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Fuels and Prophecy

by Conn Nugent

1. 2006.

Something important happened this year that took two decades to achieve, required prodigious work, and was resisted by stubborn and well-financed opponents. America got climate change. Global warming entered the conventional wisdom.

In 2006, climate science reached operational unanimity. Respectable doubters acknowledged that their doubts were no longer justified. The most influential of the doubters had been Thomas Karl, Director of the National Climatic Data Center. In May of this year the Center released a report, edited by Karl, concluding that "The data show clear evidence of human influences on the climate system." When Karl testified before Congress in July, he declared that "Greenhouse gases are increasing in the atmosphere because of human activities and increasingly trapping more heat." When questioned about the reliability of predictive computer models – a favorite theme of climate change deniers – Karl replied: "They're reliable enough to be a very useful guide into the future."* Case closed. Despite sniping from intransigents sponsored by industry groups, all major specialists now agreed that temperatures of the ocean, land, and atmosphere had increased at an unusually rapid rate over the last thirty years, and that most, if not all, of the warming was due to unprecedented levels of gases produced by human activities.

Public opinion soon followed. The best-informed doubting journalist, Gregg Easterbrook, annnounced in a *New York Times* op-ed (May 24) that "... based on the data, I'm now switching sides regarding global warming, from skeptic to convert." Newspaper articles finally dispensed with the dueling quotes from "both sides of the global warming debate." Stories were leaked about political appointees squashing climate science in federal agencies. Chevron launched a high-profile advertising campaign on climate change and conservation.** President Bush went on record that human activities had changed the weather "to a certain extent." Rev. Pat Robertson told his television audience "I am a convert on global warming." And, for the first time, the polls were emphatic: a consistent majority was persuaded that global warming was real and that humans caused it by burning fuel.

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* *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*, US Climate Change Science Program, May 2006; testimony before House Government Reform Committee, 20 July 2006.

** Exxon/Mobil, the least defensive member of Big Oil, shifted grant money from global warming deniers to cost/benefit analysts who argued that the cure of doing something would be worse than the sickness of a few upward ticks of temperature.

In 2006, the price of the most popular fuel – petroleum – reached a record high of $72 per barrel (back to $60 as of October 30). Investors agree that the price might come down a little more, but not much: oil futures through July 2009 are still trading above $70. As a Wall Street commodities broker explained, "The market is saying this is going to be with us for a while."

"We are addicted to oil," said George Bush.

The oil price spike – and the attendant magazine covers and daily television bulletins – called attention to what might otherwise have been an obscure debate among petroleum geologists and oil industry analysts. The question was whether the world supply of oil had "peaked," i.e., if the annual consumption of oil would henceforth always be greater than the annual discovery of new reserves. The Peak Oil standard was carried by some well-regarded oil company geologists – Colin Campbell, formerly of BP and Amoco, being the most conspicuous – and hence the argument didn't fit the standard default position of environmentalists versus practical men of the world. The practical men were now talking about petroleum on the downward slope of its supply curve. A small eruption of books soon followed: *The End of Oil*; *The Party's Over*; *Beyond Oil*; *Out of Gas*.

The end of this notable year provides a good opportunity to take stock of the knotted themes of fuel and climate. Since most of us are interested less in the history of these subjects than in their future – What's going to happen? Are we going to run out of oil? Is it going to get really hot? – I will offer some predictions. By design, these are not bold predictions. They fall within the broad middle of professional respectability. But I also believe they are accurate. In fact, I would wager large sums on them. To each of these predictions is appended a parenthetical gloss which includes statements that I believe to be more likely true than not. I would entertain side-bets on these.

2. Sure Things and Likelihoods.

• Global demand for oil will increase until it costs at least twice as much as it does today. [Probably three times as much, adjusted for inflation. We will not develop alternative fuels nearly so efficient or convenient as gasoline or diesel, nor will we develop attractive alternatives to petroleum as a feedstock for making plastics. Increased demand from Asia will outweigh conservation in Europe and North America.]

• Global demand for oil will dependably exceed global supply – year-in, year-out – no later than 2020. By the end of the century, more than ninety percent of all recoverable oil deposits will have been consumed.

[The time required for the transition from cheap petroleum to expensive petroleum will take longer than predicted in some recent extrapolations about Peak Oil. Daniel Yergin, author of *The Prize* and a studied anti-alarmist, probably has it right: As prices rise, they spur the discovery of new reserves (mostly deepwater), render economical oil-shale deposits hitherto regarded as not worth the bother (Alberta and the Orinoco Basin), and spread new extraction technologies that rejuvenate wells thought to have been tapped out (Russia and Mexico). But petroleum *is* finite. Oil supplies may not have reached their peak yet, but you can certainly see the peak from here. When will oil become irrevocably expensive, i.e., four times as costly as today? I'll take even money on 2040-2060. From that point on, petroleum will be used more as a manufacturing feedstock than as a fuel.*]

• Natural gas will follow the same general trajectory as oil, but at a slower pace.
[Slower by a couple of decades. Since agriculture is the most gas-intensive sector of the economy, and since governments are likely to subsidize food production, there will be strong upward price pressures for gas used in other sectors. Gas to generate electricity and heat buildings will be in especially high demand in nations committed to anti-pollution standards and reduction of carbon dioxide emissions.]

• Global demand for coal will increase throughout the century.
[Coal reserves dwarf those of all other fossil fuels combined. Spurred by growing demand from Asia, coal once again will be the world's dominant fuel.]

• Much more coal will be liquefied and gasified.
[As oil and gas become expensive, coal will be transmuted to do their work. The substitution process will not happen quickly, however, given the inefficiencies and higher emission levels of liquefied and gasified coal compared to oil and gas. Coal and coal-based liquids and gases will themselves become costly if mercury and other toxic emissions are removed and if carbon dioxide is "sequestered" so as to mitigate the impact of coal-burning on atmospheric warming. Keep coal cheap and you speed the ruination of the natural world. Make it behave politely and it gets expensive.]

• Non-fossil sources of energy – primarily nuclear power and solar power – will increase their shares of global energy supply, but will not rival coal.
[Many rich countries will follow the French model of using nuclear power as the primary source for generating electricity. Wind turbines and solar electrical arrays will make significant contributions in countries uneasy with nuclear power but dedicated to lowering carbon dioxide emissions. Biofuels will play a modest role in some local applications, mostly in the tropics.]

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* For the most recent installments of the Peak Oil debate, see Colin Campbell's www.peakoil.net and Daniel Yergin's www.cera.com.

• The rate of increase of aggregate temperature will accelerate over the next twenty-five years. The overall warming trend will continue for another sixty years at least. Ecological losses will be severe. A large share of private and public expenditures will be spent coping with the effects of climate change on human activities.

[Those effects will vary widely. Growing seasons will stretch in Russia and northern North America, and plant growth will be enhanced in many places. On the whole, though, negative effects will much outweigh the positive. "Dramatic weather events" will increase. Prolonged droughts will afflict farmers in the lower latitudes, especially in Africa. Flooding of coastal areas will increase as a result of rising sea levels, and low-lying settlements too poor to build seawalls will be devastated (Micronesia, most of Bangladesh). Tropical diseases will spread to once-cooler regions. Agricultural expansion and environmental disruption will expose humans and farm animals to new viruses*]

• Global food production will increase over the next twenty years, thanks to the spread of high-input agriculture in the developing world. Soil loss and soil degradation will increase as a result. Hypoxia from fertilizer runoff will form extensive "dead zones" off the coasts of every continent. Aquifers will be depleted and water supplies salinated. Claims to irrigation rights will foment domestic and international disputes.

[For a while, Green Revolution-style innovations will help agriculture keep pace with human numbers, now expected to peak at 9.1 billion in 2050 (the middle-range projection of the United Nations Population Fund). Government subsidies for food production will postpone the effects of rising natural gas prices on the use of synthetic fertilizers, but the subsidies will eventually prove untenable. The greater threats to food production will come from the ecological degradation intrinsic to modern farming methods, especially as they are applied to soils that are thin to begin with (much of Africa and Central Asia).** Benign alternatives to high-input farming – no-till, perennial cereal crops, for example – will not emerge commercially until 2020.]

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* For consideration of climate change and public health, see "Climate Change Futures: Health, Ecological and Economic Dimensions" (Center for Health and the Global Environment, Harvard Medical School, 2006).

** The complex relationships of fuel prices, world food markets, soil quality, and fresh water are well traced in Lester Brown's altogether commendable *Plan B 2.0* (Earth Policy Institute, Washington, 2006).

3. The Dark and The Light.

On the other side of likelihood, in my opinion, but very much on this side of plausibility, are two contrasting scenarios: The first envisons global catastrophe; the second foresees the triumph of reason and renewable sources of energy.

Certainly there is a chance of an international collapse due to war, crop failures, economic depression, or all three. The spark could come from dramatic changes in climate and weather. James Lovelock, father of the Gaia Hypothesis, thinks that spark has been struck already. His most recent book* argues that the world's climate is well launched onto a trajectory in which apalling effects spawn apalling effects until, in a matter of decades, most places on earth are uninhabitable by humanity. Billions die. Lovelock may be moved by his own inner doomsday (we hope), but more sober types, such as Jim Hansen of NASA, credit the idea that climate change has already gained an unstoppable momentum, and that there may be little we can do in the short term to brake that momentum. Bill McKibben argues that sudden, extremely disruptive changes in weather patterns are "entirely possible, even probable." His fear is nourished on recent data. As McKibben recently wrote:

... (M)ost of the effects of heating on the physical world have in fact been more dire than originally predicted. The regular reader of Science *and* Nature *is treated to an almost weekly load of apocalyptic data, virtually all of it showing results at the very upper end of the ranges predicted by climate models, or beyond them altogether. Compared with the original models of a few years ago, ice is melting faster; forest soils are giving up more carbon as they warm; storms are increasing much more quickly in number and size... (A) new study shows methane leaking from Siberian permafrost at five times the predicted rate, which is seriously bad news since methane is an even more potent greenhouse gas than carbon dioxide.***

New findings from glacier cores and the fossil record show that climate can "flip" more or less abruptly, and with great force. Instead of a straight-line continuum of temperature rise and incremental consequence, the earth's climate system now looks like a sorcerer's apprentice nightmare with a mind-of-its-own force of "emergent qualities." Vital grain-growing regions could become desertified in a matter of a few years; Western Europe could wake up shivering to a massive shift in the course of the Gulfstream.

Another vision of collapse concentrates less on climate chain than on the inherent fragility of global systems and the illusion of control. Humanity has created a complicated network of global interdependencies to meet the demands of 6.6 billion souls: energy; food; goods; services; finance; labor; information. Everything is

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* James Lovelock, *The Revenge of Gaia: Earth's Climate in Crisis and the Fate of Humanity*, 2006.

**Bill McKibben, "How Close to Catastrophe?," *New York Review of Books*, 16 November 2006.

connected. A catastrophe in any one might set off a chain reaction. David Orr, the author of *Ecological Literacy*, writes that the "tight coupling of so many systems makes the odds of events cascading out of control rather high. The mega-system, which no one understands, at some time will probably operate to amplify disturbances and not dampen them." Who knows?

What we do know is that human history provides ample precedent for the collapse of systems that their beneficiaries thought were robust. We might not know the consequences of our interconnections today any better than the optimistic Europeans of 1914 understood the dynamics of alliances, mobilization requirements, and industrialized weaponry or the optimistic Americans of 1929 understood the dynamics of speculation and investment. If you take the basic twenty-first century energy/environment powder keg and pour in the venerable explosives of national rivalries, uneasy electorates, market panics, and a few bad leaders, the odds on calamity can never be long.

There is a contrasting vision, of course, in which humans pull themselves out of this mess before climate change and ecological deterioration get too much worse. No one makes the case more appealingly than Amory Lovins who, thirty years after his influential *Foreign Affairs* article, "Soft Energy Paths: The Road Not Taken," maintains that economic growth and environmental restoration can be mutually reinforcing. Start with energy efficiency, Lovins says, and then go on to replace fossil fuels with renewables. All that is required is normal self-interest pursuing re-aligned market incentives: "...(T)he transition beyond oil will expand customer choice and wealth, and will be led by business for profit." What's needed are "novel public policies to accelerate this transition that are market-oriented without taxes and innovation-driven without mandates."*

Many others are almost as optimistic as Lovins, and share his conviction that private economic incentives will be the driving wheel of positive change. But they tend to want government to intervene more strongly on behalf of getting prices right. On the demand side, they say, the federal government should withdraw all fossil-fuel subsidies and impose a significant carbon tax on goods and services. On the supply side, government should speed renewables through R&D, massive procurement policies, and tax breaks for manufacturers and consumers. With vigorous prosecution by the nation-state, the war on global warming can be won.

In contrast to both Natural Capitalism and the New New Deal, other visionaries of a soft landing say that the only sure way to save the earth is to jettison consumerism and giantism, cultivate local support systems, protect local ecosystems, and make of oneself and one's neighbors a demonstration project of the proposition that middle-class Westerners can lead comfortable, interesting lives with dramatically less use of fossil fuels. The counterculture lives, and will probably grow.

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* Amory R. Lovins et. al., *Winning the Oil Endgame*, Rocky Mountain Institute, 2006.

4. The Golden Age.

All terrestrial species need fresh infusions of carbon in order to survive. As an efficiency measure, natural selection prompts us to seek energy-rich carbon, as found in sugars, fats, and carbohydrates. To simplify matters, whenever the term "carbon" appears in this paper, it will be shorthand for "energy-rich carbon" or "concentrated carbon."

For almost all our history, *Homo sapiens* acquired its carbon like any other species, by eating plants and animals on a scattered and more or less replenishable scale. About ten thousand years ago, humans learned to organize their carbon sources by domesticating plants and animals. They were able to form larger, non-migratory communities with the capacity to generate surpluses large enough to permit the emergence of classes that did not have to produce food. These capacities came at the cost of chronic soil loss and other depletions of natural capital. As Wes Jackson describes it, "That's not a problem *in* agriculture. That's the problem *of* agriculture."*

Over the last two hundred years, humans have exponentially multiplied their carbon acquisitions by learning to extract the energy contained in the buried remains of hundreds of millions of generations of plants and animals (hence "fossil" fuels). This new capacity enabled an enormous leap in both human population and ecological damage. That is the problem of industrialization and, later, industrialized agriculture.

The wide adoption of coal-burning marked the beginning of the fossil fuel era. But perhaps the most socially transformative development was the first commercially successful petroleum well, drilled in Pennsylvania in 1859 (the same year as the publication of *On the Origin of Species*). It took about fifty years for King Coal to give way to King Oil, but petroleum has reigned ever since. Its popularity is growing still, and at an astonishing rate: one-quarter of all the oil ever burned has been burned since 1994; one-half of all the oil ever burned has been burned since 1980.

Among our oil dependencies, the strongest attachments are to portable petroleum fuels. And the reason we are so attached is because they are truly wonderful.

Consider gasoline, petroleum's most refined offspring. Gasoline is safe, even when dispensed by amateurs at the SelfServ. It is efficiently concentrated: an ounce of gasoline contains more potential energy than an ounce of any other fossil fuel, and consequently, makes available more vehicle space for passengers and cargo. Gasoline is easily stored and transported, and doesn't have to be re-charged, re-constituted, or re-anything. After combustion, the most noxious of its emissions are rendered relatively harmless by an inexpensive catalytic converter. It is by far the most convenient of fuels.

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* Wes Jackson, *New Roots for Agriculture*, 1985.

Gasoline (and diesel fuel) enables mass mobility, and the lure of mass mobility has proved irresistible in every society that could afford it. So long as we prize mobility – for our goods as well as for ourselves – we will buy gasoline until its price becomes just too onerous to bear. At some point, high gasoline prices might move us to other forms of vehicle power, and we might even choose to move around less. But price signals will have to be bright and unambiguous. Gasoline is just too good.

Natural gas is not quite in gasoline's league as a portable fuel, but it is certainly versatile and altogether handy. Natural gas is dense and burns relatively clean. It can be transported as a gas through pipelines and as a liquid in tanks. It can power vehicles and electric generators; it can heat buildings; and most importantly, it provides the feedstock for the synthetic fertilizers upon which industrial agriculture relies.

Modern agriculture, in fact, is enmeshed in a web of cheap oil and gas. Farmers need off-farm, imported carbons for the nitrogen fertilizers that compensate for their annual losses of soil and fertility; off-farm carbons to power the machines that plant, cultivate, and harvest; off-farm carbons for herbicides and pesticides; and off-farm carbons to transport products to consumers. This system works as a successful strategy for increasing food supplies. But it works only until the prices of off-farm carbon go high or until soil depletion precludes any kind of agriculture at all.

It is hard to find *any* sector that would be unaffected by a meaningful rise in the prices of oil and gas. Closely examine a slice of a modern economy, and you recognize that the physical and human infrastructures – the buildings, the machines, the supplies, the transport, the life supports of workers – are created by burning carbon fuels. Make carbon fuels expensive and those infrastructures become expensive, both to build and to operate. This is true not just for farms and factories, but for offices, schools and homes.

There have been some interesting recent attempts to quantify the materials and energy embedded in everyday objects and behaviors. The best known is probably the Carbon Footprint, a calculation devised by Canadian scientists to measure carbon dioxide emissions occasioned by typical North American consumers. Basically, you estimate how much carbon went into the making of a product, the transportation of the product, the use of the product, and the disposal of the product. Your breakfast cereal requires X amount of carbon for growing the grains (fertilizers, tractors, combines, fuels), Y amount of carbon for processing (trucks, truck fuel, mill operations, packaging), and Z amount of carbon for moving it to your supermarket and then your kitchen table and then the landfill. The footprints of certain activities, like eating and commuting, can vary according to personal custom, as in where you shop and whether you ride a bus to work. The footprints of other kinds of activities, like jet travel, are pretty much set: once you decide to fly somewhere, there's not a lot you can do to modify your demand.

And yet research shows that households that make a small carbon footprint in one realm tend to make a big footprint in another. At least in this time and on this continent, the size of a household's carbon footprint is directly correlated to its overall expenditures. Spend money and you burn carbon. Spend lots of money and you burn lots of carbon. Even a service economy of educated symbol manipulators is still intensively material, and every day more so.

But it's been a great ride, has it not? Cheap carbon has allowed a billion people to lead lives available to only the thinnest upper crust of two hundred years ago. Most contemporary North Americans, West Europeans, and Japanese obtain food, shelter, transport, material goods, and medical care through labor that requires about one-quarter of one's time and little physical pain. The suburban grandchildren of peasants and millworkers enjoy the luxuries of mini-Versailles, and with better plumbing. This state of affairs has held steady for those of us born into the postwar American middle class, and it is available today to ambitious and lucky Asian teenagers: jump into global capitalism and the chances are good – maybe not great, but good – that you and your family will live longer, eat better, and acquire more possessions than your parents did. The Asian teenagers know that petroleum is finite and due to become more expensive. But they would rather face that eventuality as rich people rather than as poor people. As a Chinese energy official told an American engineer recently, "As soon as anyone develops a clean way to generate power, we'll be the second ones to use it." He is not wrong, not yet. We are still in the Golden Age.

5. Nuclear and Solar.

In order to prolong material abundance and service economies, and thereby preserve domestic tranquility, the governments of the developed world will eventually adopt policies designed to favor energy conservation. They will probably buy into at least a significant fraction of Amory Lovins' efficiency-first approach, though I suspect they will use tax policy as the instrument of choice. But they will also have to assure new energy supplies. They might open up more public lands to fuel production, they might threaten or wage war to assure continuity of supply, but they will almost certainly increase their reliance on nuclear and solar energy.

The maximalist pro-nuclear strategy is twofold: one, electrify sectors that now rely on oil and gas (transport, fertilizers, heating); and two, generate almost all electricity from nuclear power plants. Converting this strategy into realty in the United States would require hundreds of new reactors. The minimalist pro-nuclear strategy demurs on the electrify-everything idea, but calls for oil and gas to be reserved for portable fuels only.

Many solar engineers agree with the nuclear maximalists that electrification is the way to go, but they argue that the best way to generate electricity is to deploy solar converters in huge arrays in places with optimal weather. Windmills covering North Dakota, for example, or "solar-concentrator" furnaces throughout the Southwest. According to a recent bulletin from the federal government's Sandia Labs, "... (E)nough electric power for the entire country could be generated by covering about nine percent of Nevada – a plot of land 100 miles on a side – with parabolic trough systems."* Other solar experts are skeptical of that claim, to put it mildly, but most of them still like to hear the solar side of the energy-future argument expressed in the can-do language of American technological optimism.

The more localist elements of the solar world tend to favor site-specific, task-oriented applications such as photovoltaic panels for domestic electricity or rooftop heaters for hot water. They also like windmills, but in smaller arrays. The Big Solar and the Little Solar approaches are not mutually exclusive, of course, nor indeed are solar and nuclear. I suspect we will see both sources meeting larger shares of energy demand as increased coal-burning becomes too environmentally intolerable. But neither the nuclear paths nor the solar paths will lead us back to cheap energy in general and cheap portable fuels in particular.**

Nuclear power has attracted some new environmentalist allies who see no other practical way to arrest global warming. They may be right, but it won't be easy. An economy that provides most mechanical energy through electricity and that produces most electricity through nuclear reactors would require enormous and abiding capital investments. Nuclear plants are extremely expensive to build and run, and they have usable lifetimes shorter than most coal-burning plants. And, as anyone who has lived in an all-electric house can tell you, using electricity to heat air and water is a costly inefficiency.

Even more costly are the burdens of our nuclear ignorance. The safe disposal of radioactive wastes (for ten thousand years) will be expensive when we finally figure out how to do it. But our gravest ignorance is that we have not developed a commercially successful system to generate electricity from a nuclear reaction with the assurance that the material going to a plant, being used at a plant, and leaving a plant could never be used to make nuclear weapons. Facilities must therefore be rendered as close to invulnerable as possible, and that task demands heavy security. Just as a significant

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* See http://www.energylan.sandia.gov/sunlab.

** Lately there's been considerable enthusiasm for biofuels. The arguments are now being thrashed out in journals and conferences. At this stage of the discussion, the papers I find most persuasive argue that no biofuel feedstock north of sugarcane is worth the small amount of carbon-equivalence it would produce and the large number of acres it would remove from food production. See Michael B. McElroy, "The Ethanol Illusion," *Harvard Magazine*, November – December 2006.

fraction of the current United States defense budget should be calculated as part of the price of gasoline, the costs of securing four hundred power plants should be counted as part of the price of nuclear electricity. It is this element of nuclear power – its attractiveness to weapons builders and the consequent requirements for an expensive and onerous security apparatus – that is the most profoundly disagreeable.

Some say the risks can be reduced. Nuclear engineers describe "fast neutron reactors" that burn only Uranium-238 (and neither require nor produce plutonium) and whose wastes must be protected for hundreds, not thousands, of years. If such reactors were safe to operate; not more than twice as expensive to build; and thoroughly proliferation-proof – then that would surely affect any cost/benefit analysis. We will have to wait.

Solar power is certainly safer and more resilient than nuclear, but the inherent inefficiencies of using electricity to provide thermal and mechanical power also limit the potential of solar installations to handle large industrial and commercial demands. There is an added problem of location. Reliably strong winds usually blow a considerable distance from major demand centers, just as sunny deserts remain relatively unpopulated. Transmitting electricity over long distances becomes very expensive if utilities take counter-measures against the normal dissipation of electrical energy as it travels. Solar energy will probably make significant and economical contributions to the domestic energy needs of nearby consumers, but its uses for transportation, manufacture, and space heating would require capital investments as daunting as any. I strongly favor those investments, but there are no slam dunks in this game.

Nuclear future or solar future, Big Solar or Little Solar, the largest "new" source of energy in rich countries will come from energy conservation. More efficient engines; better insulated appliances and buildings; thriftier vehicles; reductions in tillage and fertilizer use; fuels and machinery matched to "end uses" – all will help smooth the rough social and political edges of the transition to an era of expensive energy. But because oil and gas markets are global, conservation in one sector actually impels greater demand from the whole: energy efficiency in Germany makes available more carbon energy at more attractive prices to the Chinese and the Americans. The overall, planetary trend moves ineluctably toward more demand, less supply, and higher prices for the fossil fuels.

6. Ignorance and Know-How.

It is difficult for contemporaries to dwell on problems that might beset their descendents. As Keynes said, in the long run we're all dead. Still, we have a pretty good idea of the nature of an upcoming sea change in the material circumstances of our grandchildren, and for many of us, fretting comes natural. Will they manage? Will they *know* enough to manage?

Americans set great store by knowledge, and we assign special value to knowledge that expands productive capacities. The exercise of those capacities – knowledge turned to work – we call know-how. We praise knowledge but we treasure know-how. In fact, knowledge unattached to know-how ("mere knowledge") we tend to regard with amused tolerance or open suspicion. We also think we know what kinds of knowledge lead most efficiently to the kinds of know-how we regard most highly. We tend to promote and reward those kinds of knowledge, lately under the banner of "preparing our kids to compete in a global economy."

But we do so in ignorance, I believe. We are ignorant – innocently and willfully – of the degrees to which the character and utility of our know-how are predicated on the availability of cheap carbon. The value of certain kinds of know-how we now deem essential will decline as the costs of carbon rise. Other kinds of know-how will become more valuable.

It's not simply a matter of rising demand for wind turbines and declining demand for V-8 engines. The general sets of know-how required to prosper in an international system based on cheap access to distant energy sources are different from the sets of know-how you need to prosper in a local system where energy is expensive. A large-scale spinach grower knows things of which an Amish farmer is ignorant, and vice-versa. Today's common cultural know-how assumes conditions familiar to the large spinach grower, but those conditions are now revealed to be impermanent. The Amish farmer suddenly gets smarter. He has know-how useful to a society that needs to feed itself without immense amounts of purchased carbon. I don't doubt that our grandchildren will get most of their food from farms with computers and tractors – the most valuable kind of know-how will probably be a blend of traditional knowledge and ultra-modern knowledge – but the giant high-import farms of today should become increasingly unprofitable and the types of know-how they summon should become decreasingly relevant.

As oil and gas become expensive, production of goods that are transport-intensive will be disadvantaged, as will production that relies on high carbon-energy inputs for the creation of the goods themselves. Enterprises of far-flung suppliers and far-flung markets will need to adjust. Local low-input producers will appeal to new markets. As that trend grows, so will the probability that, relative to today, a larger share of the population of rich countries will produce goods and a smaller share will sell services. If so, that would constitute an important reversal of the heretofore irresistible momentum of developed countries toward the service economy model first described by Daniel Bell forty years ago. I worry that we are too ignorant to handle the change.

First of all, I assume that most consumer goods will cost more than they do today, as measured by per-capita purchasing power, if for no other reason than because of a general rise in material and energy costs. I would also assume that our grandchildren's societies will probably suffer from at least an initial scarcity of cultural capacity to cope with a decline in purchasing power (however slight), and to reinvigorate and manage local and regional economies. A fundamental difficulty is that cheap-energy know-how has atrophied expensive-energy know-how. Just as pre-Gutenberg savants had powers of memory and recitation not found in the print era, pre-oil-and-gas farmers mastered agronomic and mechanical systems alien to their descendents but of potential utility in developing the optimal 2030 toolbox that hybridizes old and new approaches to farming. New circumstances will favor skill sets and attitudes that once flourished in harder times – knowing how to fix things, for instance – but have latterly fallen into disuse.

OK, we moderns say, so we've lost some old-timey know-how – we haven't *lost* it, actually, it's more like we've *mothballed* it – but all in all, it's a fair exchange. We know things our ancestors couldn't imagine.

But perhaps we underestimate the value of old know-how and the difficulty of a re-diffusion of it among the populace. There are scores of historical examples where high-level skills once common became rare or debased. J. B. Bury, the great scholar of the ancient Mediterranean, observed that it took only three generations for a people to lose a craft. And maybe we overestimate the applicability of current know-how. Most of us are aware that mobility depends on carbon fuels, and most of us are aware that carbon fuels power industry, but few conclude that our knowledge is *embedded* in cheap carbon fuels, and may be of scant use in another energy context. It could be that the person best prepared for the age to come is the skeevy 19-year-old who drives a pickup filled with wires and machine parts that he's going to try to rig up next week. Today he's a disappointing dropout, ill-equipped to compete in that global economy we talk about. Later on he's a very useful guy to have around.

7. The Most Important Question on Earth.

When I discuss these fuel and food questions with non-specialist colleagues, their reactions often tend to a sort of humanistic uplift. Don't worry so much. Don't underestimate ingenuity and the human spirit. Science and technology will respond in ways yet inconceivable to our blinkered imaginations. Don't be one of those Neo-Malthusians.

Yes, human ingenuity is powerful and surprising. Few seers of 1900 foresaw airplanes or antibiotics. But there's a huge difference between new technologies and new energy sources. We can be dazzled, even changed, by new machines and new processes, but the

form of energy on which they depend is usually familiar. New, transformative sources of energy don't appear very frequently. Hans Bethe used to point out that no form of energy – from the drafthorse to coal to petroleum to nuclear power – ever became a fuel for commonplace technology in fewer than fifty years. Bethe said that the first half of the twenty-first century would be powered by energy sources familiar to the scientists of the second half of the twentieth century. Perhaps magnetic-levitation systems deserve a close look but it's difficult to extend the list any further. Cold fusion, anyone?

And so I fear that the post-2030 world will be extremely difficult for hundreds of millions of people. Climate change plus ecosystem destruction plus soil depletion plus high fuel and fertilizer prices plus continued population growth – it reads like a recipe for famine and disease. And it would be surprising if competition for depleted resources did not contribute to, or impel, wars and banditry and social upheavals of all sorts.

That is not to say that everyone everywhere will feel imperiled, much less uncomfortable. Rich people and rich countries will protect themselves. Money will be more useful than ever. I expect that the manner of living enjoyed today by the middle classes of the developed world will hang in there for a few more decades at least, and probably longer. If our national governments can resist the temptation to use force to secure energy supplies; if they and we can manage our fiscal and economic affairs to avoid a sudden plunge into a new Great Depression; and if the weather doesn't turn completely haywire – big ifs – life for most Americans in the twenty-first century might be as rewarding and as miserable as it is today. It's not a material issue per se: people have led healthy, complicated lives on one-tenth of our current per-capita energy diet, and people can do it again. It's more a question of our social and personal reactions to the new expensive-energy environment. Will an increase in fossil fuel prices reduce the size of the service economy, curtail air travel, and limit consumer choice? Yes. Will new houses be as big and as cheap to heat and air-condition as the new houses of today? No. Will our beach house wash away? Probably. Will we have our laptops and iPods? Yes, and better than ever. Will more people be thrown back (as they say) on their own capacities – and the capacities of their neighbors – to grow, make, and repair? Yes. It might not be so bad.

It might even be good. Already a significant minority has found that the pursuit of happiness is well taken on a path marked by energy conservation, local food, and a general attentiveness to the natural world. I am not referring only to the counterculturalists – though they certainly count – but all sorts of people: new traditionalists attracted to rural life and agrarian values; cyberphiles pioneering the hybridization of old and new know-hows; settlers of energy-efficient urban neighborhoods; Mexican workers balancing on one foot in the industrial world and one foot in the village. (The two most broadly competent subcultures I've encountered in the last ten years – the ones most ready for any contingency – are North Dakotan farmers and Chihuahuan mechanics.) Just as it's conceivable that the giant flying apparatus of the global economy will crash and burn, it's also conceivable that Americans will learn how to adapt, even flourish.

My personal rosy scenario is New Deal Jeffersonianism, if that's possible. I can imagine a federal government that hastens the development of solar energy as the great public works project of our time. Solar trains speed you from New York to Obama City (formerly San Francisco) in under fifteen hours. All new buildings incorporate photovoltaic arrays. The Dakotas produce a bumper crop of Lutheran "windmillionaires." I can also imagine a fruitful repopulating of the North American countryside. I can imagine a new commonwealth of vital local institutions, synthesizing the voluntarism limned by de Tocqueville and the ideal of universal human rights that has animated our own times.

I am more worried about poor people in poor countries. No soft landing for them, no character-building belt-tightening. My basic fear is that a tropical agriculture strategy successful in the first third of the century will – because of high fertilizer prices, soil loss, and the baneful effects of climate change – undergo a terrible decline in productivity just as the number of human souls exceeds nine billion.

The most fundamental need of the poor, and of all of us, is the same: food. What poor farmers need in a matter of decades – and what everyone else will need sooner or later – is a high-yield agriculture that does not rely on off-farm sources of energy and fertility. One would suppose that major research institutions are doing serious work on this. But they are not. There is no large-scale program anywhere to inquire into farm regimes that could run themselves exclusively on contemporary sunlight. Only a handful of scientists – botanists, plant geneticists, plant breeders – are pursuing the most pressing question on earth: Can we develop food systems that produce high yields, provide their own fertility, build their soils, and handle pests and diseases with the resilience of a natural ecosystem?

And that most pressing question might be regarded as the introductory assignment for the most important question: Can we devise support systems that provide us with the means to gain sustenance and shelter, promote health and longevity, and afford ample opportunities for free expression without depleting the common stock of natural resources? Put another way: Can we live in a world where conservation is a consequence of production?

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