# The Blueprint

## Averting Global Collapse

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We are faced with an impending calamity that threatens to bankrupt the planet. This is one of those times when doing our best is not enough. We must do what is necessary.

Global warming is one of the global stressors afflicting our world. It is not the only one, though. And perhaps it is not even the main one. There are others, such as water shortages and scarcity of fossil fuel. What is on the table is the imminent withering of the planetary ecosystem, and with it much of the manmade world.

Halting the emission of greenhouse gases is easy; it would have taken all of one paragraph to spell it out. Doing so while keeping us minimally comfortable is a different matter. In part, that's what this book is about. And at times, it won't be all that comfortable. But then again, when there is an environmentally-devastating asteroid heading your way, you do what needs to be done. Nature cannot be negotiated with. In part, that's what this book is about, as well.

The blueprint laid out in this book contains the called-for breadth of vision, laying out an utterly new course for our technological and industrial engines. The plan is audacious, casting aside sacred cows and calling for measures that will impinge upon our comfort. It cuts through the haze, with immediately employable solutions. It goes the distance, using myriad computations and models to validate the content.

The intent here is a makeover of the manmade world within fifteen years.

It will cost a lot of money—if you must look at it this way. What it really means is that a lot of people will have to perform. It will take many millions rolling up their sleeves, but the means are at hand.

Neither the deliberate pursuit of profit nor the dynamics of existing governments quite lend themselves to getting us from here to there. Had they been able to do so, they would have—during the last half century, since the alarm bells first rang. Let's put national governments and current economic dynamics aside and consider what actually needs to be done. Function will dictate form; these will be what they need to be.

Get ready to embark on a powerful, demanding journey: with tough choices and tougher numbers, permeated with the grit of concrete. It will be labor-intensive. It will be challenging. It will be taxing. In short, it will be thrilling and meaningful. This is a call to action for all the grownups out there to knuckle down and buckle up. It asks of us to do the job that the adolescents of the past left for the adults of the present to handle.

It is time we steer our civilization on a new course.

# 1
# CLIMATE CHANGE

## what's in store

### CLIMATE DYNAMICS

There were times when tropical forests dominated all continents except Antarctica. There were other times when Earth was almost frozen solid from pole to pole. Life has existed in between those two ends of the climatic spectrum.

What has been controlling the climate of the world is a symphony of myriad notes generated by many instruments.

Beyond the annual cycle of seasons, the shortest notes are the minute fluctuations in solar intensity. Minimal sunspot activity is suspected to be one of the instigators in the climate blip that was the Little Ice Age from about 1300 CE to 1800 CE.

Another short-term player is the sulfur haze vented by the occasional volcanic eruption. The haze deflects sunlight back into space. When Mount Pinatubo erupted in 1991, the discharge of aerosols reduced the amount of incoming solar radiation. Consequently, the global mean temperature dipped by 0.6°C for a period of two years.

The occasional changes in warm ocean currents can also impact the climate. Their effect ranges from the relatively mild, as in the case of the El Niño phenomenon, to the relatively significant, as when the Atlantic conveyer belt, circulating warm tropical water northward, got stalled about 12,000 years ago. Climatic changes driven by ocean currents are usually regional rather than global in nature.

Superimposed on these rapid climatic fluctuations are the cyclical changes of the Earth's orbit. These cycles span tens of thousands and hundreds of thousands of years. In some eras, the Earth's orbit is more elliptical, in others less. In some eras, the Earth's axis is tilted slightly more toward the sun, in others it is tilted slightly less. The combined effect of these cycles is to redistribute the heat between the two hemispheres and otherwise widen the gulf between summer and winter temperatures. During a given ice age, when the climate is colder to begin with, these orbital oscillations have a pronounced effect: they are the main instigator in getting the Earth in and out of glacial periods within a given ice age.

A bit of an explanation is in order. A glacial period of an ice age is when North America is under a two-mile-thick ice sheet and when ice cover is widespread. The interglacial period of an ice age is what we have had for about the last 10,000 years: permanent ice sheets that are largely constrained to the polar regions.

The two driving engines that get our planet to swing between glacial and interglacial periods are the changes in atmospheric levels of carbon dioxide ($CO_2$) and the amplification effect of the reflective ice cover. (The more widespread the ice cover is, the more sunlight is reflected back with consequently less ground warming.) However, the orbital changes of the planet start these two big engines—the extent of ice coverage and the rates of $CO_2$ emissions—leaning one way at the beginning of a glacial period and the other way at the onset of an interglacial period.

On a scale of tens of millions of years, the thickness of the $CO_2$ blanket changes markedly. The thicker the atmospheric blanket of $CO_2$, the warmer it gets. Over the long run, the foremost mechanism controlling the thickness of the blanket is a ponderous interaction between volcanic activities, which emit $CO_2$, and the weathering process, which locks down the carbon that is in the air.

Over periods of eons, volcanoes belch out $CO_2$. Everything else being equal, the higher the volcanic activity in a given Age, the more $CO_2$ released into the air, and the thicker the greenhouse blanket.

Counteracting this mechanism is the weathering process. Rainfall reacts with the $CO_2$ in the air, creating carbonic acid. The slightly acidic groundwater attacks rocks containing silicate minerals. The ensuing chemical reaction locks into these rocks the carbon contained in the groundwater, taking the carbon out of circulation for a very long time.

The volcano–weathering interplay is probably the greatest climate-engine of them all. When it is all said and done, the ever-shifting balance over millions of years between the rate of weathering and the rate of $CO_2$ emissions from volcanoes and hot springs accounts for the ponderous oscillations of Earth between an icehouse and hothouse climate through the geological epochs. A Hothouse World is predominantly a tropical world. An Icehouse World is what we have had for the past thirty-four million years.

On a longer time scale yet—that of hundreds of millions of years—is the ever-intensifying radiation of the sun. Four and a half billion years ago the sun output was but 70 to 75 percent of its current level. However, the ever-increasing sun radiation has been compensated by a potent greenhouse blanket in the early period, followed by an overall decrease in greenhouse gas concentrations through the ensuing thousands of millions of years.

Those are the prominent, more obvious instruments controlling climate. There are many ancillary ones, such as the patterns of wind, dust,[1] precipitation, and clouds, which all amplify or mitigate the effects of the key instruments. As the climate changes, so do the patterns of vegetation, soil exposure, and ice coverage—and with them the level of reflectivity of the sun's rays. All of these parameters interact, producing a symphony of dazzling complexity and dynamics.

Then we showed up on the scene.

## GLOBAL WARMING

The planet's surface emits the energy from the sun in the form of infrared radiation, or heat. Some of that makes it to outer space, some is absorbed by the so-called greenhouse gases. Those in turn emit some of the heat downward. The net result is augmented warming of the planet surface. Thanks to this blanket of greenhouse gases, Earth does not have an average temperature of –18°C (−.4°F). The resultant 33°C higher average temperature makes life as we know it possible on Earth.

Carbon dioxide is constantly being cycled through the vegetation, ocean surface, and atmosphere. Most of the landmass, and therefore vegetation, is situated in the northern hemisphere. When it is winter in the northern hemisphere, the bulk of the world's leaves shed and release their $CO_2$, and consequently the atmospheric concentration goes up a bit. In the summer it goes back down.

At the beginning of the current interglacial period, eleven thousand years ago, the $CO_2$ concentration in the air hovered around 259–265 parts per million (ppm). This is pretty much how it stayed until about 3600 BCE, when the carbon dioxide ($CO_2$) levels in the atmosphere started to inch their way up and then plateaued at 276–283 ppm around 480 BCE,[2] where they stayed until the early 1800s.[3]

About that time, we got into the fossil-fuel business and started releasing massive amounts of $CO_2$ into the air. Some of it was picked up by the ocean, some by the land.[4] However, about half of it remained in the air. And we went from an atmospheric concentration of around 283 parts per million (ppm) in 1807 to 391 ppm as of 2011. This $CO_2$ concentration is the highest in the last 800,000 years and potentially for the past few million years.[5]

Carbon dioxide accounts for about 77 percent of the effects of our annual greenhouse gas (GHG) emission.[6] Methane and nitrous oxide account for most of the rest. The main source of anthropogenic, or human-induced, greenhouse gases is the combustion of fossil fuel. We use the resultant heat to generate electricity, to warm indoor spaces, to power our motor vehicles and various industrial processes. Other significant sources of anthropogenic GHG emissions are due to carbon outgassing from the soil, from cement production, and from deforestation. Secondary sources of anthropogenic GHG emissions include landfills, rice paddies, the production of steel, and the manufacture of petrochemicals. It is unclear whether livestock emissions should also be added to this tally. Our cattle take in $CO_2$ from the air and turn it to the far more potent methane at the back end of the process. Hence, no cattle, no extra methane. Yet, in some roundabout way, the domestic cattle of today stand in place of the hordes of bison and musk ox of bygone days—which also contributed their share of converting $CO_2$ to methane.

At the end of the day, what matters most is the resultant level of warming from it all. Currently, we are at 0.9°C mean global warming, and there is no doubt that human activities are at the root of it.[7] In fact, if not for the offsetting effects of aerosols and minimal solar activity, the warming would have been greater yet.[8]

Under the business-as-usual, fossil-fuel intensive scenario, in which $CO_2$ concentrations are projected to rise to 872 ppm by the 2090s, an integrated model at the Hadley Centre projects that by that time, the temperature will have increased by 4.4°C to 7.3°C from pre-industrial temperature levels.[9] Under a comparable emission scenario, MIT Integrated Global Systems Model projects between 5.1°C and 6.6°C warming relative to pre-industrial levels by 2100.[10] In accordance, I assume a median figure of 5.5°C global mean temperature increase by the end of the century as a likely outcome under the business-as-usual, fossil-fuel intensive scenario.

As of 2010, the year 2010 was one of the two warmest years on record.[11] In fact, as 2011 came to a close, nine of the ten warmest years in recorded history have been since 2000. During the spring of 2011, fires of epic proportions raged in Texas, which had its driest spring on record. Australia and New Zealand had mega-floods, and the Midwest had record snowfall. This is just the beginning; this is just at 0.9°C warming. These are but first, timid forays of a new weather regimen.

The routine 4°C–7°C oscillations between glacial and interglacial periods[12] take thousands of years to run their course, not one hundred years, as is projected to happen under the current emissions trajectory. Moreover, in the last few million years, the changes have been occurring within the bounds of a certain temperature range. At present, we are *already* at the warm end of the pendulum. Pushing it 5°C farther out may prove to be outside the operational specs of some of the existing species and ecosystems.

In terms of global mean temperature, we are travelling back in time. In our current trajectory, around mid-century we will have gone back in time to the Pliocene epoch, a few million years back. Toward the end of the century, we are likely to have reached the Mid Miocene

Climatic Optimum period, around 15 million years back. And then on to the twenty-second century and further back in time, getting to temperature levels that are likely to have last existed during the Eocene epoch,[13] perhaps around 40 to 50 million years ago—along with ocean acidity not on a comparable time scale.[14]

This is where the similarities may end. It is one thing to have global transitions of climate over millions of years or over many thousands of years, allowing most species to migrate, evolve, or work their way to suitable changing climatic distribution. It is an entirely different ball of wax to turn the dial 5°C–6°C over a one hundred year period for a planetary ecosystem that is largely bankrupt with only isolated, hemmed-in pockets of intact nature.

# 4
# HUMAN HABITATS

**stressors and prospects of further degradation**

## GLOBAL WARMING

The coolest summers of the future may make the hottest summers of the present appear balmy.[1] It is going to get stifling hot in some places.

But then, it is stifling hot in some places right now. Other locations will join them; this is not the end of the world.

But then again, maybe in some places it would be, or at least a good imitation of it.

Two highly populous regions are at the high end of the heat-humidity spectrum: Indo-Gangetic Plain (including Delhi) and the Yangtze River Delta (including Shanghai). It is important to ascertain how these two population centers may fare around 2100 under existing emission trajectories.

For the ability of our bodies to function, Apparent Temperature is a more meaningful indicator than air temperature. Apparent Temperature is the way temperature is perceived, which is a combination of relative humidity and the actual air temperature.

**TABLE 4.1.** The American National Weather Service, Apparent Temperature ("Heat Index")

| Fahrenheit | Celsius | probable results under continued exposure |
|---|---|---|
| 105°–130° | 40.5°–54.5° | sunstroke, heat cramps, and heat exhaustion likely |

| Fahrenheit | Celsius | probable results under continued exposure |
| --- | --- | --- |
| above 130° | above 54.5° | heatstroke (life-threatening) highly likely |

For the cities of Shanghai and New Delhi, I have obtained the humidity, temperature, and cloud conditions for every hour between 11:30 a.m. and 4:30 p.m. for every day of summer 2010.[2] This data set represents what the situation is at present.

Under existing trends, come 2100, the Indus Valley will experience an average temperature increase of 5.5°C warming and the Shanghai region will experience an average 5°C warming. I kept all parameters of 2010 the same and just tacked on 5.5°C and 5°C respectively to the hourly dry temperature values for each of the two regions. This is a simplistic computation, which in turn is based on a low resolution, global-scale model:[3] a crude set of calculations atop a crude model. Yet, what follows does provide a *sense* of what the weather may be like one lifetime away in those parts of the world.

In 2010, the threshold of 54°C (≈130°F) Apparent Temperature was crossed only during one day in New Delhi. In the 2100 scenario, it was a daily occurrence in July and August, that is to say, heatstroke would be very likely to take place on almost every summer day—absent some mitigation measures, such as air conditioners. In fact, in the simulation, during one particular day the Apparent Temperature surpassed 82°C (≈180°F). This is like being shoved into and then left in an oven set on low heat for a few hours.

All of this is in the shade, not taking into account any possible enhanced effects of the sun rays.

For the significant number of people who work outside in the Indus Valley during the day, the Wet Bulb Globe Temperature (WBGT) is a better measure. This index factors in air temperature, radiant temperature, humidity, and air movement. The WBGT is used to determine the safe limits of working outdoors: how much is too much.

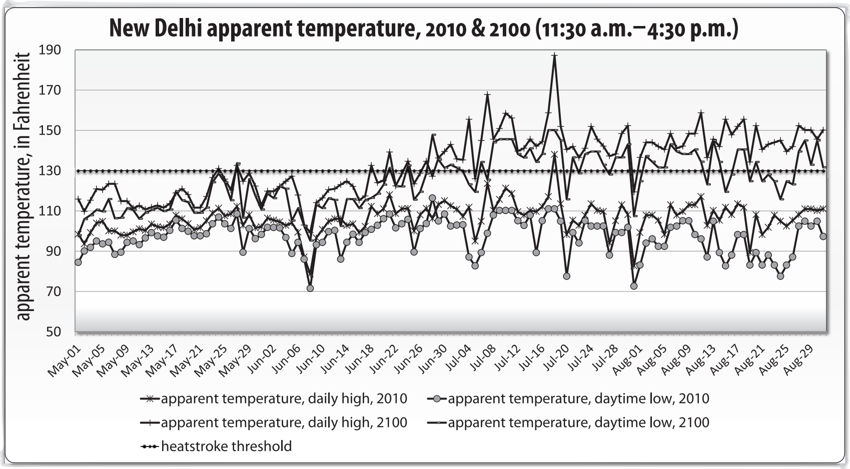
**TABLE 4.2**

| WBGT | NIOSH recommendations |
| --- | --- |
| 31–32.5 | rest required three-quarters of the time |

| WBGT | NIOSH recommendations |
|---|---|
| 36 | no heavy work at all |
| 39 and above | no work of any kind |

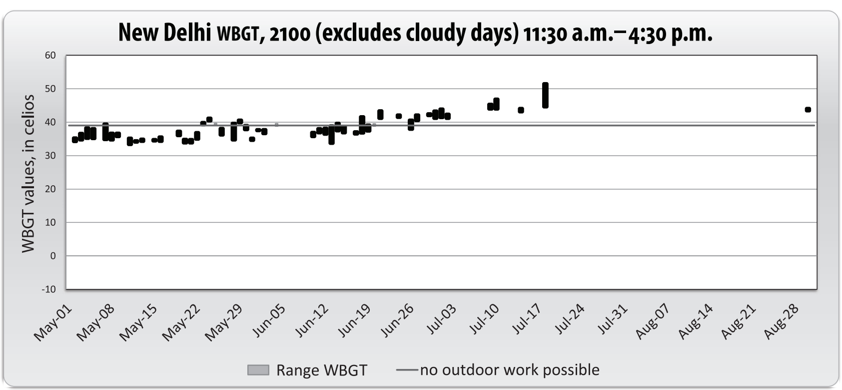
*Source of data:* J. Malchaire et al., "Criteria for a Recommended Standard: Occupational Exposure to Hot Environments," *International Archives of Occupational and Environmental Health* 73, no. 4 (2000):215–20.

**FIGURE 4.1**




*Note:* Data extrapolated from Freemeteo.com, Weather History.

**FIGURE 4.2**

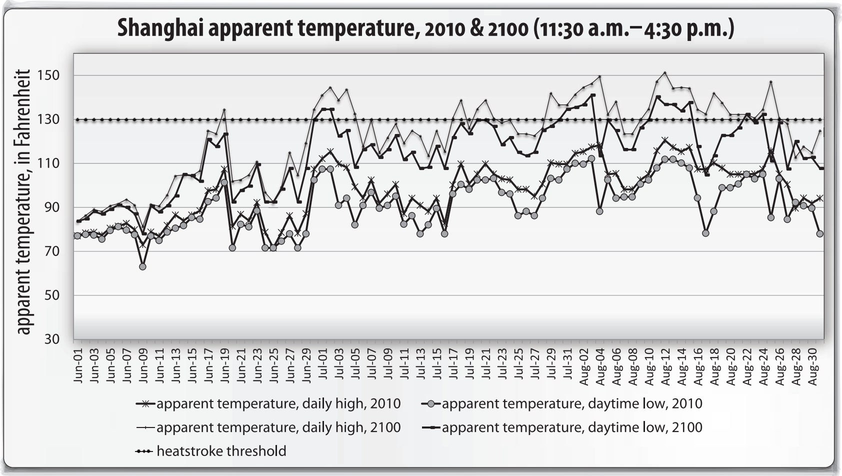



*Note:* Data extrapolated from Freemeteo.com, Weather History.

I tracked only summer days that were sunny or partially sunny. The Indus Valley is currently experiencing WBGT temperatures that range from 28 to 34, which are still within human tolerance for outdoor labor, at least some of the time. Under the 2100 scenario, WBGT values range from 35 to 44. This means that many days would be too stifling hot to work, with potential for collapse due to heatstroke.

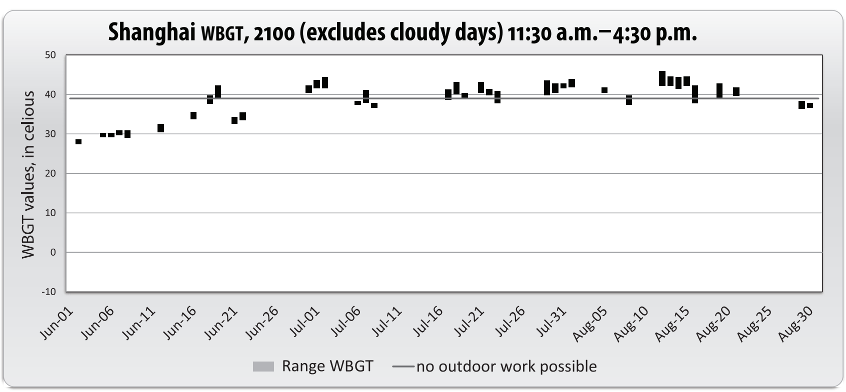
The Shanghai region is also projected to have its share of woes under the existing global warming trajectory.

**FIGURE 4.3**




*Note:* Data extrapolated from Freemeteo.com, Weather History.

**FIGURE 4.4**




*Note:* Data extrapolated from Freemeteo.com, Weather History.

Judging by this simulation, Shanghai's Apparent Temperature on most August days would be above 54.5°C (≈130°F) in 2100. These are conditions likely to cause a heatstroke under continuous exposure. Occasionally, the Apparent Temperature would reach past a scorching 60°C (≈140°F) in the shade. There would be multiple days in Shanghai in which the WBGT value would transcend 39, and during those days no outdoor labor would be possible.

Finally, straight wet-bulb temperature (a combination of humidity and temperature) may express the ultimate climatic threshold that humans can withstand, irrespective of clothing, activity, and acclimation. Humans maintain a core body temperature of around 37°C. Skin is always a few degrees colder. Once skin temperature rises to 37°C or higher, the derivative core-body temperature reaches lethal levels. Hence, prolonged periods of wet bulb temperatures above 35°C (≈95°F) are literally intolerable. At the moment, wet-bulb temperatures are usually around 26°C–27°C (≈ 78°F–81°F).[4]

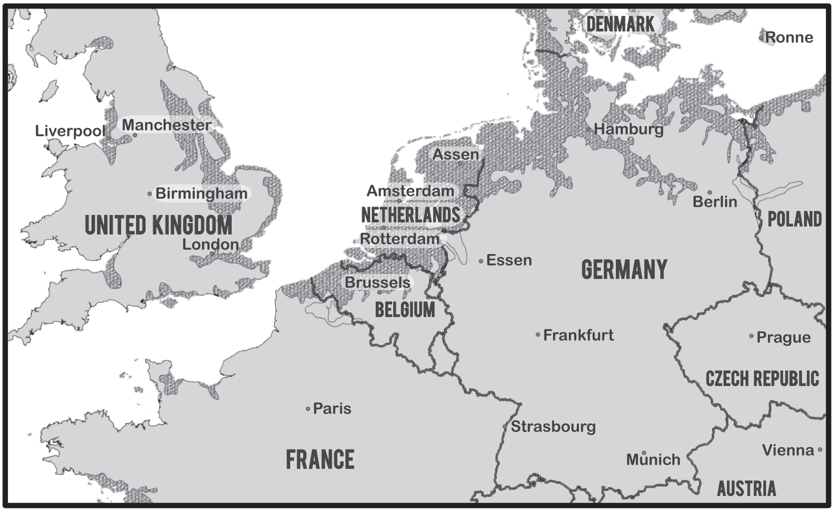
In New Delhi circa 2100, the simulation tracks one day in which the wet-bulb temperature spikes to lethal levels of 37°C (≈99°F). Currently, there is no place on the Earth's surface that even remotely experiences lethal wet-bulb temperature levels. During those hours on that possible future day, there would be air conditioners for those who have them; body ice packs or deep underground shelters for those who could; and possible death for the rest.

Under existing emission levels, is it likely that we would see those temperatures by the end of the century? Yes, and perhaps worse. Coinciding with the overall warming trend, we experience increasingly extreme temperatures; that is to say, the variability is greater.[5] Thus, a more representational projection would indicate the low temperatures as colder and the high temperatures as hotter than assumed here.

## SEA LEVEL RISE

As stated in the second chapter ("Land"), under a business-as-usual scenario, average global sea level rise is projected to be around 1 to 1.5 meters (≈ 3 to 5 ft.) by the end of this century. Within a few millennia, sea level rise may reach 35 to 40 meters (≈ 115 to 131 ft.).

**FIGURE 4.5.** A thirty-five meter sea level rise in populous regions that would be particularly vulnerable.





The big impacts of sea level rise are shoreline erosion, flooding, and salinization—coupled with waterborne diseases contaminating drinking water.

In the context of sea level rise, deltas are the most vulnerable areas. By the time the children of today are at the twilight of their lives, there won't be any Mississippi River Delta to speak of—that is, without due levees and walls. However, I will focus on river deltas where the economic impact is projected to be more severe and adaptation measures less likely.

Egypt has a coastal zone more than 3,500 kilometers long and contains 40 percent of the country's total population of 82 million people. At present, a large portion of the 50-kilometer-wide coastal strip lies 2 meters below sea level and is protected from inundation and flooding only by a coastal sand belt a few kilometers wide. The sand belt, which also protects coastal lakes and lagoons, is experiencing rapid erosion associated with the construction of the Aswan dam. Sea-level rise will exacerbate the problem, endangering the fishing industry as one third of the country's fish catch derives from these threatened lakes and lagoons. Inundation and erosion could result in a loss of a significant portion of the northern part of the Nile Delta. With one meter of sea level rise, Egypt may experience the loss of 28,000 sq km of agricultural land and 25,000 sq km of urban area.[6] Under a 5 meter sea level rise, 35 percent of Egypt's agriculture is projected to be impacted.[7]

The rice-growing river deltas in Asia are particularly vulnerable to sea level rise. A World Bank map indicates that a one meter sea level rise would flood half the rice cropland in Bangladesh, home to about 160 million people. This country is the second largest rice exporter in the world. A large portion of Viet Nam's population and economic activity are located in two river deltas, the Mekong Delta in the south and the Red River Delta in the north. The overall effect of sea level rise would be catastrophic.[8] One meter of sea level rise would put an end to the rice harvest in the Mekong Delta, which produces more than half the rice in Viet Nam. A substantial part of the Red River Delta in the north may join it. With the two deltas largely submerged, every tenth person will be a refugee. With a five meter rise, about a third of the population will be looking for a new place to call home; the old one will be gone.

It is projected that between 50 to 200 million people will become climate refugees before the end of this century.

Armoring the coastline can be done, but at a cost. The natural dynamics that occur between water and land would be disrupted. Beaches and wetlands would disappear, and habitat would be lost. However, under existing priorities, when it is the ecology of beaches and wetlands on one side of the scale and the protection of hospitals, wastewater-treatment facilities, power plants, mega-resorts, and coastal roads on the other side of the scale, our collective real estate would tip the scale its own way.

Seawalls are designed to resist the forces of storm waves; bulkheads are meant to retain the fill; and revetments are laid out to protect the shoreline against the erosion associated with light waves. When we talk about a 1 to 2 meter rise, we can stop the rising ocean in its tracks. In that context, a 2010 study determined that a combination of levees and seawalls spanning 100 miles will average about 1.6 billion US dollars.[9] Under those costs, Egypt can put a buffer throughout their entire delta region for what would amount to 0.5%–1% of their annual GDP. (And in fact a much smaller percentage of their GDP, if the investment is spread over a few years.) However, this logic can be pushed only so far, even if we discount the impact such walls would have on trade and fishing.

Would we try to stop sea level rise 35 meters high? One crack, one mega-storm, and a biblical water column could bear down on the coastal population center, possibly killing millions of people. Thus, even if every few decades or centuries we build up the wall ever higher, there will be a point where a disaster will happen or people will finally choose to retreat. The last chapter of the story would be one and the same, regardless: the largest retreat and resettlement campaign in the history of humanity. Or worse, if international borders and immigration policies refuse to yield.

## FOSSIL FUEL

Our labor and ingenuity may be the motor of the world, but without fuel this colossal motor won't run. At the present time, this fuel largely means fossil fuel.

As of 2009, fossil fuels comprised 81% of the total energy sustaining our world. Another 10% came from the burning of wood and biofuel. The remaining 9% was mostly nuclear with a bit of hydro power thrown in.[10]

Industrial society is predicated on cheap fossil energy. Our society's very existence is owed to ungodly amounts of fossil fuel injections. In 2010, we went through the equivalent of around 190 million oil barrels worth of fossil fuel a day to keep our industrial society running. Had it all been comprised of liquid oil, the annual volume that we burn through would have been equivalent to the volume of water in Lake Superior.

Cheap fossil energy has made possible the automobile, the aviation industry, mechanized agriculture, and the advent of economic globalization. From airplanes to backhoes to tractors to trucks to ships to scooters to cars: 98 percent of what has fueled motor vehicles has been fossil hydrocarbons, directly or indirectly.

Perhaps 40 percent of the world's dietary protein now comes from synthetic fertilizers derived from carbohydrates, and estimates suggest that if not for that, at least two billion people could not exist.[11]

As of 2008, fossil fuels generated 71 percent of all electricity. Electricity makes possible street lights and residential lighting. It makes possible the ubiquitous media players, computers, telephones, and the Internet Highway. Fossil fuels cool, via air-conditioners or swamp-coolers, many homes during the summer; and they heat, directly or via electricity, most homes in the winter.

Fossil fuels are practically the sole source of petrochemicals: nylon, polyester, formaldehyde, polystyrene, and synthetic rubber. Petrochemicals are in everything. They are in inks and dyes, bottles, packages, food additives, adhesives, and sealants. They are in computers and cell phones, in tires, and in steering wheels. They are in the credit cards we use, trash bags we throw out, and tennis shoes we run in.

As things stand, the dearth of fossil fuels—cheap, expensive, or otherwise—spells the collapse of our society alongside mass mortality whose magnitude goes beyond anything ever experienced before.

Fossil fuel is nonrenewable; it has always been just a question of *when*.

So then, when?

Long before we deplete fossil hydrocarbons, we will stop extracting them from the ground when it takes more energy to extract them than they yield. And long before that, we will stop extracting them when they are simply too resource-intensive to extract. In other words, we will stop when it becomes economically senseless. Thus, the question is not how much resides underground, but how much is economically-recoverable.

One Gtoe (giga-ton of oil equivalent) is the amount of energy embedded in one billion tons of oil. Adjusting for likely political biases and sloppy reporting practices, there were about 127 Gtoe of recoverable reserves of conventional oil as of 2008. This estimate is based on research done by the Smith School of Enterprise and the Environment at Oxford University.[12] Compensating for production since that time, the 2010 reserves may stand at 120 Gtoe.

Beyond conventional oil, naturally-occurring tar can be extracted, processed, and refined to produce the equivalent of crude oil. Natural bitumen, as it is referred to, is reported in 598 deposits in 23 countries.

By far, the largest deposit is located in northern Alberta, Canada. Total recoverable reserves of natural bitumen are estimated at 35.5 Gtoe.[13] For every 3 barrels of oil, it takes the energy equivalent of 1 barrel of oil to extract the nasty tar and refine it.[14] Thus, after deducting the amount of energy required for processing, net energy yield from natural bitumen reserves is about 22.6 Gtoe.

Viscous, extra-heavy oil of a slightly different sort is found predominantly in Venezuela and to a smaller extent in a few other locations. The total recoverable reserve for the so-called extra-heavy oil is estimated at 8.7 Gtoe.[15]After subtracting the energy required for extraction and refining, the available yield would come to 5.8 Gtoe.

Last but not least is oil from oil shale.

Oil shale is a dense rock that has a waxy substance tightly bound within it. When the waxy substance, kerogen, is heated at high temperatures, it liquefies, producing compounds that can eventually be refined into synthetic petroleum products. There are two basic methods to get kerogen out of oil shale. The first is to mine the shale with traditional hard-rock mining methods, then crush the rock, and cook it without the presence of oxygen. The second method is to heat the underground shale rock. The now liquefied kerogen is pumped to the surface. Estonians have been commercially producing shale oil since 1924. China has had industrial production since 1930, and Brazil got into shale oil extraction in 1981.

Oil shale can be found in many parts of the world. Sediments range from small occurrences of little or no economic value to vast deposits covering thousands of square kilometers and containing billions of barrels of potentially-extractable shale oil. In some deposits, the main hurdle for shale oil extraction would appear to be scarcity of water. It takes between one and four barrels of water for each barrel of oil processed.[16] The Green Formation in Colorado is the granddaddy of all oil shale deposits: the Saudi Arabia of shale oil. And if anything, this is an understatement.

Alas, water is hard to come by in Colorado.

**TABLE 4.3. Water requirements for shale oil in context**

| | amount of water used in the Denver, Colorado area, 2005 (population 560,000)[a] | amount of water required for 0.56 billion barrels of shale oil a year[b] | amount of water required for 10 billion barrels of shale oil a year |
|---|---|---|---|
| residential, industrial, agricultural, irrigation, mining usages | 265,000 acre feet | … | … |
| required for related power generation | … | 245,000 acre feet | 4,375,000 acre feet |
| required for shale oil processing | … | 113,000 acre feet | 2,018,000 acre feet |

*Notes:* Figures indicate total withdrawal, not net consumption. In the case of shale oil, net consumption is 76% of indicated total withdrawal. It will take a couple of decades for a major operation to come online. Let's take the year 2035 as a reference point. According to the US Energy Information Administration, world demand for oil in 2035 will be around 40 billion barrels of oil. With declining supplies of conventional oil, it is highly likely that shale oil will be expected to pick up the slack. I have run two figures in the table: production of 0.56 billion barrels (1.4% of expected demand) and production of 10 billion barrels of oil (25% of expected supply).

[a]*Source:* "Estimated Use of Water in the United States County-Level Data for 2005," United States Geological Survey, United States Department of the Interior, last modified August 25, 2010, http://water.usgs.gov/watuse/data/2005.

[b]*Source:* Lawrence J. MacDonnell, *Water on the Rocks: Oil Shale Water Rights in Colorado*, (Boulder, CO: Western Resource Advocates, 2009).

Water demand outstrips water supply in Colorado. The Department of Natural Resources in Colorado projects a 20 percent statewide gap between water supply and demand by 2030. It states that many of the local streams are over-allocated and furthermore, that some climate-change models project as much as a 20 percent reduction in the local water availability in the future. I surmise that no shale oil will be extracted from the Green Formation in Colorado, at least not in any amounts that would matter.

To assess the world's economic reserves of shale oil, I use Mohr's estimates.[17] After excluding the Green Formation and then applying a 25% deduction due to the assumed energy used for the extraction and refining of shale oil,[18] the global recoverable reserves are between 43 Gtoe and 114 Gtoe.

Thus, total reserves of all sources of economically-recoverable oil range between 191 Gtoe and 262 Gtoe.

**TABLE 4.4**

| Oil | economically-recoverable reserves, estimates (in Gtoe) |
|---|---|
| **conventional oil** | 120 |
| **natural bitumen (tar sand)** | 22.6 (after subtracting energy required for extraction) |
| **extra-heavy oil** | 5.8 (after subtracting energy required for extraction) |
| **shale oil** | 43 to 114 (after subtracting energy required for extraction) |
| **Grand Total, rounded** | **191 to 262** |

The second of the three forms of fossil fuel whose reserves are to be assessed is natural gas, whose GHG (greenhouse gas) emissions, incidentally, have been shown to be as bad as coal's.[19]

The reserve estimates for natural gas made by *Oil & Gas Journal* and by *BP* are fairly close to each other. I averaged the two estimates and converted the resultant gas volume to its energy equivalent,[20] arriving at 169.4 Gtoe. This estimate includes only what could be regarded as natural gas from traditional sources.

Essentially, natural gas is natural gas is natural gas. However, it is found in different types of deposits. Beyond traditional sources, natural gas is found in a few other types of geological formations.

While gas has been known to exist in coal seams since the beginning of the coal-mining industry, only since 1989 has a significant gas production been realized from that source, with the advent of a new technology. Recoverable reserves of coalbed methane, as it is termed, are estimated to be 21.7 Gtoe.[21]

And we are back to shale. This time, shale gas.

Just as with coalbed methane, it is only recently that we have had the technology to truly tap into this vast natural gas resource. It has been made possible via horizontal drilling coupled with hydraulic fracturing.

Horizontal drilling allows us to drill laterally and thus across much of the horizontal shale strata, coming in contact with far more of the desired, natural-gas-embedded rock. Hydraulic fracturing, or hydrofracking, cracks the shale rock by injecting at high pressure enormous amounts of water mixed with chemicals and sand. These fissures are then held open by the injected sand particles so that natural gas from the shale can flow up the well.

A shale-gas well can produce over one million gallons of wastewater, which is often laced with highly corrosive salts, carcinogens such as benzene, and radioactive elements like radium. All of these substances may occur naturally thousands of feet underground. Other carcinogenic materials may end up in the wastewater from the chemicals used in the hydrofracking process itself.[22] The wastewater may be hauled to a water treatment plant, purified to the best of our abilities, and then discharged into rivers, sometimes just miles upstream from drinking-water intake plants. There is nothing affable about shale gas. When one accounts for the fugitive emissions of methane as a result of the hydrofracking, the GHG emission of shale gas may be a bit more than that of conventionally drilled natural gas,[23] or a lot more[24] (which is more likely[25]).

Under business-as-usual practices, I assume that in spite of the above, shale gas drilling *will* continue at full steam—in the short term in the United States, and soon thereafter throughout the world. The situation at present seems to support this prognosis. There were more than 493,000 active natural-gas wells in the United States in 2009; this is almost double the number in 1990. And around 90 percent of the wells have used hydrofracking.

We don't know how much shale gas is out there, but we do know that there is a lot of it. An initial assessment in 2011 reckons technically-recoverable shale gas to be 173 Gtoe, spread in fifteen large regions around the world.[26] Yet, this estimate may prove to be overly optimistic.[27]

The last viable source of natural gas is found in reservoirs with low porosity and low permeability. The natural gas in such deposits is referred to as tight gas. It requires multiple fracturing in order for any significant amount of gas to be made available. Drilling for tight gas has been compared to drilling a hole into a concrete driveway: the rock layers that hold the gas are very dense, so the gas doesn't flow easily. Until recently, tight gas was not considered economically viable to produce. Recent technological advances on a number of fronts have made it increasingly possible to extract tight gas. No systematic evaluation of tight gas reserves has been carried out for the world, and for what it is worth, preliminary estimates of recoverable tight gas stand at 30 Gtoe.[28]

In total, about 394 Gtoe of natural gas is estimated to be economically recoverable in the world from all sources.

**TABLE 4.5**

| Natural Gas | economically-recoverable reserves, estimates (in Gtoe) |
|---|---|
| **traditional sources** | 169.4 |
| **coalbed methane** | 21.7 |
| **shale gas** | 173 |
| **tight gas** | 30 |
| **Grand Total, rounded** | **394** |

Last but not least is coal.

What we expansively term "coal" ranges from the brown, almost peat like lignite, which has high moisture and low carbon; all the way to the black, carbon-rich, energy-packed anthracite.

The World Energy Council estimates that the world's recoverable reserves are 405 billion tons of bituminous coal, 260 billion tons of sub-bituminous coal, and 195 billion tons of lignite coal.[29] In converting the various types of coal to their energy equivalents, I have arrived at a combined total of 461.6 Gtoe.[30]

**TABLE 4.6**

| Coal | economically-recoverable reserves, estimates (in Gtoe) |
|---|---|
| **All Forms of Coal, rounded** | **462** |

Now we can tally all recoverable fossil-fuel reserves: they come to between 1,047 and 1,118 Gtoe. This tally incorporates the whole enchilada. If it is even remotely economically recoverable, it is accounted for in this assessment. It accounts for every scrap of conventional oil, extra-heavy oil from Venezuela, and tight gas from Russia. It includes all black coal and also all available brown, inferior coal. It accounts for all of the viable shale gas and shale oil.

If we have it our way, this will all be consumed within less than a century.

The US Energy Information Administration projects annual global demands for coal, natural gas, and petroleum through the year 2035. From 2036 through 2100, I used the 2035 projected demand figure and adjusted it to reflect anticipated global population for each of the subsequent years, derived from UN's *World Population Prospects: The 2010 Revision*.

I compare these demand figures against the total economically-recoverable reserves that were just chronicled.

**TABLE 4.7. Projected global demand for fossil fuels**

| Year | Coal | Oil | Natural Gas | Total |
|---|---|---|---|---|
| 2010 | 3,282,497 | 4,553,631 | 2,980,152 | 10,816,279 |
| 2015 | 3,504,505 | 4,728,955 | 3,277,116 | 11,510,576 |
| 2020 | 3,840,416 | 4,909,608 | 3,581,964 | 12,331,987 |
| 2025 | 4,227,481 | 5,202,170 | 3,807,972 | 13,237,623 |
| 2030 | 4,678,301 | 5,535,765 | 3,949,884 | 14,163,951 |
| 2035 | 5,197,665 | 5,893,874 | 4,107,564 | 15,199,103 |
| 2040 | 5,629,104 | 6,073,303 | 4,224,682 | 15,927,089 |
| 2045 | 6,070,904 | 6,232,068 | 4,326,999 | 16,629,971 |
| 2050 | 6,520,795 | 6,369,019 | 4,413,800 | 17,303,614 |
| 2055 | 6,977,720 | 6,484,532 | 4,485,432 | 17,947,685 |
| 2060 | 7,442,231 | 6,580,537 | 4,543,312 | 18,566,080 |
| 2065 | 7,916,235 | 6,659,936 | 4,589,515 | 19,165,685 |
| 2070 | 8,402,044 | 6,725,576 | 4,626,065 | 19,753,685 |
| 2075 | 8,901,043 | 6,779,202 | 4,654,215 | 20,334,460 |
| 2080 | 9,414,651 | 6,822,366 | 4,675,073 | 20,912,090 |
| 2085 | 9,945,590 | 6,857,320 | 4,690,222 | 21,493,131 |
| 2090 | 10,497,230 | 6,886,392 | 4,701,281 | 22,084,903 |

| Year | Coal | Oil | Natural Gas | Total |
| --- | --- | --- | --- | --- |
| 2095 | 11,071,081 | 6,910,352 | 4,708,800 | 22,690,233 |
| 2100 | 11,667,884 | 6,929,396 | 4,712,930 | 23,310,210 |
| total demand | 645,826,040 | 562,845,597 | 390,089,408 | 1,598,761,044 |
| | | | | |
| total supply | 461,650,000 | 227,006,387 | 394,014,000 | 1,082,670,387 |

*Notes:* Units are in Ktoe (the energy of one thousand tons of oil). Table shows projected demand irrespective of available reserves. The two darkly-framed cells indicate projected supply has run out.

Provided the *rate* of extraction is unbounded, then under projected demands and estimated reserves, we will run out of oil around 2051; we will run out of coal around 2084; we will run out of natural gas around 2101. And if we use the three forms of fossil carbohydrate interchangeably, we will run out of all three around 2077.

This hypothetical scenario can never occur: the rate of extraction is subject to constraints. In fact, the overall rate of extraction is already declining on some fronts.

The lowest hanging fruits have been picked; the cheap oil, gas, and coal are all about gone.[31] In recent times, we have had to invest ever more resources for extracting and refining fossil fuels in order to arrive at the net energy yield of former years—whether it means drilling under the sea beds or extracting tar from sands and subsequently refining them to a lighter material.

The rate at which we can extract fossil fuel is of paramount importance. Think of it as a pool of water that feeds us through straws. The pool may hold plentiful reserves of water; however, what matters more is the rate of water provided by the straws.

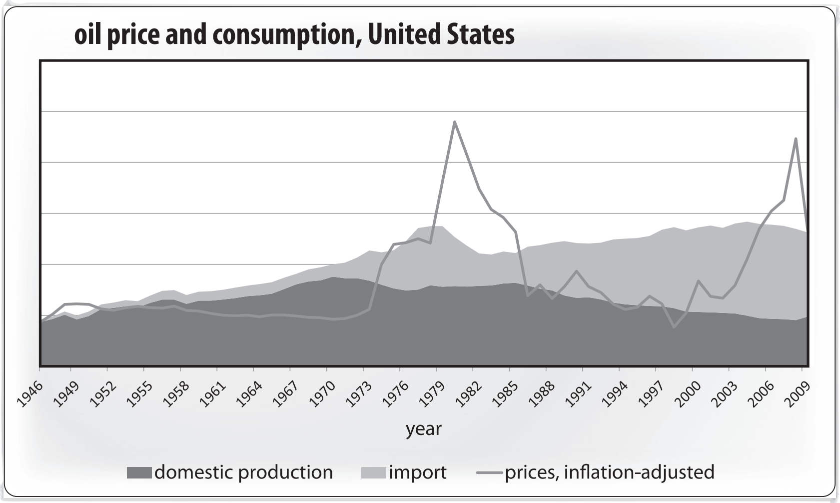
Thousands of individual oilfields have produced ever less quantities of oil. Overall, the oil production of some countries has been declining for some time now, including that of the United States, Norway, Mexico, and the United Kingdom. It is important that we identify the underlying reason. Is it largely because there comes a time when it is more expensive to coax oil from a field while there is a lower hanging fruit elsewhere? Or is there a geological constraint that limits the total output, irrespective of our efforts? If it is predominantly a matter of cheaper prices elsewhere, then fields can be revisited and production revved up again once all the lower hanging fruits have been picked. In such a case, it may get more expensive to drill, but the flow of oil may continue unabated. However, if it is predominantly due to geological constraints, it is likely that there will come a time in which the global extraction rate of oil will begin a path of relentless decline, much as happened in the United States in regards to its conventional oil.

The peak production of conventional oil in the United States was in 1972. It had a smaller peak in 1987 and has declined ever since. As of 2009, the total production is at 56 percent of 1972 production figure. As of 2009, for every barrel extracted domestically, about 1.7 barrels were imported.[32] The fact that the more risky and expensive method of horizontal drilling was widely implemented since 2009 indicates that given half a chance, the United States *will* get its oil domestically. It just couldn't extract more before horizontal drilling came of age.

Perhaps the most compelling piece of evidence for geological constraints is the US oil production during the 1970s. When the price of crude oil was around USD 21 a barrel in 1972, the United States was producing more oil than ever. Production declined in subsequent years. Eight years later, the price of oil climbed to USD 102 (Both the 1973 and the 1980 prices are inflation-adjusted). If America could churn out oil domestically, 1980 was the time. But although they were more than willing to drill and sell for USD 21 a barrel a total of 3.45 billion barrels in 1972, American drilling ventures were evidently unable to do the same for about 5 times the selling price a few years later. Thus, it seems that the decline in production is predominantly a geologically-driven phenomenon. In fact, it appears that a market price of oil plays but a small role, as is evident from figure 4.6.

We also see a comparable lack of correlation in the global arena. Despite a near tripling of world oil prices in the past decade, non-OPEC production hasn't increased since 2004. Geological constraints seem to be both paramount and impervious to market pressures. Some experts think that insofar as conventional oil is concerned, non-OPEC countries have already reached their peak production rates.[33] In other words, this is as good as it gets.

**FIGURE 4.6**




Sooner or later, gas or oil fields start losing pressure and the rate of extraction declines. In order to wring out as much of the oil as we can, we inject high pressure gas, water, steam, or even chemicals to make the oil flow better. However, there is only so much we can do, and more often than not, there is only so much that it makes economic sense to do.

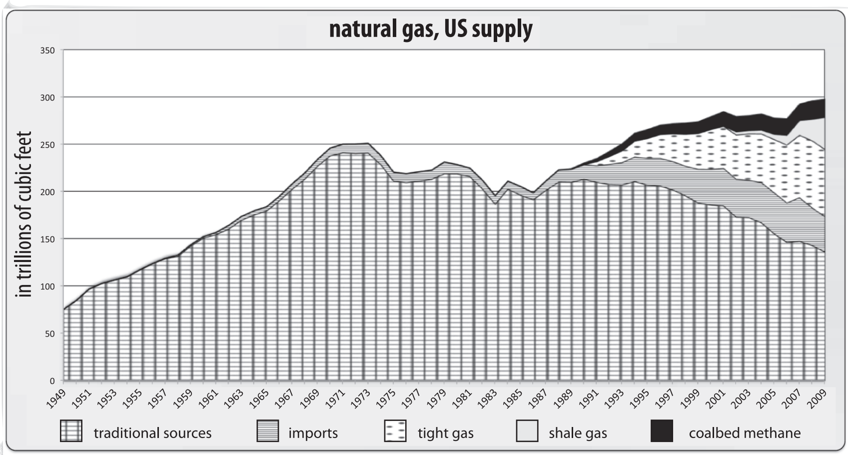
Technology does save the day, if not the day after. There have been significant, ongoing improvements in recent decades in methods of oil extraction. The last two years have seen production rates that buck historical, declining trends. Recent improvements in horizontal drilling made it economical for the United States to coax its depleting fields and raise the total US production rate for the year 2009 and then again in 2010.[34] In the end, these are technologies that expedite the rate of extraction, but as the cumulative amount of oil is the same for a given field, an increased extraction rate comes at the expense of faster declining rates later.[35]

As with conventional oil, natural gas extraction rates peak and then decline. And perhaps in a manner that is even more pronounced.

Pumping natural gas is like poking a hole in a car tire. Production increases rapidly from the time a field comes online. Extraction rates rise as more and more wells are added within a given field. Eventually production plateaus and is followed by a rapid decline.

In the United States, the production of conventional natural-gas plateaued in 1971 through 1973 and since then has broadly declined. In 2009, the United States produced about 56 percent of the natural gas from traditional sources as it produced at its peak in 1972 (which oddly is identical to the performance profile of US oil). Initially, the Americans supplemented their piping gas from Canada. In the early 1990s, more was required to offset the continuing decline in production and increase in demand. Americans started to access non-traditional, more resource-intensive gas sources, which as of 2009 account for roughly half of all natural-gas extraction in the United States.[36]

**FIGURE 4.7**




Coal is different from natural gas or oil. It is mined, not drilled.

On one hand, we may find ways to extract what at present is too resource-intensive, and thus the total estimated coal reserves would turn out to be larger than currently assumed. On the other hand, our assessment may show that there is less coal than assumed, and the total reserve amounts would be adjusted down—as has occurred time and again in the past.[37]

The Earth holds considerable amounts of recoverable coal. The question is whether it would be possible to obtain coal at desired rates of extraction until we basically run out of all that can be recovered, or whether there are technical constraints that will see annual coal yields decline long before the end of recoverable coal is in sight—in a couple of decades, as some analysts maintain.[38] I find no evidence, one way or another, for declining rates of extraction from individual coal mines. Combining the production output of all mines is a different story, though.

Imagine coal deposits around the world as thousands of bonfires across a vast plain. Some are large, some are small, some hold a lot of wood, other don't. As the bonfires exhaust their fuel load, one by one they go out. At first, the plain is very bright. Slowly it becomes dimmer as more and more individual bonfires go out. This would occur irrespective of whether individual bonfires snuff out abruptly or die out gradually. In other words, looking at the total picture, it matters little if technology can coax an individual fossil-fuel deposit to give up its energy at a higher rate and deplete faster or do it at a slower rate and have it last longer. Viewing the combined supply, a declining trend prior to the total exhaustion of resources will occur either way.

Now, in reality, some bonfires (that is, coal, oil and gas deposits) die out and new ones are added (as new deposits are being discovered). However, at some stage more bonfires die out than new ones are added—as has been the case with conventional oil and traditional gas fields.

Coal and natural gas are largely used for heating and for power generation. Petroleum is largely used as a transportation fuel. However, it is possible to synthesize most forms of hydrocarbon and make them perform whichever function is called for. Natural gas is a major feedstock in the production of ammonia for use in fertilizer production. Yet, coal can be gasified and made to perform the same function. By the same token, if we run out of oil, we can liquefy coal and use it to run motor vehicles, as they did in Germany during World War II. Alternatively, we can take natural gas and convert it to oil, as they started doing in the large Pearl GTL plant in Qatar.[39] When push comes to shove—as it is likely to—the fossil fuels are interchangeable.

Once the energy required for conversion is accounted for, what matters is the total recoverable energy of those resources stored in the Earth, combined.

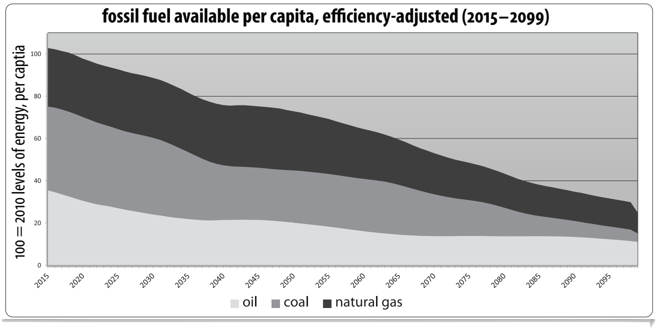
A meaningful way to view at things is how much fossil energy is available per capita, year-by-year. As we do that, a few things need to be accounted for.

Through time, we accomplish more with the same amount of energy due to efficiency gains in design. In fifty years, we are likely to get more mileage out of a ton of oil equivalent than we do at the present. For all intents and purposes, it is assumed that 1 ton of oil equivalent in 2099 is the same as 1.35 tons in present-day terms.[40] This was taken into account in the graph in figure 4.8, along with annual population projection.[41]

Earlier, I examined and determined that overall rates of extraction will decline across the board. This is one of the premises that underlies the graph below. The projected schedules of decline were derived from a model created by Steve Mohr.[42] There was some departure from Mohr's model: shale oil, natural bitumen, and Extra Heavy oil take a lot of energy to extract.[43] I made due deductions to arrive at net energy yields. Furthermore, 25 percent of the global shale oil reserves were omitted as I assume that we will not extract oil from the Green River Formation.

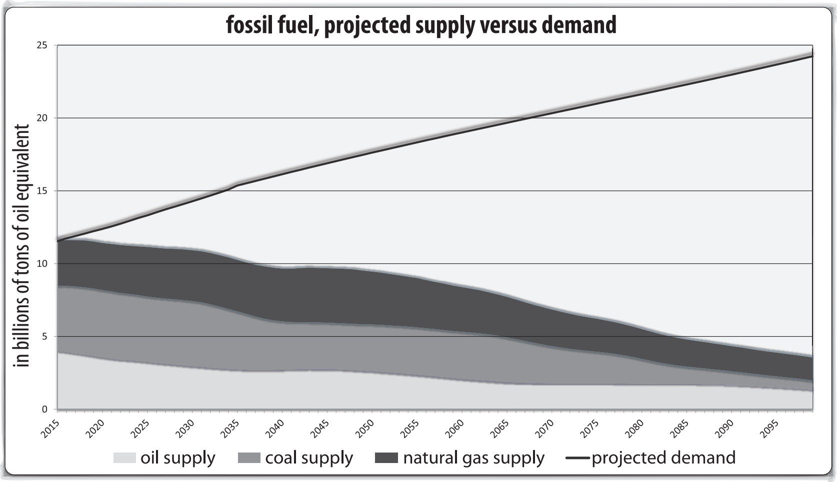
The graph in figure 4.8 suggests that in 2099 each person will have, in effect, 29 percent of the energy available in 2010, that is, after factoring in projected efficiency gains and population growth. This does not account for any energy losses due to possible conversions of one form of hydrocarbon to another.

**FIGURE 4.8**



Another meaningful analysis is to compare anticipated demand with the anticipated production rate.[44] Once again, it is adapted from Steve Mohr's model with the adjustments noted earlier. The difference from the previous graph is that possible efficiency gains are not accounted for. The graph in figure 4.9 notes energy availability in absolute terms. The projected demand in this graph is based on data from the US Energy Information Administration.[45]

**FIGURE 4.9**




Based on this projection, in the year 2099, the world under a business-as-usual scenario would need over 24 million Ktoe (kilo-ton of oil equivalent) of energy.[46] Combined, all forms of fossil energy would yield about 3.5 million Ktoe during that year. Thus, in the year 2099, fossil-based energy would be able to provide but 15% of the needed raw material for the making of petrochemicals, fertilizers, transport fuel, and energy for the generation of electricity and space heating.

From a broad, planetary perspective, it is debatable whether the main problem is that we are running out of economical fossil-fuel, or whether we are not running out of it fast enough.

Be that as it may, we have gone out on an energy limb that is propped by the gargantuan injection of fossil fuel, allowing the existence of billions of people that arguably would not have lived otherwise. The obvious question is what happens to the many billions

# 7
# ENERGY

## lower-impact technologies

### TRANSCONTINENTAL GRIDS

Not every population center in the world has the needed energy resources in its vicinity. Accounting for this, the plan calls for the interconnection of myriad sources of energy with population centers that are hundreds or thousands of kilometers apart.

Specifically, fourteen transcontinental energy regions would be established and cover most of the land area of the world, and more to the point, would service over 95 percent of the world's population.

The backbone of each self-contained, transcontinental region is to be a grid of ultra-high-power lines. Hence, the sunny Syrian Desert will supply solar power that would serve people throughout the immediate vicinity and also all the way up to the northern reaches of its designated region, at the Baltic Sea. Wind turbine installations in the windy Great Plains of North America will provide power reaching all the way to the population centers of the East Coast.

Every one of the transcontinental regions has its own specific needs and its own distribution pattern of natural resources. As a case in point, I will cover in detail one region: the North American region, which encompasses the contiguous United States and the population centers of Canada. Henceforth, the term "North America" refers not to the continent of North America but to the energy region as delineated


**FIGURE 7.1.** Fourteen world energy regions overlaid on a population-density map of the world.

in figure 7.1. I chose to analyze this particular energy region because it has the most comprehensive statistics available.

The delineation of the planet to fourteen regions reflects population distribution on one hand and the distribution of wind and sun resources on the other. The delineations also take into consideration the existence of large mountain ranges, which may bar long-distance transmission lines from passing through them.

The small population segments outside those energy regions would be off the grid—as most of them are at present. More on that later.

Before we get down to the specifics, a few basic things about electricity need to be explained.

A power-generation plant has two figures useful for our purposes: its capacity and its yield ("capacity factor"). The capacity is like the diameter of a pipeline. The larger the diameter is, the more water—that is, electrical current—can potentially pass through it at any given time. How often and how much water is flowing in the pipeline is another matter. A 100% yield ("capacity factor") means that the pipe provides water at its full capacity, day-in and day-out. No electricity-generation technology is quite there. Nuclear is the closest, with an average yield of 90%. In contrast, with solar photovoltaic power, the metaphorical water flows only during daytime, when the sun is overhead. It dries up to none during the evening and throughout the night. Hence, the power output of a photovoltaic array is intermittent, and its yield is low, around 30%.

Capacity, the rate at which energy can be delivered, is measured in watts. The total, actual energy produced or consumed is measured with watt-hours—the very same thing that joules, Btu, and calories measure. I chose to use the watt-hour unit when discussing electrical energy.

**TABLE 7.1**

| order of magnitudes, energy amounts |
|---|
| 1,000 watt-hour (Wh) = 1 kilowatt-hour (kWh) |
| 1,000 kilowatt-hour (kWh) = 1 megawatt-hour (MWh) |
| 1,000 megawatt-hour (MWh) = 1 gigawatt-hour (GWh) |
| 1,000 gigawatt-hour (GWh) = 1 terawatt-hour (TWh) |

What matters is the pattern of the yield: how often, how predictable, how much. Ergo, what matters is the rate and frequency of power, and how dependable its yield pattern is in a given twenty-four-hour period and throughout the year.

Now we are ready to get down to business.

As stated, the plan calls for fourteen transcontinental electric grids. Each energy grid would cover thousands of square miles, connecting remote power plants from various sources to the myriad population centers within a given region. This is very different from the existing setup, where the power sources are on average no farther than 25–50 miles from every household and destination.[1]

Under this plan, a grid of underground superconducting direct-current (DC) cables would connect the power stations with the consumers. Superconducting cables are not your garden-variety transmission lines. They have an attribute that makes the whole scheme of transcontinental grids possible.

The passage of an electric-current in conventional conductors, made of aluminum or copper, incurs heat and energy-loss, as the electrons responsible for the current continuously collide with the atoms of the conductive metal and thus lose energy. Now, something interesting happens when you cool a conductive material: it begins to lose its resistance. Better yet, once the material is cooled sufficiently, the resistance abruptly drops to zero, as the flowing electrons move in an orderly fashion and do not collide with the atoms of the conductive metal.

This is a game changer. This makes it viable to generate power in the Chihuahua Desert in southern Texas to serve customers in Toronto, two thousand miles away—provided of course that the power line is kept duly chilled along the way.

Most conductive materials need to get close to absolute zero[2] before they manifest zero electrical-resistance. Alas, it is virtually impossible to have a power line kept at close to absolute zero temperatures. However, some conductive materials have zero-resistance at the relatively warmer temperature of 70 Kelvin.[3] The foremost conductive materials to have this property are two chemical compounds: yttrium barium copper oxide (YBCO) and bismuth strontium calcium copper oxide (Bi-2223).[4]

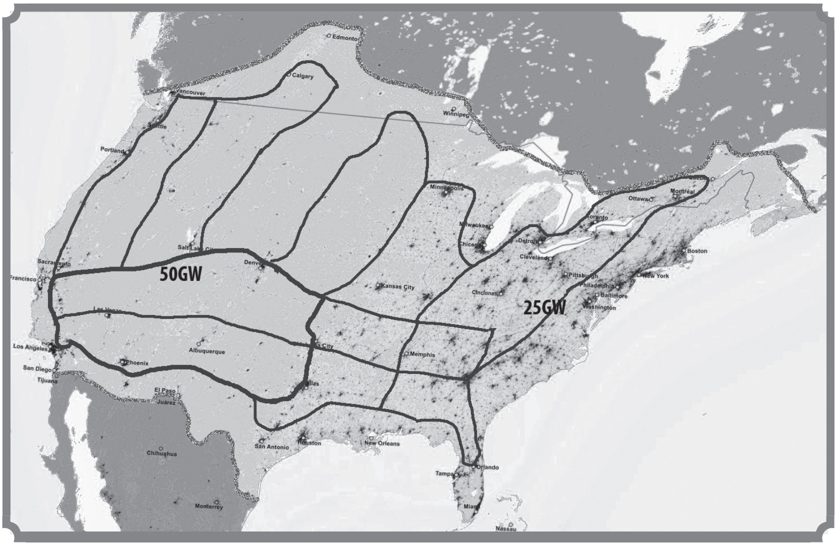
This is very good news, as at 70 Kelvin, nitrogen is liquid under a normal atmospheric pressure. Liquid nitrogen is a mature, readily available technology, which can keep duly chilled the superconductive cable made of either of these two compounds. A refrigerator unit is to be placed every 5 to 10 kilometers to keep the liquid nitrogen at temperatures between 66 to 70 Kelvin. Along the refrigerant units, a series of pumps will keep the nitrogen flowing. Cryogenic, vacuum, and refrigeration systems capable of meeting the capacity requirements of long DC cables are in existence.

The technology of superconducting DC cables makes possible a low-voltage transmission, as there is no need to compensate for transmission losses. This in turn makes it possible to incorporate a second important piece of technology: voltage source converters (VSC). If superconductor cables in this plan are the highways, the voltage source converters are the on-ramps and off-ramps. They allow some power to come off the main line and feed local, AC (alternating current) transmission lines. Furthermore, with the VSCs this can be done in precisely controlled amounts. These converters would be placed along the cable route and let us feed the line from myriad power plants along the way.

Another important attribute of the VSC technology is its ability to reverse the flow of power. If the superconductor power line is cut, the grid operators can reverse flow from that point to service the entire circuit minus the very junction that is faulty. The loop design of the grid (shown below) will assure that even if a point in the loop is cut or otherwise malfunctions, the current will just flow the other way and provide power for the entire length of the loop minus the very point the power is severed. The VSC technology has been in operation since 1999 and is considered mature enough for a full-scale deployment.[5]

A report by the Electric Power Research Institute (EPRI) concluded that a large grid of superconducting DC cables is practical and ready using today's technology.[6] Another study finds that such cables, at 10–15 GW capacity, are indeed achievable but do require significant design-optimization and equipment development.[7] At present, our manufacturing and engineering facilities of superconducting cables are Mickey Mouse class. Our claim to fame is a measly 660-meter-long superconducting AC cable at the Holbrook substation in Long Island, New York, which has been in service since 2008. In addition to the 660 meters we already have, we will need 182,000,000 meters of superconducting cable for North America.

**FIGURE 7.2.** North America with the called-for network of primary transmission lines.



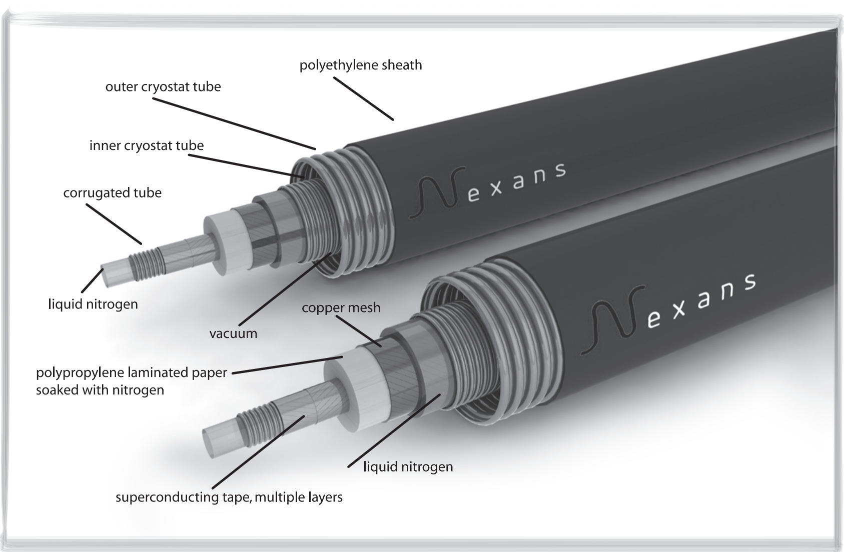

It is not anything I would have put on the table if there was another, more mature technology that fits the bill. There isn't.

Well, there is an option B: high-voltage overhead lines carrying direct current (HVDC). However, it is not exactly a mature technology, either. Furthermore, it has an ugly and a considerable footprint in the form of giant pylons that, with projected power needs, would require over one hundred-meter-wide corridors. Even at their highest commercially-available voltage, the direct-current overhead lines lose considerably more of the transmitted power along the way.[8] Furthermore, having superconducting DC cables would also eliminate the accompanying risks of possible damage due to ice, snow, lightning, and tornadoes. When the power is all underground, one doesn't have to worry that a tornado will knock out the power line supplying power for tens of millions of people. With underground superconducting DC cables there is no electromagnetic radiation to speak of, either.

There is some toll-road fee for getting the power on the main DC power line of such a grid and transferring it back to AC as it is siphoned off at some locality. It also takes some power to keep the nitrogen chilled and moving. Not too much, though. Whenever some electric current leaves the highway via a VSC off-ramp to connect with a local AC grid, there is a 1.5 percent toll on that energy. In addition, we would lose 20 MWh per 1,000 km of cable, due to the power required for refrigeration along the way. However, this is 0.4 percent of the anticipated power per 1,000 km of cable (i.e., 20 MWh out of the transmitted 5,000 MWh).[9]

Fancy a superconducting tape. The heart and soul of the tape is a superconducting material, 1 micron thick, sandwiched by layers of steel, silver, and copper. For one meter of superconducting cable, there is a need to wind within it 115 meters worth of this superconducting tape. The tape is wound around a hollow core in which super-chilled nitrogen is flowing. Around the tape is a shielding copper, more cooling nitrogen, a layer of insulating vacuum, and a layer of insulation. In all, about a 20-cm-thick cable to support 1-micron-thick superconducting material that makes the whole thing work.[10] (See figure 7.3.)

**FIGURE 7.3. A cross section of a superconducting cable.**




*Source:* courtesy of Nexans, Inc.

The cable would come in 100–500 meter long sleeves, in effect self-contained segments. Thus, if a cable is punctured and there is a vacuum breach, only a given segment would be affected—not a 3,000-kilometer cable stretch. In such an eventuality, the segment can be replaced with another or be repaired on site. There is no need for a trench; it is possible to drill horizontally underground and pull the cable through, leaving the surface undisturbed. It is to be a bipolar system made of a pair of cables laying side by side, about 0.5 meters apart. In some nodes of the grid, two bipolar pairs would be required. In other nodes, as many as five pairs would be needed. Each pair of cables would be set 10 to 50 meters apart to reduce the chance that more than one set of cables would be damaged in any given instance. All considered, I will assume each cable within the pair has a 5 GW capacity, which is currently feasible.[11]

We have the basic technological building blocks for the above scenario engineered out in recent years; we have plenty of people that can be trained; we have all the needed raw materials; and we have about fifteen years to lay down the most sophisticated and far-reaching grid ever devised.

## ENERGY NEEDS OF NORTH AMERICA

Come 2027, how much juice would North America need every hour of the year?

For arriving at the electricity needs of 2027, I used as a basis the energy projection for that year done by the US Energy Information Administration in their Annual Energy Outlook, using the National Energy Modeling System. I assume that, come 2027, technology and products offered to the public will only be the energy-efficient variety. Therefore, I used the agency's Best Technology Case projection, which assumes exactly that. This projection also accounts for the anticipated population growth. While this plan assumes a decline in population numbers (see the twelfth chapter ["Consumption"]), I went along with the population increase assumed by the US Energy Information Administration all the same.

The projected energy needs for the year 2027 in North America depart in various ways from the Best Technology Case to better reflect the assumed improvement in housing technology and overall energy restructuring indicated in other chapters.

What follows is a series of tables.

**TABLE 7.2**

| energy needs, residential, USA | 2008 | 2027 |
|---|---|---|
| space heating & cooling | 4,465 trillion Btu | 3,000 trillion Btu |
| water heating[a] | 1,440 trillion Btu | 525 trillion Btu |
| cooking | 250 trillion Btu | 296 trillion Btu |
| drying clothes | 70 trillion Btu | 83 trillion Btu |
| other needs | 427 trillion Btu | 506 trillion Btu |
| electricity | 1,380 TWh | 1,222 TWh |
| Total | … | **1,779 TWh** |

[a]Reduction of 25% due to solar water heaters on rooftops.

**TABLE 7.3**

| energy needs, commercial, USA | 2008 | 2027 |
|---|---|---|
| space heating | 1,797 trillion Btu | 1,400 trillion Btu |
| water heating | 460 trillion Btu | 409 trillion Btu |
| cooling | 30 trillion Btu | 36 trillion Btu |
| cooking | 170 trillion Btu | 201 trillion Btu |
| other uses | 1,291 trillion Btu | 1,530 trillion Btu |
| other fuels | 290 trillion Btu | 344 trillion Btu |
| electricity | 1,442 TWh | 1,454 TWh |
| Total | … | **2,027 TWh** |

In both residential and commercial sectors, the big change is the electrification of all the heating devices. First I extrapolated future heating needs, and then I computed their anticipated electrical equivalents. One watt-hour is the same as 3.41 Btu.

**TABLE 7.4.**

| energy needs, industrial, USA | 2008 | 2027 |
|---|---|---|
| electricity | 1,114 TWh | 1,159 TWh |
| fossil fuel (excluding nonfuel feedstock) | 8,339 trillion Btu | 8,650 trillion Btu |
| **Total** | ... | **3,186 TWh** |

*Note:* assuming gas heating process would be in 2026 at 80% efficency average, while resistence heating is at 100%. And so it is a 20% reduction of 2026 projected Btu figures for non electrical usage.

From all the sectors, the projection of the industrial sector is on the most shaky ground. The called-for technological and economic changes are so sweeping that it is hard to project the resultant power needs. Entire industries, such as those related to fossil fuel, would go by the wayside, while new industries, such as those related to new forms of energy and to recycling, would come online. In the end, I suspect that the actual power consumption would be less than suggested here due to a marked decrease in consumption in the private sector. More on this in the twelfth chapter ("Consumption").

**TABLE 7.5**

| energy needs, transportation, Canada and USA | 2027 |
|---|---:|
| passenger cars | 333 TWh |
| motorcycles | 1 TWh |
| buses | 35 TWh |
| vans, pickups, SUVs | 557 TWh |
| passenger trains[a] | 204 TWh |
| freight trains[b] | 121 TWh |
| trucks, class 4 and 5 | 86 TWh |
| **Total** | **1,337 TWh** |

*Notes:* I assume that passenger cars require 0.19 kWh for 1 km of driving. Motorcycles require 0.04 kWh for 1 km of driving. Buses require 0.55 kWh for 1 km of driving. Vans and SUVs require 0.34 kWh for 1 km of driving. Trucks class 4 and 5 require 0.57 kWh for 1 km of driving. I assume and factor in a 12% loss of electricity en route to the battery. For passenger trains, I assume 0.08 kWh per passenger km. For freight trains, I assume 0.07 kWh per ton per kilometer. For power requirements of trains, the source is Matthew Wright and Patrick Hearps, *Australian Sustainable Energy: Zero Carbon Australia Stationary Energy Plan* (The University of Melbourne Energy Research Institute: Beyond Zero Emissions, 2010), 135.

[a]With the elimination of domestic flights and with the introduction of high-speed bullet trains I assume that in the United States, numbers will go from about 583 billion passenger miles to 1,492 billion passenger miles.

[b]Key assumptions: 38% of the existing freight traffic would be eliminated as it is currently used in the freight of coal.

For the above transportation table, there is no 2008 equivalent, as the motor vehicle fleet of 2008 is largely running on fuel combustion, not on electricity.

As a basis, I use existing numbers of total vehicle-miles[12] for both urban and rural roads adjusted to projected population growth. I make further adjustments to the various vehicle-miles categories based on the significant transportation changes described in the fifth chapter ("Transportation").

Table 7.5 can be split into two consumption categories: those vehicles that feed in real-time (rail-based, such as trains), and those that have batteries (e.g., cars and buses), which can be charged at off-peak times. This is a very important distinction when we come to ascertain the total power generation needs of the region.

**TABLE 7.6**

| total hydrogen needs, USA + Canada | 2027 |
|---|---|
| boats | 3,642,000 tons per year |
| trucks | 14,204,000 tons per year |
| annual hydrogen / electricity to generate it | 17,846,000.tons / 892,000 GWh |
| daily hydrogen / electricity to generate it | 48,890 tons / 2,440 GWh |

Regarding boats, I assume that marine fuel in the United States comes to about 7.4 billion gallons annually. Due to equipping some boats with a kite, I shaved 22.5% of the energy needs. I conservatively deducted 10% of the portion taken up by nuclear propulsion. Then I added the Canadian portion (6.6%) and computed the total needed fuel in tons of hydrogen. In the context of boats, the key assumption is that 1,000 gallons of diesel fuel is the energy equivalent of 609 kilograms of hydrogen. The total hydrogen requirement for all boats comes to about 3.64 million tons of hydrogen.

When it comes to heavy trucks that are to run on hydrogen, the pertinent assumptions are these: In 2009, heavy trucks in the United States required about 25.5 billion gallons of fuel. One gallon of diesel averages 4.8 highway miles for a class-8 truck, while one kilogram of hydrogen averages 6 highway miles. This is in effect the key for conversion of diesel fuel to hydrogen (1.25 gallons of gasoline is the energy equivalent, in this context, to 1 kilogram of hydrogen). I made a further adjustment to account for anticipated changes in transportation patterns and the anticipated introduction of fuel-saving measures. Finally, I added the Canadian portion and accounted for the energy required for transport of the hydrogen (1%) to the truck stops. It came to about 14.2 million tons of hydrogen. Assuming it takes 50 MWh to produce and duly compress one ton of hydrogen, it means that the total required electricity to produce all needed hydrogen is about 892 TWh.

However, all of it will come from excess electrical generation and won't need to be budgeted for in the generation capacity or grid demand. More on this later in the chapter.

**TABLE 7.7**

| summary, projected power needs for the year 2027 for North America | |
|---|---|
| commercial, industrial, and residential sectors of USA | 6,992 TWh |
| with the addition of the Canada portion[a] | 7,910 TWh |
| with the addition of transportation sector of USA and Canada | 9,247 TWh |
| minus Canada's and USA's outlying areas (i.e., Hawaii, Alaska, northern Canada) | 9,173 TWh |
| added electricity to compensate for transmission losses[b] | 13% of consumption |
| **Grand Total for North America** | **10,365 TWh** |

[a]With the existing energy usage of Canada, I assume that the Canadian portion is 13.1% of the U.S. one.

[b]Largely due to local, existing AC transmission losses.

The projection is that we will need a total of 10,365 TWh in North America for the year 2027. This is well over twice our current consumption of electricity. This is to be expected, as we electrify transportation, heating, and practically everything else that is currently using combustion as a source of power. This also assumes that we will have a population larger than that of the present time.

In coming to determine our electric generation needs, the annual total (10,365 TWh) is of little use. What matters is how much we need at any given time. Had the required total (10,365 TWh) been spread evenly throughout all the 8,760 hours of the year, it would come to 1,162 GWh per hour. However, power consumption is never spread evenly. The hourly demand varies, depending on the time of the day, the day of the week, and the season.

While the volume may change, the pattern in western countries is fairly standard: evenings are busier than mid-days, and the hours after midnight are the least busy.

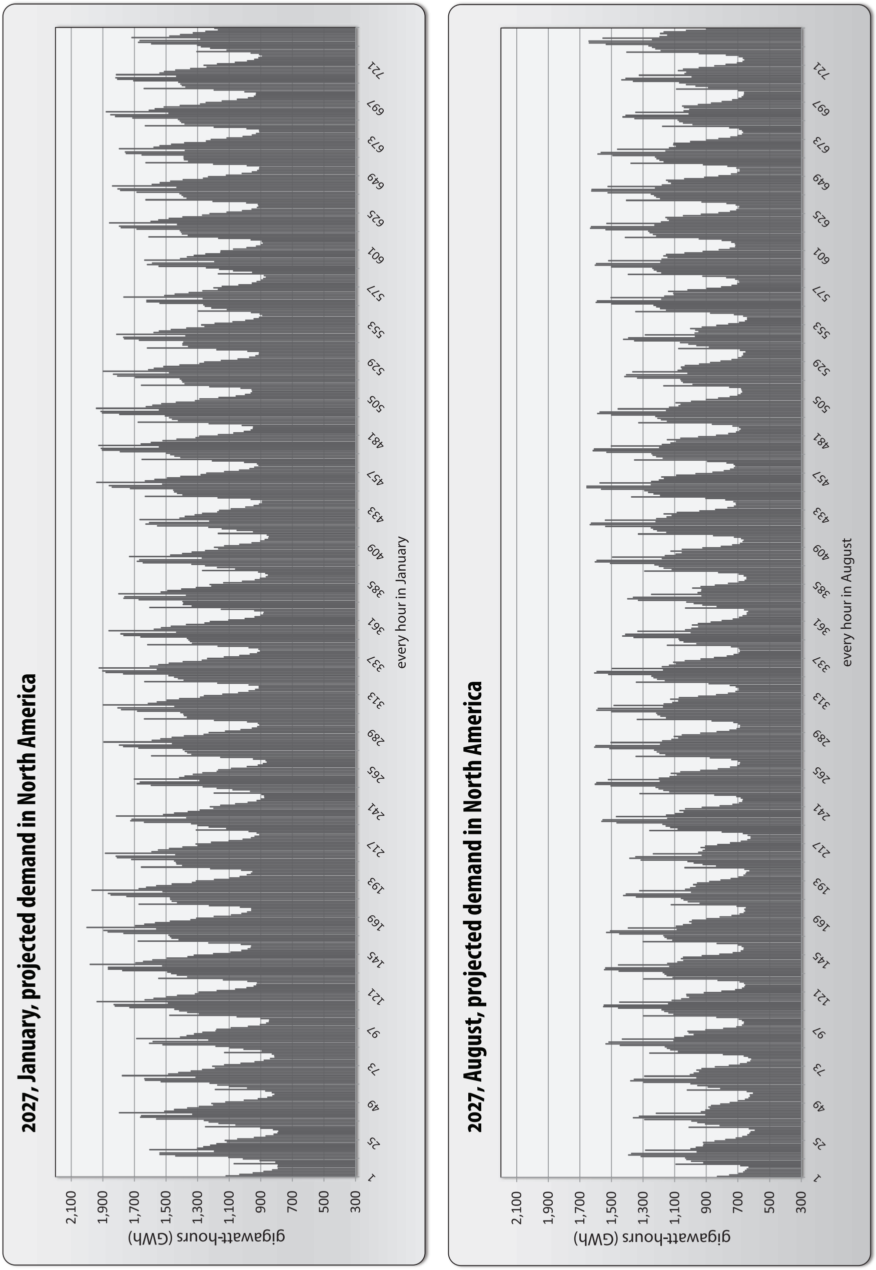
As there are no national hourly statistics for the United States, I have used as a basis the national hourly pattern of Ireland.

I took the existing consumption patterns and scaled them up so that in total they would come to 10,365 TWh. Once the total for the year matched that of our projection, I took note of the derived hourly usage values. As it turns out, demand on the North America grid would range from 600 GWh in low, off-peak hours to 2,000 GWh for the busiest hours of the year. (See figure 7.4.)

Therefore, whatever generation capacity we are to establish, it has to provide for this usage pattern, which ranges from 600 to 2,000 GWh. And on top of that, we need to factor in the unexpected.

As there is a considerable amount of flexibility around what battery is to be charged at what time, I scheduled the charging of batteries in the hours in which the grid has a lot of power with no takers. Basically, this lets us run the entire fleet of public and private battery-operated vehicles without the need for any additional generation capacity—about 1,012 TWh worth of energy. Thus, in truth, I scaled up the Ireland power consumption power to 9,353 TWh and than tacked the 1,012 TWh in key hours of each day.

**FIGURE 7.4**


2027, January, projected demand in North America
gigawatt-hours (GWh)
2,100
1,900
1,700
1,500
1,300
1,100
900
700
500
300
every hour in January
1
25
49
73
97
121
145
169
193
217
241
265
289
313
337
361
385
409
433
457
481
505
529
553
577
601
625
649
673
697
721
2027, August, projected demand in North America
gigawatt-hours (GWh)
2,100
1,900
1,700
1,500
1,300
1,100
900
700
500
300
every hour in August
1
25
49
73
97
121
145
169
193
217
241
265
289
313
337
361
385
409
433
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481
505
529
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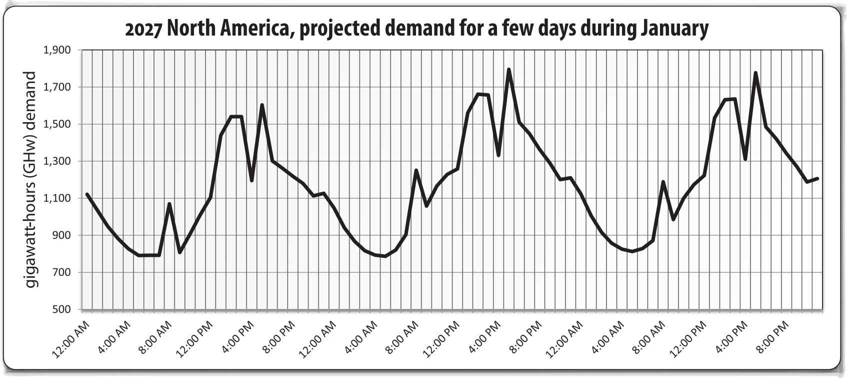
577
601
625
649
673
697
721

**FIGURE 7.5**




This very deliberate battery charging schedule accounts for the unusual spikes in demand in the daily-demands graph shown in figure 7.5. This is all behind-the-scenes, hands-off operation; the vehicle is plugged in for the night or otherwise for a certain amount of hours and the user does not need to get involved in the how and when. All they need to know or care about is that come morning or the end of the workday, the car is fully charged.

Now that we have arrived at an estimated power demand of North America, it is time to see how we are going to meet it. Let's start with the technologies that currently provide the vast majority of power in the region.

## EXISTING POWER-GENERATION TECHNOLOGIES

At present, belching coal and natural-gas power plants generate the vast majority of electricity in North America. By 2027, all of these power plants would be shut down, get decommissioned, and perhaps be converted to memorials or penitentiaries. They already look the part.

Joining them would be the concrete walls bottling up the rivers; they are to be torn down.

The need to do away with coal and natural-gas power plants is clear as a bell in the context of climate change. The tearing down of dams requires some explanation.

Rivers are the veins and arteries of the planet. They carry off toxins and provide nourishment. Dams clog those arteries.

There are good reasons to be done with dams.[13] Their removal has shown to promote the rehabilitation of native species[14] with an overall upturn in species diversity.[15] Dam removal would restore low-flow periods of the river. This in turn would promote vegetation growth, which improves the spawning habitat for fish in the area.[16] A reservoir may separate into several layers of water with varying temperatures due to increase in water depth and decrease in flow velocity created by a dam. Dam removal can restore a river's natural water temperature range.[17] Sediment transport to the river system could also resume. The largest and coarser sediments facilitate population growth of some native fish species.[18] Gravel or stones that were previously covered under fine sediments would be re-exposed and provide new colonization habitats for aquatic insects and revitalized spawning habitats for fish. Lastly, reproduction success, which often depends on appropriate timing for reaching spawning or breeding habitats, would be improved by the removal of dams that prevent the migration of aquatic organisms.

In conclusion, natural gas would go; coal would go; dams would go.

Nuclear would stay, though.

At the moment, there are 122 working nuclear plants in North America. With the additional 10.3 gigawatt capacity projected to come online by 2020, we can assume a total generation of 968,800 GWh from nuclear plants per year. More to the point, we can count on a fairly steady 110 GWh output each hour.

Providing but 8 percent of the projected needs, the existing nuclear plants won't make too much of a dent. But these workhorses are virtually emissions-free and have been reliably chugging along year-in, year-out; decade-in, decade-out. Waste not, want not. This excludes any nuclear plant that would not meet stringent safety standards—whether due to a potentially hazardous location, lack of a containment building, or the such.

We even have enough uranium to keep them running. The OECD Nuclear Energy Agency estimates total global uranium identified resources to be 6.3 million tons. The current annual worldwide output of all nuclear plants is about 2,731 TWh. Combined, the world's fleet of nuclear plants consumes 68,000 tons of uranium annually.

We would have finished the entire known resources of uranium in less than ten years had we run the world entirely with existing nuclear technology.[19] Nasty, but the plan does not call on nuclear plants beyond those in existence or under construction. Current uranium reserves will supply the existing nuclear plants for fifty years with a lot left over, which suits the plan. For the next fifty years, about half of the uranium will run the nuclear plants; a big chunk of the rest will fuel the larger marine vessels as discussed in the fifth chapter ("Transportation"); and the rest will be allocated to micro nuclear plants in the sparse regions outside the fourteen blocks where the sun and wind won't quite suffice—much as the pending proposal of a micro nuclear plant in Galina, Alaska. More on this later in the chapter.

After fifty years, it is highly likely we would find more uranium. But as will be explained toward the end of this chapter, whether we find more uranium or not may matter little.

## WIND TURBINES

Almost always, electric power is generated by spinning a turbine. In the case of wind power technology, the wind does the spinning. The power-generation process of wind turbines is as straightforward as it gets.

A computer-controlled motor positions the three gigantic blades of a modern wind-turbine into the wind. The airfoil shape of the blades causes uneven air pressure, which in turn prompts the blades to rotate around the center of the turbine. The rotating blades spin an attached shaft. The shaft moves a series of gears at a greatly amplified speed, and these gears turn an electric generator. Voilà: electricity is produced. Alternatively, some manufacturers (e.g., Enercon) offer wind turbines with a gearless, direct-drive mechanism. Fewer rotating parts reduce mechanical stress and at the same time lengthen the service lifetime of the wind turbine.

Generally, a turbine will start producing power in 8-mph winds (≈ 3.5 m/s) and reach maximum power output at about 27-mph winds (≈ 12 m/s). Windier conditions won't increase electrical output. At around 56-mph winds (≈ 25 m/s), the turbine calls it a day and shuts down until the strong gales subside. It can be described thus: the turbine starts generating electricity under gentle breezes; peak performance is reached and plateaus at strong-breeze conditions; and the wind turbine has to shut down under a full gale, that is, storm-force winds. A dozen sensors help the controlling software to regulate the power output and rotor speed in order to prevent overloading the structural components of the wind turbine. And in overly high winds, the controller software rotates the blades out of the wind's way.

A modern wind turbine is *large*: just the tower that the turbine is mounted on can reach 100 meters (≈ 330 feet). The height of the tower is not in order for the turbine to avail itself of a better view but to access the more steady and forceful winds of higher altitudes. The blades of a wind turbine are impressive in their own right; each may be 50 meters in length (≈ 165 feet). They are made of advanced fiberglass composites possibly reinforced with carbon. The tower itself is constructed of steel.

Fancy a 100-meter-tall steel pole with three massive blades rotating by wind power and getting a turbine to spin and generate electricity along the way. Fancy hundreds of thousands of such hulks next to each other. Had such an array been installed at sea along the shoreline, it would have formed what appears from shore to be an unbroken wall that irrevocably would alter our experience of the open sea. This cluster of wind turbines would be somewhat reminiscent of the towering fence structure in the movie *King Kong*.

Wind turbines widely interspersed throughout the vast farmland regions of the world would aesthetically be a different proposition. We can do farmlands. The only question is where ample winds are to be found.

There are good to excellent wind resources in some regions: in the Great Plains (North America), Patagonia (South America), the Horn of Africa, Scotland, southern Morocco, Gobi (northern China), Norway, and northern Chad.

Averaging data from dozens of modern wind farms, the permanent footprint of a wind turbine comes to 4,300 square meters (≈ one acre). About 80 percent of that is taken up by access roads, and most of the rest comes from the substation and the concrete foundation for the pole. In addition to the permanent footprint, temporary disturbances seem to average either around 29,000 square meters (≈ 7 acres) or around 9,700 square meters (≈ 2.3 acres) per wind turbine. This depends on the terrain and possibly on the design of the wind farm. The temporary footprint is associated with the wind-farm construction (e.g., temporary roads and staging).

Smaller turbines, such as 1 MW (megawatt) wind turbines, don't give one all the possible bang for the buck. Jumbo turbines like the 7.5 MW Enercon E-126 are too big for some sites. And within reason, the more turbines on the grid, the more their combined yield smoothes the erratic energy yields of the individual turbines. There are considerations either way for what particular size of turbine is to be used for a given location. For the purpose of arriving at projected estimates, I have relied upon a one-size-fits-all model: a mid-range turbine such as the ev100 model by Eviag with a 100-meter-high pole and 2.5 MW rated capacity.

After studying dozens of modern wind-farm configurations, I arrived at an average distribution of 1.85 wind turbines per square km for 2.5 MW wind turbines.[20] Based on the performance of the Eviag's ev100, it appears that a 2.5 MW turbine has a 42% capacity factor at 7.5 meters-per-second winds, and 50% capacity at 8.5 meters-per-second winds. For the North American region, the deployment of the wind turbines is to take place in the Great Plains, where wind speeds at 100 meter height typically range from 7.5 to 8.5 meters per second. Hence, I assume an average generation-output at 45% capacity. This means that a square kilometer, averaging 1.85 wind turbines, would yield 18.2 GWh annually (while each individual turbine yields around 9.9 GWh annually).

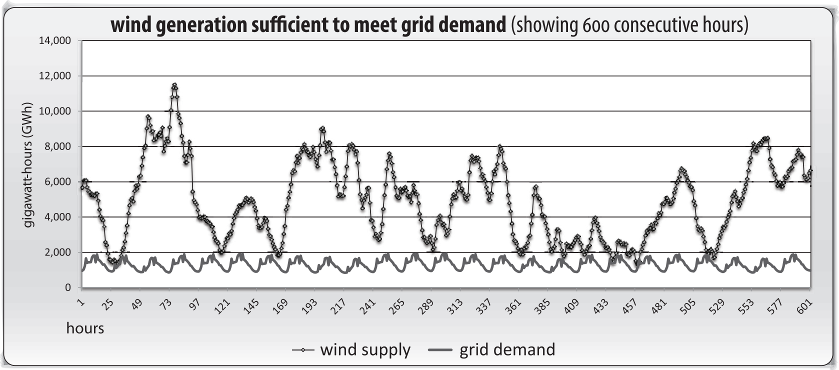
If the total annual electrical demands in North America would be 10,365 TWh, as projected, there would be a need for just over one million 2.5 GW capacity wind-turbines in the Great Plains, which, combined, would produce an average of 1,183 GWh each hour.

Unfortunately, an average is not cutting it.

Given the intermittent and highly variable nature of wind, the output pattern of a single wind turbine is just plain awful. Unfortunately, a field of wind turbines is better than a single wind turbine only in the sense that eight consecutive life sentences for a criminal are better than twenty consecutive life sentences. The best to be had is a transcontinental array of wind farms spanning thousands of miles, where the weather pattern of one area is independent and at times negates those of other areas. An array of hundreds of thousands of wind turbines scattered over vast distances and all feeding the power grid would smooth out some of the fluctuations.

To create a simulation of wind-turbine deployment in North America, I have used actual data of the entire array of wind farms in Denmark and that of Ireland and that of Australia for every hour of the year and then created a unified, harmonized composite of their total electrical output.

**FIGURE 7.6**




Studying the simulation in figure 7.6, the kindest thing that can be said is that the wind *always* blows somewhere. But otherwise, to provide sufficient energy at every hour of the year requires what for most of the time proves to be an incredible amount of excess generation-capacity. Many times the generated electricity could exceed the needs of the moment by a factor of three. However, a chain is as strong only as the weakest link. In this case, a grid comprised solely of wind turbines is only as viable as the lowest output it is likely to generate at any one point throughout the year.

In concrete terms, it means that to run North America solely on wind would require 3.6 million large wind turbines. This figure is based on the simulation above. At 1.85 turbines per square kilometer, this array will be deployed on over 1.9 million square kilometers—an area about the size of Mexico. Yes, at times the combined output of this array could reach staggering output levels of 7,000 to 8,000 GWh hourly, but far less than that can really be counted on.

Unfortunately, even if we were willing to commit to a 100% wind penetration scenario, it should not be done. And there are two very good reasons.

First, it is alleged that a few decades ago there was one week in which the wind did not blow in the United States at all, not enough to turn a turbine blade, at any rate. One does not design a grid with the prospect of shutting it down for a week—not even once every few decades. This entire setup is worse than useless to us if the wind does not blow for one straight week. We cannot shut down North America for seven days and make up for it the following week with some excess electricity.

Second, it seems that operating a lot of wind turbines is not all that good for the planet.

Wind turbine deployment at those levels would entail extraction of a significant portion of the energy embodied in winds. Millions of giant turbines collectively soaking up a big portion of the winds of our world, debilitating them, would have real repercussions on weather patterns, and none for the better.

A modeling study calculated the effect of covering the Midwest with an array of wind farms containing millions of wind turbines. On average, the study found that wind speeds were lowered by 5.5–6.7 miles per hour immediately downwind of the giant machines. More significantly, the wind turbines caused large-scale disruptions of air currents, which rippled out like waves leading to substantial changes in the strength, motion, and timing of storms over the entire North Atlantic. And indeed, scientists have noted considerable warming in west-central Texas—the home of massive wind farm installations.[21]

Much is unknown, but what is suggested in the study above urges prudence. The plan aims to stay far below the magnitude of the wind-turbine array modeled in the study. Making a judgment call, I put the cap on wind turbines installed in North America at the equivalent of 250,000 turbines, 2.5 MW capacity each. In other words, a combined total capacity is to be capped at 625,000 MW.

Another problem is that wind turbines have been killing bats in unprecedented numbers.[22] And as the bats die, the population of pest insects is likely to rise.[23] It is bad no matter how we care to look at it. Yet, I reckon there is more to gain than to lose if we keep the wind turbines. Incidentally, the weight of evidence suggests no association between noise from wind turbines and psychological distress or mental health problems in humans.[24]

As of 2011, the total installed capacity of wind turbines in the United States was 42,432 MW.

As it turns out, there is a creative way to put to good use the energy generated by the whimsical wind turbines, but we first have to introduce and set in place the other members of the energy-generation team for the year 2027.

## SOLAR POWER TOWERS

Without a doubt, solar power towers are to be the backbone of the entire power-generation scheme. They have the incredibly useful capability to take in the sun's rays and provide energy at noon on an August summer day and also in the middle of a frigid night in January.

There are other concentrated solar power technologies; however, I deem the solar power tower to be the most suitable.[25] The solar power tower is a fairly recent technology, and it comes in a few flavors. At the moment, the only commercial plant that has the technology suitable for our needs is the Gemasolar plant in Spain, which became operational in 2011. However, the Gemasolar is a pint-sized installation. Furthermore, it is optimized and designed to have but a secondary role in the local grid. A few larger installations, more in line with what the plan calls for, such as the Rice Solar Energy Project and Ivanpah Solar Power Facility, have been announced or are under construction.

The mechanics of a power tower are straightforward enough.

Thousands of tracking, moveable mirrors—called heliostats—follow the sun's path throughout the day. In tandem, they reflect the sun's rays, directing them to a bank of tubes located on top of a central receiver tower at the heart of the installation. The tubes contain molten salt, which the converging rays of the sun heat up to a sizzling 565°C (≈1,050°F). Subsequently, the molten salt flows down into a storage tank. Later, the heat embodied in the salt is used to generate steam and electricity in the traditional fashion. However, in the interim, the tank stores the molten salt until it is time to generate electricity. This is a big deal. Essentially, this decouples power generation from the capture of solar energy. This makes it possible to have power on demand, both when the sun is shining and when it is not.

When electricity is to be generated by the solar power tower, the superhot salt is routed from the storage tank to heat exchangers. The resultant steam is then used to generate electricity in a conventional steam turbine cycle that is found in coal or natural gas power stations.[26] The heat energy extracted from the molten salt in the exchanger brings it down to 290°C (≈555°F), a temperature at which the salt still remains molten. After exiting the steam generation system, the cooler molten-salt is routed to a second insulated storage tank where it waits. When it is needed, the salt goes up the tower via pipes for reheating to blistering temperatures again.

The solar power tower is to have dual salt storage units that together provide up to 17 hours of storage, 17 hours of reserve power. The salt used in a solar power tower is a mix of 60% sodium nitrate with 40% potassium nitrate. These minerals are abundant. Nitrate salts are made by the oxidation of ammonia, while sodium and potassium are very common components of the Earth's crust. This is today. Halotechnics has discovered and is developing glass material that can operate at much higher temperatures (1,200°C), which would allow the turbines to operate at higher efficiencies and thus require fewer mirrors to produce the same yield. That may translate to 15%–20% less overall footprint for the solar power towers than reckoned for here.

The molten salt can be kept in reserve to be used as needed in a molten state for at least one week before it would inch down to dangerously low temperatures and turn solid within the pipes. In the liquid state, salt has a viscosity and appearance similar to that of water and has several highly beneficial properties in solar power applications. First, liquid salt has highly efficient heat transfer properties, and it retains heat for long periods with minimal losses. Second, the salt can be heated to high temperatures without any degradation, resulting in efficient energy storage and electricity production systems.

The following specifications scale up the tower technology as far as it can go without reaching diminishing returns.

Each heliostat is to be comprised of a multitude of mirror panels that are laid out together, forming one large 12.2 × 12.2 meter reflective expanse (148 $m^2$).[27] This is about half the size of a standard movie theater screen. Each 6-ton heliostat unit would be mounted on a steel pedestal which in turn would be anchored down to a concrete foundation.

Each installation would have about 18,500 such heliostat units, arranged in 10 radial zones. The farthest zone is about 2 kilometers away from the central tower. The total power plant area is 1,340 hectare (≈ 3,300 acres), spanning about 4 kilometers from edge to edge.

The central receiver tower within each installation is to be a steel lattice tower,[28] much as the Eiffel Tower is. And as it happens, with a required 327 meters in height (≈ 1,070 ft.), the receiver tower would also be about the same height as the Eiffel. The height ensures that the reflected energy from the heliostats at the outermost edge of the solar array will have enough of an angle to reach the receiver on top of the tower.

The turbine is to have a gross capacity of 135 MW.

In order for the solar installation to provide power around the clock, we will need two fully independent facilities working in concert. So everything I have just described is to be multiplied by two. One facility would be tuned up and configured to generate energy during the night, the other would take care of the day—thus ensuring twenty-four hours of continuous power supply. To my knowledge, the idea of two solar towers working thus in tandem is novel.

Using the reserves of molten salt, the charge of the nighttime installation would be to provide juice during the night time, with a distant second goal of producing energy during the day. The charge of the daytime installation is the reverse. It kicks into a high gear during the hours that the night installation is at low ebb. Together, the two installations complement each other. Together, they provide continuous power.

During the summer months, the tower installations would generate enough energy to come out of our collective ears, day and night.

However, during the winter months, there is a need to control the amount of molten salt that is released in any given hour of the night, when the sun is not supplying the system with any additional source of heat.

It requires a creative and stringent regimen to coax electricity in the cold months from the relatively limited supply of pitch-hot molten salt that is in storage once the sun sets. Too much released at any one time will not leave molten salt in sufficient amounts for subsequent hours of the night. It is a balancing act.

Both the nighttime and the daytime installations aim to provide a steady generation of energy during the night hours and the day hours, respectively. In the night installation, you release but scant quantities of molten salt during the day, just enough to provide for internal operation requirements of the plant. You open up the machines in earnest in the late afternoon hours. Every month of the year calls for a somewhat different 24-hour schedule of molten-salt release, depending on the amount of sunlight available. In some winter months, a night installation may open the valves all the way around 4:00 p.m. and cut them to 25% output around midnight. Summer months have more play. It is possible to start with valves wide open around 5:00 p.m. and keep at it up until 1:00 a.m., dropping then just one notch, down to 90% output capacity. The amount of pitch-hot salt during the summer months is so considerable that even keeping the valves wide open will still see considerable levels of power output in the pre-dawn hours, when the reserves are at their lowest levels.

If every day, or every second day, was sunny, the above scenario would be sufficient. However, this is not the case. There are many consecutive days that are cloudy, at which time the reserves of salt would run down and with them the power output. To assure a continuous power supply throughout the year irrespective of local weather, there is a need for a network of such tower installations, scattered over many hundreds or thousands of kilometers. It may be rainy for a few days in one location or in two. But it is not cloudy *everywhere* for days on end, at least not in arid or semi-arid regions.

Thus, between many thousands of installations, each with a seventeen-hour reserve of molten salt, we can achieve year-round energy for the entire North American grid. Between weather variability spanning vast distances and the ability to store energy for many days at a time, this network of power tower plants would do the trick. I know, I modeled this.

I ran a simulation on every temperature, cloud coverage, solar radiation, humidity, and wind parameter of every hour of the year in a number of key locations around North America: in all, about sixty-five different meteorological parameters for each hour of the year for each location. I used a meteorological data set that had been carefully chosen to typify the weather in given locations sampled over decades.[29] I optimized the hourly power output for every hour of the day, for every month of the year, and for every one of the five different regions. Then I combined it all into one energy-generation composite and reviewed the resultant hourly energy outcome against anticipated demand for every hour of the year. The damn thing works.

## FOOTPRINT CREDIT

In the context of advocating a resource-based economy, Peter Joseph, founder of The Zeitgeist Movement, said he often runs into people who challenge the precepts of the economic model his movement espouses. They may ask, "What if I want a fifty-room mansion in a Resource-Based Economy? Where's my freedom to have that?" Peter Joseph fires back with "'OK, well, what if I want a million-room mansion?' or perhaps 'What if I want the entire continent of Africa as my backyard?'" He goes on to ask at what point the selfish, acquisitive, spoiled interest becomes blatantly irresponsible and socially offensive. Given that we live on a finite planet, he argues, and in a society in which resources must be shared, excessive and ostentatious living is really an anti-social form of neurosis.[22] And so it is.

We have to work within the confines of the planetary ecosystem—much as pilots have to work with the fact that they've got gravity on their hands, and much for the same reasons.

The first priority of the ecologically available natural resources and activities should be applied to the creation and maintenance of infrastructure facilitating our basic needs. Insofar as the balance of the environmental footprint we can exert, it would be apportioned among all the people of the world to be used as each sees fit. People would be given a monthly allotment of *footprint* and this would hem in, define, the outer limits of their consumption activities. This quota would be determined by a global body. Every month, *footprint* credit is added to one's account, adjusted to the current state of the planetary system and the number of people alive.

Naturally, people would be wise to manage their *footprint* with care, much as they would be wise to manage their money with care. Money does not grow on trees and *footprint* even less so.

The introduction of a *footprint* allotment for each person fundamentally alters the thrust of the marketplace. The incentive would be to purchase, and therefore produce, commodities and services that have a lower *footprint* price tag. It also means that a twenty-room mansion is far more of a liability than an asset. This wouldn't just be a socially-contrived principle; this really is the case.

The ecological footprint, referred to as *footprint*, is complex and comprised of many parameters. Some of its aspects have already been described in the previous chapter ("Consumption").

**TABLE 13.1**

| environmental footprint throughout the lifecycle of a product ("footprint"): six parameters |
|---|
| **Direct Disturbance and Degradation of the Earth:** acuteness of disturbance, volume of earth affected, duration of the disturbance, and the ecological sensitivity of the locale involved. |
| **Toxins, Pollutants, Debris:** effects, coverage, persistence (includes heavy metals that are not salvaged, global-warming potential, ozone potential, various forms of water contamination, acidification, harmful radiation, aerosols, poisons, and solid non-recyclable waste). |
| **Material Scarcity:** Each non-renewable commodity is assigned a scarcity value. Different values are assigned to virgin materials than recycled ones. |
| **Water Resources:** amount of water used compounded by the sustainability of the source. In the case of desalination, the footprint is just that of the power required. In the case of recycled graywater, it is assigned a zero footprint value. |
| **Biomass Used:** Renewables are measured against a natural rate of regeneration. Generally, the rate of replenishment will dictate the rate at which renewable material is harvested. Beyond that, this parameter measures the amount of biomass displaced on Earth and the overall degradation for given ecoregions. |
| **Special Considerations:** effect of wind turbines on the global winds, marine noise pollution, etc. |

Every product and service would display both a price tag and a *footprint* tag. While people may waive off the monetary charge of products and services, they can never waive, unless they have a magic wand, the related *footprint* charge, whatever it may be. When a person obtains a product, a due amount of *footprint* credit is deducted from one's account alongside, if applicable, a due deduction to their currency credit. More specifically, insofar as the *footprint* credit is concerned, there will be a deduction in the allotted credit along each of the parameters that make up *footprint*; the specifics depend on the particular product or service. Beyond the cost in dollars and cents, a cell phone may come with a *footprint* overhead of 53 Direct Disturbance, 79 Toxins, 122 Material Scarcity, 39 Water Resources, and 16 Biomass Used. One's balance—both monetary and *footprint*—is something that could be accessible from any terminal, checkout counter, or hand-held communication device.

Once a person uses up his *footprint* quota, that would be it until one's tank is refueled again with more *footprint* credit at the beginning of the next month. To avoid finding oneself with zero *footprint* credit, it would be possible to set up an automated system that will keep some *footprint* in reserve, setting aside monthly savings to use as a buffer. It is also possible to have a publicly-traded loan website. Participants set up a contract with hundreds of millions of others, each agreeing to loan to each other automatically when any hit a zero balance in a given month. The system would look at other accounts and would borrow based on carefully pre-set criteria. Each person can define a threshold in which he is comfortable loaning out and can define the loan period. There would be no technical possibility for the borrower to obtain some of the lender's *footprint* and make a run for it. When the borrower is due to receive a new allocation of *footprint* credit, before it hits his account, a portion of it is automatically credited to his lender's account. The incentive for partaking in such a loan scheme is that it is to be a two-way street: today one person may loan out, but tomorrow, he may be in need of a loan. What goes around comes around. This aside, the extent of *footprint* loans would universally be capped by the system. If one was able to borrow a five-year supply of allotted *footprint,* later this could very well come to a choice between waiving off the loan and letting the reckless borrower starve—neither of which is really acceptable.

It may be evident from the example of the hypothetical cell phone that the measure of *footprint* is not as simplistic as suggested in the above paragraph. *Footprint* is comprised of at least five independent parameters. It is not only possible but also likely that one would use up all of his credit in one parameter (e.g., Toxins) before the other four at any given time. However, with billions of *footprint* accounts, this is not much of a problem.

It would be possible to trade credit in one *footprint* parameter for that of another. For instance, if a person has an abundance of Earth-Disturbing credit, he can trade with someone else who is low on that count but has an abundance of Toxin credit, which the first party happens to need. In fact, what would be called for is an automated management program that balances one's credit on the fly. The system would make millions of transactions at lightning speed every second of every day. It would all be seamless and would operate behind the scenes. Thus, if someone draws heavily on one parameter, the overwhelming chances are that the system can trade some of his credit in other parameters and even out his *footprint* credit across the five different parameters, or, better yet, study one's purchasing patterns and attempt to maintain an optimal profile of parameters at all times. Naturally, it would be possible to manually program the trading profile, if one needs to amass credit in, say, the Water Resources parameter in anticipation of a trip that would draw heavily on that parameter.

Behind the scenes, the trade system would be able to smooth out the daily operation to a large measure. Yet, we must never forsake the underlying reality. Water Usage has nothing in common with Earth Disturbance—let alone Material Scarcity, which puts value on the availability of nonrenewable resources. Thus, if many in the world draw heavily on Earth Disturbance, we may all run into the imposed ecological limits in a given month. If push comes to shove, no amount of creative accounting and trading would change that fact. Unlike the concocted notion of money that has always been just a cultural construct, *footprint* has a physical reality and very physical consequences, if overplayed.

It could be that some people would end up with more *footprint* credit then they really need in their lives. Beyond the desire to sustain the biosphere, the incentive to conserve excess *footprint* resides in the fact that at any time it would be possible to redeem some of the *footprint* credit for currency credit. *Footprint* would be worth money. However, there is no intention to allow the well-off to buy their way to eco-salvation, and in accordance, a few restrictions would be set in place. While within the automated system one can redeem some of his *footprint* for currency credits, no one can buy or sell *footprint* from anyone else. Furthermore, it is a one-way street; it is not possible to purchase *footprint* credit from the system, only to redeem it.

There would be a universal, fixed exchange rate between currency and *footprint* credit points. The money redeemed from *footprint* ought to be high enough to encourage people to trade in excess *footprint* rather than squander it on what is decadent, but low enough that it will not start to constitute a source of income, which would bring us back to people making money out of thin air.

As mentioned above, it would be possible to accumulate *footprint* credit, allowing one, for example, to take a *footprint*-draining vacation once in a while. However, there would be a ceiling on how much could be accumulated so as not to create a considerable disparity between the actual ecological footprint we exert on the environment and the credit that could be exercised—and was not. Hence, once a certain ceiling is reached, all additional *footprint* credit would be automatically converted and then deposited in one's account as currency credit.

Most everyone will have the same *footprint* credit, adjusted to the number of dependents. Yet, this *footprint* equity would exist only once a certain, minimal income level is reached. To encourage people who make USD 300 a year to conserve environmentally, their *footprint* cap is to be lower than those having one hundred times their income. Or else, we may find businesses producing ultra-high *footprint* items for the poor—knowing that they wallow in excess, well above their means to spend. There is an additional reason for a *footprint* quota adjusted down for people with ultra-low income. If there is no lower allotment for the poor, they could forego work, converting excess *footprint* to money and simply live off it. As is discussed later, the intent is to rapidly eradicate poverty. Thus, lower levels of *footprint* for the poor are only an interim measure. The long-term aim is to maintain an identical *footprint* credit for all.

The *footprint* is amortized over the lifespan of the product usage. If a person purchases a chocolate bar, the entire *footprint* is deducted immediately from one's account. If one buys a house, the *footprint* over the lifecycle of the house is amortized over the projected period the house is going to be in existence. Whether a one-time lump withdrawal or installments, the schedule of *footprint* withdrawal is set for every commodity and service to reflect its individual nature. The practice of *footprint* amortization of some products would create a disparity between actual *footprint* exerted on the planet in a given period and the *footprint* on record. In actuality, the construction phase of a house accounts for the bulk of the house's *footprint*, and the notion that we can amortize it over time in equal installments is but a necessary fiction.

The construction of a manufacturing plant needed for the fabrication of a certain commodity bears its own *footprint*, and it is to be passed on and distributed equally among all consumer goods that would be produced in that plant. This is of course also a necessary fiction. We cannot know how many products are going to be sold, thus we cannot know what is the fractional share to pass out to each individually sold commodity. When it comes to overhead *footprint* costs, creative accounting is called for. The agency governing *footprint* would forecast, or estimate, the number of units that would be sold—based on historical records, market trends, and such. This would determine the fractional share of the overhead *footprint* to be added to each sold commodity. If it is projected that one thousand units would not be sold— due to loss, returns, or lack of demand—their combined *footprint* is to be equally apportioned and tacked on to those units that are sold. In other words, unsold or recalled units are to be treated as a part of overhead *footprint* costs.

If a person gets something as a gift or inheritance, they are responsible for any *footprint* balance of that artifact. This is of course also the case when one purchases something from a private party. Along the same vein, if a man rents a table saw, he would be responsible for the fractional *footprint* of the incurred usage.

In theory, it should be possible to make and subsequently sell a product that on some or all parameters has a positive *footprint*. Put another way, the product has a net benefit to the ecology of the planet. In this eventuality, one's *footprint* credit actually increases along that given parameter. And why indeed not?

Everything else being equal, it is obvious that people living in heavily degraded, ecologically-fragile regions of the world have to tread more lightly than those who live in a relatively intact environment. Indeed, commodities and services have *footprint* that is locale- and context-dependent. See the previous chapter ("Consumption") for more on this.

Every additional layer of nuance would allow the *footprint* system to track more closely the reality of our ecological activities. Every added layer contributes.

The Toxins parameter belies the true complexity of hundreds of very different toxins, not interchangeable in any sense. So even the ostensible complexity of having five different parameters to keep tab of is a vast simplification. It is a balancing act between what is practical to manage and what still presents an effective tool to monitor and constrict our environmental impact. Having said that, what would be overwhelmingly complex for people would be but child's play for a computer. Once again, behind the scenes, every commodity may be comprised in truth of hundreds of distinct parameters, such as those indicating the level of arsenic or GHG emissions. In fact, everyone would get a *footprint* allotment that would be comprised of those hundreds of parameters. So while it would appear to us that we purchase a pen that has five Biomass Used points and this is the amount being deducted from our account, in actuality numerous, differing deductions would occur in dozens of sub categories within the Biomass Used umbrella. The system will continuously trade from within all the users' deficits and excesses of the various sub categories, compensating and adjusting. None of this may be apparent to the consumers, but in setting up the next month's *footprint* balance, the agency administering it would adjust the *footprint* points of various products to reflect our activities. If we, across the board, pushed seawater acidification to the outer edges of ecological wellbeing, the