and boiler manufacturers have old alliances with foreign companies from whom they have learned both technology and efficient management. Take power equipment companies as an example. All of the top OEMs use foreign technical designs. Harbin Boiler Works cooperates with Mitsubishi Heavy Industry, Shanghai Boiler Works collaborates with Alstom and Siemens, Beijing Boiler Works is a joint venture with Babcock & Wilcox, Wuhan Boiler Works is held by Alstom, and so on. These companies are now very strong and selling excellent equipment globally. Much of India’s rapid infrastructure growth, for example, is being powered by equipment from Chinese companies.

At the same time, the state got a big boost from growth in the private sector. In fact, although this growth was supported by policy, the result was perhaps a good deal more then they either planned or expected – a windfall. In the same period under consideration, the sheer number of registered private companies rose nearly 14 fold from 10,667 to nearly 150,000. Moreover, private sector employment grew even faster, from just about 1.6 million to an

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incredible 19.7 million – slightly greater than the 19.4 million jobs *lost* in the SOEs. So by some obscure alchemy combining careful planning, good timing and great luck, the deliberate demise of the SOEs has worked out quite well for China.

The OECD looked at these same issues and came to very similar conclusions. In the Figure 4[6] below, we look only at comparison ratios instead of absolute numbers for just two years, 1998 and 2003, and the results are the same.

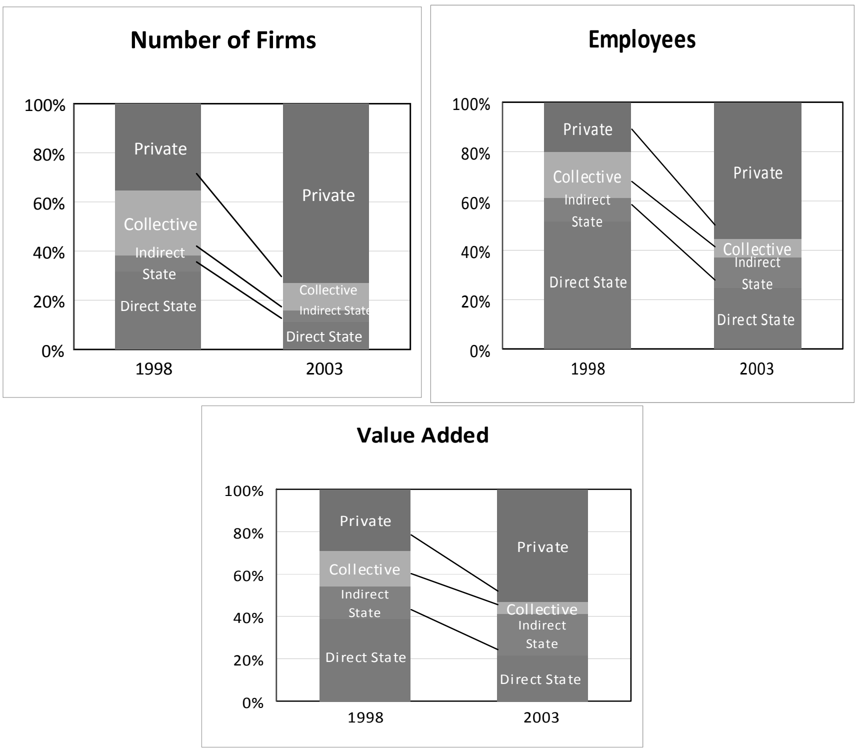

Figure 4: SOE and Private Company Indicators from OECD
(See page 1 of color inserts.)

In view of these kinds of data, the Chinese authorities have proved themselves quick studies. They understand very well how the rising private sector has taken up the slack from the legacy SOEs. In response, they moved virtually 180 degrees from their early hostility to private enterprise to robust policy support. It is also this support which is critical to China's movement up the value chain, and is the focus of the balance of this chapter.

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The Rise of Entrepreneurs

A little history is in order here because the rise of entrepreneurial business in China is one of the great achievements – and great mysteries – we have seen in the last 100 years.

Entrepreneurs were not welcomed by the new China after 1979, at least not at first. They still suffered from the stigma of Maoist suspicion and hostility. Nonetheless, countless small, 'mom and pop' enterprises sprung up almost instantly after China opened its doors. You could see them along the city streets and in the impromptu markets that sprung up in both the cities and the countryside. They were small, unsophisticated, self-employed ventures and they were the dominant 'entrepreneurs' throughout the 1980s. There were basically no rules to guide or protect private companies at that time, and no funding available. All available funding went to the SOEs. The only 'law' limited employment in private enterprise to seven people, so arbitrary bureaucratic decisions could make or break an entrepreneur, and he or she had no recourse.

During this same period, however, a new class of enterprise emerged called the 'township and village enterprise, or TVE. They grew out of the collectives and were generally under the auspices of local government, so they were not genuinely entrepreneurial. Yet they had a great deal of freedom in the market to decide what they wanted to do and how to do it, and thus showed many entrepreneurial characteristics. They made a wide array of products from fishing rods to medical instruments to soil pipe, etc. Some data suggest that TVEs accounted for as much as 20% of China's gross output by as early as 1990.[7] TVEs paved the way for the next wave of entrepreneurs.

1987 was a turning point. In that year the private employment law was repealed and the private sector began to burgeon almost over night. The number of enterprises grew by an incredible 97% that year.[8] Even at that early time the government had begun to recognize the tremendous burden the SOEs presented and to seek alternatives. This second phase of entrepreneurship was more sophisticated than the first. It included SOE spin-outs (suppliers and competitors), as well as educated newcomers with new ideas, and it spread across many fields. An anecdote of one of these "newcomers," the founder of Yada Metals, is provided here. Yada's founder, Mr. Liu, worked for a state metals trading company for most of his career, but broke out to form his own, competitive trading company. The story is classic. He saw many mistakes in the state trading company that he thought he could correct and be more responsive to customers – oil fields, petrochemical complexes, etc. So he took the leap. For a time, he was forced to take other positions – like taxi driver – because stainless steel prices had spiked unexpectedly and he could not afford the initial import. Finally prices came down and he bought his first container. It worked. With this seed money he and his family could begin to grow the company, slowly and carefully. Then he added a 'just in time' system to improve his responsiveness to customers – something that had never occurred to his old boss. The rest is history, as they say. Mr. Liu is today a millionaire and Yada is still growing.

We could say that a third phase of entrepreneurship began with the rise of the Internet in China in the early part of the new century. In this phase, expatriate and foreign educated Chinese began to return to China to make their

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fortunes. We all know the great successes today of Sohu.com, Baidu.com, Alibaba.com, and many others in telecommunications, home appliances, and so on. The growth curve began to take on its hockey stick look in this period. Another is in order. It is not Haier, or Huawei or Hainan Airlines, but an obscure electronics engineer in Nanjing, Mr. Ma. He began his first company, an LED display company, in the late 80s and it quickly became very successful – too successful. The company was basically taken from him by government officials, an event he just smiles about today. There was nothing he could do – except start another company, this time in transportation software. His development investment came from friends in China, but also from Silicon Valley! Today his software is being used by transportation companies in many major Chinese cities.

By the mid-2000s, another attitude shift had taken place among China's entrepreneurs. Until then, as noted earlier, nearly every Chinese business person wanted a joint venture or merger with a Western company. But a new strength and confidence arose as Chinese companies met with success in the market. The change was striking. Many Chinese companies began to show *no* interest in being acquired or even joint ventures. They essentially said, "We have good products, a strong market, and we're growing fast. If you want to buy from us, or team up on a project, great! But we have no interest in being 'gobbled up' and losing control of our baby." McKinsey estimates that Chinese companies will hold as much as 80 percent of China's high-tech market by 2010 (about $260 billion), up from just 67 percent in 2004.[9]

The 11th Five Year plan essentially legitimized and even sanctified this kind of innovation and new company development. Today, a number of successful entrepreneurs have been invited into the upper levels of the communist party, and well over 100,000 party members either manage or are key participants in private businesses. In fact, it has been noted that, increasingly, sons and daughters of high ranking officials are, for the first time in China's history, choosing to go into business instead of following in their parent's footsteps. For 2000 years, the top of the pecking order in China was officialdom. Of course, these new bureaucrat/ entrepreneurs still hope to capitalize on their status, but they are looking to the market and not to the bureaucracy to build their reputations and their wealth – a sea change.

Support from Business Incubators

Chinese authorities have also adopted the idea of 'business incubation' to support and feed into this trend in entrepreneurship, innovation, and technology development. Business incubation began in the United States and has spread virtually worldwide over the past 50 years. The National Business Incubator Association (NBIA) was formed in Philadelphia in 1988, and this author was honored to be one of the founding organizers. A key presenter at this conference was Dr. Rustam Lalkaka, then a key manager of the United Nations Development Program (UNDP), and also highly respected at the top level of China's influential Ministry of Science and Technology (MOST). It was Dr. Lalkaka who introduced the business incubator concept to the Minister of

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MOST, where it was received with enthusiasm and incorporated into its famous TORCH program.[10] Table II shows the results over the past 20 years.

Table II. Development of Business Incubators in China[11]

	1986	1994	1999	2000	2005	2010
# Incubators in China	0	73	119	131	534	1000
# Tenant Companies	0	1854	5293	7693	39,491	50,000

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The National Business Incubator Association estimates that there are fewer than 4000 business incubators worldwide, which means that today China has perhaps 15% of the total. Obviously, China has offered fertile ground for business incubators, and one will find nearly every variety imaginable – general, technology-specific, university-related, internal state-enterprise, international, etc.

This last variety, international incubators, is especially noteworthy in the context of moving up the value chain. Every major city has at least one, and often more. They actually target returning Chinese expats, and when you walk down the halls you will meet graduates from many top US universities who have come back to China to start their businesses and make their millions. They receive very favorable rental terms and often direct grants and loans. The obvious purpose is to recapture the intellectual capital that had been lost abroad, and this has become increasingly significant, as shown in Figure 5.

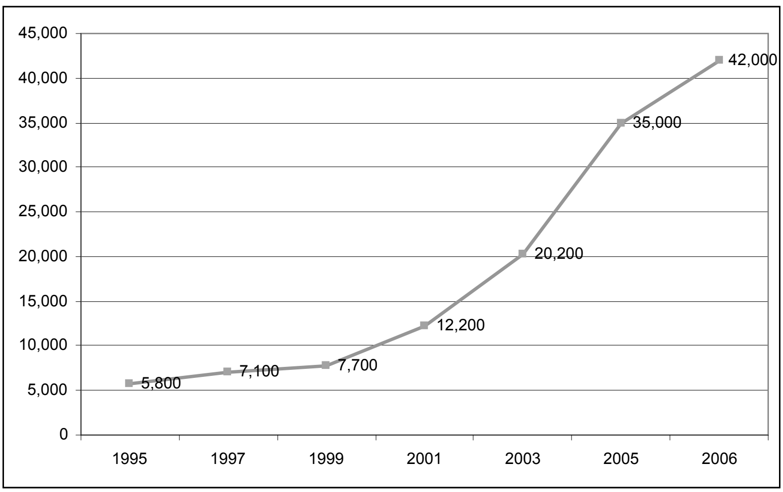

Figure 5. Chinese Overseas Students Returning to China[12]

The Shanghai National IC Design Center provides another example of how incubators try to capture value. 1n 2000, the municipality of Shanghai observed that, while it was becoming an international center for high tech electronics, over 80% of IC products were imported. China simply did not have the necessary IC design capability. The problem was not intellectual capability, but the fact that IC development requires multi-million dollar computers for design and testing which small design houses and entrepreneurs just couldn't afford. The incubator solved this problem by supplying this expensive equipment for use by incubator companies at a nominal charge. It also entered into a training partnership with LSI Logic. An entire building in downtown Shanghai is devoted to this incubator, with the top floors focused on early R&D and the lower floors focused on office space for successful designs. It also received national support from MOST. When I visited this Shanghai showcase in 2004, it was packed with new companies.

The city of Tianjin has developed numerous business incubators, mostly with the support and guidance of the Municipal Commission of Science & Technology, which is a branch of MOST. The Tianjin Women's Business Incubator, while not especially high tech, has received international acclaim because it addresses exclusively the novel economic problem of the re-employment of laid-off women workers. It seems to be remarkably successful. Tianjin also has designed a number of focused professional incubators in bio-medicine, electronic information, aerospace, photosensitive and digital video output materials, energy and electric power.

R&D and Innovation

China is gaining a double R&D benefit, first from increasing foreign research centers, and second from its own internal policies and investment in R&D. Regarding the first, United Nations Conference on Trade and Development's (UNCTAD's) 2005 survey of multinationals showed that China has become their number one R&D destination, as shown in Figure 5. Kofi Annan stated the situation well in the preface to the survey: "Firms now view parts of the developing world as key sources not only of cheap labor, but also of growth, skills and even new technologies."

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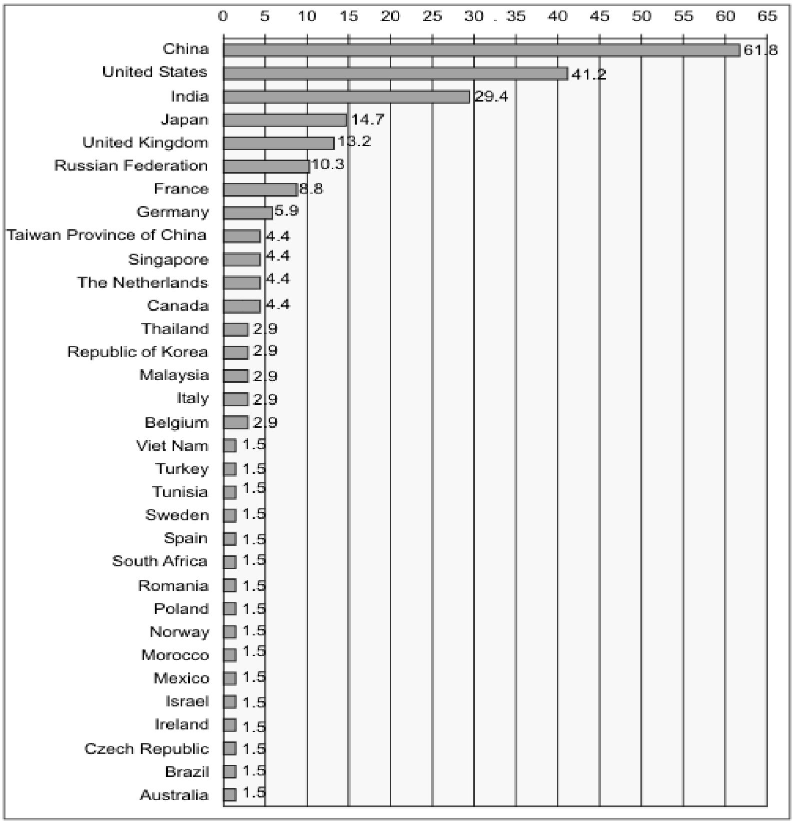

Figure 6. Most attractive prospective R&D locations, 2005-2009 - (Per cent of respondents mentioning the location) [13]

As the figure shows, China is way out in front. This is especially interesting because in the earlier 2004-2005 survey, the US and UK were numbers 1 and 2 and China was third with just 35.3%. It is estimated that today foreign companies have set up around 800 R&D centers in China which account for some 25-30% of total business R&D in China, and about a quarter of the 800 are "joint units" with universities or research institutes.[14] Jorg Wuttke, GM of BASF China provided a simple explanation for this rapid change. As part of the OECD Innovation study issued in 2007, he explained that "We need to innovate where our customers and latest technologies are." He said that both chemical consumption *and innovation* were shifting to Asia. In fact, China's chemicals market has grown extremely fast, outstripping Japan which was the largest in Asia. So R&D in China means companies have a better understanding of customer needs, faster reactions, and "wider access to the latest technologies," said Wuttke.[15] This attitude is supported and encouraged by tax holidays that are now only available to innovative and high tech businesses, by a policy of 150% tax deduction for R&D spending, as mentioned earlier, and by accelerated depreciation of R&D equipment.

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On the side of internal policy and investment, R&D spending has increased with incredible speed. China began reforms as far back as 1985. In that year it announced a policy to actually cut back on funding for the hundreds of so-called 'research institutes' associated with all of the industrial sectors, and encouraged them to "jump into the sea" – that is, develop marketable products and become entrepreneurs.[16] By 2003, it is said that over a thousand research institutes had transformed themselves into businesses.[17] In the 90s, China announced the famous TORCH and "863" programs to help fund high-tech programs and innovation and to support the development of high tech development zones and university-related enterprises. Measures were also taken to consolidate universities and permit local management. And state-owned enterprises were also encouraged to set up internal R&D centers, although it was hard to make this top-down innovation mandate effective.

Building on this policy history, the 11th Five Year Plan dreams big dreams. The new policy took three years and involved thousands of people to define a long term vision and plan for science and technology. The result, in 2006, was called *The National Program 2006-2020 for the Development of Science and Technology in the Medium and Long Term.*[18] In fact, even by this time, China had a good start, as shown in Figure 7, taken from the OECD Innovation Study completed in 2007. According to this study, "China is already a major S&T player in terms of inputs to innovation. Since 2000, it has ranked second in the world after the United States and ahead of Japan in number of researchers. As noted earlier, R&D spending has increased at a stunning rate of almost 19% since 1995 and reached USD 30 billion in 2005, the sixth largest in the world." Based on the Science Citation Index, China ranked 5th in that year after the US, UK, Germany and Japan.[19] Overall, China's share of the world's scientific articles has increased from 1.6% in 1995 to 5.9% in 2005, putting it in fifth place.[20] In nano-science, China is second only to the US in the production of original scientific articles. However, it is important to note that the *impact* of the growing number of articles and citations is still rather low, according to the citation index.

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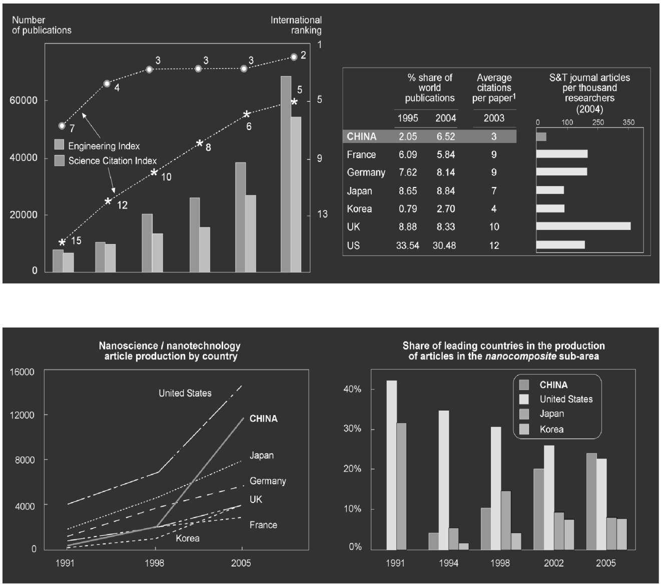

Figure 7. Growth of Chinese Scientific Publications and Emphasis on Nano-science[21]
(See page 1 of color inserts.)

The major goal of the *National Program 2006-2020* is to increase R&D expenditure to 2.5% of GDP by 2020 from its 2006 level of 1.4%. Using even conservative growth rates, GDP is likely to triple by 2020. Thus the 2.5% goal implies a huge expenditure in absolute terms.

The size and scope of the science and technology plan is massive. Here we list just a few of the “Priority Programs” for the science and technology “infrastructure” listed on the NDRC website:

- Core electronic devices, high-end general chip and infrastructure software
- Manufacturing technology and processing of ultra large-scale ICs
- New generation broadband wireless mobile communications
- Top-grade CNC machines and basic manufacturing technologies
- Large scale oil and gas fields and coal-bed methane
- Nuclear power with large-scale advanced pressurized water reactor and high temperature gas-cooled reactors
- Water pollution control and treatment
- R&D of new transgenic lines
- R&D of innovative medicines
- Prevention and control of major communicable diseases
- Large airplanes
- High resolution earth observing system
- Manned space flight and lunar exploration
- Science and technology infrastructure advancement to a world class level

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Further, the plan emphasizes that strengthening indigenous innovation is at the heart of this planned growth. NDRC issued a statement saying, "We will strengthen the innovation system, boost research and development of major technologies and build the country into an internationally competitive, technology-rich nation with significant innovative capabilities."

This is not yet the case. For example, although patents have grown dramatically, they are still heavily dominated by foreign-invested companies. China wants to reverse this situation – reduce its dependence on foreign technology and increase its own ability to innovate. They have even set a goal of reducing reliance on foreign technology to 30% or less – although exactly what this percentage means is not so clear.

One striking example is nuclear power, listed above. Currently China has eleven nuclear power reactors in operation with about 9 GW of capacity. Six more reactors are under construction and several more will soon begin, and all this was part of the original plan for power development some ten years ago. But the country has decided to expand its commitment to nuclear power and now aims at 50 to 60 GW of installed capacity by 2020, and 120-160 GW by 2030, which could mean more than a 100 new units. However, at the same time, the country is committed to becoming self-sufficient in reactor design and construction. So, although all the early technology is being imported, tech transfer and local production are required of foreign players. At the same time, the government is strongly supporting advanced R&D at Tsinghua University, China Institute of Atomic Energy (CIAE) and the Nuclear Power Institute of China (NPIC).

Another example is the civil aviation industry. China's now famous ARJ 21 regional aircraft is to be completed by the end of 2008 and delivered in 2009. GE, Rockwell, Hamilton Parker, Liebherr, Honeywell, Sagem, Eaton, etc. helped to develop the ARJ21 from the very beginning. GE Aviation even developed an engine especially for the ARJ21. All this helped domestic producers obtain the necessary know-how and experience needed to begin to design and build China's jet aircraft. Based on this experience, the government decided in 2006 to develop large aircraft over a 10 to 15 year period. But this time, Boeing and Airbus refused to help, since they would just be helping to create a major competitor. Further, large aircraft are a "strategic product" by the Chinese government, so foreign suppliers are carefully controlled. So far, Rolls Royce is the only major foreign supplier to express interest in cooperation. Thus the transition to purely domestic know-how and production is well under way, but not without challenges.

The Educational Foundation

At the foundation of this movement up the value chain is education. Under Mao, education policy developed in, at best, an uncertain manner, as it tried to maneuver between changing ideological moods and the desperate need for practical training. Many say that an entire educated generation was lost to the Great Cultural Revolution just prior to the "Opening Up" in 1978. As a result,

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the "opening up" found China with a fairly weak educational infrastructure and a poorly educated population of young working-age citizens. Deng Xiaoping declared education to be the cornerstone of modernization and, a few years later, in the Seventh Five Year Plan, 1986-1990, China took aim at this situation with the "Provisional Regulations Concerning the Management of Institutions of Higher Learning" which greatly expanded local control and responsibility to develop institutional quality. Education received over 70% more funding than in the previous plan. Reform continued and expanded after the turn of the century and included the development of university-based technology parks, as discussed earlier. Some key initiatives include the government's "985 Project," which aims to create a number of world class universities in China, and the "211 Project," which aims at building 100 new universities in the 21st century.

The educational system today still has many problems to solve - a legacy ideological orientation, inadequately trained professors, and heavy dependence on the examination system which does not foster creativity, etc. Nevertheless, its success in terms of sheer numbers is absolutely stunning. Figure 8 shows the total enrollment in higher educational institutions in China has increased some 20 times since 1978, from a mere 856,000 to over 17 million in 2006. Moreover, this has occurred while primary school enrollment has actually declined, due primarily to the effect of the long-lived one-child policy. Figure 9 shows this trend.[22]

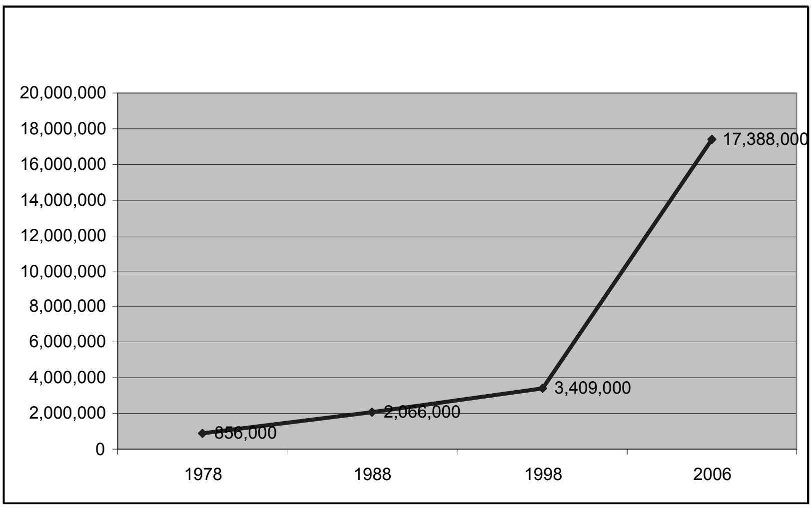

Figure 8. Total University Enrollment

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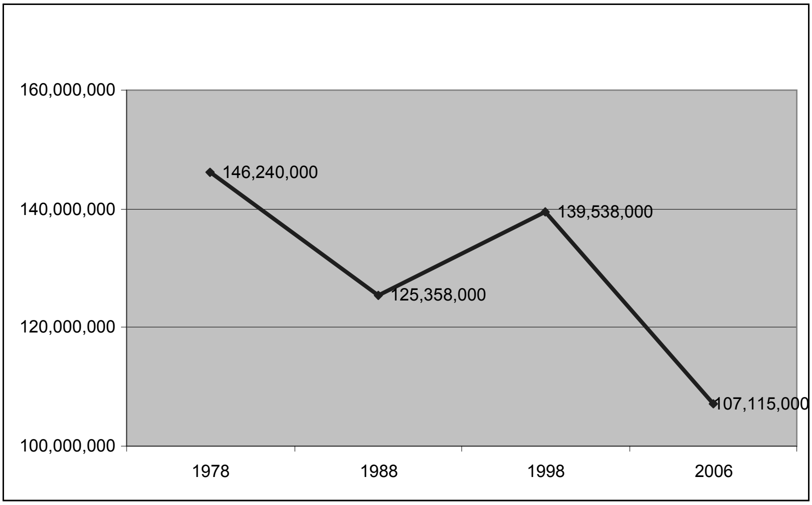

Figure 9. Primary School Enrollment

From the mid-1980s, science and technology education quickly became a key focus in support of the goal of rapid economic development. But in the mid-90s this emphasis really came to fruition. According to the OECD, "Enrolments in sciences, especially engineering, stand out as exceptionally high by international standards." In fact, some 50% of all new university entrants, total enrolments and graduates are in engineering and the natural sciences. And, although this percentage has been declining as employment demand diversifies, the absolute numbers continue to increase remarkably, especially in engineering. Figure 10 illustrates this point, showing that by 2005 engineering enrolment had reached some 5.5 million students.

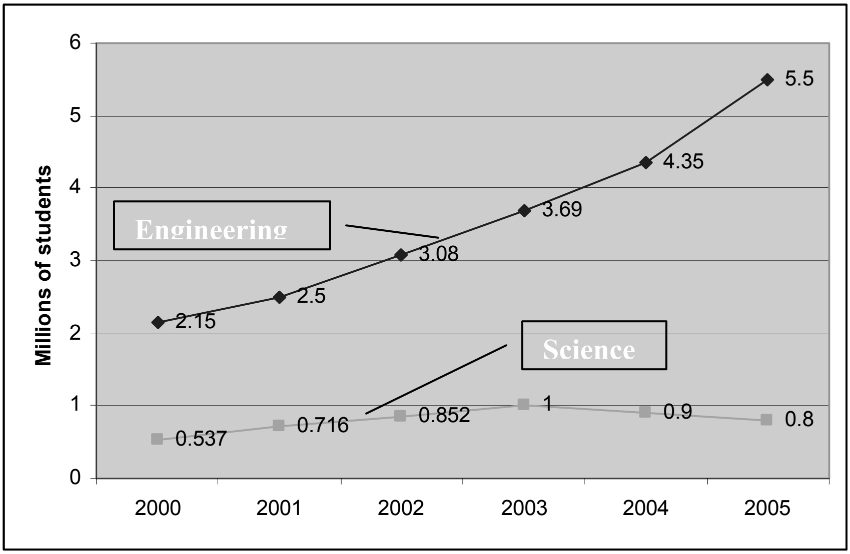

Figure 10. Undergraduate Enrolment in Science & Engineering[23]

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Table 3 suggests that even in 2005, China graduated nearly five times the number of engineers as the US. However, since the educational policy is recent, China still lags well behind the developed world in the education level of its adult population. As the OECD study has shown, only about 10% of China's population between 25 and 64 have attained a university education, while the OECD country average is about 25%, and the US is nearly 40%.[24] We can therefore expect to see continued increase in the number of technically trained people in China, both in terms of absolute numbers and relative to other countries. In addition, even if the training is inferior to what one would find in more advanced economies, the sheer numbers suggest a high probability of at least some success. And the fact is, the quality of education and training is improving each year.

Table 3. Comparative Engineering Graduates[25]

	Total	Undergrads	Masters	Doctorates
US, 2004	119,405	78,227	35,197	5,981
China, 2005	590,166	517.225	63,514	9,427

Conclusion

We have tried to illustrate how China has successfully moved up the value chain with remarkable speed. Moreover, we have tried to explore the contention that this vast economic achievement has been supported by two seemingly contradictory sets of circumstances: one is the powerful role of central planning and control, and the other is the meteoric rise of a private sector driven primarily by traditional market forces. It is tempting to digress into the issue of unfair trade and competitive practices fostered by strong central control, but there is much debate on this subject and not the key point here.

This commentary is being written during the worst financial crisis since the Great Depression and the combination of central planning and the free market is especially important at this time. Our Chinese friends, including government officials, now often joke that the US is increasingly becoming the "socialist" king of developed economies with its ever greater government "interference," while China is increasingly becoming "capitalist" to deal with issues of innovation, revaluation, unemployment and the public markets. It makes one wonder what the new economic paradigm will look like ten or twenty years downstream. What will be the balance between pure market forces, regulatory mechanisms, and central planning and control?

In any case, one thing is clear, and that is the deep interdependence of the US and China – a relationship that may portend more for the world's economic future than nearly anything else one can imagine.

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China has depended on exports for growth to a much greater degree than other countries. So when a global recession hits, China gets hit disproportionately. The current slowing of the US economy has already caused many small and medium-sized export-oriented Chinese manufacturers, located mainly in the Pearl River Delta, to close their doors, putting thousands out of work. And the fear of social disruption due to labor unrest is always a red flag for China's leaders.

Conversely, it is China's buying power – i.e. import power - that has been the engine of the global economy for the last decade. If China's infrastructure growth slows up, the US (and the world) will slow up accordingly, or quite possibly seize up. If we think the sub-prime crunch is bad, imagine what would happen if China's economy suddenly stopped expanding! Boeing, for one, might well join the car companies on Congress's doorstep.

This is why Beijing announced its 4 trillion yuan ($586 billion) stimulus package, the largest in the country's history, in late 2008. It was a strong move to try to keep the world economy from getting even worse. Beijing also sharply increased export tax rebates for over 3000 products in an attempt to re-stimulate exports, and it will loosen credit, cut taxes, and embark on a massive infrastructure spending program to boost internal market demand and create jobs. With these moves, China sends the message that it recognizes its role and importance in the global scheme of things, and it was not going to miss the chance to point this out to everyone.

Most important, China will protect its own interests first, which include protecting its largest export market, the US, and its largest investment, US Treasury bonds. China's export value to the US in 2007 was US$232 billion, more than twice the value to its number two export target, Japan. And late in 2008, China surpassed Japan to become the largest holder of US government bonds, at a whopping value of nearly US$600 billion. China desperately needs a strong America to protect these values.

Forecasters believe that China's growth will slow from 11.9% in 2007 to under 10% in 2008 and less in 2009. Most of the impact is being felt in the low end, export sectors, like toys and tee shirts. However, in many high end marketplaces, China continues to hum. Earlier we emphasized the growing number of entrepreneurs and the rising levels of technical education. But there are many other examples including nuclear power, wind power, high speed railways, and aircraft, as mentioned earlier. At the Zhuhai Air Show in late 2008, the Commercial Aircraft Corporation of China (COMAC) signed a 5 billion yuan (US$ 735 million) contract to sell 25 ARJ21-700 regional jets to GE Commercial Aviation Services (GECAS) – a huge step for China's homegrown aircraft business. Related to this, Boeing announced that it will expand its composite materials JV in Tianjin by 60%, as it sees demand for light-weight materials picking up substantially. So, from alloy steels for landing gear to traffic control systems to avionics, China is developing expertise quickly and that development is critically important for the global economy.

The Yuan-to-USD revaluation has made US exports much more attractive. Sales of capital equipment continue strong – turbines, diesel engines, transportation equipment, etc. In fact, this is a perspective on the financial crisis that one does not normally hear. The *productive* economy, as opposed to the

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financial economy, has been doing fine, at least so far as US-China business is concerned. The power industry provides a related example. China continues to build hundreds of new, sophisticated power plants to support growing internal electricity demand, and is investing heavily in wind and hydro power and alternative energy development. It is highly likely that this expansion will continue, even if the rate slows somewhat.

The current financial crisis is huge and we cannot know how it will end. But the powerful US-China economic dynamic is the critical element not only in this particular crisis, but for the foreseeable future in this century. China's GDP now ranks third in the world in absolute terms, having grown over 22 times its 1978 size of $147 billion to $3.28 trillion in 2007. And *per capita* income has grown from $190 to $2,360 in the same period, bringing hundreds of millions of people out of poverty, according to the World Bank. But this *per capita* achievement still only ranks about 107th globally. This means that China still has a lot of room to grow as her citizens continue to dream of a better future. And so China is likely to remain the engine of world growth for a long time to come.

China's march up the value scale will continue; her burgeoning private sector will continue to grow and innovate; her educated population will continue to expand in both quantity and quality. If entrepreneurship and innovation have been the keys to US dominance in the world, we will surely find that position challenged as these trends continue. In this context, the leader of the West – the United States – and the giant of the East – China - would be wise to engage each other in defining new directions – for example, alternative energy - for the prosperity of the entire globe.

References

[1] National Bureau of Statistics

[2] Above figure derived from 2007 China Statistical Yearbook, Table 21-52, and below figure is from *OECD Science Technology and Industry Outlook 2008*, p 169

[3] A related indicator is the intense environmental scrutiny that any new investor must face. These policies are serious. If you apply today to set up a WFOE (Wholly foreign-owned enterprise) in SIP, and the authorities determine that the WFOE poses an environmental risk to the air or waste water, you will be denied. This simply would not have happened in the 90s.

[4] Personal correspondence with the author

[5] 2007 China Statistical Yearbook, Industry data, Table 14-8, *Main Indicators of State Owned & State Holding Industrial enterprise(2006)*, and Table 14-12, *Main Indicators of Private Industrial Enterprises, 2007.* Data on numbers

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of companies, employment, etc. are very hard to reconcile from source to source in China, or by outside sources. It is also difficult to get exact category definitions. For example, the exact definition of "state-owned" and "private" is not given in the Statistical Yearbooks. Some things we can surmise. For example, "private" does not include the millions of mom and pop shops throughout China that sprang up like grass after the opening up. Rather, they are only counting companies above a "certain size," as mentioned occasionally. It is also unlikely that the so-called "Township enterprises" are included in these data, although we cannot be certain. These enterprises are especially interesting because they are owned by the "community" but often display many characteristics of private enterprise. Last, the numbers do not include the millions employed in the courtside on farms.

[6] OECD Economic Surveys, China, September 2005, p. 95.

[7] There is a good discussion about the rise of entrepreneurs in China by Debbie Liao and Philip Sohmen, "The Development of Modern Entrepreneurship in China," Stanford Journal of East Asian Affairs, Spring 2001. The TVE data comes from this and I am thankful to the authors for other insights as well.

[8] Liao and Sohmen, p 28.

[9] Ingo Beyer von Morgenstern and Xiaoyu Xia, "China's High-Tech Market: A Race to the Middle", McKinsey Quarterly, September 2006.

[10] The Torch Program is a national program administered by the Ministry of Science and Technology which supports the development new high tech industries in China. It originated as far back as 1988 and included support for numerous "Science & Technology Industrial Parks" (STIP), incubators, and more. It is a far reaching program.

[11] Sources: China Business Review, July-Aug 2002 for data from 1994 to 1999; for 2005 Ming-feng Tang, Patrick Llerena, "Who runs better, a business incubator located in a science park or in a high-tech development zone?" 2007. 2010, MOST, Liang Gui, Dec. 2007, Xunhuanet.

[12] Adapted from a presentation by Mu Rongping, Institute of Policy Management, Chinese Academy of Sciences, August 27, 2008, as part of OECD Innovation study.

[13] UNCTAD's, *World Investment Report 2005: Transnational Corporations and the Internationalization of R&D*

[14] Guinet & Zhang, "OECD Reviews of Innovation Policy, China, Synthesis Report", 2007, in collaboration with the Ministry of Science & Technology.

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[15] J. Wuttke, “Framework conditions for innovation: The business perspective”, August 28, 2007, a presentation given as part of the OECD Innovation Policy Survey, 2007.

[16] “Research Institutes” in China are quite different from the image we have of such organizations in the West. Under Mao, such institutes were set up to complement virtually every industrial sector – from shoes to aerospace. Their job was to be the technical leader in the field, a kind of bellwether for industry to follow. Many still remain today and are highly influential – for example, in the energy sector – while others have become moribund, and still others have gone into business for themselves in order to survive.

[17] Lan Xue, Tsinghua University, presentation entitled “China’s Innovation Policy in the Context of national Innovation System Reform”, as part of OECD Innovation study; August 2007

[18] A good and succinct discussion of this 15 year plan is provided by Serger and Breidne, *China’s Fifteen-Year Plan for Science and Technology: An Assessment,* The National Bureau of Asian Research (NBR), July 2007.

[19] Op Cite, Guinet & Zhang

[20] *OECD Science Technology and Industry Outlook 2008*, p 168

[21] Op Cite, Guinet & Zhang

[22] Figures 8 & 9 were developed by the author with data taken directly from China Statistical Yearbook, 2007.

[23] This table was derived from a combination of the China Statistical Yearbook for 2001 though 2004, and estimates based on the OECD Innovation study, Ch.6, table 6.5. Both sources were used because the Statistical Yearbook ceased carrying identical year-to-year tables on this subject in 2005. But what was available closely paralleled the OECD numbers. The problem was that the OECD Figures did not display values, so we estimated, and we are confident that the numbers are close to reality.

[24] It is not clear if the OECD data include only graduates or all people having attended a university, whether they received a degree or not.

[25] Power Point presentation by Dewey Ballantine LLP, 2007, as part of OECD Innovation Study

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Chapter 5

Hydrogen PEM Fuel Cells: A Market Need Provides Research Opportunities

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Introduction

This chapter addresses the activities of the International Partnership for a Hydrogen Economy (IPHE) and the U.S. Department of Energy (DOE) in response to specific research opportunities associated with producing a market-competitive hydrogen proton exchange membrane (PEM) fuel cell, namely research opportunities to develop advanced:

- Membrane materials, and
- Catalysts.

Research strategies and summaries of research progress for each of these areas are outlined.

It has been said that necessity is the mother of invention. Another way this can be stated is "market demands create research opportunities." Because of a globally increasing demand for oil, which is a depleting (not renewable) energy source, the market also demands alternate sources of energy that are competitive in cost and use. This market demand offers opportunities for investment in hydrogen PEM fuel cell research.

Moreover, this is a global market need and as such it should be addressed globally. The IPHE was formed in 2003 to address the aforementioned opportunities. The IPHE Partners members include: Australia, Brazil, Canada, China, European Commission, France, Germany, Iceland, India, Italy, Japan, Republic of Korea, New Zealand, Norway, Russian Federation, United Kingdom, and the United States. By creating the IPHE, the Partners have committed to accelerate the development of hydrogen and fuel cell technologies

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ACS Symposium Series; American Chemical Society: Washington, DC, 2009.

to improve international energy security, environmental security and economic security.

Hydrogen PEM Fuel Cells

Hydrogen PEM fuel cells are an attractive source of clean, reliable, and safe energy. However, research is still required to develop a market-competitive (i.e., high performance, low cost, and high durability) PEM fuel cell. Two of the key areas still requiring research is membrane materials and catalysts. The DOE has identified specific strategies to develop these fuel cell technology areas, with the aim of ensuring that the United States has an abundant, reliable, and affordable supply of clean energy to maintain its prosperity throughout the 21st century.

In the area of membranes, DOE research strategies include studies of hydrophilic additives, non-aqueous proton conductors, and phase segregation control – both in polymers and two-polymer composites. The DOE's catalysts strategies include lowering platinum group metals (PGM) content, developing affordable platinum-based alloys, and developing non-platinum catalysts.

Additionally, the United States has partnered with the European Commission on research projects such as the development of diagnostic tools. This multinational-project aims to develop new diagnostic tools, improve the application of existing tools, and advance the interpretation of data. The increase of knowledge from this project will lead to more durable and reliable fuel cells, as well as contribute to lowering the cost of operation.

Further, The IPHE Coordination Action for Research on Intermediate and High Temperature Specialized Membrane Electrode Assemblies (CARISMA) seeks to network research activities in Europe on high temperature membrane electrode assemblies (MEAs) and their components. Coordination activities are centered on membranes, catalysts, and high temperature MEAs.

Many PEM fuel cell research projects are being performed by IPHE members. IPHE fuel cell projects include the development of advanced membranes, the application of gradient porous composite MEAs for different types of fuel cells, and the development of novel polymer electrolyte membranes for MEAs capable of operating in the temperature range of ≤-20°C to ≥+120°C at zero humidification.

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A categorization of IPHE PEM Fuel Cell Projects appears in Table I below.

Table I. IPHE PEM Fuel Cell Projects

Category	***Projects***
Demonstration	7
Fuel Cell	7
Production	3
Storage	5
Transmission & Distribution	1
Regulations, Codes & Standards	5
Socio-Economics	2
Total	30

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Objectives

The overall objectives of PEM fuel cell research include providing an efficient, cost-competitive alternative to fossil fuel as a source of energy and protecting the environment by eliminating the emission of greenhouse gases from motor vehicles. A competitive market requires an affordable, durable, high-performing alternate source of energy. System affordability will be determined by the market but will provide direction for some research activities focused on reducing the cost of key components (e.g., membranes and catalysts.)

Figure 1 shows the relative cost contribution of a hydrogen PEM fuel cell as reported at the 2008 DOE Hydrogen, Fuel Cells, and Infrastructure Technologies Program Annual Merit Review, June 2008, held in Washington, DC. From this table one can see the large impact that catalysts have on the system cost (approximately 30% of system cost is associated with catalysts.) The fuel cell membrane, on the other hand, has a significant role in the performance of the fuel cell. Thus, these two items, one having a significant affect on the system cost and the other having a significant cost on the system performance, will be examined.

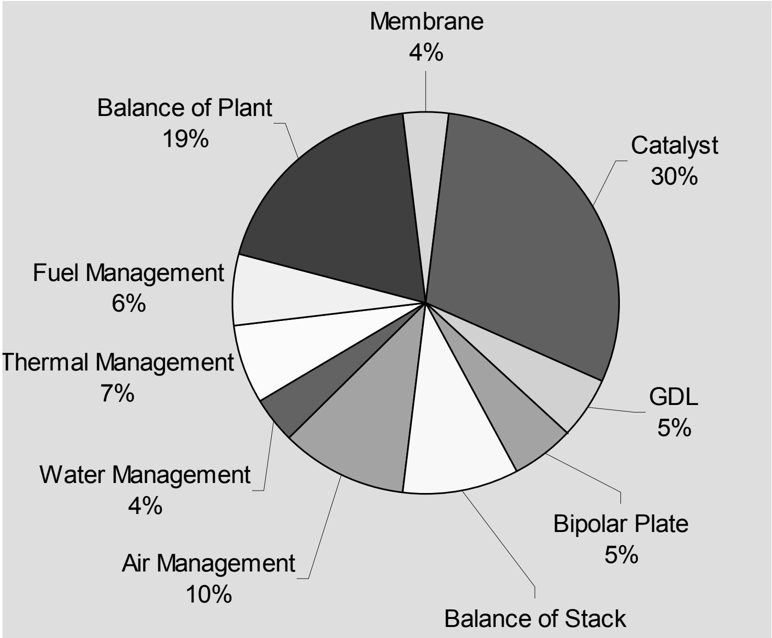

Figure 1. 80 kW Fuel Cell System Cost Breakdown

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Barriers to Achieving Objectives and Strategies Being Pursued

The barriers to widespread utilization of fuel cells as a power source for vehicles are several and not trivial, but they are the focus of a number of research and development programs, both government and commercial. Specifically, barriers to utilizing fuel cells as a source of power for vehicles may be overcome via technological advancements as they are not viewed as dependent upon uncontrollable factors. The barriers are in the general areas of energy conversion (fuel cells), hydrogen storage, production, and delivery.

This chapter will focus on some key barriers to development of the energy conversion (i.e., PEM fuel cell) technology, and, will discuss the primary strategies being pursued to overcome those barriers.

Membranes. A key component to the fuel cell that directly impacts performance and cost is the membrane. Therefore, research is being conducted to identify new membrane materials (e.g., polymers) that are lower cost (i.e., reduced cost materials that offer potential for better manufacturability), and, possess equal to or better performance.

One research area of particular interest is new proton-conducting solid polymer electrolyte membrane (PEM) materials possessing the desired properties, namely, (1) high proton conductance at high temperature (up to 120^{o}C), (2) effectively no co-transport of molecular species with proton, (3) reduction of electrode overpotential, and (4) good mechanical strength and chemical stability.

Research under this strategy includes:

- Protic salt electrolyte concepts (i.e., ionic liquid filled PEMs, and, non-leachable PEMs),
- Graft polymers and copolymers of the rigid rod liquid crystalline poly(p-phenylene sulfonic acid),
- A new class of NanoCapillary Network (NCN) proton conducting membranes, and
- New proton-conducting electrolytes based on the fluoroalkylphosphonic acid functional group.

Results to date have been good, with many of the strategies attaining the intermediate milestone of 0.07 S/cm at 30°C and 80% relative humidity.

Note that other strategies are being pursued to develop cost-effective membrane materials, but additional details on those have not been included in this chapter.

Catalysts. One of the barriers to developing a cost-effective PEM fuel cell is the high cost associated with the catalyst. The most effective catalyst is platinum. However, the current cost of platinum is approximately $2100/troy ounce. Thus, research activities are being pursued directed at

1. identifying alternative catalyst materials, and,

2. reducing the required platinum loading to obtain the required catalytic benefit.

Overall Progress to Date

The cost of an 80-kW hydrogen PEM fuel cell has been reduced substantially over the past several years. Figure 2 below depicts the projected reduction in total system cost. (These projected costs are based upon the manufacture of 500,000 units per year.)

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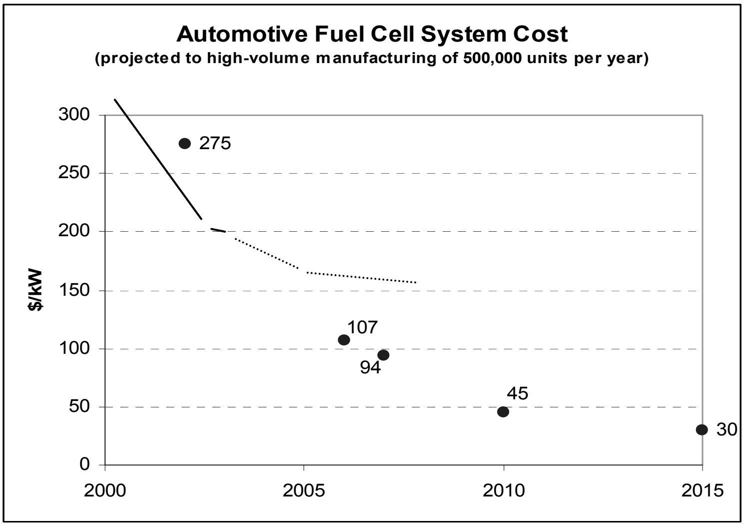

Figure 2. Cost per Kilowatt Reduction of Automotive PEM Fuel Cell (Based on Manufacturing Rate of 500,000/year)

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Conclusions

Ultimately, the decision to develop hydrogen fuel cell vehicles should be a business decision. Assuming the price paid for gasoline will increase and as the cost associated with fuel cell vehicle operation will decrease, a market opportunity will be created. The advancements currently being achieved in the development of hydrogen fuel cell technologies, as discussed in this article, shorten the time until that decision will be made.

Editor's Note

PEM fuel cells have been the focus of activity for transportation applications but are not projected to be commercially available until 2015 or later. However, smaller, lower power PEM and solid oxide fuel cells appear to be much closer to commercialization in a wide range of applications including standby power, portable and remote power. Small fuel cells to replace or augment conventional batteries in unmanned airborne vehicles (UAV's), remote sensors, and wearable power for the individual soldier are in various stages of evaluation in the military...In commercial quantities, these would be lower cost and lighter in weight than conventional batteries while providing extended operating time. These fuel cells require hydrogen replenishment, in the form of gas, liquid, or solids. Hydrogen production, distribution, and storage remain the largest barriers to PEM fuel cell commercialization.

The above information was presented at The Chemical Heritage Foundation, Joseph Priestly Symposium, Philadelphia, PA, Feb. 14, 2008: "Fuel Cells on the Road to Commercialization.".

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Key words

catalyst, fuel cell, global, hydrogen, impurity, international, market, membrane, PEM

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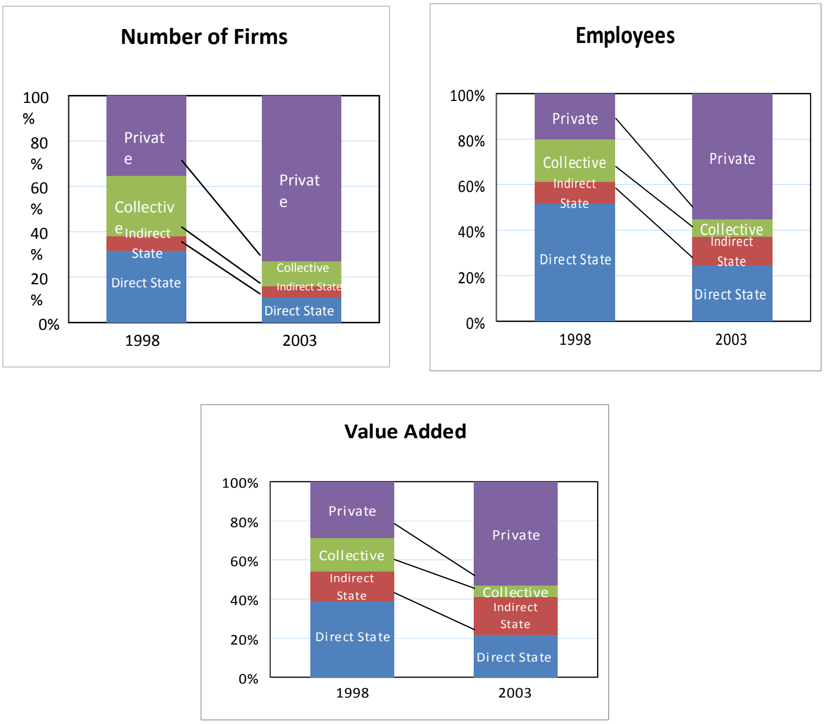

Figure 4.4: SOE and Private Company Indicators from OECD

Figure 4.7: Growth of Chinese Scientific Publications and Emphasis on Nano-science[21]

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