Asia's Energy Security and the Middle East

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Abstract

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Introduction

People around the world are demanding improved living standards—and they are getting them. Global growth this year is likely to exceed 5%, the highest rate in nearly a half-century. Developing Asia—the epicenter of the world's economic growth explosion--will grow at nearly twice that rate, led by the spectacular reform-driven performances of China and India.

Advances in information technology and communications networks have driven recent increases in global growth through three primary channels. First, they have made it possible for all people on earth to view each other's lives, in real time, for the first time in history. This has exposed the gaping income and wealth differentials across nations to public view, making people in low-income countries demand pro-growth policies from their governments to give them the opportunity to improve their lives.

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Second, technology has made it easier, faster, and cheaper to move resources around the globe to take advantage of the price and return differentials that drive economic activity. Labor, capital, and technology now move at the speed of light through fiber-optics networks at practically no cost.

Third, rapidly developing capital markets since the early 1980's have reduced the cost of moving capital and the minimum differential-return threshold for triggering its redeployment.[1] Policy reforms, including the recent WTO-mandated opening of China's capital markets, have made capital still easier to move. The result has been faster speeds of adjustment and higher economic growth.

The resulting massive re-deployment of resources has increased global growth, but has also created economic and political conflicts, both within and among nations. These conflicts are manifesting themselves as rising protectionist pressures around the world.[2]

Rising economic activity has also increased Asia's energy needs faster than can be provided by local supplies. This is increasing Asia's reliance on locally available coal supplies, which has costly implications for air and water resources. And it is increasing Asia's reliance on oil and gas imports from the troubled and potentially unstable Middle East, where the lion's share of the world's known oil and gas reserves is located.

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[1] See Atkins (1991), pp. 104-105. It is almost always true that the rate of a chemical reaction increases with rising temperature. This rule describing what is now known as Aarhenius Behavior—first proposed by the Dutch Chemist Jacobus van't Hoff (1884) and interpreted by Svante Aarhenius in1989—states that reaction rate is an exponential function of temperature, or Rate = $e^{-Ta/T}$. In this expression, T_a represents the reaction-specific activation temperature—the threshold below which no reaction will occur. Ludwig Boltzmann derived an expression for the proportion of collisions between molecules in a reaction that occur with at least the activation level of energy E_a (the threshold below which no reaction will occur) as $e^{-Ea/kT}$, where k, known as Boltzmann's constant, is a fundamental constant of nature. As we will see below, the economic interpretation of E_a is the minimum price difference, in microeconomics, or return on capital difference, in capital markets, required to trigger a profitable arbitrage transaction, akin to the gold points during the time of the gold standard. E_a represents the friction, or transactions costs of engaging in markets. Reducing E_a increases adjustment speed.

[2] There are many examples in all regions. Recent examples in the U.S. include the aborted attempt of China's CNOOC to acquire Unocal and the failed Dubai Ports deal—both killed by political backlash in the U.S. Congress—the recent action against the Chinese paper industry by the U.S. Commerce Department, and the Schumer-Graham legislation now under discussion in Congress.

Figure 1
Proved Oil Reserves at end 2005
(Davies, 2006, p. 3)

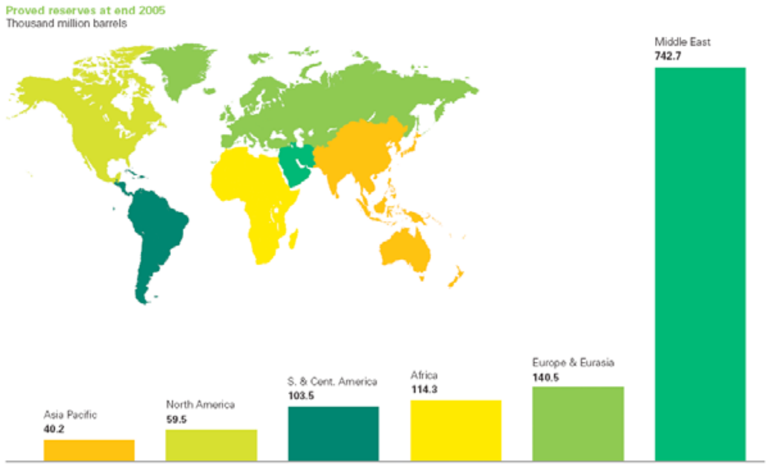
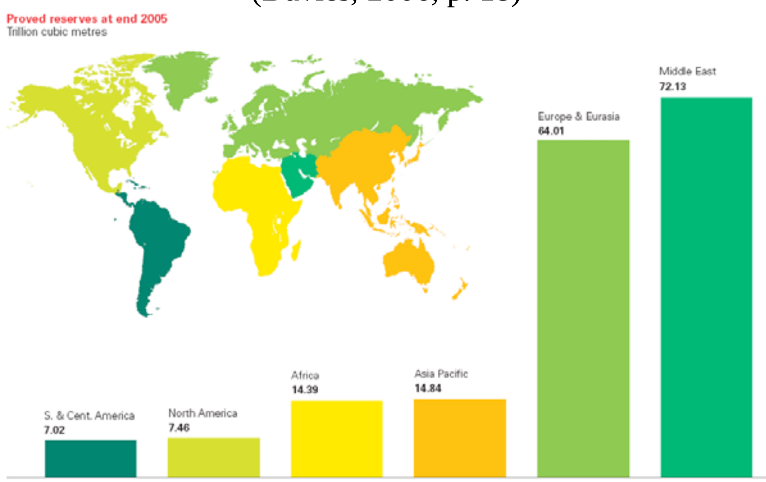


Figure 2
Proved Natural Gas Reserves at end 2005
(Davies, 2006, p. 18)



Without secure future energy supplies a nation cannot provide its people with the stable political and economic environment that underpins strong and sustainable economic growth. This is especially important for Asian nations, where the imbalance between scarce energy resources, large populations, and growing incomes is greater than in other areas.

For emerging economy governments, whose people have tasted rising incomes, halting growth is not an option. Energy security—securing long-term access to the energy resources that Asian nations need to provide sustainable long-term growth and rising living standards for their people-- has become an urgent matter for Asian governments.

Some governments are taking steps to attack the energy security problem by increasing exploration for new resources, investing in resources outside their borders, undertaking long-term supply contracts, expanding use of nuclear power, investing in alternative fuel technologies and encouraging conservation.[3] Yet, in spite of great efforts and some successes, the ADB's Asian Development Outlook[4] forecasts rising Asian oil and gas imports in the years ahead. The energy security problem grows larger every year. Access to energy resources is the most likely cause of future conflict among nations. Clearly, we need new thinking to solve this problem.

This paper presents a new framework for thinking about the relationship between energy and growth based on the broad concept of energy in the physical sciences and on the laws of thermodynamics that describe the energy transfers that drive all activity on earth.[5] In this framework, entrepreneurs respond to gradients (price and return differences) by employing both *current* solar energy and *stored* solar energy, in the form of natural resources, human capital, physical capital, and technology, to create *work*, which we refer to as economic activity. Resource flows between nations are driven by price and return gradients according to the second law of thermodynamics. Policies impact resource flows by impacting price and

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[3] For a recent discussion of China's efforts to address energy security see Amy Myers Jaffe and Matthew Chen, Testimony Before the U.S. China Economic and Security Review Commission Hearing on China's Role in the World, August 4, 2006, available at http://www.uscc.gov/hearings/2006hearings/written_testimonies/06_08_3_4wrts/06_08_3_4_jaffe_amy_statement.pdf

[4] Asian Development Bank, Asian Development Outlook 2007, March, 2007, available at http://www.adb.org/Documents/Books/ADO/2007/default.asp.

[5] I am only too aware that, writing as a non-specialist in thermodynamics, I am wading into difficult and dangerous waters. As Gustave Flaubert wrote in a letter to Louise Colet in 1854 during the writing of *Madame Bovary*, "One ought to know everything to write. We writers are monstrously ignorant. If only we weren't so lacking in stamina, what a rich field of ideas and similes we could tap! Books that have been the source of entire literatures, like Homer and Rabelais, contain the sum of all the knowledge of their times. They knew everything, those fellows, and we know nothing. " Alas, I am monstrously ignorant as well. My hope is that the insights gained by applying the metaphors of physics to the problems of economics makes the result worthwhile.

return gradients, providing incentives, or signals, for entrepreneurs to change their behavior.

This framework allows us to draw on recent important developments in non-equilibrium thermodynamics (NET)[6] developed by Ilya Prigogine and others that can help us understand the dynamic behavior of systems, including economic systems, over time. NET sheds valuable light on questions of recession, market failure, price bubbles, and stability.

This broader view of energy points toward unconventional structural solutions to the energy security problem including 1) investing in communication networks, information technology, and education; 2) investing in agricultural research to increase the efficiency of plants solar energy capture and to improve the productivity of farm workers to release manpower to the energy-efficient and environmentally-friendly services sector; and 3) legal, regulatory, and exchange rate policies to provide the stable economic and capital market environment needed to attract the vast amounts of high tech capital and technology that Asian economies need to transform their economies.

A New Framework

In this section I outline a new framework for thinking about the role of energy in the economy, based on research that I am conducting at the Chinese Academy of Sciences. This framework is based on the tested laws of natural science. It relies on a broader, more fundamental, notion of energy and on a new way of looking at the relationship between energy and economic activity.

To Democritus, writing 2500 years ago, the universe was comprised of "atoms and the void.[7]" To a modern physicist there is only matter and energy. In fact, as Einstein (1905) showed in his famous equation, $E=mc^2$, matter and energy are interchangeable. In this view there can be no energy

[6] For a review of recent writings in NET see Schneider and Sagan (2005) and Prigogine (1997).

[7] "According to convention, there is fire, there is water, there is air, and there is earth. There is a sweet and a bitter, and a hot and a cold. According to convention there is inherent order in the universe. In truth, there is only atoms and a void." (Democritus, 400 B.C. , quoted in Discovering Enzymes, David Dressler and Huntington Potter, 1991.

shortage; only a shortage of the knowledge we need to mine, through controllable transfers, the abundance of energy that surrounds us.

Mining energy, the domain of physics and engineering, starts with the law of conservation, as Richard Feynman (1989) writes,

> There is a fact, or if you wish, a law, governing all natural phenomena that are known to date. There is no known exception to this law—it is exact as far as we know. The law is called the *conservation of energy*. It states that there is a certain quantity, which we call energy that does not change in the manifold changes which nature undergoes. That is a most abstract idea, because it is a mathematical principle; it says that there is a numerical quantity which does not change when something happens. It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same. (p. 4-1)
> …energy has a large number of forms…gravitational energy, kinetic energy, heat energy, elastic energy, electrical energy, chemical energy, radiant energy, nuclear energy, mass energy. (p. 4-2)
> …it is important to realize that in physics today, we have no knowledge of what energy *is*. (p. 4-2)
> …although we know for a fact that energy is conserved, the energy available for human utility is not conserved so easily. The laws which govern how much energy is available are called the *laws of thermodynamics* and involve a concept called entropy for irreversible thermodynamic processes. (p. 4-8)
> …Finally, we must remark on the question of where we can get our supplies of energy today. Our supplies of energy are the sun, rain, coal, uranium, and hydrogen. The sun makes the rain and coal also, so that all these are from the sun. Although energy is conserved, nature does not seem to be interested in it; She liberates a lot of energy from the sun, but only one part in two billion falls on the earth. Nature has conservation of energy, but does not really care; she spends a lot of it in all directions. We have already obtained energy from uranium; we can also get energy from hydrogen, but at present only in an explosive and dangerous condition. If it can be controlled in thermonuclear reactions, it turns out that the energy that can be obtained from 10 quarts of water per second is equal to all of the electrical power generated the United States. With 150 gallons of running water a minute, you have enough fuel to supply all the energy that is used in the United States today! Therefore it is up to the physicist to figure out how to liberate us from the need for having energy. It can be done. (page 4-8)

In the next section we will describe the link between physical energy flow and economic activity.

Work, Coherent Energy, and Economic Activity

Orthodox macroeconomics, developed following last century's Great Depression, is obsessed with total spending, or aggregate demand, and by analyzing who is doing the spending, as expressed in the well-known relation, Y = C+I+G.

More recently, supply-side economics, pioneered by 1999 Nobel-winner Robert Mundell, has focused attention on the resources available for production and on the incentives to use those resources productively.

To a physicist, there is only one resource—the energy from the sun—that drives all activity on earth.

Our purpose in macroeconomics is to measure how much work the people in an economy perform in a given time period. Work, after all, is what creates wealth and generates incomes. Work earns paychecks and generates profit.

Work is what physicists have been measuring since Galileo rolled a ball down an incline 500 years ago. Work, to a physicist, is a result of energy transfer. Physicists refer to work as *coherent motion*, and refer to incoherent motion as heat, as shown in the figures below.

Figure 3
Work vs. Heat

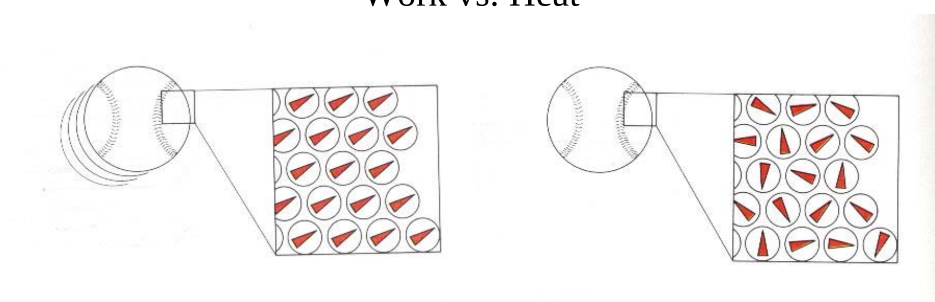


Figure 3(a): Coherent Energy (Work)

Figure 3(b) Incoherent Energy (Heat)

As an example, think of two baseballs. Every particle in the baseball on the left, in Figure 1(a), is moving at 97 miles per hour on its way from Roger Clemens's hand to the catcher's mitt. This is an example of *work*, also known as *kinetic energy*, or *coherent energy*.

Every particle in the baseball on the right, in Figure 1(b), is moving at 97 miles per hour as well but the baseball itself, viewed as a macro object, or system of particles, is not moving. In this case, we have produced the motion not by throwing the baseball but by heating in an oven; the particles are moving in random directions, colliding with each other. This is an example of *heat*, *thermal energy*, or *incoherent energy*.

In macroeconomics, the picture on the left represents economic activity, where people are engaging in work to produce valuable goods and services. The picture on the right represents instability, wasted effort, inefficiency, or conflict.

In this framework, the objective of economic policy is to encourage people to do the things that result in the largest possible amount of work, or coherent energy. That policy will result in the highest national income and the highest living standard for the people. This suggests a simple litmus test for every new policy suggestion. Does it increase the amount of useful work people will do? If the answer is yes it is most likely a good policy. If the answer is no it is probably a bad, i.e., anti-growth, policy.

Everyone since Adam Smith agrees the government is well suited to providing certain services to its citizens. Most of them – laws, property rights, defense, common measures, and Interstate highways -- are work-increasing activities.

Unfortunately, however, there is no law of conservation of work to protect us from bad policies. Work can be destroyed by policies that blunt incentives or make it more difficult (require more energy) for people to create wealth. Subsidies, tariffs, quotas, price controls, excise taxes, and burdensome or unpredictable regulations are bad policy. Taxing an activity destroys work. A government that desires to increase incomes should collect tax revenues in the manner that destroys the least amount of work. Taxing work directly, by imposing taxes on income and profits, is an especially efficient way to destroy work.

Markets are information networks; they are extraordinarily efficient structures for processing information on wants and relative scarcities to help people create work out of available energy. In markets, work is created when people respond to arbitrage situations that signal profitable opportunities to redeploy resources. In flow markets we call it supply and demand; in asset markets we call it portfolio balance. Both represent arbitrage behavior driven by the second law of thermodynamics. In summary, arbitrage behavior, fed by price and return differentials, is the only concept we need to build a macroeconomic theory of work.

All work is driven by solar energy.

All activity on earth, including economic activity, is driven by the flow of energy from the sun, "that orbed continent, the fire that severs day from night"[8]. The Second Law of thermodynamics states that heat flows from warm to cold bodies. The difference between the 5800 K surface temperature of the sun, and the temperature of the earth, at 280 K, causes energy to flow from the sun to the earth in the form of radiation, producing work and heat on earth.

Figure 4
Sun-Earth Flux
(Schneider & Sagan, 2005, p. 164)

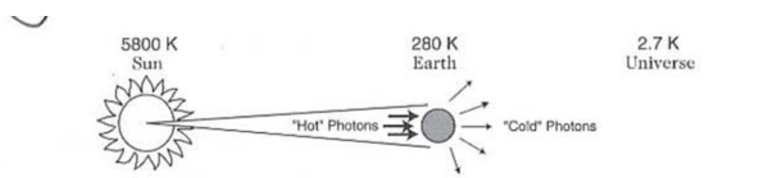


FIGURE 12.1. There is a giant radiation gradient between the 5,800 K temperature of the sun's surface and the 2.7 K Hawking temperature of outer space. The Earth is suspended in this gradient, and disequilibrium processes such as chemical associations, weather, and life can and do occur because of the access to this high-energy flux.

The sun is a giant thermonuclear reactor that has been turning 5 million tons of hydrogen into helium each second for 5 billion years. Its temperatures vary from 15 million K at its core, to as low as 4000 K in sunspots. The rate of energy delivered to earth by the sun to the earth, 1.36 kilowatts (KW) per square meter, has long been referred to as *the solar constant*[9], although

[8] Shakespeare, Twelfth Night.

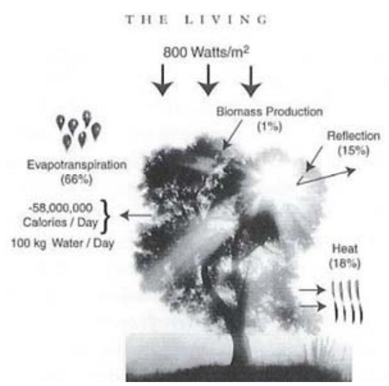
[9] The largest drop yet measured, .23%, occurred in July, 1981 during a period of intense sunspot activity partially blocking radiation. Friedman ( ), p. 87.

recent measurements show it varies by as much as .2%, which equals four times all human energy consumed on earth today
In all, only one billionth of total solar energy falls on the earth. But even this tiny fraction amounts to 5 million horsepower per square mile.

About two-thirds of the radiation that hits the earth's atmosphere hits the surface, with the remaining one-third absorbed by clouds as heat or reflected back into space.

Only about 1% of captured energy, itself only a small percentage of the energy that hits the earth's surface, is converted into stored energy in organic molecules through photosynthesis. The energy stored in this way each year is about 10^{18} kilojoules, which is about 30 times the global consumption of energy today. (Atkins, p. 210)

Figure 5
Storing Solar Energy
(Schneider & Sagan, 2005, p. 222)



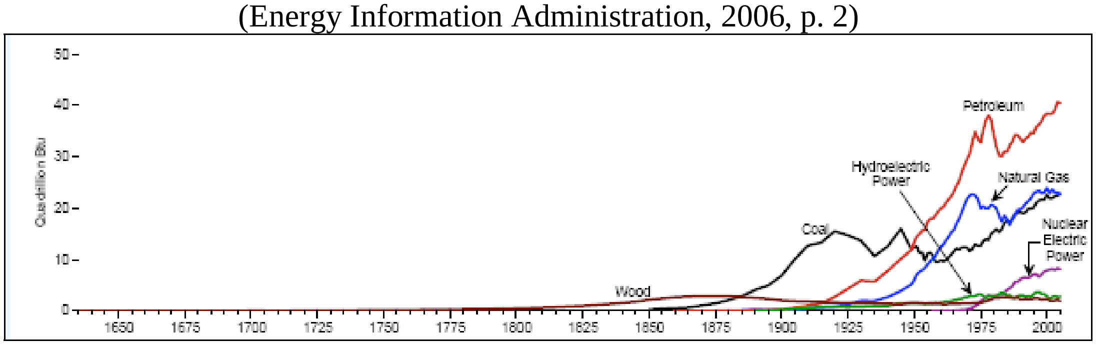
Through this seemingly wasteful collection process, stored sunlight makes the earth inhabitable. Sunlight trapped by photosynthesis produces the carbohydrates that feed the plants themselves (plants are *autotrophes* that produce their own food), which in turn provide the food for *heterotrophes*, species that do not produce their own food, made up of plant-eaters and animal-eaters, including humans.

Economic activity is the directed transformation and distribution of solar energy to satisfy the needs of man. For most of history, people eked out a bare subsistence living as hunter/gatherers by harvesting current and recently stored solar energy in the form of living plants and animals. We can think of stored solar energy as having a *solar vintage*, similar to the vintage marked on a bottle of wine that marks the year during which the solar energy captured in its organic molecules reached the surface of the earth. The hunter-gatherers harvested only very young solar vintages; for them the oldest vintage available was the wood they used for fuel, stored only decades before their time.

Modern man enjoys a dramatically higher living standard than the hunter-gatherer because we have recently learned to augment current solar energy by reaching deep into the wine cellar of vintage sunlight to mine stored energy from the distant past.

Wood, has been man’s primary fuel source for all of recorded history. Wood was only surpassed by coal in the closing decades of the nineteenth century, as shown in figure 6, below. Wood energy has a solar vintage measured in decades. In contrast, the sunlight stored in the form of coal reached the earth 350 million years ago during the Carboniferous Period of the Later Paleozoic Era when vast forests flourished in river deltas (Maiklen, 1998, p. 269). Coal was succeeded first by oil, then by gas, after 1950. Together, fossil fuels provide about 85% of the energy we use today.

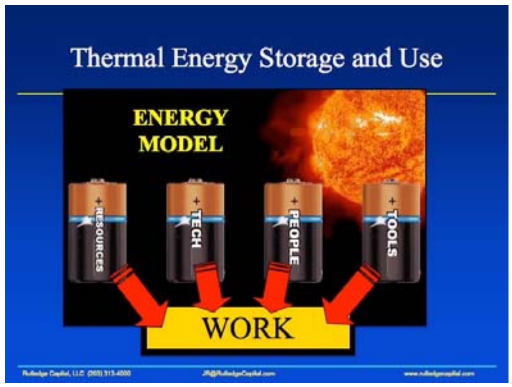
Figure 6
Stored Energy Consumption
Energy Consumption by Source 1635-2005
(Energy Information Administration, 2006, p. 2)



But this is too narrow a definition of energy to account for today’s levels of economic activity. Traditional fossil fuels and other natural resources are only one form of stored energy; their consumption accounts for only a small percentage of GDP in most nations. The bulk of energy used to produce work is the energy stored as human capital (stored food energy, knowledge, and experience), as technology (stored work and knowledge), and as tools (technology and knowledge stored as physical capital goods), depicted in

Figure 7. All are mechanisms for transferring energy from one period to a later time when it can be used to produce work by making people's efforts more productive.

Figure 7

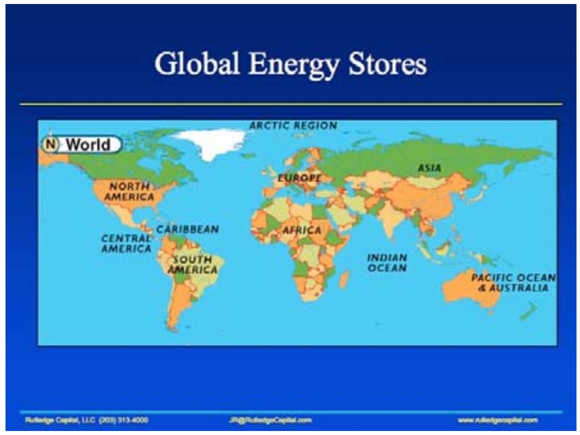


In this framework, then, wealth represents command over stored energy. Stored energy is used to produce work. Work is valued in markets by setting prices which reflect relative scarcities. National income represents gross national work, the price-weighted sum of all work produced.

Arbitrage Drives the global Economy

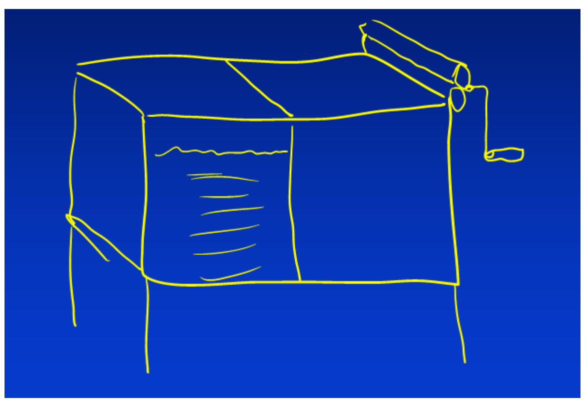
For historical reasons, stores of energy are not evenly distributed around the globe. Oil and gas are concentrated in the Gulf Region, with significant deposits in Russia, Africa, South America, and Australia. Technology and physical capital are concentrated in North America, Western Europe, and Japan. Human capital is concentrated in Asia.

Figure 8



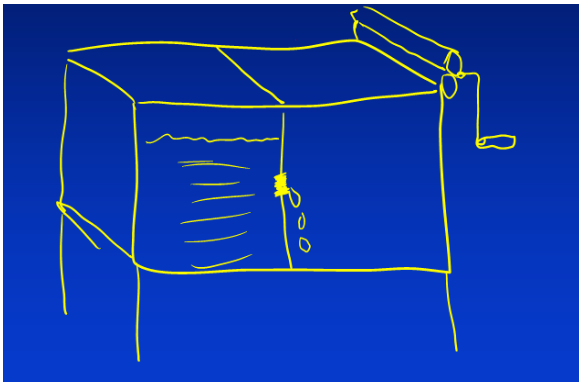
If national economies are closed, with no trade, then national endowments of stored energy will determine prices, which will vary from nation to nation. This is illustrated in Chart 9 below by the two compartments of a washtub, separated by a solid barrier. International trade textbooks refer to this as a state of autarky.

Figure 9
Closed Systems



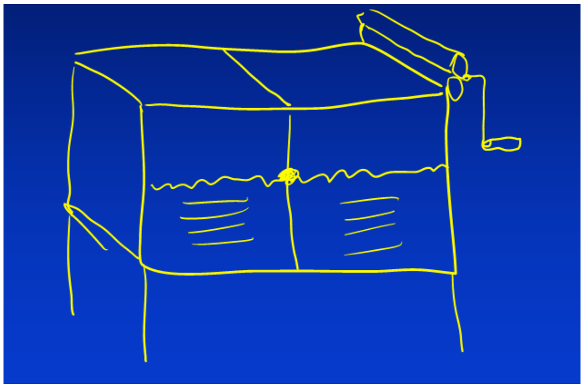
When two formerly closed systems are brought into contact to form a new, single, open system, the second law of thermodynamics forces energy to disperse. In the washtub example, in figure 10, the pressure differential caused by different water levels in the two tanks forces the water to flow from the full tank to the empty one. This adjustment also works for temperature adjustments, between high and low pressure systems in meteorology, and in chemical reactions. All are, formally, cooling processes in which a new open system moves toward a low energy state. In economics, this situation describes arbitrage behavior, where entrepreneurs redeploy resources in response to price or return differentials.

Figure 10
Open Systems (Arbitrage)



In the absence of continuing energy flows, the end result energy flow will be thermal equilibrium, illustrated in Figure 11, in which no further energy flow takes place. This is also known as the *zeroth law of thermodynamics*. In economics, a market is defined as an area in which prices will tend to converge to a single level; this is also known as the law of one price. The law of one price in economics corresponds to thermal equilibrium in thermodynamics. It is the point at which no further arbitrage will take place.

Figure 11
Thermodynamic Equilibrium

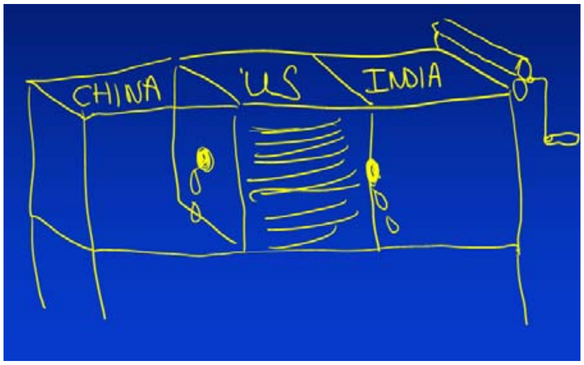


In the global economy, stored energy imbalances lead to price and return differentials that trigger arbitrage activities in which entrepreneurs redeploy resources toward areas of greater relative scarcity. This can be viewed in two equivalent ways.

From the point of view of the owner of physical capital, shown in Chart 12, the U.S. is abundantly supplied, while capital in China and India is relatively scarce. Returns on capital will be lower in the U.S. than in China and India. The relative price of capital goods will be higher in China and India than the U.S. Opening trade, and creating a single open market, will create incentives for owners of capital to redeploy their resources out of the U.S. and into China and India. This will take place as a combination of Foreign Direct Investment (FDI) and Portfolio Investment. This redeployment redresses the imbalance, forcing returns closer together.[10]

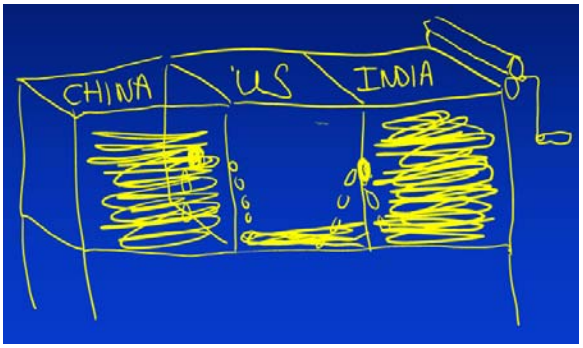
[10] American investors will not see this because financial statements of U.S. public companies report the profits and returns of companies listed in America, not for capital deployed in America. This is one of the major reasons why U.S. companies have been reporting record profits as a percentage of GDP for some time.

Figure 12
Arbitrage – Physical Capital



From the point of view of the owners of human capital, the situation is depicted in Chart 13, below. Human capital is abundant in China and India relative to the U.S., which makes wages and incomes lower in Asia than the U.S. Linking the three nations in a global economy will result in a net flow of human capital from Asia to the U.S., which will raise wages in China and India and lower wages in the U.S.

Figure 13
Arbitrage – Human Capital



The influx of human capital in the U.S. will take the form of immigration, outsourcing, and imports of goods and services, which embody human capital in their values.

Nonequilibrium Thermodynamics (NET)

Adjustments of the sort we have been describing are typically thought of as taking place smoothly and gradually. That may have made sense when resource redeployments principally took place as international trade in final goods. After all, the potential resource transfers can be very large relative to the capacity of the channel linking the systems—the hole in the wall is small. It takes about two weeks to load goods on a ship in Shanghai, sail to Long Beach, and unload the cargo, and the number of containers a ship can carry is strictly limited by its designed capacity, currently less that 14,000 standard 20 foot containers.

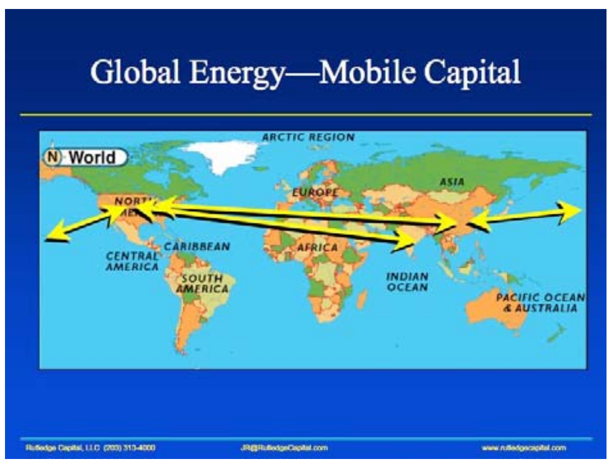
Through most of its history, thermodynamics assumed that adjustments toward thermal equilibrium were smooth and gradual, known as *reversible* thermodynamic change. Reversible change assumes that the distance from equilibrium is very small and that the adjustment takes place at infinitesimal speed. Attempts by researchers to examine the behavior of systems far from equilibrium, according to Ilya Prigogine (1997), including those of his Professor at the Free University of Brussels, the brilliant Belgian chemist Theophile de Donder, were actively discouraged within the physics and chemistry professions during the formative early decades of the 20th century. This is unfortunate, because far from equilibrium is where all the interesting behavior of thermodynamic takes place far, as Prigogine was later to prove in the work for which he was awarded the Nobel Prize in chemistry in 1977.

The work of Prigogine and his colleagues, known as the *Brussels School*, showed that distance from equilibrium is a fundamental parameter of systems. As the distance from equilibrium, along with the size of the accompanying temperature, pressure, or energy gradient, increases beyond a certain point, known as the bifurcation point, qualitative changes in system behavior appear that give rise to abrupt, unpredictable, and discontinuous changes, and in the formation of completely new coherent structures, which Prigogine referred to as *dissipative systems*. Today, this dynamic new field of study is variously called chaos theory, complexity, complex adaptive systems, network theory, self-organizing systems, nonequilibrium thermodynamics, or simply NET.[11] It is especially valuable for thinking through questions of stability and system failure.

[11] See the work of Barabasi (2002), Buchanan (2002), Gleick (1987), Holland (1995), Kauffman (1993), Nicolis and Prigogine (1989), Prigogine (1996), Schneider and Sagan

Today's networked global economy is certainly far from equilibrium, as measured by price, wage, or return differentials, making nonequilibrium thermodynamics extremely relevant for current policy analysis. And nations today are not only connected by slow-moving ships of limited capacity. They are connected by communications networks that can transport vast amounts of resources across fiber-optic networks at the speed of light, as illustrated in Figure 14. These links dramatically increase the adjustment speed of the global economy to price and return differentials. The resulting capital flows, outsourcing, cross-border M&A, supply-chain, and restructuring activities have also generated political backlash, the social equivalent of turbulence, in many countries, raising important questions of economic and political stability.

Figure 14



NET has particularly interesting things to say about recessions, asset price bubbles, and other temporary market failures. All are system, or network properties that, in general, cannot be understood by reductionist analysis the behavior of sub-groups of market participants. In other words, Y=C+I+G may be true as an accounting identity, but it is likely to be useless for forecasting recessions that can be better understood as temporary network "blackouts". Recessions occur when the information network we call a

(2005), Strogatz (2003), Watts (2003), Watts (2002a), and Watts (2003b). The father of them all, however, is Irwin Schrödinger's (1944) little book, What is Life?, based on three lectures delivered at Trinity College, Dublin in 1943, the lectures that, arguably, spawned both molecular biology and NET, the science of creating order from disorder.

market economy temporarily stops processing information—usually the result of an intervention by a policy maker, such as credit rationing, fuel rationing, or the imposition of quotas, which result in a situation of temporary non-price rationing.

NET also has important things to say about innovation and entrepreneurial behavior. Although economists write about the animal spirits of *the entrepreneur*, I suspect that entrepreneurship is a system property, rather an example of Darwinian natural selection. A recently discovered paper by Joseph Schumpeter (2005), written in 1932 but first published in the American Economic Review in March 2005, shows that he ultimately came to a similar view.

Implications for Energy Security Policies

The thermodynamic framework presented in this paper suggests fruitful areas for future discussion and research and has important applications regarding the question of energy security. In particular, it suggests that energy security should be analyzed in light of the full economic, financial, political, and social situation in a country, not just by counting up barrels of oil or cubic meters of gas.

I will take as a definition of energy security the situation where a national government has command over sufficient controllable stores of energy to maintain, with a high level of confidence, stable and rising living standards for its people over time, the prerequisites for maintaining social and political order.

The critical words in the above definition are “command” and “controllable.” For example, a nation may have a long-term supply contract or even legal ownership rights over energy resources located in another nation but may not control them because supply contracts and legal rights may not be enforceable in times of crisis when they are most needed. In this case, a seller continues to hold a real option to “call” for delivery of the resources in specific situations. Energy reserves are bulky and difficult to transport and store. Aside from modest strategic reserves, you can buy them, but you can’t bring them home.

Resources located within a country's national borders are likely to be more controllable, but even then may be subject to intervention from foreign governments—witness the recent activities in the Gulf Region. Secure energy resources must be both controllable and defendable.

A nation's most controllable resources are its endowments of natural resources, the physical capital within its borders, and the energies and knowledge of its people.

Governments today are pursuing various strategies to move toward energy security, including building strategic petroleum reserves, acquiring reserves in foreign countries, undertaking long-term supply contracts, exploring for additional reserves both inside their borders and offshore, forging alliances with countries rich in oil and gas, investing in pipelines, LNG ports and other distribution infrastructure, and implementing policies to encourage investment in solar, wind, water, and bio-fuels, policies to make more effective use of coal deposits, and policies to encourage conservation. I would suggest that, with few exceptions, such policies have too narrow a focus on fossil fuels only, and place excessive reliance on collecting current flux, as opposed to mining alternative sources of stored energy.

The thermodynamic framework suggests that we define energy broadly and that we use our human energies to find ways to improve the efficiency with which we capture, mine, store, attract, and deploy solar energy to produce economic activity. Fortunately, as outlined in previous sections, there are ample opportunities to improve efficiencies in all these areas.

Strategies to increase flux.

Economists will be tempted to try to solve the energy security problem, of course, by simply *assuming* increased solar radiation. Conjectures about positioning mirrors at stable points in outer space, explored by some scientists, seem impractical. But it is not impractical to acknowledge evidence, reported in (Singer 2007 p. 118), showing that solar radiation has, indeed increased by .05% per decade since the 1970's, an amount roughly equal to total human energy consumption that will increase crop yields through increased photosynthesis.

Strategies to increase our ability to capture solar energy

This is an area of research with great promise. Research areas include:

1) Large-scale collection of solar energy in desert regions, used to produce hydrogen,
2) Developing new varieties of chlorophyll to increase the ability of plant matter to harvest more energy from the sun (Atkins p. 216),
3) Genetic engineering of crops to suppress the photorespiration that wastes as much as half of the carbon fixed by photosynthesis, increasing crop yields by allowing plants to process carbon dioxide more efficiently (Atkins p. 224),
4) Research on the beneficial effects of higher recent temperatures and increased carbon dioxide levels on crop yields (Singer, p. 119),
5) Research on environmentally safe fertilizers, insecticides, and fungicides to increase crop yields and reduce manpower needed for growing food,
6) Genetically-engineered seeds that improve crop yield, resist drought, insects, and disease, and increase protein and amino acids critical for human nutrition, like the Quality-Protein (QP) maize developed at Mexico's International Maize and Wheat Improvement Center (Singer 2007),
7) Biotech –modified corn, cotton, and soybean crops, like the new pest-resistant hybrid cotton that has been genetically engineered in China, freeing up 600,000 hectares of land for growing food (Singer, 2007 p. 125).
8) Infrastructure projects to improve irrigation and control flood damage, improving crop yields.

These research topics increase our ability to store solar energy in the form pf plant life. All increase productivity of agricultural labor, freeing manpower to grow the energy-friendly service sector.

Strategies to increase our ability to mine stored solar energy

The oil, gas, and coal reserves reported in official statistics only reflect the amounts that can be economically extracted at known prices. This leaves out vast amounts of resources in economically depleted fields and low-yield tar sand deposits. Asian nations have a wonderful opportunity to use their most abundant resource—human capital—to develop technologies for improving recovery yields. This can be done in partnership with the governments of the

Gulf Region in countries that are rich in fossil fuels but do not have sufficient populations to conduct the research by setting up joint research laboratories at leading Chinese and Indian Universities. The same human capital resources can be used to solve the Feynman problem from page 6, by investing in research on economically producing hydrogen, controllable nuclear fusion, and other forms of energy.

Strategies to attract stored energy

Another strategy for increasing energy security is to become a destination resort for stored energy in all its forms. Like a photon, a capital good is a quantum unit of stored energy. The same is true for a scientist, an R&D lab, or a scientific discovery. Government policies can alter the likelihood that existing stores of stored energy located around the world will migrate to their countries. Like the bacteria that once lived as parasites within our bodies but decided to stay as mitochondria, foreign capital, foreign-developed technology, and foreign-born human capital improve our energy security.

1) Policies to attract foreign sources of stored energy include:
2) Political and social stability,
3) Rule of law, methods for enforcing contracts and settling disputes, property rights, intellectual property protection,
4) Legal and accounting environment, trust in public institutions and public officials, lack of corruption,
5) Tax laws, infrastructure, education,
6) Visas and immigration restrictions,
7) Communications networks,
8) Stable currency, inflation, growth
9) Capital markets,
10) Media access.

In each case, when deciding whether to welcome foreign stores of energy, there is a simple test—do they bring more energy into the country that they will consume, i.e., will doing so result in a net increase in our supply of stored energy.

Strategies to increase our ability to convert energy into economic activity

The final strategies I will mention are perhaps both the easiest to achieve and have the most impact, policies that make a nation more efficient at converting energy into economic activity. These strategies increase worker productivity and increase incomes for a given supply of energy. In doing so, they make a nation more energy independent.

Primary industries, such as mining and agriculture, use a great deal of fossil fuel per unit of output. Secondary industries, manufacturing, use less energy. Tertiary, or service, industries use least of all. For this reason, strategies that improve productivity in agriculture, mining, and manufacturing, leading to the redeployment of manpower to the service industries, reduce the amount of fossil fuel needed to produce each unit of output, making a nation more energy independent.

These policies are based on the notion that human capital and technology can, and should, be viewed as sources of energy.

Conclusion

The 20th century was the century of dinosaur energy; the 21st century will be dominated by human capital, Asia's most bountiful resource. Investing in human capital is the only path to rising incomes, energy security, and truly sustainable growth. To tap that resource, Asian governments need to invest in educating their people to the highest level, especially in math and science, and in building the fiber-optic communications networks that will allow the work produced by their human capital to be distributed quickly and inexpensively to end-users around the world. And Asia must be at the forefront of research and development in new technologies. In the end, the productivity of the Asian people is the only true path to energy security.

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