Cooling It! No Hair Shirt Solutions to Global Warming

By

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Dedication

Sometimes harsh criticism is an act of true friendship; this book is dedicated to all the new friends it will make me.

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A Real Fine Place to Start: Introduction

This is an optimistic book about a gloomy subject - the need to reduce fossil fuel use to fight global warming. It argues that we have technological substitutes available for oil, gas and coal **now** - at market prices comparable to those we currently pay. Neither cost nor technical barriers prevent drastic and speedy reductions in greenhouse emissions; slowing global warming is no longer a technical problem (if it ever was). It is structural, institutional, social, and political.

Why cover this particular topic? The carbon lobby[1] has mostly (not entirely) given up disputing that global warming is occurring. They know that they won't be able to confuse the public on its human-caused nature much longer. (~75% of the U.S. public understands global warming is a real problem[2]. If you are one of the remaining ~25%, please read the appendix **Hot Lies and Cold Facts**.) But a final stalling tactic is open to deniers - to pretend that nothing can be done, or at least nothing that most people are willing to live with. There is an old engineering saying: "no solution, no problem".

Converging with this, there is a small, but unfortunately influential primitivist movement. In their belief that technology itself is totalitarian, they also contribute to the idea that the only solution to global warming is a drastic reduction in the technical level of civilization - perhaps down to the hunter-gatherer level. Many well-meaning, intelligent people promote a less extreme version of this trope - the conviction that we need to impoverish working people in rich nations to solve our environmental crisis, and deal justly with the poorer countries.

The primary purpose of this book is to ensure that energy efficiency and renewable energy technologies become known as inexpensive fossil fuel substitutes available today, rather than a high priced vision of tomorrow. The U.S. needs to understand that continued use of fossil fuel is a political decision, rather than a technical one. It argues against the belief that the only choices are destructive, expensive, continued burning of fossil fuels, or dramatic cuts in the standard of living. It tries to accomplish this by gathering in one place information that has been widely scattered; it also tries to organize the information and clearly separate what we can do cheaply now, what we can do expensively now, and what we may be able to do in the future.

The argument that more and more global warming deniers will rely on is that it is too expensive to phase out most fossil fuel use.

There is a certain absurdity to spending the bulk of a book refuting the idea that saving the world is too expensive. But this absurd task is also a necessary one. If the methods offered to stop global warming are too costly or too unpleasant, many people will prefer to wait and hope that technology provides some magical painless solution.

Other popularizers have written about efficiency and renewables. This book differs in not assuming major technical breakthroughs, or drastic price drops in prices of existing technology; while these are both likely and desirable, we have cost-effective solutions available now.

Also what if the breakthroughs that are only six months away are still only six months away twenty years from now? It is not exactly unknown in the renewable energy field. This book will not argue against any of the "Gosh! Wow!" stuff; more serious R&D would probably produce exactly what many predict. But it seems urgent, absolutely essential to show that we can phase out most fossil fuels at an equal or lower cost than continuing to use them – even if there is no hydrogen path, no cheap solar cells, and no inexpensive carbon fiber.

Once that is done, the book will deal with R&D agendas - near term, long term and blue sky, but in the form of a sample research program, rather than a core requirement of the transition to a carbon neutral future.

To begin with, we need to explain how we can we make the switch at the same or lower prices than we pay now. Mostly, renewable energy costs more (at market prices) than fossil fuels.

No one uses kilowatts of electricity, or BTUs of heat, or gallons of gasoline for their own sake; energy provides service--comfort, cooked food, hot water and so on. If we can invest a tiny amount of money to drastically reduce energy needed to get the same results, more expensive renewable power can supply that reduced consumption at total cost comparable to what we spend now--including capital costs for increased efficiency. For example: we can inexpensively insulate a house so that it needs only a small portion of the heating and cooling energy of the average US home. Buy high-priced solar thermal panels to supply most of that remaining climate control demand, and we still have an overall heating/cooling bill less than before (including the cost of insulation). The bulk of the book will specify how to institute this type of efficiency in all areas - buildings, transportation and industry. We can reduce our energy consumption to a fraction of what we consume now, without reducing our standard of living, and then supply that fraction with small amounts of expensive renewable energy. Thus, renewable energy can supply all the services fossil fuel provides now – warm toes, cold beer, fast transportation--at a comparable cost. We will be dividing the money differently – more for capital expenditures, less for fuel and operating costs – but spend the same or a bit less than at present.

Through increased efficiency we can phase out a high percentage of fossil fuel use essentially for free. Again, energy is almost never consumed for its own sake. We use power to accomplish goals. If your new car can get you where you want to go as quickly, safely, and pleasurably as your old one, you don't mind that it runs of a battery charged by wind, generated in the U.S. rather than overseas.

(If we did not care about global warming, air pollution, and human health, this would not be our lowest priced alternative. Excluding such effects, it would be cheapest to install the least expensive of the efficiency and renewable measures, and use fossil fuels to supply most remaining needs. But we care how long we live, and how much of our lives we spend healthy rather than sick. Most of us would prefer to switch to renewable power at the same total price as we pay now for fossil fuels, rather than lower our energy bill and continue to use oil, coal and natural gas.)

The first chapter will document that almost our entire energy consuming infrastructure has a lifespan of thirty years or fewer. This is important to improving energy efficiency at low cost. If you have to replace a perfectly good (but inefficient) car with a new high mileage model, then the cost of that fuel saving is the entire cost of the car. But if you wait until you have a buy a new car in any case, then the prices of saving gas is only the difference between the cost of more and less efficient models. We will document that cost can be very low indeed.

The next two chapters will show that industrial infrastructure may be upgraded over the course of thirty years to use about 75% less energy per unit of output--at very little additional cost. They will cover Material Intensity, indirect savings through producing less intensive types of material goods. For example they will document construction methods that reduce consumption of metal, cement, lumber, plastic and other building materials; these save the energy needed to make metal, cement, lumber and plastic before one factory is made more efficient. Once this is covered for a variety of areas, direct savings through making factories more efficient are documented.

Similar savings will be documented in transportation, and on residential and commercial buildings.

A total savings chapter will total these percentage reductions, incorporating population growth projections and dealing with questions of per person economic growth as well. That will allow the projection of likely consumption in 2040 if efficiency measures are adapted – and calculate major additional savings in converting primary energy to useful power.

Right now a great deal of primary energy is used to produce an especially important form of secondary energy – electricity. Nearly three units of fossil fuel are burned for each unit of electricity delivered from fossil fuel plants. Total efficiency measures documented will provide a large enough absolute savings to allow all electricity to be produced via non-combustion sources – wind, hydroelectricity, geothermal, solar thermal and so forth. Thus, not having to burn fuel (either fossil or from renewable sources) to produce electricity will provide a significant additional savings.

The chapters on sources will provide much less detail than the efficiency sections – because the glamour of various renewable sources receives a great deal of publicity in any case. Instead they will focus on costs of large scale implementation, total resources available at that cost, and environmental consequences of deployment.

Chapters on electricity will deal with existing hydroelectricity, geothermal electricity, wind electricity, and solar thermal electricity. They will also cover storage for wind and solar thermal electricity. While some of these sources are comparable in price to that generated by fossil fuels, the total dollar figures including storage and expansion of the electric grid to make renewable electricity full available and fully dispatchable (there when you want it) will be significantly higher than the market price of fossil fuel generated electricity. This is why the main chapters dealt with efficiency; smaller amounts of more expensive electricity will provide the same services thanks to greater efficiency in using that electricity; total costs won't go up.

One area we will spend some time on is biomass (plant matter grown and harvested for fuel use). We won't drill down much into forms (biodiesel, ethanol and so forth); instead we will concentrate on how to sustainably grow enough biomass to convert. Producing usable fuel from biomass is not the primary challenge; sustainably growing enough biomass to run even greatly reduced demand by transport, industry and climate control without compromising food or fiber production is the more difficult challenge.

The final chapter hints at the economic, political, social and institutional barriers to implementing these solutions, and tentatively explores the politics of overcoming these barriers.

From here forward, this book will be fairly number-heavy. In Hollywood, when a plot starts dragging, writers often add a powerful visual image, to hang on to audience attention. At any time in the discussion, please feel free to mentally insert a butterfly-laden sunrise, a chase scene, or two girls kissing.

The Love You Save: Improving Energy Efficiency

Here Today, Gone Tomorrow: Nothing Lasts Forever and a Day

As promised in the introduction, this chapter deals with the question of whether infrastructure improvements will work in existing buildings and equipments. After all it is one thing to document that we can build radically new types of homes and cars. But, what about all the homes that already exist? What of the cars people already drive? Are we going to just throw them away and build new ones? Even if efficiency improvements were free, that kind of premature depreciation and discarding capital goods would be expensive indeed. How are we to increase efficiency with this rock solid infrastructure in place?

Of course, that is a trick question, whose answer is implied by the chapter title. The infrastructure of modern industrial society is not rock solid at all.

“I’ve been thinking” says a farmer, in conversation with a city bumpkin, looking proudly at his acres of ripening wheat, “I might put in a new variety next year – one that should get my yield way up.”

“Hang on” says the city bumpkin. “You already planted your fields. Are you going to pull them all up, and replant?”

And of course the farmer explains that he does that every year anyway. He is going to harvest every blade of wheat he planted; planting something new only costs the differences between varieties.

The same thing is true of almost our entire infrastructure - on a time scale of thirty years or less.

Let's start with residential buildings – which can easily last over 100 years[3]. But, look at major components, not only the whole building, and your home is anything but static. According to Freddie Mac[4] the average life of most types of roof is 12-20 years depending upon materials. Dishwashers and disposals last 5-12 years, clothes washers, dryers, water heaters, warm air furnaces, heat pumps, and air conditioner compressors from 8-12 years, refrigerators and stoves from 15-20 years. Modern residential windows typically have 25 year life spans[5]. Wood, vinyl, fiberglass, and most metal siding last between twenty and thirty years[6]. As homes age, bits and pieces break down or suffer damage.

Similarly, most commercial buildings need a major rehab after 25 years[7]. Individual components such as roof, exterior, HVAC, and plumbing tend to wear out in thirty years or less[8] .

According to the OECD, Deutsche Bundesbank, and U.S. economists, industrial and manufacturing equipment wears out within an average of twenty years at most[9]. This covers a huge variety of lifespans. The most energy intensive equipment often tends to last longest and dying industries will sometimes continue to use equipment long after its normal effective lifespan has passed. For example, PCs, which cost little compared to most capital equipment, and use very little energy in operations (though they require a lot to manufacture), have an estimated average lifespan of around two years[10]. On the other hand, the effective lifespan of coke ovens (which are very energy intensive pieces of equipment) is normally taken to be about 25-30 years[11].

There are exceptions of course. Infrastructure such as bridges, dams, sewage plants, pipelines, and water purification plants tend to last a great deal longer – forty, fifty even 100 years. But maintenance for such infrastructure has been neglected for decades in the name of "cutting fat". The American Society of Civil Engineers says America's infrastructure is deteriorating rapidly - report card style they give it an average grade of D+ [12].

Transportation changes ceaselessly too. The single largest component of U.S. transportation consumption, the automobile, has an average lifespan of about 20 years[13]; but most are driven very lightly after their first thirteen years of life. Many are used so lightly as not to constitute a significant emissions source; those which do produce significant emissions could be bought out cheaply, in programs similar to those used to retire the worst junk cars in many European nations. Freightliner gives the lifespan of a bus chassis as about ten years[14], though I suspect many bus companies manage to go longer between major overhauls. Under optimistic assumptions average heavy truck engines last about 21 years between major overhauls[15]. Airplane bodies last fifty thousand cycles or more (which can translate into fifty+ years); but engines seldom last more than thirty years[16], and usually need major service of some type every ten years or so[17]. On average, freight train locomotive engines need overhauls every six years[18] during their 40 year lifespan[19]. Large scale freight ships (container, bulk cargo, and tanker ships) need to overhaul their engines every ten years or so[20]. The upper limit for the latest generation of ship engines appears to be 25-30 years[21].

So, with minor exceptions, we will replace virtually our entire energy consuming infrastructure within the next thirty years. The bulk of this book will show that as parts of our human built world break down, much more efficient replacements will cost around the same as less efficient ones – making up for the higher prices of renewable sources to run them. Thus the U.S. can drop net greenhouse gas emissions to zero over thirty years at essentially no net cost - even without dramatic technical breakthroughs or drastic lowering of renewable energy costs.

Saving Grace: Industrial Efficiency

Lightening Up: Reducing Material Intensity

Most products ultimately provide some sort of service; we own them because they do something for us. If we can get the same service out of fewer goods, or use less energy and material to make the same goods, no sacrifice is involved. Keeping food cold or frozen is the goal of owning a refrigerator; surrounding that food with a quarter ton of metal is a side effect, not a goal.

90% of the material by weight that humans extract from the environment is discarded before final products reach the consumer. 90% of finished products are discarded within six months, Real thermodynamic efficiency of material output over input is not 94%, not even 15%, but around 1%[22]. 99% of all material extracted is discarded within six months. If we multiplied our efficiency in material use by ten - we would still discard 90% of all material used within six months - nowhere close to the limits physics set.

Increasing eco-efficiency by lowering material intensity saves energy as a side effect.

Reduce the amount of concrete, metal, wood, and plastic used to construct buildings, and we save energy in cement plants, foundries, lumber mills, chemical refineries before we make one factory more efficient. Reduce the use of heavy farm machinery, nitrogen fertilizer, pesticides and herbicides (without increasing labor costs or reducing food production) and we save energy use in agriculture and support industries before we make one tractor more energy efficient.

Lowering material intensity does not save energy in linear proportion. A tentative rule of thumb is that you cut energy use by about half the factor by which you reduce total material displacement and environmental impact. That is, a factor ten reduction in material use per unit of service results in a factor five reduction in energy use[23]. (I.E. reducing environmental impact by ten (a 90% reduction) results in reducing energy use by five (an 80% reduction). Similarly, reducing material use by a factor of four (a 75% reduction) reduces energy use by a factor of two (a 50% reduction).

What exactly do we mean by saving material? We are not talking about the weight of materials used, but of total environmental impact per unit of service. We are concerned about organic and inorganic material displaced, about water used, about toxins added to the air and to the water table.

The basic methods used to accomplish these savings include the following:

1) Look at the actual service the goods provide. Take a holistic approach, a systems approach and find out if there is a better way to accomplish the same service.

2) Look at the lifespan you can gain for the product. Very seldom does doubling the lifespan of a product require coming close to doubling either the cost, or the impact of materials involved. However beware of increasing lifespan past the point where a good will be discarded regardless of condition.
3) Reduce the total impact of material used in constructing a good. This can mean drastically reducing the weight, but it can mean the extreme opposite. In most cases this can be done in a way that contributes rather than detracts from increasing lifespan.
4) Reduce the amount of waste created while producing the good, the amount of material scrapped. Quite often something as simple as reducing defect rates can pay both economically and ecologically.
5) Try to make the good recyclable on as high a level as possible. That is if possible, make it repairable, so that when worn out it can simply be refurbished into like new condition (again though not to the point where it is repairable in obsolescence). Make it modular, so that parts that may be repaired and reused. Make parts of material that may be recycled into itself - so that waste from a product can be turned into raw material for that same product. Only as a last step, do conventional recycling where you recycle scrap into lower quality goods, such as using old tires for foundation, and turning old cars into scrap metal.
6) Use the principles of environmental ecology. Try to find another industry that can accept any waste you cannot avoid producing as an input for their process. Similarly try and find industries that discard waste products you can use as inputs.

Note that while in some cases you can do all of the above, often you will have to choose, and balance one against another for maximum economically feasible saving. The object in all this is biomimicry. Create industrial ecosystems that work like biological ecosystems - cycling material from cradle to grave back to cradle again - using sunlight as the main outside input, pulling in very small amounts of minerals and water from outside the system, and for the most part circulating the same material over and over again within the industrial system.

As we move to specifics, we won't cumulate savings for industry sectors. Most information available on reducing MI is not structured in such a way as to allow reliable drawing of boundaries. We look at fibers, at fabric made from fiber, at clothes, furniture, and buildings that include some fabric, at transportation infrastructure that includes some buildings and fabric. We look at paper (including paper packaging) and packaging (much of which is made from paper). In short there would be a huge double counting problem if we cumulated, and avoiding it would be the work of a major study in itself. What is obvious is that when you look at the topics – buildings , food, water, appliances and office equipment, packaging, paper, furniture, fiber, and transportation infrastructure you are covering 70%-90% of all consumer goods. It is reasonable to take this as at least a rough sample of the whole.

Sticks N' Stones N' Straw N' Steel: Material Intensity in Building Construction

Building construction worldwide uses about 40% of mineral and metal products, and 25% of forest products[24]

One example of how to reduce this is the "Super-block" or "Super-adobe" construction technique Nader Khalili[25], California architect/author and founder of the Hesperia, California based CalEarth Institute[26] invented that is very similar to rammed earth. Wet soil under pressure (mixed with a little cement) turns into a sturdy and long lasting building material. Khalili's innovation is to pump the soil into bags that are continuous coils, and bind them with barbed wire.

These small changes accomplish big things. The bags and steel reinforcement make the results proof against earthquakes, a way to avoid devastation such as regularly occur in Iran. The steel wire adds tremendous amounts of tensional and shear strength - something lacking in many traditional forms of earth based construction. Because the bags are a continuous loop, you may fill them by machine instead of by hand, reducing construction labor to something comparable to traditional stick built construction. The steel in the barbed wire is less than the steel in nails used for traditional wood frame buildings. There is less plastic in the sandbags than in the vapor barriers often used in conventional construction. There is less cement mixed in with the sub-soil dirt than is typically used in normal foundations, probably less than is often used in internal plastering alone. And since the bulk of the home is built from on-site dirt, you don't need to truck in huge amounts of construction material. Further, the only machinery used for foundation and shell phase of construction is digging out the subsoil dirt and pumping it into the bags. This technique can be used for the entire rough shell - foundation, floor, walls, roof, even rough cabinetry and built-in furniture. It can then be insulated and finished by conventional or low impact techniques, as you please.

Super adobe is sturdy and durable – an earthquake safe variation on a technique that has been know to last centuries in Iran. How sturdy? In Hesperia, the consultants who tested one for earthquake safety still don't know the limits of super-bloc strength. They intended to test one to destruction, but their bulldozer was not powerful enough to actually destroy it, no matter how hard they tried.

That Khalili is a poet as well as an architect probably influenced his choice of materials. He himself has said that he likes the fact that sandbags and barbed wire, often instruments of war, are used to create beautiful spaces for people to live in.

Think about the embedded energy saved by this technique – reductions in steel, and plastic, and cement and wood boards. It saves the power needed to transport these things - and construction electricity and fuel too. Durability means you replace buildings less often – more conservation; all this occurs before you have made one mill, factory or plant more efficient.

A brief survey of material intensity lowering building techniques follows in tabular form:

Savings in Building Construction			
Methods	Intensity Reduction (%)[i]	GHG Savings (%)[i]	Comments
Rehabilitate, don't demolish[27]; even if only frame and foundation recovered, savings is substantial	75%-90%	50%-80%	% reduction depends on portion of shell saved.
Super Adobe[28]	90%-99%	80%+	Low rise construction only. (cost[29])
Straw Bale Walls[30] - an agricultural waste that makes sturdy comfortable, climate controlled homes.	90%+	80%+	Low rise, other limitations (cost[31]); Unlike many agricultural wastes, more is produced than can be used as a soil amendment; too much straw in soil is a nitrogen robber.
Strawboard[32]	75%	50%	Replace particle board, fiber board, most manufactured woods.
Bamboo[33] - much less land, water, fertilizer per pound of output than wood. Responsible harvesting may leave roots intact, and plants alive.	90%	80%	Potential to cultivate native U.S. Bamboo[34] and non-native varieties[35] in U.S. or import from Latin American varieties too. (cost[ii])
Truly sustainably harvested wood and salvaged/recycled wood	90%	80%	Thinning for benefit of forest health not lumber companies--unlike harvest of prime trees, often falsely labeled thinning. True thinning could produce only a tiny percent of what current harvesting yields.
Wood/Bamboo framing in buildings 4[36] to 7[37] stories.	90%[38]	80%	Wood and bamboo frames in building from 4 to 7 stories save substantial impact compared to conventional concrete, brick or metal – common construction methods above three stories.
Wood Efficient Approaches to Design[39]	26%	10%	Cumulative with some other methods.
Geopolymeric Cement[40] (roofing tile as one commercial example[41])	90%	66%	This alternative cement is based on natural silicates, which requires neither limestone nor anything like the amount of energy Portland Cement needs. Economical in uses where greater strength per lb makes up for MUCH higher cost per lb.
Rastra[42] - an efficient insulated concrete form made from recycled EPS plastic and cement	90%+	80%+	Shallow frost protected foundations[43] or buildings around ten stories.
Pozzalano (fly ash and other waste or natural replacements for a portion of cement in concrete) + recycled steel	50%	25%	Useful to further lower impact of Rastra
Wood/Bamboo above seven stories	?	?	History & practice suggests possibility[44]
Skyscrapers need to make up higher embedded energy with operational efficiency			Skyscrapers will require more embedded impact than shorter buildings. To make up for this they need to attain operational efficiencies exceeding even "passive" smaller structures. After making them hyperefficient, solar cells can be added to make them net energy exporters. Because skyscrapers are so expensive to construct anyway, in many cases solar cells won't increase their cost by a significant percent, even at current photovoltaic prices.
Panelshake roof[45] - from completely recycled ingredients	90%	80%	Recycling, not extended lifespan, lowers impact.
Linoleum, bamboo, cork, recycled wood, and recycled glass floors	75%-90%	50%-80%	All well known "green floor" techniques
Interface Carpet Tiles[46]	90%+	80%+	All carpet tiles lower intensity over conventional carpets because wear occurs faster in heavily traffic areas. With tiles, just the worn areas may be replaced – extending overall lifespan of carpet. In addition, the tiles are recyclable, and the backing has been designed to be recycled back into itself; that is, you can make backing material for Interface

[i] % Savings refer to part, construction stage or whatever technology listed replaces – not entire building.
[ii] Asian imports will always be more expensive than native North American wood. For bamboo to be competitive here, North America must turn to closer sources – native or Latin American.

			tiles from the old backing from old Interface tiles
Unburned clay based finishes[47]	85%	50%	
Other natural finishes	?	?	Huge variety, intensity unanalyzed. Some probably produce significant savings.
Low impact site design and grading[48]	75%	50%	
Mechanical Equipment (climate control, plumbing, ducting etc.)	75%	50%	Result of operating energy savings in buildings - dealt with in later sections on buildings
Pex[49] - Advanced plastic plumbing as long lasting, and lower impact than copper.	90%	80%	More expensive than copper, but less labor to lay pipe; installed cost is the same or lower. Repairs are less expensive as well. Becoming standard.
Fiberglass window frames[47] - Compared to aluminum, based on recycling % figures[50]; also lower impact and longer lasting than vinyl	80%	75%	100% recycled aluminum would have lower embodied impact than fiberglass[47], but higher operating impact. Vinyl, though better than aluminum, is a worse insulator than fiberglass
Cellulose insulation[51]	80%	75%	Must be careful not compromise operating efficiency – insulating properties comparable to fiberglass, but not as good as foam.
Glazing, Plastics, natural gas piping, wiring			No savings in processes representing 10% of all embodied impact and energy.
Note: savings include increases in lifespan and durability unless stated otherwise			

In total, processes representing 10% or less of all embodied energy and impact in buildings may not be subject to significant reduction. Given the other reductions listed, this means that total embodied impact in building site preparation, construction and finishing can be reduced by 75% to 80% - at essentially zero market cost. Very roughly this would reduce energy consumption in site preparation, building construction, and finishing by a bit more than half.

Fields of Barley, Fields of Gold: Material Intensity in Agriculture

If heaven was a pie it would be cherry
Cool and sweet and heavy on your tongue
And just one bite would satisfy your hunger
And there'd always be enough for everyone
Gretchen Peters – 'If Heaven'[i]

Agriculture for food and fiber represents another significant category of environmental impact. Before we worry about how to farm, we should consider how much agriculture we need. If you read the technical news, when this subject comes up, it always discusses how to increase food production for a hungry world.

This is completely misleading. If you look at the total food produced world wide, there is enough food produced (including meat and fish) worldwide not just to feed everyone on earth, not just to make everyone fat, but to make everybody morbidly obese. Counting grain, beans, roots, fruits, vegetables, nuts and other plants and fungi (not including animal feed), plus livestock, dairy, fish, eggs and other animal products raised for human consumption we produced nearly 2,800 calories per person per year in 2001[52] - including 75 grams of protein. 2,200 calories per day are generally accepted, as the average needed to keep a person healthy -neither losing nor gaining weight[53]. 56 grams of protein is the U.S. RDA for adult men[54].

Many people have higher requirements than this – most grown men, pregnant and lactating women for example - as well as athletic women. (As one instance, Lucy Lawless used to perform gymnastics and horseback riding in fairly heavy armor ten or more hours per day while starring in "Xena - Warrior Princess", and probably burned 6,000+ calories daily at the peak of her schedule.) Children, and median height adult women mostly need less. Below 2,200 calories, and 56 grams on average is considered an absolute shortage; if we allow a comfort and safety margin that would mean we want at least 2,300 calories on average per person available worldwide.

How big an increase do we need to keep up with population growth? According to the U.S. Census[55], if you assume the same production with projected increases in population we will still average ~2,500 calories per person per day in 2010, ~2300 per day in 2020. Without cultivation of more acreage or an increase in production per acre, we then approach absolutely scarcity, falling to 1,900 in 2050. We need no increase in total food production before 2020, and only a 21% increase by 2050.

[i] "If Heaven" lyric used with permission from songwriter Gretchen Peters, and copyright holder Sony/ATV Music Publishing.

Moreover, in a sense the problem of getting that increase is solved. I'm going to suggest reasons to go beyond plain old organic farming in a moment. But it turns that even conventional organic farming could feed more people than our current industrial system[56]. Normally when people measure land use for organic farming, they look at the rich nations, see that rich nations on average can grow less per acre via organic means than with conventional ones. (It turns out that the difference is smaller than we thought, though - about 20 %.) However, it is a different story in the developing nations. According the Brian Halweil in World Watch Magazine:

> *…scientists from the University ofMichigan tried to estimate how much food could be raised following a global shift to organic farming. The team combed through the literature for any and all studies comparing crop yields on organic farms with those on nonorganic farms. Based on 293 examples, they came up with a global dataset of yield ratios for the world's major crop for the developed and the developing world. As expected,organic farming yielded less than conventional farming in the developed world for most food categories, while studies from the developing world showed organic farming boosting yields. The team then ran two models. The first was conservative in the sense that it applied the yield ratio for the developed world to the entire planet, i.e., they assumed that every farm regardless of location would get only the lower developed-country yields. The second applied the yield ratio for the developed world to wealthy nations and the yield ratio for the developing world to those countries.*
>
> *<…>*
>
> *…The second model* [the realistic model - Gar] *yielded 4,381 calories per person per day, 75 percent greater than current availability—and a quantity that could theoretically sustain a much larger human population than is currently supported on the world's farmland.*

So our problem is NOT how to massively increase food production. We need to make sure everyone has access to the plenty that already exists. Hunger in the world today is due to injustice, not shortages[i]. That doesn't mean that injustice is the only problem with the international food system.

Current agricultural production consumes far too much water and contaminates far too many clean water sources. Water is a renewable resource, but not in unlimited quantities. If we contaminate enough of the water cycle, we will have less water available at any given moment. Future clean water does us no good when we need it in the present. If we don't drastically lower agricultural consumption and contamination of water sources, we will eventually suffer a genuine food shortage.

[i]As confirmation, most nations with hungry people produce enough for everyone; it is just that not everyone can buy what is produced. Many hungry nations are net food exporters. And many hungry nations devote a large percentage of their agricultural land to producing coffee, flowers, and other non-food or luxury products for export; in others most farmland is owned by a few large families who keep a large portion of it out of production for purposes of real estate speculation.

Similarly, worldwide we erode topsoil every year. Again, we need to reverse this to maintain the ability to feed everybody. There are some questions about mineral sources and soil micronutrients as well.

In addition, the IPCC has pointed out the some of the global warming that is already locked in will decrease food production in some of the worlds poorest nations. But if we can confine the damage to less than a 2 degree centigrade warming we will actually have an overall 20% **increase**. Of course this increase won't do people in the poorer nations any good if they are not given access to this food. That is a critical problem, probably the most critical problem -- but the point is it is not a technical obstacle to feeding the world.

The technical problem is to maintain food production for the next ten+ years, then increase it slowly, while using far less water, far less energy, eroding less soil, using fewer mineral resources, and releasing fewer toxins into the water table. Conventional organic agriculture is not the limit of how we do this.

A good start would be to reverse the currently trend of destroying farmland that continues every year. This both takes the form of converting croplands to urban uses (roads, buildings and so forth) and destroying suitability of land for farming by erosion, destruction of water sources, mining, and toxic contamination.

Meat production is another example. In 2000 the U.S. used ~27%[57] of it's cropland to grow grain for animal feed; the world used ~18.5% of it's production for the same purpose[58]. Yet it turns out that feeding grain to cattle, sheep, goats and other ruminants is not particularly healthy for them or for people who eat them. Forcing animals to spend up to half their lives confined in feedlots causes all sorts of problems. They need hormones to handle grain--far richer food than they are designed to digest. They need antibiotics to stave off the diseases that come from close confinement, and overfeeding - which creates antibiotic resistant strains of bacteria. (Meanwhile hospitals try to minimize antibiotic prescriptions for people.) This still results in occasional e-coli scares. Further, in an effort to increase weight gain, until quite recently we fed animal byproducts to cows and steers - which are really not well designed to be carnivores. This contributed to cases of mad cow in the United States, just as it did in the UK previously.

There is an alternative. Cattle evolved over a long period of time to eat grass. Even today, meat cattle are grass fed in pastures or ranges for around half their lives - and confined to feed lots only during their final months. But there are farmers out there who "grass-finish" their cattle - raise them to their final slaughter weight on plain grass, and produce healthier lower fat, better tasting beef.

Doesn't that lower the tons of beef you raise per acre? It certainly would seem logical. If you pack cattle as tightly as if already dead in steel and concrete feedlots, you can raise more cattle per acre than on pasture. But it takes land to raise the corn and grain and soybeans upon which feedlot cattle subsist. Count this, and grazed cattle have about the same production per acre as feedlot beef[59].

Will this lead to range and pasture erosion from overgrazing? It won't if we use green grazing (intensively managed rotational grazing) which has a long and honorable history. Instead of eroding pasture or range, land intensively grazed for a short time, then rested, gains topsoil and fertility - just as the Great Plains did when grazed by buffalo instead of cattle. So we can produce as much beef per acre via grazing as we can with feed-lots, without the soil erosion of conventional pasture or range, let alone that of row crops[59]. (Note - we may not produce quite as many pounds of meat, since grass-fed cattle move more, and build muscle. But the protein is likely to be the same, and the taste is better.)

Grass finished beef require between a fifth and a third of the fossil fuel energy needed by feedlot cattle[60]. (Substituting other ruminants - bison, beefalo, sheep and goats can reduce this further.)

How do the economics of this work out? Given an equal playing field, the costs of grass-finished beef (and milk as well) are lower than conventional ranching[61].

Grass-fed beef currently sells for more than feedlot beef. Demand is high relative to supply. Because ranchers who grass-finish cattle tend to raise small herds, they don't have access to the economies of scale that larger ranchers have--facing higher transportation, slaughter and marketing costs per cow than the big guys. Also, regulations tend to favor the giants. For instance, health regulations very strictly enforce exactly what equipment is used in slaughter, whereas actual bacteria present tends not be measured. An opposite approach, one that specified results rather than the means to obtain them would give the little guy a better chance to compete, while protecting consumers better than present rules.

(In one recent case, John Stewart of Creekstone Farms Premium Beef Co., wished to test every animal his company slaughtered for mad cow disease; permission was refused out of fear that if one processor did this, others would be pressured to do the same[62]. [Note: he won his case, and gained the right to test.)

How does green grazing preserve the soil? It avoids root damage; disturbing roots disrupts the growth of key soil micro-organisms--especially the fungi that produce glomalin (one key glue that holds soil in place). Grazing seldom pulls roots; normal grazing weakens plant health by returning to the same spot too often; management intensive grazing gives plants time to heal--and thus completely preserves root structures. The difference compares to that between an annoying cousin who drops by for dinner a few times weekly, and an irritating one who stays over one holiday weekend per year, but leaves you alone the rest of time.

Just as with animal husbandry, we can grow row crops by means that don't disrupt root structure. No-till farming with crop rotation is a first step in this direction. In no-till farming, roots are left undisturbed, and any part of the crop not actually harvested is returned to the soil. This not only cultivates glomalin, but retains soil nutrients. If a legume and a green manure are both included in the rotation, no-till can completely eliminate any need for nitrogen fertilizer, and greatly reduce other fertilizers as well--usually producing slightly greater output than ploughed soil[63].

From a global warming perspective, a critical additional factor is that glomalin accounts for 27% of carbon stored in soil[64]; cultivating glomalin actually serve as a significant carbon sink.

The Rodale Institute makes an important point; often, those who promote no-till simply seem to be encouraging the use of Roundup (the world's leading herbicide). Without tilling, weed control appears at first glance to require more herbicide. With all the extra uncomposted plant matter in the soil, it is difficult to avoid attracting insect pests that require pesticide as well. A great deal of grain in the U.S. is grown by no-till methods without crop rotation; this actually increases chemical use. But with proper rotation, cover crops and the use of a chop stalker or roller to convert agricultural residues to an in-place no till mulch, it is possible to reduce herbicide and pesticides by half to two thirds, and water use by 30% to 50%[65]. Because, in a no-till field, pesticides and herbicides remain in the soil until they decompose, pesticide and herbicide run-off is reduced by 90% or more.

Biointensive integrated pest management can reduce chemical pesticides and herbicides further. This includes early pest detection and monitoring, use of predator insects and other biological controls, and least toxic, targeted pesticide and herbicides specific to particular pests as last resorts. This in combination with well designed rotation lets more or less conventional no-till reduce chemical herbicide and pesticides by three quarters. In some case it even allows completely organic methods. For example, Rodale has developed a new cover crop roller that may make no-till without herbicides competitive with herbicide production in yield in per acre[66]. Thus no-till can increase yield per acre, preserve the soil, and reduce or eliminate pesticide, herbicide and artificial fertilizer use - without increasing costs.

How are the economics of no-till farming? Generally you get more production per acre, lower labor costs, and lower capital costs as well. (Thus, while conventional organic agriculture decreases production per acre in rich nations, low input biodiverse no-till increases crops harvested.) There are transition costs. Converting ploughed land to a no-till system takes between three and five years to build the soil enough for increased production. (Lower costs normally increase net profitability even during the transition period.) No-till with fiber crops such as kenaf or hemp can lead to increased compaction - though it has been found that improved drainage, combined with crop rotation will solve this problem.

How much energy does this save? Nitrogen fertilizer use (eliminated in no-till), and farm equipment operations (drastically reduced) are the two biggest energy consumers in row-crop cultivation. Drastic reductions in, (or elimination of), other fertilizers, herbicides and pesticides cut energy use further. So again lowering material intensity indirectly saves energy – in this case by half. Carbon emissions are reduced even more. As with management intensive grazing, building soil structure transforms agriculture from a carbon source to a small carbon sink – providing minor amounts of sequestration.

Beyond this, recent work on charcoal as soil amendments may allow us to go further - sequestering significant amounts of carbon and building soil to a far greater extent[67]. However, there are significant limitations we need to watch out for here, Just as conventional chemical fertilizers add nutrients without building soil structure, charcoal agriculture build soil structure without adding nutrients. So you want to limit the percent and type of agricultural waste you convert to charcoal for this purpose--especially avoiding nitrogen rich materials. Additionally, charcoal making is usually very air polluting. There are charcoal making methods this is not true of, but they are expensive, especially on the small scale you want to use for conversion of agricultural wastes. None of this is insurmountable. Rodale is working on incorporating charcoal agriculture into its no-till farms. It just should not be seen as a quick fix that can avoid the need for emissions reduction.

The following table summarizes some methods of lowering material intensity in agriculture.

Lowering Material Intensity in Agriculture			
Means	Intensity Reduction (%)	Energy Savings (%)	Comments
Green grazing of ruminants[59] (Management Intensive Grazing)	78%-90%	66%-80%	(lower cost[61])
Green grazing non-ruminants (Management Intensive Grazing)	50%	25%	Pigs cost less[68]; chickens more
Rotational No-Till[63] Row Crops, including Legumes, Green Manure, and Biointensive Integrated Pest Management	75%	50%	
Slight or great reduction in meat production depending upon how quickly we move[69].	Meat requires more land per ton of usable complete protein than vegetable sources; to what extent we continue to eat meat depends upon how well we preserve existing agricultural land.		
Sense of location – planting crops appropriate to location. Example: not growing cotton in desert	Cumulates with other means to achieve maximum savings.		
Attention as substitute for inputs. Example: visually inspecting drip irrigation system to verify that it is watering plants as instruments show.	“ “		
Hemp as partial cotton substitute – 100% in some applications, mixes 50/50 in others – overall could substitute for 75% of cotton use. (Most non-clothing use, and clothing that does not touch skin directly such as jeans, and jackets, plus 50/50 mix with cotton in other applications such as T-shirts.	40%[70] (given 75% substitution)	15%	Hemp is an excellent crop to include in rotation with grain, legume and green manure. So it can contribute to much larger savings. Advanced cottonization lets hemp be processed in a soft fiber that may be 100% substituted for cotton. However this is water and energy intensive. 75% substitution with organic cotton used for the remaining 25% would be better ecologically.

Because ruminants and row crops account for overwhelming majority of agricultural impact and energy use, very roughly we could expect a 60% reduction in agricultural energy consumption from this. The key point is that we could increase production - per acre and per hour from various near organic techniques, while lowering ecological impacts more than pure organic production can. This is sometimes described as a "middle path", though the non-organic inputs are fairly trivial.

Before we leave the subject of agriculture we may want to examine the current outer limit of low input cultivation.

Biointensive farming is many steps beyond no-till. Generally through double digging and the use of compost, aerated soil is provided to a depth of 24 inches, either in raised or sunken beds. A variety of crops, not just one or two plants but a multiplicity, are grown closely spaced. The close spacing shuts out weeds, as does the filling of all available niches by multiple crop plants. The biodiversity also discourages pests, since very few insects, diseases or fungi are generalist enough to attack all the species grown.

It produces far more food per acre than other form of agriculture, excluding some forms of hydroponics. It is so land efficient that 100% of a vegan diet may be produced on less than 3,200 square feet - fertilized only by compost from the person the garden feeds[71].

Now this is also a very labor intensive form of agriculture, perhaps slightly less labor intensive than the traditional pre-industrial farming, but much harder work than modern no-till farming. It is not something to implement on a large scale, in its present form, in the long run. But a large part of the world lives on less than two dollars a day; this type of system certainly makes sense in places where people are starving and without work. It is undesirable, though, that people stay poor. Hopefully any nation poor enough that this makes sense for a large part of it's people would use it as a stepping stone to improve their lives, and not leave them with subsistence agriculture (no matter how ecologically correct the type) as all that held off starvation.

The main point of bringing it up in the context of the U.S., where we don't live on two dollars a day, and hopefully won't in the future, is to show that we have by no means begun to tap the potential of what sustainable agriculture will do. While current sustainable low-labor no-till techniques will meet our needs in the long run it is important to gain resource efficiency in agriculture comparable to that of biointensive techniques without the waste of valuable human labor.

Water is More Precious than Gold: Material Intensity in Water Use

Before discussing water savings, we need to define what we mean by "use". The EPA refers to withdrawal and consumption. Withdrawal is the amount taken from surface water and the water table. Consumption refers to the amount chemically combined with something (so that it is no longer fresh water) or evaporated. Water discarded instead of consumed is referred to as "returns", because it is supposedly reusable. This does not even approximate the impact of water use.

One example the EPA gives is power plant cooling. The water is withdrawn, and used to cool the plant. A little evaporates; and the rest returned (still more or less clean) to the source. This overlooks a certain amount of impact (fish killed during withdrawals, aquatic plant, fungal and microbial growth encouraged by the change in water temperature), but is basically correct. However they apply the same logic to water used for irrigation. With very few exceptions, irrigation water "returns" are loaded with fertilizer salts, growth hormones, microbes, and often pesticides and herbicides as well. Even runoff from organic farms usually contains salts from the manure and composts used.

So the proper way to count water is consumption, plus polluted returns - in most cases all withdrawals. The table below translates standard EPA figures into real consumption number[72]:

EPA Classification	**Withdrawals (%)**	**Consumption (%)**	**Withdrawals (millions of Gallons)**	**Consumption (millions of gallons)**	**Consumption + polluted returns = use (millions of gallons)**	**% total use (excludes clean returns)**
Irrigation	40%	81%	137,000	76,200	137,000	66.38%
Thermoelectric cooling	39%	4%	131,000	3,500	3,500	1.70%
Industrial + mining	8.2%	5%	27,800	4,500	27,800	13.47%
Domestic	7.5%	6%	25,300	5,900	25,300	12.26%
Commercial	2.4%	1%	8,300	900	8,300	4.02%
public uses and losses (clean returns)	1.6%		5,500	0	0	0.00%
Livestock	1.3%	3%	4,500	3,000	4,500	2.18%

Note that by any classification, the single largest use of water in the U.S. is irrigation - around two thirds of total water consumed or polluted. The following table includes selected methods of water conservation:

Water Savings		
Row Crops		
30%-50% from converting to no-till, 25%-30% locating crops appropriately. Withdrawals are reduced by about 48%, but polluted returns by much more.	50%	as described in previous section *Fields of Barley, Fields of Gold: Material Intensity in Agriculture*
Convert all less efficient irrigation to low-energy precise application micro-sprinkler, drip irrigation, subsurface irrigation and other ultra-efficient irrigation methods	33%[73]	
Since drainage required for no-till anyway, capture, filter, recycle and reuse run-off	27%[74]	
Row Crops	*75%*	
Buildings – Domestic and commercial use		
Residential Buildings	50%	**A** Very, Very Fine House: Saving Energy in Residential Buildings
Commercial Buildings	50%	Most of the savings possible in residential pay back even more in commercial buildings.
Rainwater capture + Greywater/ blackwater separation with Greywater treatment and reuse + super-efficient commercial toilets (heavier use allows us to spend more and recover those costs in water savings.)	50%	Blackwater treatment can be done on smaller scale – single commercial building or residential neighborhood/apartment complex
Total savings in buildings	*75%*	
Industrial water use savings		
Computer chips: more efficient filters[75],reduction in output waste combined with recycling[76], slowing speed of rinse processes[77]	80%-95%	
Other industries, similar savings in subsequent sections of this chapter	80% +	
Total water savings in industry	*80%+*	
Total savings in livestock watering	*~none*	
Total savings in thermo-electric cooling	*~none*	
Total savings in water for firefighting and other public uses.	*~none*	
Total water savings	**~72%**	**Thus around 40% energy saving**

Working for the Weekend: Material Intensity in Appliances & Office Equipment

We are still looking at getting the same services from consumer goods, with lower intensity of environmental impact – and indirect energy savings. One of the big end uses is appliances and office equipment. (Technically office equipment is part of the production process; but we will treat is as a consumer good.) Now it would be beyond the scope of this book to look individually at what it takes to make a can opener, and what it takes to make a microwave oven, and a washer and dryer and printer and copier and paper shredder and every possible consumer or office appliance. So we shall simply look at two ends of the spectrum; computers and refrigerators – the newest most complex technology, and oldest most mature one.

Appliances	
Computers: the materials discarded in making the average desktop computer and monitor weigh about the same as an SUV[78].	
Chips – Water and chemical use may be reduced from 80%-95% through techniques from simple things like extending the length of soaks in cleaning baths ,to using dry processes and clean chambers to reduce the need for water and chemicals, to improved purification and recycling of used water and chemicals [75;76;77]. These constitute 86% of chip manufacturing impact - thus 75% reduction	50% energy savings
Circuit boards: silk screening substitutes for etching process[79]. The result is lead, halogen and bromide free, uses fewer harsh chemicals, produces less manufacturing waste, and contaminates less water – 75% - 80% reduction environmental impact.	50%+ energy savings
chip packaging - epoxies and films that can complete replace solders[80] - 75% reduction	50% energy savings
Monitors: LCD monitors have much lower lifetime impacts than CRTs[81] - ~73% (must incorporate technologies to reduce nitrogen and phosphorus pollution[82], and recycling and major reductions in emissions of Sulfur hexafluoride[83].)	40% energy savings
Assembly – lead free solder, less toxic plastic, easier recycling - example - Fujitsu's Scenic Green E -75% impact reduction	50% energy savings
Average life of computer 2 years[84]. Double it! Four years was average computer lifespan at the height of the internet bubble. Make computers with easier to open cases, and roomier bays. (Dell, and many other manufacturers already do.) Limit software license restrictions that forbid selling obsolete computers with old obsolete software. That will encourage "second lives" for business computers that are currently scrapped to avoid copyright liabilities.	
Manufacturer liable for recycling computer end of life (as in Europe). This will both encourage longer lifespans, and encourage manufacturers to make computers easier to recycle…	
Computer total impact savings 80%	*60% energy savings*

If computers are leading edge appliances, refrigerators are perhaps the oldest, most mature technology. Heat pump based cooling was invented and commercialized in the late 19th century, mostly to make ice for distribution. Can we lower the intensity of the manufacture of heat pump refrigeration, and improve efficiency too?

The Wuppertal institute proposed (and built an example of) an alternative[85], based on looking at refrigeration in a new light. What services exactly does it provide?

> *...produce or groceries should be kept cool and dark so that they will not spoil; the storage space should be located in immediate proximity to where food is prepared; it should be hygienic, able to accommodate the usual containers, as well as meet the reigning aesthetic standards, and it should be easily accessible....*
>
> *...why should a refrigerator not be a part of the house similar to our grandmother's root cellar or pantry? … The doors, seals, control technology, as well as the separately incorporated refrigeration unit, should be exchangeable....*

So instead of building what amounts to a cupboard, and transporting it to the home, build it in place like any other cabinet and add a high quality thermostat, heat pump, vent and insulation. In operation, it uses around 145 kWh per year - about a tenth of the average U.S. household refrigerator. (In fairness new U.S. refrigerators consume a great deal less than average U.S. consumption.) At the time the analysis was done they simply noted that they used around the same weight of material, but designed it to last the life of the house instead of the usual refrigerator lifespan. Their material substitutions, greatly reducing steel (and other metals), glass, and plastic, replacing them with wood and cork or paper will reduce material intensity even of manufacture by a factor of four or greater - before you consider the greater lifespan – four or five time the U.S. average. So you end up with a factor 16 to 20 reduction in embedded impact, a 90% or better reduction in embedded energy over the life of the refrigerator (not counting operational savings.)

That defines a spectrum - but what about appliances in between? There may well be some room for material substitution and rethinking of the same type we saw in refrigerators, or drastic changes at the manufacturing level as we saw with computers, or a combination of both. Microwaves are closer to the computer end of the spectrum, dishwashers, washers and dryers closer to the refrigerator. Really small appliances, like can openers, and toasters could probably reduce impact in a third way - by a drastic increase in lifespan. A 21st century slice toaster does little a 1965 slice toaster did not do. A 21st century can opener does little a 1978 can opener did not do. There is no reason not to manufacturer such very small appliances with sufficient durability to multiply their years of service four times or more. In many cases increased durability can combine with lower impact materials.

In total we can reduce major appliance impact by 80% to 90%, minor appliance impact by 50% to 75%. A factor four to five reduction in total impact would be reasonable estimate – a 50% energy savings or a bit more.

Can't Hide Your Lying Eyes: Material Intensity in Packaging

Of course there is another way to reduce the impact of can openers - eliminate cans! No, we don't need to give up the convenience of modern packaging; rather there are improvements in packaging that make cans obsolete; we can also eliminate wasteful overuse.

Packaging fulfills three purposes, but is only needed for one. It helps preserve goods during storage, shipping, and in the consumer's home - fair enough. Packaging also provides security - often packages are designed larger than preservation requires to make stealing more awkward. But there are plenty of other means to prevent or reduce theft - including a less predatory social atmosphere. Finally packaging is a marketing tool - used to persuade people to buy goods and services. In a modern U.S. supermarket, the floors now compete with ceilings for what can hold the most advertising. Dividers used by customers to separate orders each carry a one line slogan. Conveniently placed at eye level above the urinals in the men's restrooms you find more paid advertising. Do we really need to make packaging two to four times the size protection against spoiling and shipping damage requires, to grab shelf space, and take one last chance to grab the customer's attention?

Even for preservation, there are huge opportunities to reduce packaging:

Reducing Packaging for Food and Sundries		
Packaging Change	Intensity Reduction %	Energy Reduction %
In modern aseptic packaging food can be cooked and sterilized in a single batch within an aseptic chamber, then poured into packages that are also sterile, which are sealed without ever allowing pathogen exposure. This can allow lower temperature preparation or very high temperature preparation for a very short period of time; food tastes better and processing uses less energy. The packages can be cartons or even flexible pouches rather than cans - using a great deal less material.		
Foil wrapped coffee bricks compared to coffee cans[86]. (Note: steel cans are currently recycled; coffee bricks are not. But bricks can be[87].)	80%	60%
Aluminum pouches vs. aluminum cans (both equally recyclable)	75%[88]	50%
Milk pouches compared milk bottles (both recyclable)[89]	70%	40%
Cereal pouches vs. cereal boxes[90]	83%	60%
detergent pouches vs. detergent bottles[90]	84%	60%
Juice boxes vs. juice bottles[90]	90%	75%

We can reduce packing for furniture, appliances and other non-food items as well, while providing continued protection. A properly designed single layer of packaging may provide enough protection to avoid the need for multiple layers. Instead of multi-bubble back, single large bubbles may be used. In some cases a single inflated inner layer combined with a rigid outer layer can protect very delicate appliances.

We also need to consider pre-consumer packaging. Consumer goods, package and all are usually stored in other packages to protect them during various shipping stages. Like consumer packages these can often be lightened. But in addition there is a lot of potential in something difficult at the consumer end - reuse. Quite often a mutually beneficial agreement between retailer and wholesaler or manufacturer can result in return of packages, for use in future shipments. Unlike consumers, both parties know precisely what they stand to save in such arrangements, and the exact cost of additional labor in making them.

Business to business packaging examples		
	Packaging Reduction	Energy Saving
Waterstones, a UK book retailer, receives books in reusable tote boxes returned to its distributor when next shipment arrives[91]. Reduction in damaged stock reduces labor costs for both distributor and Waterstones.	95%	80%
Harman Pro Audio Manufacturing reuses delivery packages to regular customer by up to seven times. It uses larger multi-packs holding more transducers per package, and reduced package weight by a third[92]. Payback was 12 weeks.	93%	80%
Target required vendors to eliminated inner packaging; so multi-pack contents are no longer individually wrapped. Saved packaging and extra labor it spent unwrapping items to hang them.	75%	50%

Total packaging can be reduced by at least 75% to 80%, saving 50% to 60% of energy consumed in making it.

Paper in Fire: Material Intensity in Paper Use

When cardboard and paperboard are included, packaging and shipping constitute around half of paper use[93], which packaging reductions discussed in the section immediately prior to this one can reduce by 75%-80%.

Another 12.5% is used for newsprint[93]- mostly to be read once, and then thrown away. The major potential for reducing newsprint size lies in reading daily newspapers on screens rather than on printed pages. This does not refer to current fuzzy monitors, not even LCD types. Comparatively new technology exists that allows electronic printing onto extremely thin laminates at resolutions better than that of newsprint. This is no longer experimental. Sony now sells the 160 dpi Librie EBR-1000EP e-reader - whose six inch screen has (as promised) a better resolution than a newspaper[94]. I don't expect the Librie to prove a great success. On initial release, it accepted documents only in a proprietary format[i]. The controls are unresponsive. And, as befits a bleeding edge product, it is expensive - over $400 for a machine with computing power exceeded by some calculators.

But none of this is inherent in the technology. According to Reuters, the cost of the screen itself is in the "tens of dollars"[95]. So there is no reason a decent e-ink reader about the size and weight of a thick trade paperback could not sell for $120 dollars or under, probably less than the cost of printing a typical U.S. daily newspaper for two years[96]. It would have no keyboard, only the minimum controls for navigating documents; the screen would be easier to read than most paper pages.

What about the manufacturing and operating impacts of such readers? E-book readers normally use much smaller screens than desktop LCD monitors. Smaller sizes are more convenient, and higher resolution screens don't need to be as big. And even for a given size, e-ink type screens have about a third less impact than LCD monitors[97]. Similarly, in operation e-ink readers use drastically less energy even than a typical PDA. Energy to download and read is probably around a tenth that required to make and deliver the paper to the printer, print the paper, then distribute and deliver it to the reader. And you don't need the fastest chips or memory for this purpose[ii]. While reading on a full size desktop with a CRT has a similar impact to a paper periodical, an e-ink style reader has between a tenth and quarter of the impact of real paper – even allowing for the "clipping" of articles, ads and coupons by printing. There is no reason e-ink could not eventually completely replace printed newspapers. It is absurd to use enormous amounts of material to produce newspapers which are almost never completely read, mostly read only once, and then discarded the next day. And with a properly designed newsreader, there is no reason there should be any loss of convenience.

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[i] Remember Sony is the same company whose marketing geniuses chose to keep the superior Betamax format proprietary - which is why the technically inferior VHS was the standard video format until DVD replaced it

[ii] Because screen refreshes really are done by printing to the screen, they take a noticeable fraction of a second. So fast chips and memory would not be useful in any case; they would still run into a screen refresh bottleneck. That is also why this technology is only useful in niche applications such as e-readers. The screen refresh rate is too low for normal computing.

There are plenty of other publications the same reasoning applies to. Many popular periodicals are read a limited number of times and then discarded. So is a great deal of popular fiction. And even a lot of periodicals or papers that are kept over the long run and intensively studied don't need to be written in. E-ink, at its current stage of development, can be used to created inexpensive readers, suitable for any publication or document that does not need significant markup. There is no reason this should not apply to at least 80% of books and periodicals. So a three quarters intensity reduction in 80% of published work is a 60% reduction.

Office paper (including home offices) is another major portion of use. (Remember that along with magazines and books it constitutes about 30% of the total.) There are fairly low tech means that can cut paper use in offices by 60%-90%. These include:

1) Replace all non-duplex printers as they wear out with duplex ones - then instituting a policy of using both sides of all paper when practical.
2) Keep a reuse bin, and use the back side of paper printed on only one side for in-house work.
3) Making minor correction on in-house work and preliminary drafts in pen without reprinting the document.
4) Don’t print e-mail and other electronic documents unnecessarily.
5) Make a practice of reducing margins for in-house work,

For example British Petroleum's Melbourne office reduced paper use 61% by these methods[98]. One office of Innovative Management Solutions, a Canadian environmental company operating out of Ottawa managed to reduce paper consumption by 84% in a seven month pilot program[99].

There are also some high tech ways to reduce paper use. An old idea from decades ago has justifiably fallen into disrepute – the hypothesis that computers and electronics would eliminate the need for paper. In point of fact, by making more documents accessible for easy printing, information technology has increased paper use. Abigail J. Sellen and Richard Harper's wrote an entire book about this - "The Myth of the Paperless Office" [100].

There are several ways in which electronic documents are inferior to paper - print resolution, readability, and multi-document interfaces. Paper has higher resolution than normal screens, better portability, and is easier to position. Multiple paper documents on a desktop handle more simply than multiple electronic documents on a screen. Paper is easier to mark than electronic documents of any sort. Compare the use of a red pen to using Microsoft's Word's "Track Changes" feature.

But this does not mean electronic storage does not have strengths too. If you don't already know exactly where your information is, it is a whole lot faster and easier to search properly indexed electronic files than thumb through paper archives. Similarly, electronics can store large amounts of information more easily than paper. A red pen may be convenient for one person to make simple changes - but electronic change tracking systems make collaborations among many people easier than paper. This is especially true if some are in remote locations.

By working with the strengths of electronic storage, while not trying to make it replace paper for the things paper does well, you can create an office that is not paper-less, but uses less paper.

O'Driscoll O'Neill , a Dublin a major Irish insurance brokerage operating out of Dublin, switched from a paper to an electronic document management and paper handling system in January of 2003[101]. I can't find information on the exact amount of paper reduction, but paper files have been reduced in number by at least 90%, and file clerks eliminated, along with 1,200 square feet of file rooms. Mail is processed faster than in the old system, and all documents are available electronically from any desk with appropriate security authorization. Because of this, people are spending 60% more time at their desks. "Lost documents" have been almost eliminated. As is normal in such system the gains in productivity and customer service are the main point, paper savings being a minor secondary effect.

KAF financial group, an accounting and consulting company reduced paper by 75% - again as a side effect of productivity increases[102]. The same article discusses even larger gains Nevada County in California made by automating its system, and essentially putting all public documents on line.

It seems like a combination of "less paper" technology, common sense paper saving techniques, ought to easily save 75% - 90% of paper used in offices. The cost for common sense techniques is low enough to more than pay for itself in paper saved. Electronic document interfaces are normally installed to produce productivity gains; paper saved is a side effect. The cost is better than free – a side effect of something that is already producing a net gain.

Another "business use" of paper is junk mail - unsolicited advertisements. It is often argued that these "subsidize" the U.S. postal service - paying for first class mail. Even if true, such subsides are not really free. Obviously these, like all advertising and public relation costs, are incorporated into the price of products sold. If junk mail was eliminated or reduced the U.S. postal service could be subsidized in some other way. But the claim that this is a subsidy depends upon how post office accounting procedures match costs and revenues. It is at least possible that first class customers are paying a bit more than their fair share, and influential large mailers a bit less.

We won't discuss the 6.5% of paper used for tissues - paper towels, Kleenex, napkins and such, assuming no substantial saving there.

So, adding it all up in the table below we end up reducing intensity by over 68% and paper tonnage by a bit under 75%.

Paper Use Category	**% Use**	**Reduction in Intensity**	**Net Reduction**	**Reduction in Paper**	**Net Reduction in Paper**
Paperboard and cardboard	45.3%	75.0%	34.0%	75.0%	34.0%
Packaging	5.4%	75.0%	4.1%	75.0%	4.1%
Printing,home+office paper,books, magazines -30.3%					
Home + Office printing - copiers, laser, inkjet etc.	15.2%	80.0%	12.1%	80.0%	12.1%
Books + magazines	15.2%	60.0%	9.1%	80.0%	12.1%
Newsprint for Newspapers	12.5%	75.0%	9.4%	100.0%	12.5%
Tissues etc.	6.5%	0.0%	0.0%	0.0%	0.0%
Total			**68.6%**		**74.8%**

What about the 25% of paper we would continue to use (while still producing 32% of the environmental damage due to impact of additional electronics)? The first step would be to reduce the intensity of fiber grown for raw material.

Making paper from dead trees is comparatively recent in history. The ancient world produced it by boiling and hand pulping harvested fibers. Only in the 19th century was industrial technology strong enough to be able to make pulp from wood fibers. Only in the 20th century did wood become paper’s main ingredient.

There are, however, crops that can provide fiber every bit as good or better. In the U.S., it looks like the best for this purpose is kenaf.

Kenaf is part of the hibiscus family, related to cotton and okra. As you would guess from that family tree, it needs plenty of moisture, and grows best with plenty of light - in short is best suited to the Southern parts of the U.S. It can be grown in dry sunny climates like New Mexico as well - with plenty of irrigation, which I think is a bad idea for the same reason as growing cotton in Arizona.

Before proceeding with this analysis let's deal with an objection emphasized by the timber industry, but raised by many environmentalists as well. Granted that timber farming is not particularly ecologically sound, isn't replacing timberland with cropland a further degradation? If that was what we would be doing, they might have a point. But it does not particularly make sense to grown kenaf and fiber crops on land currently devoted to forestry. Kenaf requires only four to five months from planting to harvest[103]; devoting any parcel of land entirely to it would cost farmers money. Both ecologically, and economically it makes the most sense to include it as part of a rotation with other crops on existing farmland.

Now this doesn't mean we don't lower the yield of other cultivars; adding a fiber crop to a rotation does reduce total food produced on average per acre per year. Not every piece of land used to grow food will convert to a kenaf rotation, of course. Still we are going to have to increase the total acreage of land under cultivation to accommodate the kenaf[i].

A significant amount of cropland held out of production is in economic reserve or as a part of a soil erosion program – without being used for wildlife preservation or converted to non-farm uses.

Converting some of this to no-till rotational agriculture could increase total acres under cultivation - while (as we have already shown) building the soil[ii]; cropping this acreage by such means would help rather than harm the environment.

Further, shifting some production from timber to agriculture could help provide more income to farmers – contributing toward reducing the single greatest threat to long term food production - loss of agricultural land.

Intensive industrially farmed kenaf production uses about one half the water that intensive production short rotation timber does[104], erodes soil at about half the rate, uses about a third less fertilizer, and slightly few pesticides and herbicides, and produces about three times the fiber per acre once credit is given for soybean production in rotation on the same land.

Kenaf could also be produced more sustainably via a system similar to "the old rotation", the longest running experiment in rotational agriculture in U.S. (run by Auburn University College of Agriculture), which began in the late 19th century[105]. The old rotation grows cotton (no nitrogen), crimson clover or hairy vetch as green manure (no nitrogen), corn (no nitrogen), rye as cover crop (60 pound nitrogen), soybeans (no nitrogen) in a three year rotation. Given that Kenaf can mature from planting to harvest in two months shorter time than cotton, you could probably get the same effect with a two year rotation, alternating between soybean/corn, and kenaf/corn and putting in clover or vetch every year. The annual use of a leguminous green manure would eliminate the need for nitrogen fertilizer. The variety of crops and crop types would allow farmer to use true no-till farming, as the old rotation does for cotton[106].

[i] Just a reminder - this is a long run problem. In the short run we grow more food than the world needs. World hunger is entirely due to injustice and stupidity. There is no food shortage.

[ii] Other conservation tillage alternatives can do this to some extent too. But any level of plowing disrupts glomalin completely; soil without glomalin will never hold together as well, or be as fertile, or as good a carbon sink as untilled land.

Kenaf farmed in a modified "old rotation" system would consume about one fifth the water, fertilizer, and land area of long rotation tree farms (where trees grow 45-75 years before being clear cut), and build soil instead of eroding it, and need fewer herbicides and pesticides as well. Because we are doing no-till with green manure we are building soil at the fastest rate possible - and offering the greatest carbon sink harvested plants are capable of. We are going beyond carbon neutrality to do a very small amount of greenhouse gas mitigation.

The superiority of kenaf to timber is even greater than a comparison to timber farms alone would suggest. More than half of new (as opposed to recycled source) pulp comes from clear cut natural second growth timber[107]; an additional ~15% is logged from natural old growth forest.

408 Million acres are classified as timberlands, not including any lands removed from production, in the U.S[108]. Around 29% of this is used to produce paper[109], so 118 million acres are currently devoted to paper. If we institute a 74.75% paper reduction, then around 30 million acres will still be needed for that purpose with conventional timber harvesting. Population growth will increase that to ~44 million acres by 2050. Kenaf tends to range from 3 times more production per acre (comparing most intense to most intense) to 7 times more production per acre (comparing longest pulp-farm rotations to lowest impact form of kenaf rotation). Halfway between those two would be five, to be conservative, let us model kenaf as producing 4 times as much per acre. (Remember this gives credit for the fact that kenaf rotates with food, and thus does not use 100% of the capacity of the land.) We would need 7.5 million acres of kenaf to replace wood pulp for paper with today's U.S. population, and a bit over 11 million to replace timber needed to serve reduced paper needs by the projected U.S. population of 2050. In 2002 57 million acres of cropland was idled according to the 2002 U.S. Department of Agriculture's Natural Resource Inventory[110]. Even given that much of this would be wildlife reserve land, or otherwise not suited for cropping, there should still be a lot more than 11 million acres we can use. Most of it would probably not be good land for kenaf. But more than 11 million acres would be suitable for some type of food, to replace the food production kenaf would displace when put into rotation with existing food crops.

Obviously, not one acre of timber farm has to be converted to kenaf farm to grow kenaf for paper. But let's confront for a moment the worst nightmare the timber industry uses to scare us from considering kenaf - that timber land would be directly converted to kenaf production. Currently 118 million acres of land is used to grow timber for paper. Suppose we gradually replaced 11 million acres of that with kenaf farms, as it was harvested for pulpwood anyway, then moved the rest out of production into wildlife preserves. That is still many times better than what we are doing now. As will be seen in later sections, we probably will have to do something on these lines – not to produce paper, but for energy farms.

Why not used waste straw, and other fiber waste - rather than cultivating crops on purpose for paper production? There are two reasons. One is that straw is a great building material. As previously pointed out it makes a board superior to particle board, and it can be directly used in home construction. Paper is rather a waste for it - especially since kenaf makes a much higher quality paper than straw. Most fiber waste is high in silica - making it more difficult to recycle than paper pulp. Kenaf in contrast is low silica, but has sturdier fiber that can be recycled more often. Kenaf is actually more recyclable than wood pulp as a paper ingredient. And the silica in straw is a plus for building applications - strawboard and such. Incidentally there are similar reasons for not using hemp for paper. The extremely high quality fiber in hemp is more difficult to process than kenaf into paper, and has more important uses. Hemp bast can replace a great deal of cotton; hemp hurd can produce a plaster substitute for building facings.

Now obviously we should not be wedded to agricultural fibers for paper. If the timber industry wants to propose a wood pulp source that has even less environmental impact than kenaf - more power to their elbows. But that certainly does not include anything they are doing now.

Kenaf based paper currently costs about double that of wood pulp based. Even if that remains the price, with a 75% reduction in use at a cost of "better than free" we would end up spending a lower portion of our GDP on paper than we do now. Thomas A. Rymsza, the founder and President of Vision Paper (a kenaf based paper manufacturer) claims that if can get the capital to open a pulp mill suitable to processing kenaf, the cost will be 20% lower than conventional paper[111]. Of course Rymsza is a successful entrepreneur, and therefore an optimist by definition. The case he makes is plausible, but that is part of the definition too.

Raising and harvesting fiber is only one part of the impact paper has. Just as, or probably far more, important is the conversion of fiber to pulp and pulp to paper.

Probably the single most significant part of the process in terms of environmental impact is manufacturing. A dedicated kenaf mill would provide a bit of a head start in this respect. It would use 15% less water, 25% less energy, and be totally chlorine and sulfur free. But the best of breed commercially successful pulping mills can do much better. According to the World Watch institute, the most efficient technology produces 80% less effluent than the least efficient[112]. In the same report, one mill using 100% recycled input managed to produce zero effluent of any type, and use 98% of the fiber input. They also noted that mills using the environmentally soundest technology tend to be the most profitable - since they make more efficient use of labor, and also depreciate their equipment more slowly. Not exposing your equipment to highly volatile toxins lengthens its lifespan - something it also does for the plant's workers, and the local community.

The European Commission's Integrated Pollution Prevention and Control produced an extremely detailed report on this in December of 2002[113].

Techniques recommended in this document include:

1) better training of workers, and better maintenance of equipment,
2) large enough equipment and buffer areas to minimize spills, and to capture them when they occur,
3) mills that use trees as input should debark them by dry methods to avoid wet processing of bark
4) Where bleach process are used, delignification before bleaching by extended or modified cooking and additional oxygenation, followed by chlorine free bleaching or elemental chlorine free bleaching
5) Highly efficient closed cycle brown stock for Kraft and Sulphite mills.
6) Effective spill monitoring and containment.
7) Closed water cycles where possible, water reuse, and recycling where not.
8) Counter current washing (water from cleanest process used as wash water for the next cleanest, and so on).
9) Separation of various water cycles to avoid contaminating one another.
10) Primary and biological treatment of wastewater, sometimes followed by flocculation or chemical treatment, and sometimes followed by recycling of treated wastewater.
11) Efficient processes for mechanical mills that spot potential rejects before processing
12) Avoidance of production of excessive emissions to air through precise monitoring, temperature oxygen and chemical controls,
13) Filtering, scrubbing, recovery, and in some cases incineration of noxious gases.

The next major impact is end of life. Currently around half of all paper in the U.S. is collected for recovery[114]. The Germans manage to collect around 70%[115] of their consumption for the same purpose. There is no reason the U.S. should not match that. Given reduced paper use, and thus easier management of paper burdens, we should be able to exceed it and reach an 80% or better collection rate. Also, with the use of kenaf, the longer fibers may be recycled more times than wood. So we get a higher percent of usable fiber from recycling kenaf than we do with recycling paper based pulp. The two combined mean we can reduce end of life impact by around three times. And, of course, increased recycling reduces the amount of kenaf we have to grow, and makes it slightly easier to run lower impact mills. But note that of all the steps we as a society can take to reduce paper impact, recycling (though significant) is the **least** important.

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So what are we looking at in total impact? We can reduce paper consumption by around 75%, lowering impact by about 68%. We can reduce the impact of growing the remainder by about 80%, and manufacturing it by a similar amount. Growing and harvesting fiber for paper, and manufacturing it are overwhelmingly where paper impact lies. At the end of life, through increased recycling, and the ability to recycle fibers more times, we can reduce end-of-life impact by around another two to three times. This totals better than 80% - a factor five reduction+[i] - at rough estimate leading to a 60% or better reduction in energy use for paper manufacturing.

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[i] Let us underestimate growing, harvesting fiber and manufacturing paper as jointly accounting for half of paper's impact. Use reduction saves ~75% of paper use (though only ~69% of impact). So if we were able

Bed of Roses: Material Intensity in Furniture

Furniture also consumes significant quantities of material, whose impact we may lower drastically. One example is office chairs, where "...visible and structural elements are made separately. Foot, leg mechanism, and seat are optimized for comfort ergonomics, robustness durability and easy repair. Cushions and covers and cloth changeable - both money and ecological costs are minor compared to the main parts of the chair - still dematerialized and recyclable -an 80%-95% reduction in materials[116]."

Eames, and Le Corbusier designed chairs on long these lines. Sedus, Wilkhahn and Grammer have actually added such lines to their collections. Similarly, the Chaos/GEA solid wood shelves are designed to combine minimal construction material use with a long lifespan[117]. And of course some of the same means that save materials in buildings can save them in furniture. Strawboard panel can substitute for particle board, fiber and composite boards, and even extremely low grades of plywood. Bamboo and Rattan frames can substitute for wood and metal. Hemp can substitute for plastic mixtures in furniture coverings. So we end up with a factor five reduction just from making longer lifespan furniture from lower impact material (and in many cases less material). This is another example of a 60% reduction in energy use before we increase efficiency in a single manufacturing plant.

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to eliminate 100% of remaining paper consumption at zero cost or environmental impact that would still leave ~6% of intensity that could not be eliminated. That leaves ~25% of paper whose manufacturing we can impact, with maximum arithmetically possible savings of 19%.

We can eliminate 80% growing, harvesting and manufacturing impacts of production of this remaining ~25%, and reduce end-of-life impact by 2/3rds. Since end-of-life is where the least savings are possible, we will be conservative and assume it represents half of total environmental costs. So, by these conservative and in fact extremely pessimistic assumptions:

Net Paper Reduction	74.8%
Net Reduction in Intensity	68.6%
Intensity that cannot be eliminate, due to environmental costs of use reduction	6.2%
Maximum Arithmetically possible remaining reduction	19.1%
Allocate 50/50 between growth/harvest/manufacture and end-of-life	50.0%
savings in growth, harvest and manufacturing	80.0%
savings in end of life	66.7%
net savings growth, harvest and manufacturing	7.6%
net savings end of life	6.4%
net savings in paper cycle (as opposed to use reduction)	14.0%
Intensity reduction from use reduction and savings in paper cycle combined	82.6%

Dress You Up in My Love: Material Intensity in Fibers

This leads to the question of fibers in general. We have already documented that waste straw, used in quantities that do not compromise soil fertility or structure, can supply 100% of low-grade manufactured board needs - particle board, and such. Straw obviously won't work for fabrics - for clothing, furniture covers, and many industrial uses.

One critical trick in textiles in general is the same as the one we discussed in furniture - make the lifespan longer, so we get more year of use out of whatever inputs go into making them. A fabric example we have already discussed is Interface carpets which reduced material intensity by 90%+[46]. Because much clothing tends to go out of fashion before its current lifespan is exhausted, clothing is an especially good example. There are natural fabric fashion lines based upon classic lines and color schemes to stay in style longer - Natura Linea for example[117]. (Think of little black dresses, classic cut suits, or jeans, and t-shirts.)

In clothing at least, the single biggest consumer of resource in fabrics is the cleaning[118]. (This probably applies to towels, and sheets too - not so much to other fabrics which are cleaned less often and less intensively.)

There are two technologies (really three) that might greatly reduce the intensity of laundering - if properly combined. Today you can find at least two brands of "soap free" clothes washers on the market[119]. Daewoo manufactures the Midas, which combines ozonation with a small amount of catalyst to wash clothes without need for detergent. Sanyo does not require the catalyst, but boosts ozonation with ultrasound instead. Both work extremely well at sterilizing the clothes and water. Neither actually cleans all that well. In fact the Sanyo recommends soapless washing only for marginally soiled loads, and detergent and warm water for heavily soiled loads. However, for light loads where detergent and stain remover is not used, output from the Sanyo is free enough of both microorganism and toxics that waste water from it could safely be used to water a garden. (This would be illegal almost everywhere in the U.S. - but it would be safe, and you might be able to obtain permission in some areas.)

Now there is another technology out there - resin cleaners. A team of designers has developed the EcoSafe washing machine[120]. One small resin tablet will clean clothes thoroughly, without soap for about 50 loads. There is some sort of enzymatic action; demonstration models get clothes as clean (in fact significantly cleaner) than detergent - and sweet smelling too. There is so little resin released in a single load that no rinse cycle is needed. And, from a cleaning point of view, there is no reason ever to use warm or hot waters. Cold works just fine on everything. So if you take a normal front loading water saving washer, run it only on cold water, and eliminate the rinse cycle you have maximized both water and energy savings. And the water you do use comes out less polluted because of the not needing to use soap.

So, unlike ozone ions, why has this not been commercialized? Resin, from all accounts, does a marvelous cleaning job - but has no sterilization or antiseptic properties at all. Normal detergent does a fair job at sterilizing clothes, especially when hot water is used. Commercial detergent free washers are far superior at sterilization, even though actual cleaning power is not great. No manufacturer wants the liability of selling a washing machine that has fewer anti-bacterial properties than a normal washing machine. Sure, you can use hot water to make up for some of it - but then you lose many of the advantages of the detergent free model.

Of course the solution is obvious. Combine the resin washer with ozonation or ultrasound or both. Then you have cleaning and sterilization properties combined. You never have to use detergent or hot water. You can use normal water saving technologies (make the machine front loading etc) and eliminate the rinse cycle, except for loads requiring stain treatment. Most energy in washers is used to heat water - so eliminating the need to ever use anything but cold water takes already energy savings washers and saves even more. The elimination of most rinse cycles saves a good bit of the remaining energy and water, and will combine well with normal conservation practices. In terms of water, you not only decrease use, but decrease pollution of water that is used – reducing total impact by a great deal more than normal water saving washers. Energy use is cut 80% or more. Water use is probably not lowered quite by that, but water impact by a great deal more than 80%. Because of resin and stain removal, not quite something to use on your garden, but nonetheless 99%+ less polluted than output from a normal wash load.

So we can reduce the environmental impact of laundering fabrics by 80% or more. Can we do something similar with dry cleaning? Greenpeace favors two technologies[121] that can save 80% or more of the impact over conventional perc based methods. Some dry cleaners have begun to use wet cleaning techniques first imported from Germany in 1991, that get clothes as clean, wrinkle free, and do as little damage as dry cleanings[122]. Others use carbon dioxide based cleaning that save water, energy and avoid toxic chemicals[123]. Other alternative dry cleaning methods, though better than PERC, are not so highly recommended.

Outside of clothing, sheets, towels, and other such items than need weekly cleaning, maintenance is probably not quite so large a part of environmental impact. In such items though, sturdier and easier to clean textiles will reduce such costs. We will return to this in a bit.

For most non-clothing textiles, the manufacturing process is probably the single greatest part of the environmental impact. Textile manufacturing is by nature an extremely dirty process. The steps vary from textile to textile but include texturizing human-made fibers or preparing and spinning natural fibers. They including warping, bleaching, weaving, scouring, more preparation, dyeing (and/or printing), finishing, cutting, sewing. Just about every step involves washing and rinsing. You need chemicals to help the fabric survive mechanical and thermal processes, to add special properties to the fabric, to speed up the absorption of other chemicals, to counteract the effects of other chemicals, to help clean out other chemicals. Huge amounts of water are used throughout. Large amounts of energy are used to heat that water to the proper temperature for various chemical processes. This is historically part of textiles - not merely of the modern industry. Look at the ancient Roman dyeing industry, or how leather was traditionally tanned, or how wool was traditionally cleaned and treated. The material intensity of fiber manufacturing is another area with tremendous economically feasible potential for reduction - conservatively 80%.

Shell can make Polytrimethylene terephthalate (PTT) cost comparable to PET polyester fabrics[124] PTT, unlike normal polyesters can absorb dye without carriers at temperatures as low 100 degrees centigrade.
Use wool, cotton, flax, hemp, and other natural fabrics raised without pesticides. None end in processing baths.
Standard setting for purchases[125], to avoid processing unacceptable material, reducing reworks, seconds, and discards.
Testing/pre-screening raw materials[126]
Implement simple operations and housekeeping improvements. Spills and wastage from poor housekeeping can be responsible for between 10% and 50% of a mill's total effluent load[127]
Schedule dyeing to minimize cleaning. Dye each color separately; or schedule similar colors together, dying lighter to darker colors, and brighter to duller chromas. (The first is occasionally practical, the second fairly frequently.)
Automatic stops on washing processes to stop when the processes they are rinsing or washing do. Install valves and spill prevention devices to prevent overflows.
Replace toxic chemical processes with thermal or mechanical processes, and less toxic chemicals. For example, J.P. Stevens substituted ultraviolet light for chemical biocides in air washers and cooling towers[128].
Dutch General Assessment Methodology in Netherlands (RIZA-concept) SCORE-System in Denmark, BEWAG-concept in Switzerland, and TEGEWA system in Germany.

Examples of substitution include hydrogen peroxide in desizing starch, copper free dyes, high temperature reactive dyes that can be loaded at same time as dispersive dyes - normally applied in a separate stage[129]. (This saves time, water and energy by eliminating a stage, and also eliminates the caustic bath dispersives normally require.) Use surfactants biodegradable, or bioeliminable in wastewater treatment instead of alkylphenol ethoxylates such as alcohol ethoxylates[130]. Bathless air jets can avoid or minimize the use of anti-foaming agents; to the extent they still must be used there are alternatives to conventional mineral oil based agents[131].

Avoid pre-treatment and dyeing complexing agents by softening water to remove iron cations.

Use dry processes to remove iron from fabrics.

Remove iron inside fabrics by non-hazardous reactive agents.

Minimize use of sizing agents by prewetting yarn. (There is still a net reduction in water use, because of reduction in washing requirements[131:253].)

Compact cotton spinning can cut sizing chemicals by half, completely eliminateing paraffin, and greatly reduce water use[131:254].

Ultra-low chrome wool dyeing via stoichiometrical and substoichiometrical dosage. (Stoichiometical dyeing means dyeing until all molecules in the wool that can react with the chrome have been exhausted, lowering the chrome residue. Substoichchiometical dosage means stopping before all sites on the wool are exhausted - using up even more of the chrome.

Urea in reactive dye printing paste may be eliminated, or in the worst case reduced by 73%, by foaming or spraying fabric to be printed with a trivial a mount of water. [Trivial compared to water contamination ended by elimination or reduction in urea.] Foaming works in every case - spraying for all except silk or viscose fabrics[131:357].

There are techniques to reduce printing paste volumes[131:362], and simple methods of recovering printing paste[131:364], of which between half and 75% can normally be reused.

Use a lower ratio of water to fabric (thus lowering the energy needed to move and heat the water, and the amount of chemicals in the water). For example, the Lumberton, North Carolina plant of Almanac Knits lowered the water ratio of jet dyeing machines - reducing dye chemical use by 60% to 70%[132].

Similarly, pad batch dyeing can drastically reduce chemical use for certain fabrics (mainly cotton, rayon and other natural fabrics - even then depending largely on the finish desired). In it fabric impregnated with water and dyes mixed, the excess squeezed out by mangles. It is rolled or boxed, and covered with plastic film and kept until dye is absorbed - then machine washed. It can eliminate salt and many specialty chemicals, and reduce water use by an average of 90%[133] Where it can be used it also saves energy, production time, and labor. Like many environmentally sound techniques it pays for itself in labor savings and quality improvements, with environmental gains being essentially "free".

Automated dosing systems can deliver chemicals in the right amounts at the right time. They reduce chemical and water use, make result more reproducible[134] (This is an important benefit in the textile industry - allowing delivery of exactly the results the customer ordered.) It also reduces process time (improving productivity) and reduces reworks and redoes. Bloomsburg Mills introduced automating dosing in its dyeing process, and saved 28% of water use as a side effect. In the best such systems for normal commercial use, "dosing and monitoring equipment meter exact amount of chemicals and auxiliaries ,which are delivered to machines and vessels without human intervention in exact right amounts. Wash water for vessels and supply pipes taken into consideration in preparation and dosing. Chemicals are delivered in separate streams so that no premixing takes place before delivery."[135] So cleaning is required only after completion of the final step.

Another alternative is single rope dyeing machines. According to the European Commission[136]: (note: paraphrased for brevity rather than quoted exactly)

> *Only one fabric rope passes through all flow groups and components return to the first compartment after each lap is completed. High uniformity results, because fabric passes through all nozzles and troughs at each lap. Speeds, nozzle flows and operating conditions don't vary in different compartments – conditions remain homogenous throughout. Baths reach uniformity more quickly when conditions change; this provides faster chemical injection, and steeper temperature gradient without damage to fiber. The numbers of laps, rather than hold times, are the means of measuring process. (Exception - fixatives still time dependent - but all other chemical applications as well as mechanical and temperature dependent one may be measured in laps.) This gives very high repeatability. Time saving devices are also incorporated - power filling and draining, full volume heated tank, advance rinsing programs etc. can obtain constant liquor ratio with 60% of nominal capacity.*

We already gave examples of possible savings in conventional printing, in the lists of chemical reduction. Much greater reductions are possible in extremely high volume printing (such as carpets). Digital printing can provide very exact, very precise results - with dyes shot directly into the carpet. 80% of water, and similar savings in dyes are made[137] There are tremendous labor savings - carpet is printed in a direct WYSIWYG process from design. Patterns are stored electronically. Samples are minimized or (occasionally) eliminated. These are very capital intensive machines, and only pay for themselves in extremely high volume processes. But where they pay, they really pay. It is rather a step function; it does not come close to paying or you have really big savings - not much in between.

At the other end of the spectrum, extremely low volume textile printing may be done via inkjet. You gain similar savings to any other digital printing. But because speed is low it only pays for extremely short runs - 100 meters or fewer[138].

The greatest use of water in textile processing is in various rinsing and washing stages. One simple housekeeping step is to ensure rinsing and washing processes are turned off when the process they are rinsing and washing does. (It is usually worth putting in automated stops to ensure this.) Minimize wet cleaning through means like scraping machinery before wet cleaning it.

One way to greatly reduce this is via countercurrent washing. The least dirty water from the final states in used for the next to the last stage, and so forth - until the first state where water is discharged or processed. Savings vary, but typically, in a two stage process, wash water use is cut in half; in a five stage process water use is reduced by 80%[139].

Savings almost as great can be obtained by optimizing and combining processes. One manufacturer reduced chemical use by a minimum of 20% by extending the time fabrics were dyed by 15 minutes. Some of the worst pollutants were reduced by 60% and 98%[140]. (Similarly several stages may be combined - for example de-sizing, scouring and bleaching.)

Lastly you can recycle and reuse water; most common is the reuse of dyebaths - which can be analyzed, replenished and reused[141] Amital reduced water use by two thirds via dye bath and cooling water reuse[142] . Similar savings have been reported from rinse water reuse. In addition to the counterflow washing already mentioned, there are also continuous horizontal washers - where water is sprayed on top of fabric as it travels upwards on the machine. Similarly, for bleaching there are continuous knit bleach ranges that use built in counterflow and controlled dosing to reduce water, chemical and energy consumption. The water from rinsing cleaning belts also tends not to be extremely dirty and may be used for many purposes[143].

In total every stage of textile processing there are multiple means that can reduce water and chemical consumption by between half and 90% each. While some of these are mutually exclusive, the vast majority can be simultaneously applied. There are additional multiple steps each one of which may save 10% to 33% of water chemicals, and other steps that can reduce or eliminate a specific chemical or series of chemicals. Again most of these are not mutually exclusive. It would not be unreasonable to conclude that total water and chemical use in textile processing may be reduced by 90% from the average. (Because of the combination of multiple steps that are cumulative). It would be conservative to conclude that this can be done by well over 80%.

Lastly there is the question of natural fibers. Of all the natural fibers, cotton is the most intensive - using more water, pesticides, eroding more soil, and covering more land per unit of production than any other natural fiber source; it is worse than many plastic fibers as well[47]. Hemp requires about the same water and fertilizer per acre to grow as cotton, but produces about two to three times the bast fiber per acre[144]. Hemp seed oil is a superior substitute for cotton seed oil, containing much healthier fats. As a byproduct of processing the oil out of hemp seed, you end up with high protein meal, superior nutritionally to soy meal and useful for almost every purpose soy meal has. (You don't end up with as much of it per acre as soy; it remains a byproduct, not the main crop.) It is easier than cotton to grow without pesticides or herbicides, and where they have to be used requires less. It requires significantly more processing than cotton, but also produces huge amounts of hurd which have their own uses. So the net environmental impact of hemp per unit of output remains about one half to one third that of cotton, perhaps less depending upon how one weighs the high protein meal, and the higher quality oils.

Hemp can substitute for cotton in many applications. For example Levi's original blue jeans were made from hemp, and you can substitute hemp 100% for cotton in all denim applications, as well as in most furniture fabric. Even in applications where you need to use cotton, you can substitute hemp for a percentage of fabric - producing a more robust shrink resistant fabric. (Recently some hemp clothing manufactures have been eliminating cotton mixtures from their lines. New air finishing processes apparently make the hemp soft enough to make cotton an unneeded addition.) In clothing applications we can substitute hemp for 100% of about half the uses, and around 50% for the other half. In non-clothing applications, there is no reason not to substitute hemp 100% for cotton. So we can substitute hemp of 75% or more of cotton use. The cost will be about twice that of cotton, but hemp fabrics also last longer than cotton fabrics, and require less care. For bed sheets, and rugs, and furniture covers and most non-clothing textile uses, this would more than make up for the difference.

For clothing, advanced cottonization that makes 100% hemp as comfortable as cotton increases energy and water consumption at any rate. As pointed out in the section on agriculture, mixing hemp 50/50 with organic cotton is ecologically sounder in these cases. In the case of clothing, increased physical lifespan may or may not translate into longer actual lifespan, depending on how successful designers are in developing lines that don’t go out of style. Regardless, lower production impact remains significant.

Another alternative that produces extremely soft strong fiber is bamboo – which requires even less land than hemp, though comparable water per unit of output.

Natural fibers are only one part of textile manufacturing. Polyester, nylon, and other synthetics play a substantial role - and in the U.S. constitute the overwhelming majority of fabric. Hemp may reverse this to a modest degree. It is sturdier than cotton, more durable, more water resistant, tends to shrink less. But it has no stretch, and is exceeded in water resistance, and dry strength by a number of synthetics. As previously pointed out, there are lower impact synthetic fibers such as PPT that can substitute for higher impact one.

So between better processes, longer lifespans and lower impact materials we can reduce the impact of fibers by three quarters – resulting very roughly in a 50% reduction in energy use.

Big Wheels Keep On Turning: Material Intensity in Transportation

Transportation infrastructure manufacture also uses tremendous amounts of industrial energy. Cars, trains, buses, planes, ships, boats, roads, parking areas, rail stations, bus stations, switching stations, ports, harbors, airports, and so on all require energy to make.

We will start with the automobile, which is the single largest energy and infrastructure consumer within transportation. Although people who really love automobiles will still be free to own them, we are talking about drastically reducing their use and ownership. So let's make this clear that we won't be asking for any sacrifice.

Automobile owners can be divided into two classes. For one group, either a small majority or a large minority, automobile ownership is a practical matter - the fastest, most flexible and most reliable way to get the work on time, the most convenient way to go shopping. Offer this group an alternative that is just as practical - that does not involve the inconveniences, delays, and inflexibility of most existing bus and train systems, that is not only cheaper but more convenient than cars, with the same freedom, and they will gladly use it.

For a second group, cars are not just a mode of transportation; cars are a thing of beauty, something to love. However, very few people love driving on the Santa Monica Freeway at rush hour. Only very unusual individuals enjoy crawling along at four miles an hour surrounded by incipient cases of road rage. Most car lovers prefer to drive when not too many others are on the road, or at least in traffic that actually moves. Given the chance, most dedicated car lovers would probably save their driving for occasions when it actually is a pleasure, and use a decent transit system to avoid roads that have been transformed into giant parking lots

Before continuing, let's emphasize we are not talking about eliminating all individual car ownership. As a practical matter there are alternatives that make sense for cities and suburbs. For truly rural areas, individually owned cars will remain the most practical and environmentally sound alternative. And, as we pointed out, there are people with emotional attachments to their cars that go beyond pure pragmatism. There is no reason they shouldn't own cars if they wish to.

So what is this alternative that is more convenient than individual ownership? It is a combination of an automated ultra-light rail and car sharing. Let's take them one at a time.

CyberTran[145] light rail uses small cars carrying 20 passengers. (The same sized cars could actually be configured to carry anywhere from 6 to 30 passenger.) Small light cars run on cheaper tracks. The total capital cost of a CyberTran urban system (including rail and guideways) is about a tenth or less of the per cost per passenger mile of conventional light rail[146]. CyberTran is an automated driverless system; so while fixed routes would be used during rush hour, (a series of CT cars following one another would mimic a conventional multi-car train) at all other times it would be an on demand system. Regardless, you would never have to wait more than five minutes or so for a car - usually less. In-system transfers should take even less time, because when you bought a ticket, the system would know you needed to transfer and when. And because of the high degree of computerization (each car would have an on-board computer, plus the system would have a bank of central computers as well) routing would be optimized. Transfers would be avoided when possible; when transfers were needed the routes would still be direct enough you would never go around Robin Hood's barn to get to your destination.

Given the small numbers of passengers per car (and the fact that stops would be made at offline sidings, without blocking the main track) travel would also be optimized to minimize the number of stops a given car made. That is passengers would be sorted onto cars by destination. During off-peak hours this would result in virtual expresses with few stops between a passenger and her destination. Rush hour might or might not allow this; but at minimum the number of stops made would be reduced; you would never have to stop at every, or almost every, station.

And there will be a lot of stations available. Stops are offline from main guideways - one CyberTran car stopping does not delay others. CyberTran stations can be as frequent as bus stops. Because of automation you can afford more surplus cars, since unused capacity is parked, not rolling, not consuming labor or energy. And you can also afford not to have to fill the cars. So in most cases you will have a stop within easy walking distance of both ends of your journey. In addition, even major stops don't have to be major multi-acre lots like the BART Park n' Rides in San Francisco; Park n' Rides can consist of many small parking lots; not giant branches of the night auto supply. If you live in a nightmarish suburban development, with acre after acre of housing and no shops or suitable areas for a transit stop within walking distance, you will still find a (comparatively) small, pleasant CyberTran stop with parking a short drive from your home.

Also CyberTran is not designed for people to stand in the aisles. The cost, as mentioned, is about 10% that of conventional rails and most of that is in guideways, not the cars. So it won't need to be overloaded during peak hours to pay for off-peak travel. You are guaranteed a seat. You only stand if you want to stretch your legs - an option you don't have while driving an auto.

To summarize: you have 24 hour availability; journey time is about the same as a car; your railcar is ready when you are; you always have a seat; stops are nearby; and you can read the paper on your commute.

You have the comfort of a car, probably more - and unlike buses every car is fully wheelchair and disabled accessible; there is plenty of room for luggage - more carry-on baggage space than pre-deregulation planes. (And, depending on local policy, they may easily be designed to accommodate baby carriages and bicycles as well.)

CyberTran is safer than auto travel, with a lower probability of accidents, better crash resistance, and built-in airbags.

CyberTran is better than normal transit both in terms of protection from crime and protection from harassment. Unlike normal transit, it provides a low penalty in convenience for following human instinct in choosing transit companion. A CyberTran car is divided into compartments of between two and five seats each. So upon entering you can avoid compartments with anyone you feel uncomfortable with, or wait a few minutes and order a new train if the whole car feels wrong.

In addition there are special security features; every seat has a phone that connects directly to security. and there are pull cords like old trolleys have that automatically overrides all programming and pulls to nearest secure destination, notifying security. Since you can tell which cord was pulled; and there are not many passengers to a compartment, identifying anyone responsible for "prank" stops or false alarms should be possible in almost all cases.

The question arises as to how to put CyberTran (or other new generation of transit) in place. An obvious place to start is with the fact that U.S. city and commuter buses get fewer passenger miles per gallon than cars or even light trucks/ SUVs[147]. Vehicles burn a lot more fuel stopping and starting than traveling. A bus has to deal with normal stop and go traffic and all the stops to pick up and drop off passengers besides. If they were fully loaded all the time, that might make up for it. But according to DOT in the source just mentioned, even with standing room only during peak periods, city and commuter buses on average carry only nine passengers. Buses do reduce congestion, but not by much; one bus replaces many cars that would otherwise be on the road; but buses turning and changing lanes in city traffic and especially buses at stops cause congestion as well.

Most city and commuter buses are miserable to ride. Bus trips take longer than car trips to the same destination; further, trip time can be unpredictable. Passengers breathe fumes, often have to stand, and depending on the route may suffer harassment while traveling. Buses also perform an essential function. In the U.S., city and commuter buses are the only means by which poor people or people who can't drive for any reason can get around inexpensively. (Very few U.S. cities are exceptions to this.)

To replace this with a form of transit that is less expensive, more convenient and more comfortable would be a kindness to city and commuter bus riders, and to the cars that currently share the streets with them. Replace the busiest most crowded bus routes with CyberTran first, then the next, and so on until you replace all routes with three or more runs daily. Put a transit stop at every former bus stop on these routes. The bus riders will be much better off; and the streets will be less crowded and congested.

Ridership won't be limited to former bus riders. A lot of people will decide it is better to read a paper or nap on new generation transit than spend the same or more time stuck in traffic in a commute. Many will decide it is better not to fight traffic and parking when visiting friends and relations, or eating (and especially drinking) out. Given accommodations for luggage and packages, some may even use it for shopping.

And that will lead to demand for transit on other routes. Transit routes will become selling points in real estate. Developers will build along them, and demand them near existing tracts. In short you will get the same kind of feedback cycle that currently leads to more auto use. CyberTran runs about 30 cents per passenger mile (cheaper than auto transportation) in a system with ten thousand users or over - something achievable in fairly low-density areas. (In other words if 25,000 people live within ten miles of you (taking all directions into consideration) your area could support a CyberTran system. In short, it is practical wherever population density (living and working combined) exceeds 81 people per square mile – something that is true for most of the population of the U.S.)

So how much infrastructure are we saving? For the same passenger capacity, a CyberTran consumes about less than a fifth of a land a comparable highway needs[148], and thus probably the same in concrete and steel. When stations, maintenance outbuildings, electric power generation and administrative buildings are considered compared to parking, garages, gas stations, and auto repair required for cars trucks and buses, this land difference probably is greater. Because it rest more lightly on the land (it is always elevated by at least a foot, and is quite literally lighter) CyberTran disrupts the land much less during construction. Most of the time leveling and grading can be eliminated entirely, and always greatly reduced. Further true elevation is comparatively inexpensive - thus allowing CyberTran tracks to raised above existing roads, parking lots and building, on highway or freeway medians. Because CyberTran can handle steeper grades than conventional rail, it can sometimes climb mountains and hills rather than tunneling through them. So overall it is reasonable to assume that fixed infrastructure impact is about a tenth that required for automobiles, light trucks and buses.

As extra-long electric cars, leaving their motors behind, CyberTran train cars will take less energy to build than three single family SUVs (which they are equivalent to in both length and passenger capacity). But they will be shared by about ten times the number of people. Overall they have about 1/42nd as large a rolling infrastructure as automobiles or buses per passenger mile[149].

While super-light rails is not quite door to door, there is no reason everyone in an area super-light rail serves can't have a stop within a few short blocks of their home - anywhere a bus stop could go. Unlike conventional light rail, super-light rail does not require high-density development. Although it will fit quite nicely into new urbanism, or even old urbanism, it also will work well in suburbs.

But there are times when a car will still be more convenient; two examples that spring to mind are transporting heavy or bulky items, and trips to rural areas. Instead of owning cars, people may subscribe to a commercial service that stores cars near where they live. This way they can rent the car just when they need it - without having to pay insurance, storage, maintenance and all the costs of owning a car full time while using it part time. Car sharing services already exist worldwide. There are even a number that have sprung up in parts of the U.S. Zipcar may be found in Boston, New York, New Jersey, Washington D.C. and Chapel Hill[150]. FlexCar may be found in greater San Francisco, Los Angeles, San Diego, Denver, Chicago, greater Washington D.C., Portland Oregon, Seattle and other smaller cities.[151]. Car sharing companies often inflate estimates as to how much car ownership is reduced. But the European commission financed a study that measured actual reduction in ownership and usage with such a service in Bremen[152]. They estimate that their 100 car fleet, reduced ownership for 2,200 participants by 500 to 700 cars. So each car in the shared fleet replaced five to seven individual cars. Further it is worth noting that while Europe has first rate transit - far superior to any public transit in the USA - nobody anywhere has anything like CyberTran. A 24 hour automated demand driven transit system without a significant wait time day or night – even outside urban areas - would be something new.

The combination of such a transit system with a shared car system should make car ownership truly optional for many people - where people outside of rural areas own cars only because they like them, not out of practical necessity. If people really had this choice - where car ownership was truly optional, not an economic necessity, how much would it reduce car ownership in the U.S.?

There is an example that provides a good indication. Manhattan in New York City combines the best public transit system in the U.S., with what is probably some of the worst traffic and parking. There is very little practical incentive to own a car in Manhattan. I'm sure there are exceptions, people who really need cars. But overall, I would say that the rate of car ownership in Manhattan is an example of truly voluntary driving - reflecting the number of people who buy automobiles because they enjoy and appreciate them. According to the New York Metropolitan Transportation Council (NYMTC) survey conducted in 1997 and 1998, the average number of vehicles per Manhattan household was .38 - in other words slightly more than one car per three households[153]. This compares to the USA average of 1.7 vehicles per household in 1995, and 1.9 vehicles per household in 2001[154].

So total car ownership in areas with a combination of decent public transport and some form of car sharing can be reduced by between a factor of 4.5 and a factor of 5. The public transportation this requires (as opposed to existing systems) is equivalent to about 1/20th of the impact of the remaining cars displaced, and the impact of shared cars is equivalent to another fifth to seventh. Infrastructure (vehicles, tracks, roads, parking, stations and so forth may be reduced to about 3/10ths of normal U.S. use. When the 3% or so of the USA population who live in areas that will not support automated super-light rail are included, this is almost exactly a two/thirds reduction - so a reduction by factor three.

We will actually get more than this; road-size requirements drop disproportionately as traffic loads fall. Look at it in reverse. Put one car on a road - no congestion. Add a second - both can continue at the same speed as the first. Keep this up until you reach the maximum number of cars that will fit without slowing traffic. At this point, tautologically, traffic will slow when you add one more car, and again you can add more cars without slowing things until you reach another saturation point where adding one more car will slow you further. Traffic congestion builds in a series of jumps like that. (Mathematically it is known as a step function, because a graph of this would look like a crude drawing of a staircase.) This is why school holidays, which remove only a small percent of drivers from the roads, will often drastically reduce congestion.

Reducing the number of cars on the road by two thirds (along with almost all of the buses) could be expected to reduce congestion by many more than three such steps. So while routine maintenance will not be lowered by a factor of three or four, the need for new roads, new lanes, widening projects and just about every type of improvement will be reduced by much more than a factor of four. Parking follows similar patterns, and so the need for new parking lots and parking improvements will be similarly whittled down.

Net, including those areas where we cannot reduce infrastructure significantly, we can still reduce the impact of transportation construction and maintenance by about 70%.

The following table summarizes potential improvements in efficiency for selected types of transportation:[155]

Transport Type	Percent Operating Energy*	Factor Reduction in Infrastructure	% Remaining	Explanation
Automobiles	33.87%	4.5	7.53%	CyberTran + car sharing with some individual ownership remaing
light trucks	24.70%	4.5	5.49%	“”
Motorcycle	0.09%		0.09%	no change
transit buses	0.34%	20	0.02%	Replacement infrastructure already included in autos/light trucks
school buses	0.29%	0	0.29%	no change
Intercity buses (already efficient[156])	0.12%		0.12%	no change
Medium/Heavy trucks require ~26 times the infrastructure per ton-mile of heavy rail to move freight[157; 158; 159; 160].	17.92%	6	2.99%	Rail displacing a large portion + less freight shipped (more rail infrastructure, more track, more switch yards, more freight yards, more locomotives fewer trucking subsidies, more rail ones.)
(Light trucks would be displaced to some extent by EV trucks that can run in automated mode on CyberTran rails, then shift to driver controlled for final few miles to destination; thus the battery only needs to hold a five or ten mile charge.)				

Construction vehicles	1.63%	4	0.41%	Less building infrastructure
Agricultural vehicles	2.22%	4	0.55%	No-till drastically reduces
general aviation	0.61%		0.61%	no change
International aviation	1.31%		1.31%	no change
Domestic aviation – videoconferencing[161], high speed CyberTran replaces domestic flights under 500 miles,	7.03%	4	1.76%	65% of U.S. flights are 500 miles or fewer[162]. Air infrastructure is consumed by plane slots, not miles. So not unreasonable that videoconferencing plus CyberTran can replace 75% of domestic air infrastructure
Water transportation	4.29%		4.29%	no change
fuel pipelines	3.30%	4	0.82%	Less fuel used
existing rail	2.28%		2.28%	no change :additional included in auto
Total	**100.00%**		**28.56**	
Savings			**71.44%**	

* Percentages based upon BTU figures in TED table, rather than percents listed in table - which contain rounding errors.

Note that where other figures are not available, the above assumes infrastructure is required in a rough approximate ratio to operating energy. Operating energy use is not always a proxy for lifecycle energy use, and lifecycle energy use is not always a proxy for total environmental impact. But at this extremely macro level, given the quality of information we have, it is as close as it is possible to get. And when you look at what we are doing, switching from automobiles, light and heavy trucks, buses, and domestic flights under 500 miles to rail, making more efficient use of materials so that less is shipped, a 70% per capita reduction in transportation infrastructure really is not an unreasonable estimate.

Clean Sweep: Reducing Material Intensity by Lowering Pollution

We have covered enough types of consumer goods to know we can spot ways to reduce material intensity by close to factor four just through analysis by end use classification. In some areas we can reduce by much more than factor four, in some a great deal less. It is close enough that we cannot be sure they balance out. But there is one other step; so far we have examined reduced pollution just as we examined reduced industrial energy use – as a side effect of overall reductions in material intensity.

Pollution reduction, though, is desirable for its own sake. Particulate emissions from power plants kill 30,000 people in the U.S. every year[163]. Non-particulate emissions from power plants and other sources, toxic wastes, water pollution and other pollution sources may kill a great many more than this. And as with other material intensity reductions, pollution reduction reduces energy consumption as a by-product. Not every pollution reduction technique does this of course. Some means of filtering air and water emissions decrease energy efficiency – as do lower temperature combustion processes to reduce NOx production. But overall a broad program of pollution reduction reduces energy use.

For example, a great deal of toxic waste is generated simply by leaks and spills of expensive useful chemicals. Reducing such leaks, and reducing or recovering the spills saves those same substances for input into processes and finished goods; this usually saves money over older more wasteful industrial processes, and saves the energy that would have been used to manufacture replace chemicals for what was spilled. Similarly, recovering used chemicals for reuse accomplishes the same thing. Reducing water pollution often involves decreasing total use of water, lowers the amount of energy required to heat and pump that water. Reducing air pollution often involves burning waste gas, and using the heat generated for industrial processes. A small net energy saving is pretty clear. (By some measures it provides a large one; but that is because increasing energy efficiency is one way to lower pollution. Since the bulk of this study is devoted to detailing means of increasing energy efficiency, to include this would be double counting with a vengeance. Leaving direct energy savings aside, considering pollution reduction to provide a small net energy savings is more reasonable.)

There are a great many low tech, low cost methods that produce savings. One of the first is bureaucracy - horrible old fashioned red tape. Yes, excessive un-needed bureaucracy has a well-earned reputation for preventing work; but bureaucracy, in the right place, is also a way of getting things done. Think of the flight list pilots have to go over before takeoff. A paper checklist increases the odds they will perform the proper procedure each time – without failures of human or electronic memory causing them to skip a step. There a lot of points in industrial operation where the same principles apply. A far from exhaustive list:

- Documenting startup and shutdown procedures; doing either improperly may lead to anything from a major accident to a minor wastage of material
- Documenting operational procedures; most industries have turnover; it is fairly common in industries that don't document procedures properly to run into things like failing to turn off the water when a rinsing procedure is complete.

- Documenting emergency procedures; it may seem silly to keep a manual of what to do in an emergency; but if the person who knows what to do is not immediately available you may find the manual faster than you find the person. And if the person who knows leaves, having procedures documented increases the odds that the next person to do the job will be trained properly.
- Documenting inventory on hand someplace outside the physical location; helpful to firefighters and emergency crews in the event of an accident.
- Documenting all spills and accidents – helpful in managing sites post-shutdown.

Red tape, every bit of that list; but which item would want an oil refinery or chemical factory in your neighborhood to omit? And while the emergency documentation is usually required by law, the operational documentation, lack of which is most likely to lead to accidents, is often omitted.

Returning to the "pilot's list" analogy for the moment, this entire section on pollution prevention is an example of that principle. Most individual paragraphs in it are something common sense might suggest; but as you go through paragraph after paragraph think – if you were doing pollution prevention for a particular plant, would you remember or think of **every single one of these** that are applicable? And this is by no means a pollution prevention manual or text book. Serious reference works, which I will cite at the end, generally run hundreds of pages.

Depending on circumstances there are other bureaucratic processes that can help prevent problems and lead to improvements:

- Regular reviews with major customers and suppliers of the way your processes and theirs interact. You never know when a change can lead to a product supplied to you becoming less suitable, or a product you supply being less suitable for a customer. Reworks, regardless of who pays, are a major cause of wasted material. And even if someone else pays for a problem, it is likely to come back to bite you in a future transactions. This does not just help head off problems; it can help spot opportunities too. Sometimes win-win changes can be made lowering costs or increasing quality for both parties.
- Regular reviews of standard literature to spot new processes and technologies that might lead to improvements. Most companies have informal networks - company geeks or proactive managers that keep an eye out. But – especially in larger organizations- you need a formal process or easy opportunities get missed. That is one of things bureaucracy was invented for – to allow large organizations to overcome the inertia that would otherwise stop them from doing some of the same things small groups do naturally. Why not just have small groups? Because there is stuff only large groups can do. No, turning large organizations into networks of small ones does not solve that particular problem; whether a large group is structured like a pyramid or like a web you still have cracks important things can fall into; no matter how irritating it is you need formal procedures to minimize this.

- Extending the last two a bit, regular reviews of policy from the ground up – rather than just looking at incremental changes, and taking all existing procedures for granted, occasional examination of everything from top to bottom to see if some of the routine has become obsolete, or was never the optimum approach in the first place.
- Formal training; default job training in the U.S. is often “throw her in the water, and see if she swims”. Or the previous job holder’s can spend her last day showing the new woman the ropes. This can lead to routine operating information not being conveyed properly. Almost never does it teach exception handling, shutdowns and startups, or dealing with emergency situations. You also need a clear chain of responsibility set up.
- During design phases – either of new plants or major modifications, relative risk assessment can help minimize pollution and wastages both. For a given pollutant – say sulfur or dioxin – assess what source in your plant is the greatest contributor, which is the second and so on; rank them. Now you can prioritize, find where you will get the greatest reduction for a given investment. Even if you are completely eliminating a pollutant, identifying this lets you get rid of it faster.

Similarly routine maintenance can reduce waste tremendously. For example, simply inspecting pipes and ducts regularly for leaks, and fixing them quickly can save a great deal. Inspecting and (in the case of chemicals) occasionally testing raw materials and other inputs before they come in the door can save wasted material and wasted time.

Housekeeping is even more interesting, because – though the term is used metaphorically – much of what it covers is literal. For example, dusting more frequently can prevent filters from plugging so quickly, and save both material and filters - nothing metaphorical about that use of the term “housekeeping”. Or the point that in automated cleaning processes, you can start with dry processes (essentially wiping with a cloth) before moving on to wet cleaning. This can not only save on water; the chemicals absorbed by the cloth (being more concentrated) may be recovered from the cloth if of sufficient value to do so. [Note again that these are automated processes, not somebody manually wiping a vat with rags.] Further, the cleaning step can go more quickly, allowing the next stage to start sooner, and increasing labor productivity as well. There is also the point that supplies for dealing with spills should be stored where they are likely to occur, comparable to keeping cleaning supplies in the kitchen and bathroom.

There are other related points which, while a metaphorical use of the term, still obviously would have been instituted when processes were first designed if the designers had thought like someone who did housework. For example, an important principle of design is to build vessels for liquids bigger than the minimum required to hold them - making them less likely to overflow. Anyone who cooks regularly knows a too small pot is more likely to make a mess. Similarly there is the principle of “bunds” storing dangerous or valuable material in containers held in other containers – so that if there is a leak or spill, you can catch the overflow; the same principle you use when place a coffee or tea cup on a saucer, a bowl of cereal on a plate, or use a coaster for a beer can.

Someone knowledgeable in feminist theory could do some very interesting analysis of all this. Part of it is that probably most of those who helped design industrial processes have never done significant amounts of housework. However it is unlikely that every single designer was without experience in basic household chores. Just as important may be the fact that housework has mostly been gendered, designated as women's work and disrespected. So even if an industrial designer knew housekeeping principles, most likely until recently she would not have thought of applying them in designing chemical plants, steel mills, oil refineries and such. [In the past ten years, paying proper attention to housekeeping has become conventional wisdom – though audits of actual practice usually turn up major opportunities for improvement. It is known in principle, but just barely beginning to be implemented.]

Beyond maintenance and housekeeping, come other fairly simple universal things.

Gas emergency pressure relief valves should consist of multiple valves to deal with different levels of emergency releases with treatment equipment just like routine operating valves. In some plants half of air and water pollution is from "emergencies".
Alarm systems to detect spills and leaks, warn of changes in pressure or chemical composition well short of emergencies. Regular inspection to detect ground contamination – since this is almost impossible to detect via automatic systems.
Sequence to minimize startups & shutdowns. Also, similar processes should follow one another.
Pipes should be ground level for easy maintenance & inspection.
Short in-campus, roads, conveyer belts, pipes and corridors and transport. Continuous transport such as conveyer belts and pipes than road, or steam shovel or crane or pallet. Similarly, covered transport is generally better than open transport (as covered storage is better than open storage).
Integrating processes is preferable to separating them. For example a pulp mill and the paper mills it feeds will operate more efficiently together than apart – more opportunity to reuse waste products, including waste heat. In general there are very few diseconomies of scale in pollution prevention. When it comes to minimizing emissions per output produced, big is beautiful.
Circumstances alter cases; these are all general rules, with plenty of exceptions where particulars make them the worst rather than best choice. To avoid repetition, please assume this entry appears on every list, and at the end of every paragraph on pollution prevention.

Water pollution:

Dry methods to replace water, or as "pre-cleaner" to reduce water use.
Pigging (pipelines). Solid object driven through a pipe, like a bullet passing through the barrel of a gun. (In some cases a gel rather than a solid is used.) This greatly reduces water use and pollution in many cases; it can also provide superior results to wet methods, sometimes save labor costs, and save on cleaning solutions too. The latter three benefits usually provide a much higher economic payback than the first.
Picking the optimal choice between baths and sprays where wet methods are unavoidable. Water sprays can often replace all or some bath steps, and save chemicals as well as water.
Cool via heat exchangers rather than pumps or sprays.
Shape vessels so as to have as little waste space as possible – while still leaving extra room at the top to minimize spills and overflows. (Since the point of oversizing is not to fill them all the way up, this will not waste water.)
Automatic overflow detection and shutoff valves.
high concentrations of chemicals in less water, rather than higher volumes of water with lower concentrations. Water management is easier; if chemicals are worth recovering, recovery is more likely to be economically feasible.
The more precise control over chemical dosing the better.
shorten drying times -- wringers, air jets and squeezing, etc.
Segregation of types of waste water – rain water runoff, biological treatable streams, heavy metals and other toxic or recalcitrant steams.
Near-site storage to hold results of accidents, and firefighting waters; and act as a buffer – so that irregularly produced waste can be treated steadily – without requiring treatment capabilities matching peak emissions.
Countercurrrent washing, where water from the cleanest process is used in the next cleanest.
To generalize the above, reusing, recirculating and recycling water – where costs (such as reverse osmosis filters) don't exceed benefits.
In larger scale plants, water should be treated on site; this allows specialized treatment directed towards the particular pollutants generated, and avoids forcing a general purpose plant to deal with them.
Biological treatment as one step can usually reduce emissions a great deal. (Heavy metals, and any type of pollutant that would reduce biological activity has to be dealt with prior to the biological step of course – one reason for segregation of waste streams.)
Catalytic hydrogenation can often replace catalytic reduction in industrial processes. This avoids water emissions from reduction agents.

Note that while there are energy consuming aspects to water pollution prevention techniques, they overwhelming lean towards aspects with energy saving side effects. With air pollution prevention, the energy consumption and savings aspects are much more evenly balanced – again because we are excluding techniques such as combined heat and power which aim primarily at saving energy.

Air pollution control techniques:

Double sealing where practical to minimize leaks
Flammable gas concentration below LEL (Lowest Explosive Level)
Filter out dust and large particles first, and then treat gaseous contaminants, followed by any further steps needed. Gas emissions usually need to be treated in multiple steps.
Material recovery is preferable, if practical; if not, in many cases, both waste gas and dust may be burned - providing energy, and also producing a less toxic emission that is cheaper to treat.
In many cases water based processes can be the most effective means of treating waste gas; this has to be weighed against additional water consumption and water pollution.
Even when the waste gases themselves are not sufficient fuel to support combustion, incineration of waste gases and dusk particles can be the most effective means of disposal. In this case incineration is obviously energy consuming, not energy saving.
When non-auto-thermal (i.e. energy consuming) incineration is needed, catalytic incineration rather than thermal incineration may often be used. This saves energy and the lower temperatures produce less NOx as well.
Flaring should only be used to dispose of emergency releases; and even this can minimized as noted above by having multiple pressure release valves, with normal treatments applied in smaller emergencies.
Select fuel and raw material to minimize emissions - low sulfur fuel or low voc raw materials, for example
When dealing with highly toxic or highly corrosive material follow the KISS (Keep It Simple Stupid) principle. More complexity means more to go wrong.
Prereactors and preheating of input can often shorten total process time, energy use, and air emissions.
In some cases dampening small particle material will not affect its usefulness, but will reduce dust.
Optimize pressures, temperatures and ingredient ratios. In some cases it is amazing how far from optimal a process can drift and still work; fixing or at least improving this is usually very cheap with a very short payback.
Often polluted water is a source of fume emissions; water recovery and recirculation can sometimes reduce air as well as water pollution.
Gas phase balancing between vessels containing compatible substances, so that if one empties the other fills.
Where practical, storing gases at slightly below atmospheric pressure to minimize leaks,
Leak minimization - examples: where practical, replacement of flanges by welds, the use of seal-less pumps and bellow pumps; effective gaskets or flanges, valves and pumps with high integrity packaging.
Dust from dust producing processes should be minimized by enclosures(covering conveyor belts etc.).

For more specifics on such techniques, one of the world's best resources has been put together by the EU's International Pollution Prevention and Control department. This is an attempt to put together a compilation of best available techniques for pollution control for every major industrial pollution source in Europe. Environmental representatives of every government in the EU were involved in putting these together as were representatives from every industry. Just as when using CIA documents, or UN documents or U.S. State department documents, one should be aware of biases – but that does not prevent them from being useful.

In spite of the fact that it is probably contrary to the intentions of the technical people working on them – these reference works are likely to be used to reduce environmental protection in Europe. Since each document states that it is simply a technical reference, without legal force, this is not obvious in reading them. But the legal structure of the EU makes this likely for the following reasons:

1) Each document tries to determine which techniques are cost effective. In some cases, standards that have been enforced successfully in the most environmentally aware nations are considered not to be cost effective – either by consensus or by a split decision. In the latter case, the advocates for the more stringent position are usually in a minority.
2) In the case of court cases alleging trade barriers, the EU judges tend to be more concerned with trade than environmental protection; in addition they have very few restrictions on what evidence they can use to judge by. So they are very likely to turn to these reference documents, and consider any standards beyond the majority opinion in them unfair or discriminatory trade barriers if applied to foreigners doing business in these nations.
3) If an EU constitution ever passes, and a European parliament starts passing enforceable environmental laws, these documents are likely to serve as the technical basis either for the laws themselves or for regulation created within these laws.

Likely future misuse of these documents does not prevent them from being superb technical references. While you may or may not agree with their decisions as to what constitutes Best Available Techniques, the detailed sections preceding them – consisting of techniques to consider in choosing Best Available Techniques – usually will tell you everything you are likely to wish to know about available options. Brief sections on emerging technology following the BAT sections are sometimes excellent as well. A list of the most helpful BAT sources is included in the endnotes[164].

One point not emphasized in the EU documents is "green" production of plastics by making them from biological rather than petroleum sources. It is fairly well known we can produce plastic from recent biological sources (soybeans, cotton waste and such) rather than fossil biological ones. How much environmental impact can we save by doing this? In some cases we can obtain a factor four or five reduction - in many as little as a 20% savings. And, we must be careful, because in some contexts biological sourced plastics have a higher environmental impact than petroleum based ones. An excellent over view may be found in the LCA chapter of Volume 10 of the Encyclopedia of Biopolymers[165].

We already looked at substituting waste straw, hemp and kenaf for wood as a fiber source, with an increase in agricultural land use of 11 million acres (though saving a great deal more than this is forest use). To produce today's consumption of plastics from agriculture sources as well would add another 17 million acres to this[166]. Given longer lasting consumer goods, more thrifty use of materials in manufacturing and increased recycling, it is reasonable to assume a factor four reduction in the use of plastics. So that would result in the use of four and quarter million acres. But we have to allow for population growth. That makes a total of about 6.4 million acres through 2050.

An economy that reduced material throughput per unit of economic growth by four times from the present, we could produce all our fiber and plastic needs on 17.4 million additional acres – out of 57 million acres that have been presently taken out of production by set-aside programs. Given no till farming for row crops, and intensely managed rotational grazing for meat production we ought to be able to achieve up to a 20% increase in total food production we will need with the use of no additional land – possibly needing to reduce meat production by a very small percent. This also returns to a point I made towards the beginning of this chapter. We do not face a crisis in agricultural production or even in land available for agricultural production – provided we stop paving over farmland and putting farmers out of work. We need to produce our food and fiber via more sustainable techniques. Such techniques are available, and sufficient for the land currently in production, plus a very tiny portion of the set asides. But such techniques will not be sufficient if we continue to lose land to urbanization, erosion, and farmers being put out of business by unstable and absurdly low crop prices. Every bit as urgent as other sustainability issues is the preservation of farmland, and the preservation of small farmers to keep them operating on land large agribusiness won't touch.

Every Story Has an End: Recycling

We've looked at end user goods and some of the intermediate processes in making them – including end of life recycling in specific cases. Before we sum up, we need to deal with one thing that is getting a great deal of emphasis – the "cradle to cradle" concept. As we saw in Interface carpets, building goods that last a long time, and then can be recycled back into themselves at the end of life is very important. On occasion, so-called "down cycling" can be just as important. For example old newspapers can be made into more old newspapers or into insulation. Newspaper to newspaper is true cradle to cradle, a discarded good being recycled back into itself. But it also takes a lot of energy and water to recycle a newspaper back itself. Water and energy used in de-inking can approach[i] that of making a newspaper from virgin pulp. On the other had old newspapers can also be made into insulation. Some people disapprove of this on the grounds that this uses up the best long fibers most suitable for reuse in newspaper manufacture. But long newspaper fibers can still be recycled only a limited number of times. Fibers recycled into newspapers could in theory be used up within days, certainly in practice within weeks or a few months at most. Cellulose insulation, on the other hand, lasts up to fifty years – and saves energy every day of those fifty years. This is a lot more productive use for those long fibers.

Some people have made a whole principle of this – turning the waste from one industry into the raw material of another. In one preliminary study done in the greater Durham, North Carolina research triangle area, nearly half of the sites investigated had potential local partners to provide raw materials or to consume waste as raw material[167]. About half of those actually set up relationships. There was also a famous spontaneous "industrial ecology" that arose in Kalundborg[168], Denmark as a simple economy measure.

So long as its value is not overstated, this makes sense. We do need to "close the loop" so that a great deal less of material extracted is discarded than now. But, as in the case of newspaper recycling, it is no cure-all. Recycling – whether via reuse, "cradle to cradle" or industrial ecology will not by itself result in anything like a factor four reduction, let alone a factor ten or twenty savings. But combined with all the other principles it can be the final step to lead to a factor four reduction in material intensity.

[i] Some source claim recycling newspaper into newspaper requires more energy and water than using virgin fibers. I suspect that depends on the recycling process used.

That is – provide consumer goods and services that last longer, that are easier to repair, substituting material and processes with lower ecological footprints for material and processes with larger ones to provide the same consumer services. Then do the same thing at the factory level – use less ecologically intensive goods and processes to produce the longer lasting consumer goods that provide consumer service through less intensive materials and processes. Reduce pollution from such production. And then recycle the greatly reduced waste from this. You can see that a factor four reduction is fairly straightforward technically and economically –even at current market prices, though not so easy to achieve politically. A great many things (such as buildings) can be provided at a factor five reduction even at the end user level alone. Some, such as transportation, don't quite reach that great a level, probably end user goods and services average out to factor four or close to it. When you add in the much more modest (but still significant) reductions possible via pollution prevention, and savings from recycling, you definitely end up with over a factor four reduction.

Does it pass the sanity test that this results in cutting industrial energy consumption by a bit more than half? We increase lifespans, reduce intensity of materials that constitute those goods, and the intensity of processes used to manufacture them; it makes sense that we would end up reducing energy use by a little over half as a byproduct - before we save a single quad of industrial energy through conventional energy efficiency techniques.

"Let's make it, don't waste it": Direct Energy Savings in Industry

Let's turn from simple material intensity reduction to energy processes once materials use has been reduced to a minimum.

Process heat and industrial boilers consume the vast majority of manufacturing energy[169]. We may save most of this.

	% Savings	% Net Saving	% Consumption Remaining
Refactories[170];[171];[172] 15% insulation, additional percent from smaller, lightweight refactories that hold less heat	20.0%	20.00%	80.00%
System Operation, Maintenance and Distribution[173]	35.0% of 80%	28.00%	52.00%
Boilers[174];[175];[176]	6.5% of 52%	3.38%	48.62%
Total		**51.38%**	**48.62%**

So we can conservatively save more than 51% of industrial process heat compared to current per capita consumption - if we include all means available at a market price around that of oil. So when we eventually replace industrial boilers (as we must at some time) increasing process heat efficiency will pay for itself not just in energy savings but in smaller boilers, and lowered replacement capital cost. Beyond this, when reduced maintenance costs are considered it may pay even at market prices to replace inefficient boilers process heat systems before their useful life ends.

Electric motor systems account for 23 percent of all electricity consumed in the United States, around 70 percent of manufacturing sector electricity consumption[177]; motor systems account for slightly below 14% of total U.S. industrial energy[169].

According to Lovins & Hawkins[178]: "*...At least a fifth of their total output, is pumping...In industrial pumping, most of the motor's energy is actually spent in fighting against friction. But friction can be ... nearly eliminated at a profit by looking beyond the individual pump to the whole pumping system of which it is a part*."

Big pipes and small pumps use a great deal less energy than large pumps and small pipes. A fifty percent fatter pipe reduces friction by 86%. In addition, extra bends put into most piping systems multiply friction by three to five times[178]. Designers normally ignore this because the cost of additional piping would exceed the value of energy savings. But the savings in energy, plus the capital savings through buying smaller pumps do in fact lower costs as a whole.

The savings from fatter, better arranged pipes and smaller pumps should reduce pumping energy use by over 80% of pumping energy used[179]. One example is a factory carpet maker *Interface* built in Shanghai. A top western specialist specified 95 horsepower pumps; fatter, better laid out pipes reduced this to 7 horsepower - a 92% savings.[178]

After material savings, and after various types of throughput savings, half of motor energy could be saved in the motors themselves. In electric motors this can be achieved by more efficient variable speed motors sized right for the job, with the right mechanical and electrical interfaces to what is driven[180]. Because these new motors not only cut energy, but maintenance costs, they will pay for themselves quickly. (The more efficient motors run cooler and slower. Heat and motor speed both contribute to shorter motor life.) (Note: similar savings are possible with stationary heat driven motors as well - with similar paybacks.)

Between cutting energy use for motors in half, and cutting energy use for pumping by 80% or better, it seem we can end up with a 55% savings or better in total motor usage.

Facility heating, ventilation, lighting, air conditions and other facility support represents about 8.7% of industrial energy[169]. These are the same processes we will consider in commercial buildings; we will document 70% average savings in commercial buildings; because of that, we estimate comparable potential in industrial facilities.

Uses classified as “other” and “unreported” represent about 3.4% of industrial consumption[169]. It will not be unreasonable to assume this reflects industrial energy use as a whole, and that similar savings may be found.

On-site electricity generation represents 2.3% of industrial energy use, which will be discussed under co-generation, not here.

Electrochemical processes represent about 2.1% of industrial energy[169]. Since these are already pretty efficient, most of the savings here will come from savings in material use – which we have already counted.

Process cooling, and refrigeration represents less than 2% of industrial energy[169]. Refrigeration and cooling is mostly done by heat pumps; inefficiencies call attention to themselves. Most process cooling uses at least some insulation - though probably not to optimum levels. Because it takes place in confined spaces, there is probably less avoidable loss due to friction, though there may be some. On other hand, no great attempt has been made to substitute the most efficient motors; so there is the same opportunity here as with any other motor driven process of cutting energy use in half. Thus reducing process cooling use by a bit more than half is a reasonable estimate.

On site transportation represents about 0.6%[169]. We don't bother to model any saving here.

So, adding up all direct industrial savings:

	Btu	% before savings	%After savings
Indirect End Use (Boiler Fuel)	3,635	31.81%	15.59%
Process Heating	4,055	35.48%	17.39%
Process Cooling and Refrigeration	210	1.84%	0.92%
Machine Drive	1,691	14.80%	8.14%
Electrochemical Processes	298	2.61%	2.61%
Other Process Uses	69	0.60%	0.29%
Facility Heating, Ventilation, and Air Conditioning	692	6.05%	1.82%
Facility Lighting	211	1.85%	0.56%
Other Facility Support	96	0.84%	0.25%
Onsite Transportation	69	0.60%	0.60%
Conventional Electricity Generation	243	2.13%	2.13%
Other Non-Process Use	3	0.03%	0.01%
End Use Not Reported	157	1.37%	0.66%
Total	**11,429**	**100%**	**~51%**

After first having saved a bit more than half industrial energy use via reductions in material intensity, we can save nearly another half via conventional energy savings – reducing total industrial energy use by ~75% per capita.

This also means that half the savings is essentially free, paid for by material savings and pollution reduction. The other half still is done with very short payback periods – so that we are saving energy at about 25% to 30% of the cost buying fossil fuels. So if you include the 25% of fuel we have to continue to buy, plus the saving of the other 75% at a 30% of the cost of buying it, we come down to being able to buy renewable energy for industrial use at a 110% premium (2.1 times current costs) and still break even.

As a sanity check, we will note the European Union lists a potential 40% overall savings in industrial energy from a very small selection of older technologies[181] - not including significant reductions in material intensity. Given that the EU tends to use energy much more efficiently than the U.S. already[182], this easily translates into a 50%+ savings for the U.S.

This section so far has focused on a very top down approach. That is, it has looked at very general categories, and very broad studies. So let us examine some specific examples – many of them funded by the U.S. DOE. Most are around 50%, some a bit less others a great deal more.

Example	% Saving
TurboFlo blancher by Key development uses steam convection, better insulation and better recovery valves to cut energy use in half, and water use by bit more [183].	50%+
Henningsen Cold Storage Company's refrigeration facility in Gresham, Oregon more than doubled the insulation used in normal facilities, used a thermal siphon oil cooling system, installed oversized evaporators and condensers driven by high efficiency motors with variable frequency drives. It installed quick closing doors, and dimmable lights to minimize heat gain, and sophisticated controls[184].	58%
American Water Heater Company cut the number of compressors it needed to run simultaneously by about half in its air compressor plant, and reduced cooling energy demand as well. It fixed leaks, stored air so as not to have produce it at wildly fluctuating pressures, locating compressors and end user of compressed air closer to one another, located the compressors in a single room, cleaning and dehumidifying the air to be compressed adequately, and adding a closed loop cooling system.[185] (12% increase in production, 22% drop in complaints)	~50%
The DOE developed weld computer resistance welder[186] which reduces energy used for resistance welding by precise measurement and control of electric current. This reduces the number of rejected welds and eliminates the need for destructive weld testing, saving money, materials, and energy. It performs real-time diagnostics during each weld, precisely regulates voltage to ensure a high-quality process, and documents weld integrity.90%-200% gains in productivity due to decreased welding time, 55% reduction in scrap due to increased accuracy	50%+
Normally paint booths have to be ventilated with frequent air changes, with 100% of the input from outside air in order to avoid poisoning the workers applying the paint. This requires a great deal of filtering and treatment to prevent contamination of outside air, and a great deal of heating or cooling to maintain comfort inside the painting booth. And the workers still have to wear uncomfortable protective equipment to avoid poisoning. All the ventilation is simply to reduce contamination to the point where protective equipment is effective. Instead this program developed a Mobile Zone Spray Booth Technology, a small mobile cab workers can paint from inside; it is this cab that is ventilated with outside air. So now the worker is exposed to no VOCs or pollutants, and her health is less threatened without uncomfortable masks and equipment than it was before with it. Only the air inside the small cab needs to be heated or cooled. And the air outside the cab, instead of having to be ventilated constantly, can be recirculated, reducing both costs, and emissions to outside air.[187] (This also cut capital costs and improved productivity)	85%
Irrigation sprinklers normally constantly draw AC power to operate valves and controllers – even though the systems may only run for minutes per day. Batteries avoid this drain, but only last between one and two years, cannot survive complete submersion, and make automated control difficult. Alex-Tronix Controls[188] combines a DC Solenoid that saves 60% of energy compared to an AC system with a battery control technology that extends battery life to ten years, and a sealed protection that allows the system to operated under water and be remotely controlled without opening the box. So now such controllers can be battery operated, saving energy during the short operation period, and 100% otherwise (most of the time). Copper wiring for landscape and irrigation systems tends to be a significant enough expense that reducing this saves money and energy as well.	99%
ENS development of a fan that reduces evaporator and compressor energy consumption in medium temperature walk-in refrigerators[189]. Sensor detects when refrigerant not flowing through evaporator and drops voltage, saving energy need to run evaporator fans, and reducing waste heat from un-need running of evaporator fans, which would otherwise need added cooling.	30%-50%
Merrill Air Engineers has developed a new superheated steam process that saves much of the energy used for drying of molded pulp products, and allows recovery of waste heat from the process[190].	50% saved, + up to 40% recovered
Bonal Technologies developed a harmonic resonance method of using vibrations to treat metal against temperature drop stress instead of high temperature heat[191]. Superior or equal results to heat treatment in 80% to 90% of applications.	98%
Jay Harmon's use of the principle of the logarithmic spiral to make propellers, impellers and fans more efficient[192]. Cumulative with other technology. Not yet commercially available.	40%

So we can show a variety of specific examples of efficiency improvements. We included some significantly below the 50% we wish to achieve, and a number that greatly exceed it.

Love the Way You Move: Energy Savings in Transportation

Moving people on the ground is the single greatest use of transportation energy.

Most passenger trips in the U.S. are made by automobile. People looking for a chance to bash ordinary Americans often sneer at the "American love affair with the automobile". I have to admit there is an element of that; automobiles do have attractiveness beyond their functionality. But in point of fact there are plenty of rational reasons Americans prefer cars to other forms of passenger transport in most cases.

An overwhelming one is that journeying by transit often takes longer. For example, work travel using public transportation takes about twice as long as private transportation though there is only a slight difference in travel distance[193].

There are comfort issues as well. Due to load management requirements the odds are you will have to stand part of the way if traveling during rush hour. There is always the chance of harassment or criminal victimization. Incidentally, most transit buses (as opposed to long distance coach buses) get **fewer** passenger miles per gallon than most automobiles[147].

We have already discussed a transit system that does not have these problems - which offers the convenience and comfort of automobiles at a reasonable cost – CyberTran which would attract a lot of the passenger miles currently spent in automobiles. Cars would still have advantages for physically heavy shopping, for work requiring significant equipment, and for certain types of recreation - among others. 75% of passenger miles traveled by auto in the U.S. are NOT subject to this limitation[194]. Allowing for a certain amount of pure automobile love, it would not be unreasonable to guess that a superior passenger transit system could attract 70% of the miles now traveled by automobile, light truck, van or SUV. Many of the remaining miles could be part of car sharing or other rental arrangements.

A reminder: the small light Cybertan cars run on cheaper tracks, keeping the total capital cost of an CyberTran urban (or suburban) system (including elevated rail and guideways) at about a tenth or less of the per seat cost of conventional light rail. The same light cars also mean energy costs per passenger mile are better than conventional light rail as well.

CyberTran is a computer automated driverless system; routes are calculated on the fly, meaning that passengers that will travel with either no or very few stops between their departure and destination, and that transfers will be uncommon, and without long waits or missed connections. Passengers will not need to wait more than five minutes for a car, which will be available 24 hours per day, seven days a week. Seating is guaranteed; passengers never need to stand. CyberTran may easily be made bicycle, wheelchair, baby stroller, and package friendly.

Given the combination of greater convenience to attract more passengers, and on the fly optimization of routes it would not be unreasonable to assume that CyberTran cars in operation will use a higher percent of their capacity than buses, maintaining an average of four passengers per vehicle.

CyberTran cars consume about .106 kWh per passenger mile[195]. If that electricity comes from hydropower, wind or other non-combustion sources (with a 20% loss to allow for increased line losses), this is the equivalent of 330 passenger miles per gallon. Cars and personal trucks combined averaged around 32 passenger miles per gallon in 2000[147]. CyberTran would transport passengers around 10 times more efficiently than automobiles.

The way to implement CyberTran would be to begin replacing bus routes where it would provide cheaper, faster, more comfortable more convenient and more energy efficient transport for bus riders – then lure auto riders into the now far superior mass transit system.

One thing that may ultimately help CyberTran succeed is its resemblance to a giant penis. Probably, painting it any type of flesh tone would be too obvious. But surely a marketing person could do something with the fact CyberTran is bigger than a car, but can tirelessly keep thrusting forward much longer.

Superior transit could replace all regular route city and suburban buses and about 70% of automobile mileage. The other 30% won't go away; there are all the functions mentioned at the beginning of this article that transit won't work well for. There are people in rural areas where demand is too scattered to support even the far less expensive transit CyberTran represents. And there are people who simply will prefer cars to trains.

There are two solutions for them.

A four passenger electric sedan (running at the equivalent of above 200 mpg if the electricity had come from wind, water or other non-combustion sources with a 20% transmission loss) was demonstrated in 1997 that had a range of 210 miles at normal highway speeds before needing recharging and could have retailed for as little as $20,000[196]. That is a lot of money; but it was also at the mid, rather than high end for a new car –even in 1997. There are people for whom that mile range would not be enough; but there are also plenty who would never drive more than 210 miles in a single day, not even on vacation. Note that that battery lifespan and cost are not an obstacle to this in mass production[197].

What about people who need greater range – whether in an occasional rental or for their daily driving needs? There is a solution for that too - the Hypercar[198].

As with green buildings, this is a case where whole system thinking is the key - where doing several things at once works better than doing any one of them singly.

Hybrid autos gain efficiency three places.

First, a gasoline-powered generator produces electricity that in turn drives the car motor. This is more efficient than burning gasoline to drive motor directly. Heat converts into electricity more efficiently than high torque mechanical power if weight must be kept low. Electricity, in turn converts, into high torque mechanical power with almost no loss.

Second, manufacturers have made slight weight reductions.

Third, some use regenerative braking to recover mechanical energy lost in stopping and slowing.

Hybrid engines alone only increase performance by 30% on average. But, the combination of all these factors has been known to double mileage for some models.

There have also been prototypes of ultra-light cars - using carbon fiber/fiberglass composites to produce bodies much lighter than normal cars, with the same or better strength.

These are much, much more expensive than conventional autos and get double or triple the mileage.

But if you combine the two technologies various synergies occur.

With the lighter weight the hybrid engine and batteries can be smaller and lighter - decreasing weight much more than the simple substitution of carbon and silicon for steel would suggest. The regenerative breaking gains much more stopping power - so much more that manual brakes feel like, and are as responsive as power brakes, so power brakes are not needed. Similarly manual steering is as responsive as power steering.

This increases mileage to the point that the gas tank size can be reduced, decreasing weight more. Using electric axle motors eliminates the need for a transmission and a lot of other standard auto parts.

At this point something interesting happens to cost. Even though carbon fiber is about 1000 times as expensive per pound as steel, you are using a lot fewer pounds. And much of cost of steel parts is shaping the steel; with carbon fiber/fiberglass composites, parts are extruded pre-shaped. The car uses ten to twenty composite parts vs. hundreds of steel parts. Paint is baked in, so the painting step that can represent as much as 15% of the manufacturing cost of a car is eliminated.

As a result, this ultra-light weight, ultra-efficient car costs less to manufacture than a comparable conventional car. Savings in labor, capital equipment, and manufacturing energy more than make up the increased material cost.

You end up with a better car too. Safety in even a small hyper-car far exceeds that of the best SUVs. Carbon fiber (and passengers enclosed by it) will survive collisions a lot better than steel. (This doesn't mean that you can't make a hypercar SUV as well.) A Hypercar can be expected to last much longer than a conventional car. (Carbon fiber lasts longer than steel -even when diluted with fiberglass.) Fewer parts mean that maintenance is simpler - both diagnosis of problems and their repair are easier.

They can have any feature any other car has - air conditioning, power windows, sunroofs or whatever.

No one has actually built one commercially for a number of reasons - including the fact that it would make every existing auto manufacturing plant obsolete, and cannibalize sales of existing models - forcing the write-off of unamortized capital equipment. U.S. auto makers might have done it anyway as a blow against their competition, but the American auto industry does not sacrifice short-term profits to gain market share. The manufacturers of other nations might have considered it. But US free trade principles tend to be for other nations to follow. There are already informal (but enforced) quotas on Japanese automobiles. A foreign manufacture making a radically better car than U.S. manufacturers would face significant risks of exclusion from the U.S. market.

Someone in another industry might have considered it. But there is more to the auto industry than making a good product. You need distributors, suppliers, and a unique type of marketing. So for someone other than an auto company to take this on would require a deep-pocketed risk taker with an appetite for a fight - not the world's most common animal. In short there are plenty of reasons besides practicality for auto makers to resist Hypercars.

Gasoline powered hypercars would use around one third the energy per mile compared to conventional automobiles. Battery powered hypercars would do better; the Solectria Sunrise discussed above was essentially a hypercar EV; the 210 MPG efficiency was better than a hydrogen car driven by fuel cells.

All of these, CyberTran, electric cars and Hypercars will take time to implement. Is there something that may be done immediately? Hybrid cars are growing in sales, and already run to some extent off batteries. Increase that battery capacity, and add a plug so that you can charge them from the grid; the result is PHEV (Plugin Hybrid Electric Vehicle). You can get much of the thermodynamic efficiency improvement you could get with a 100% electric car, and still have the range of gasoline engine. You don't have the improvement you would get with a true Hypercar or electric car, because you don't have the ultra-light weight, the other improvements such as good aerodynamics and low rolling resistance, and you have the mass and complexity of both a larger battery and a fuel tank. But carbon (and other) emissions are half of those generated by a conventional car[199], and they are a minor modification of automobiles on the market now. We could build them now in our current factories. In fact conventional hybrids have been customized into PHEVs[200].

This another way take advantage of batteries that may be superior to a pure electric hypercar - plugin hybrid hypercars. The could give us almost the efficiency of electric cars, all the carbon reductions we need, and the convenience of a conventional range and a 400 mile range with instant refills.

Imagine a hypercar PHEV70 with a seventy mile battery - in the Solectria Sunrise that would have been ten kWh. You have saved 2/3rds of the weight of the batteries, so you can spend them on a tank and engine to drive the electric motors when the battery is discharged the maximum that is safe for it, enough to get about 70 miles. Usually it is considered that 85% of miles driven by Americans are driven on trips of less than 60 miles in a day, so it is safe to assume that a 70 mile range will let at least than much of the mileage be driven by batteries. A hypercar should get 75 miles to the gallon, so a four gallon tank will extend your range to 375 miles, with the ability to refill in any gas station - reasonable even on long trips. If the grid you charge from is mainly wind, water and sun charged , you are getting 200 MPG for 85% of your driving, 75 MPG for 15% and ending up with 181 MPG in energy efficiency (better incidentally that the 5X efficiency Lovin's claims for hydrogen based hypercars). With a low carbon grid, you are getting the same carbon reduction an all gasoline car would get at 300 MPG. But if we can really produce sustainable, carbon neutral biomass, we can do better. Fill that tank up with 85% biofuel and 15% fossil fuel. The lowest energy biofuels have about half the BTU value of gasoline or diesel, so as a worst case scenario we need double our tank size to 8 gallons. But we do have 15% dead dinosaurs in the mix - reduce it back to 6.8 gallons. Also, the lowest energy density biofuels can also generate 30% more power per Btu in than fossil fuels, because they can be burned more completely. So reduce the tank back to under five gallons. We have not increased the auto weight substantially, but if the biofuel came from truly carbon neutral (or carbon negative) biological sources, we have reduced carbon by another ~74% - due to fossil fuel displacement (more for energy denser fuels). Carbon emissions and oil use have been reduced 98% per mile compared to a 25 MPG gasoline car.

There is one last possible efficiency gain in transportation. Assuming that heavy grocery trips would continue to be done by automobile, there is one other already existing technology that could greatly reduce energy for this purpose – internet ordering of groceries to be delivered from local suppliers. A Finnish study showed that if people had refrigerated reception boxes to hold the groceries such deliveries (so they could be delivered with an eight hour window, and stores could optimize their delivery schedules) this would save around 76% of energy use compared to individual trips to the grocery store[201].

Aside from technology, there is a policy that could win us occasional drops in emissions. A percentage of the automobiles on the road are old beater cars, worth from $400-$1,800. They are near or past the end of a conventional automobile lifetime, kept alive as the only transportation alternative for many of the poor. They mostly get very poor mileage, and generate high emissions. Periodically, offer the owners of such cars even trades of them for new or decent used cars with better mileage, lower emissions; most will be glad to accept them. Or, for a lower cost option, Europe has found that a straight buy-out (at a premium) of junk cars a very effective way to increase average mileage, and reduce emissions for the actual on-the-road fleet.

The following table summarizes selected transportation alternatives[155]: (note – percentages calculated from year 2000 table quads)

Transport Mode	**Transport Percent**	**Efficiency Improvements**	**CyberTran**	**Other Electric**	**Fueled**	**Total**
Cars	33.34%	70% of miles CyberTran factor 10 reduction /25% to electric hyper cars factor 5.8 reduction/ 5 % to fueled Hypercars factor 3 reduction	2.33%	1.44%	.56%	4.33%
SUVs & Light Trucks	24.22%	70% of miles CyberTran factor 12 reduction /10% electric SUV factor 7 reduction/20 % to HyperSUVs factor 3 reduction	1.41%	.35%	1.61%	3.37%
Motorcycles	0.10%	Savings unanalyzed, modeled as unchanged			0.10%	0.10%
Transit Buses	0.35%	CyberTran - factor 10	0.04%			0.04%
Inter-City Buses (currently very efficient[202])	0.12%	Hyperbuses 40% reduction			0.07%	0.07%
School Buses	0.29%	No significant change.			.29%	0.29%
Smart Growth (fewer subsidies for sprawl[203]) very long term – can make unknown contribution over next 30 years						
Medium/Heavy Trucks	17.65%	85% to Rail factor 10[204], 15% to Hypertrucks 20% reduction (increased use of rail requires more rail infrastructure, and changes in tax policies that subsidize trucks)			3.62%	3.62%
Construction vehicles	1.40%	20% savings replace standard diesel with hybrid			1.12%	1.12%
Agricultural vehicles	2.05%	20% savings replace standard diesel with hybrid			1.64%	1.64%
Air General Aviation	0.64%	Savings unanalyzed, modeled as unchanged			0.64%	0.64%
Air Domestic Carriers	7.34%	High speed CyberTran replaces short trips (20% of energy use[i]) + videoconferencing replaces 42% of business miles (42%[205] of 26%[206]). For remainder, operational efficiencies such as turning off engines and towing planes to runways, doing air replacement and other power requiring services on the ground, and better optimization of scheduling and traffic control also can save fuel[207]. The planes themselves can be gradually replaced with 20% more efficient models[208]; the combined savings is thus a 29.6% efficiency gain	0.14%	0.04%	2.79%	2.97%
Air International	1.35%	29.6% savings from immediately prior entry.			0.95%	0.95%
Water Freight	4.43%	25 % efficiency gain[209] non-barge traffic – ~50%. (Barges already efficienct[210])			3.88%	3.88%
Water Recreation	1.14%	25% efficiency gain (same as non-barge freight)			0.86%	0.86%
Pipeline	3.33%	75% volume reduction, + 14%[211;212] efficiency gain			0.72%	0.72%
Rail Freight	1.89%	Change unanalyzed			1.89%	1.89%
Rail Transit	0.17%	Unchanged		0.17%		0.17%
Rail Commuter	0.09%	Unchanged		0.09%		0.09%
Rail Intercity	0.07%	Unchanged			0.07%	0.07%
Tonnage Reduction		Rail, Truck, and Water freight ton miles reduced by 40%			-3.54%	-3.54%
Total			**3.92%**	**2.09%**	**17.27%**	**23.28%**

[i] See appendix "How CyberTran May Replace Short Domestic Flights".

We have an 77% per capita reduction in transit energy – at somewhere between no additional costs and a saving - a slightly higher percentage of which is electricity than at present. CyberTran is cheaper than cars, light trucks, SUVS and planes even before energy cost is taken into consideration. Hypercars are about the same cost or a bit cheaper than normal cars – ditto hypertrucks and Hyperbuses. Electric cars, if mass produced, would be comparable in cost to conventional cars, though with a more limited range. Heavy rail freight capital costs and maintenance are lower per ton-mile than roads and trucks, even before energy savings are considered. Telecommuting pays for itself many times over in fuel costs. Improved water shipping efficiency, and more efficient airplanes are pretty much break even propositions when it comes to fuel cost.

Logically it would seem that the substantial capital savings in ground transit, ground freight, short term air flights, and substantial fuel savings from telecommuting substituting for some air travel, will more than make up for the small capital costs of slightly improved shipping and planes. That the 77% per capita transportation energy savings is free, rather than a net capital savings is a highly conservative assumption. The conservative assumption that the 77% savings is free, that the costs of the savings are completely paid for by other capital savings, means we can afford to pay five times the current cost of fossil fuel to run transportation on renewables.

One note on all this: unfortunately one assumption that is normally good falls down badly here - that fossil fuel consumption roughly tracks emissions. Airplanes, sadly, produce warming far out of proportion to their carbon emissions. The problem here is water vapor.

Normally, water vapor causes greenhouse heating only in response to increases in other greenhouse gases. The troposphere (where we live) mostly is saturated with all the water it can hold. Put more water in the air and it will precipitate out within a short time - maybe a great distance from where it was absorbed. However, if we add carbon dioxide equivalents to the air, that heats it just a little. The small temperature rise lets the atmosphere absorb water vapor in greater amounts. In other words, while carbon dioxide forces the temperature up words, water vapor increases temperature as feedback mechanism. The way climate scientists often put this is that "water vapor is a feedback, not a forcing".

The trouble with jet airplanes is that they emit water in the lower stratosphere, not the troposphere. They fly above the clouds, where the air is NOT saturated with water. Water emitted at the level is a forcing, not a feedback. If airplanes were infrequent this would not matter. Water, even at that level, is not a long term feedback. As a one time thing, it would soon mix with the troposphere and precipitate out quickly. Unfortunately, airline schedule are pretty regular from day to day. So jet planes add water to the stratosphere faster than nature regulatory mechanism can keep up with. We won't have a choice but to reducing flying even after all "no regrets" reductions are made. This is not a terrible thing. A luxury configured CyberTran (six people per car - configured with bathrooms, water, drinks and snacks) could get you 3,000 miles in under two days. (It could actually travel that distance in 20 hours, but we are assuming stops for meals , stretch breaks, and an overnight stop for sleeping.) For long journeys like this, if we can get Maglev or other very highs speed electric trains to work, we could end up coming close to airplane speed, and simply eliminate air travel for any trip that does not cross large bodies of water. Ultra high speed trains are not particularly energy efficient. (Maglev is especially egregious due to the embedded energy in Maglev tracks.) But energy efficiency is not (for a change) the point; even if high speed rail consumes more energy than planes, the global warming effect is still lower. And if the electricity for this purpose comes from solar or wind energy than the global warming effect is near zero.

At any rate flying won't have to be zero. We may, due to having delayed so long to tackle a problem that was widely foreseen in the 1970's, have to drastically reduce it for a while. There will be more replacement of international travel with long distance communication. Most long distance travel over land will be by trains. Most long distance travel over water will be by ship. We will find higher speed versions of both trains and ships; but overall long distance travel will be slower. The world won't be quite as small for a while. But in the long run, if we survive otherwise, we will find a solution to this as well.

A Very, Very Fine House: Saving Energy in Residential Buildings

Residential savings may be the best known, and are certainly the most mature renewable energy technologies.

Climate control in new homes can easily be reduced from the average U.S. standard through high levels of insulation without thermal bridges, tight seals, high-quality single pass ventilation, and high efficiency windows. In Germany, Jürgen Schnieders conducted a study of various "Passivhuas" (passive house) buildings[213] in Germany, documenting that on average they saved 90% of heating and cooling costs compared to U.S. averages, while adding about 10% to construction costs. That is easily recovered (with interest) over the course of a 15 year mortgage or by slightly higher rents that will still save tenants money in lower utility bills.

In existing homes we can save less, around 60%, by weather sealing to one air change per hour, insulating attics, floors, and ducting, and installing modest window forms of window insulation – such as window insulation kits, tinting or insulated drapes.

On average in the U.S. a 60% reduction would save about $400 per year[214] . Capital costs for the saving will run between $1,000 and $3,000. So energy savings provide an eight year simple (interest free) payback; add interest to provide a 6.5% real rate of return, and this stretches out to twelve years. You can shave a bit off this by timing such remodeling close to the time you have to replace your furnace, (and air conditioner if you use one). After insulation, you can buy a 30% to 50% smaller furnace[i], at 15% to 20% less -another $200 savings; price differences between larger and smaller air conditioners will result in similar savings.

You can go further, retrofitting anything you would install in a new home, but while it may improve your home air quality, and show social responsibility, it won't pay for itself in money.

This is not just something that can be done; it is something that has been done.

The NAHB Research Center, Inc. did a study for the National Renewable Energy Laboratory documenting a gut rehab that saved over 80% of heating and cooling energy cost effectively[215].

When it comes to new homes, more than 5,000 such homes have been built in the EU - including some in areas of Finland well north of Alaska.

[i]You have to size your furnace for peak not average usage –so can't cut by as much as your total energy savings.

Professor Soontorn Boonyatikarn in hot humid Bangkok, Thailand built a home that uses 1/15th the overall energy of a normal upper middle class Thai home[216]. Its air conditioner is one quarter the tonnage of a normal Bangkok air conditioner for a home this size. This home cost about $124,000 to build, normal for a Thai home of it's size in his neighborhood. Amory Lovins claims that total cooling requirements are about 10% of average[217].

In the same book, Amory and Hunter Lovins and Paul Hawken suggest the headquarters/residence of the organization the Lovins run and live in as an example:

Rocky Mountain Institute headquarters in Colorado is at an elevation of 7,100 feet. It gets as cold as -47 degrees F in this location. Amory Lovins claims they saved 99% of space heating energy, and used 92 percent efficient heat recovering ventilators, and that they saved construction costs over conventional techniques.

We can demonstrate similar savings for domestic water-heating - after climate control the next largest energy consumer in the home - 17.28% of residential use[218], adding $207 per to the average yearly bill[219]. A systems approach to water energy savings will include water savings as well; in 2002, the average annual price of water and other public services was $326[220]. Estimating $25 a month of this as trash removal cost means that water & sewer charges ran about $300 per year. So, combined water, sewage, and water-heating dollars total around $507 annually.

To improve efficiency in both water use and water heating, we might do the following:

Expense Description	*Cost*	*Savings/Comment*
Non-emergency scheduled plumbing labor	$210	Quote from local plumber.
Find & repair all leaks - additional materials	$25	100%
2 bathroom tap aerators to lower flow from 2.6 Gallons per Minute (GPM) to .5 GPM	$7[221]	80% savings over 2.6 GPM average
1 kitchen tap aerator to lower flow from 2.6 GPM kitchen sink to 1.1 GPM	$1.50[222]	~58% savings over 2.6 GPM kitchen sink average
2 Stepflow kick pedal sinks controllers	$270[223]	50% savings
2 Aqua Helix low flow showerhead nozzles to lower shower flow from 2.5 GPM to .5 GPM	$60.00[224]	80% savings
2 Microphor 2 quart (1/2 gallon) compared to 2.6 standard "low flow" toilet in most homes (note: new toilets in U.S. cannot exceed 1.6 gallon flush - but a lot of existing ones are 2.6 and even five gallons - so a 2.6 gallon average is a LOW estimate.)	$1,078[225]	80% savings
Whole house drain heat recovery system - recovers heat from discarded hot water to raise temperature of cold water fed to water heater.	$240[226]	55% energy savings only
Difference between energy efficient dishwasher (ASKO D3350[227])and standard[228] at normal replacement time (ISO certified for 15 year lifespan[229]	$333[230]	45%
Difference between energy efficient washing machine(GWL11[231]) and standard[228] at normal replacement time	$220	78%[232]
Landscape water conservation (drip or micro-sprinkler irrigation system) combined with more efficient landscaping. (Watering at right time, rain gauge to avoid over-watering, building soil to reduce runoff, plants with same water requirements in same place, avoid watering sidewalks, driveway etc.)	$400[233]	50%
SubTotal	**$2,844.50**	

So now we can figure our heat and water savings. Note that while most of the savings apply to a particular appliance or sector of household water/hot water use, the whole house drain heat recovery system apply to all water heating.

How much do these savings total?

Given the distribution of water use, the measures we outlined would reduce hot water consumption[234] (and therefore hot water energy) as follows:

Means	Savings as % of source	Savings as % total consumption
Faucet - 34.3%	Assuming kitchen sink uses 75% hot water, we save 58% of kitchen sink hot water, and 85% in other two sinks for a total savings of 64.75% of sink hot water use.	22.21%
Dishwasher - 3.6%	45%	1.62%
Clothes washer – 15.5%	78%	12.09%
Bath - 16.7%	No savings	
Shower - 25.1%	80%	20.01%
Subtotal		**55.93%**
Leak Repair – 4.08% of remaining 44.07%	100% - We fix all leaks	2.12%
Subtotal	**Hot water savings**	**58.05%**
Subtotal - hot water energy savings	**Standby losses (due to water heater running even when no hot water used) means energy net savings are lower.**	**46.40%**
Drain Recovery System	Gross savings 55%	Less than 18.5% net[i]
Subtotal (energy)		**Less than 65%**
Tankless water heater heats water only on demand – when hot water is used.	Saves almost all remaining energy use. Tankless water heater are more expensive than conventional, but thanks to reduced demand, when current heater wears out you can buy a small tankless for the same as the old storage heater it replaces[235;236]	
Total Energy Savings		**~85%**

The same measures reduce water use as follows[72]:

Category	**Percent use**	**Percent savings**	**Total**
toilet flushing	20.91%	80.00%	16.73%
Bathing	17.95%	48.00%	8.62%
Cleaning	9.28%	70.00%	6.50%
Sinks	3.06%	64.75%	1.98%
Outdoor	32%	50.00%	16.00%
Subtotal			**49.82%**
Leak repair then saves 4.8% of remaining use			2.41%
Total			**52.23%**

[i] From 55% to 18.4% is a big drop. Remember we have already reduced hot water consumption by 46.4% - so it can only recover heat from ~53.6% remaining. A GFX heat exchanger can't do anything about standby consumption –which remains about 20% of original (not reduced) consumption; so that leaves slightly under 33.6% available to actually apply that 55% recovery to. 55% of 33.6% is slightly under 18.5%.

So we save 52.23% of water inflow and sewage outflow, and 85% of water heating energy use. Given the values we looked at for costs ($207 for heating, $300 for water and sewer), at a 6.5% discount rate, the present value of these savings over a thirteen year period is around ~$2,860 - a trivial gain over $2,845. Thus, we can save ~85% of hot water cost, and around half of water consumption at around zero costs, or a very miniscule gain. Aside from the social benefits we do have some additional personal benefits as well. Water saving dishwashers and washing machines also save soap. Ultra low flush toilets actually tend to have fewer jams, need fewer double flushes, and have fewer plumbing problems in general than standard low flush ones. Tankless water heaters occupy less space than standard ones, last longer, and are easier to repair. Kick pedal sink controls help slow disease transmission within the home, and also provide convenience when your hands are full. (In fact most kick pedal sink controls installed within homes are installed for these reasons and not for the purposes of water savings.)

The following table lists the climate control and water heating savings above, along with potential savings from other water appliances:

Residential Savings	**% Total Consumption**	**% We Save of This Type**	**Net % Savings**	**Average Net Present Value (NPV) of savings**
Heating, Cooling, and Ventilation	53.05%	New -90% Existing-60% Total-70%	New-47.7% Existing-31.8% Total-37.1%	New-$2,870 Existing-$1,903
Water Heating	17.28%	85%	14.68%	$20
Refrigeration (Wuppertal refrigerator[85]) – as described in section on material intensity a built in refrigerator freezers, constructed on the spot rather than shipped may incorporate more insulation and more efficient heat pumps and motors – greatly increasing operating efficiency.	5.69%	78.10%	4.44%	$128
Other Appliances, Lighting, and Phantom Loads (Compact fluorescent lamps [237], Washers with better spin dry cycles to reduce drying[238], Gas/Propane rather than electric dryers[239], moisture sensors[240], most efficient cooking appliances, turning computers off when not in use, LCD monitors, turning on energy saving feature, power strips on appliances to cut off phantom loads)	24.07%	51.85%	12.48%	$345
Total			New 79.36% Existing 63.44% Total 68.75%	New $3,370 Existing $2,405 Total $2,860

If you look at amount of energy consumption remaining and the NPV of the savings, you will note that after these investments are made homeowners and renters will break even buying renewables at around double the price of fossil fuels. In other words, the price we pay per amount of energy would increase – but because we would use so much less, our total energy bill (including payments on more slightly more expensive homes and appliances) will be less than at present.

Doing it in the Suites: Saving Energy in Commercial Buildings

Commercial building energy use differs significantly from residences. Such buildings tend to contain more people per square foot than homes. Lighting accounts for the most energy use. Climate control (especially air conditioning) and office equipment contribute heavily as well. The following table lists selected efficiency technologies:

Electronic ballast fluorescent lights backed by reflectors so the number is reduced by 40%. Using variable lighting, workers may dim or brighten fixtures as they please; each person gets ambient lighting they want. Add electronic ballast compact fluorescent lights on goosenecks so each person gets the exact point source they want. People who prefer dimmer light will more than make up for those who prefer brighter[241].	80% reduction in lighting energy; also reduce maintenance costs, and air conditioning
Superwindows prevent both heat buildup, and heat loss, let in the visible spectrum of light (while reducing glare); pay for themselves in reduced air conditioning heating, lighting and lamp maintenance costs.	Significant
Heat exchanging ventilators, as in residential buildings, reduce space heating and cooling, and help prevent sick building syndrome by dehumidifying; so do operable windows. Insulate unglazed spaces	Around 60% climate conditioning costs
Monitoring – otherwise energy wasting setting go undetected as in Austin green building that ran air condition and heating at same time until monitoring caught it.	At least 15%
Energy efficient appliances including energy star printers with efficient standby modes; turn off workstations or at least monitors at night; laptops don't pay for themselves in energy, but may pay for themselves in space saved and flexibility. For low volume B&W printing and medium volume low quality color, inkjets are comparable in per page cost with lasers and much more energy efficient[242].	Significant
In new buildings – under floor services, displacement ventilation – avoids air recirculation, makes heat recovery easier, pays for itself by making adds, moves and changes easier – even major changes can be done without rebuilds. In tall buildings also lets you squeeze in extra floors	

The greatest benefit of green buildings is increased worker productivity. According to a survey of the literature on this subject by the San Francisco Department of the environment, study after study shows that better quality light, especially increased sunlight, better quality air, and more worker control over their environment (being able to open windows, adjust light to personal needs, etc.) combine to increase productivity by between 2% and 16%[243]. A similar review sponsored by the state of Massachusetts gives a wider range up to 34%[244]. A recent confirmation of this was a report developed for the Sustainable Building Task Force, a group of over forty California government agencies[245]. In case some MBA type wonders, a short appendix, *The Hawthorne Effect*, deals with the question of whether productivity increase are actually due to improved physical conditions.

Unlike residential construction, there is no point in covering commercial examples on a technology by technology basis (other than the examples already given). A major cost of green building is extra design costs, money for architects and engineers. Money paid for design will not exceed that for total construction, but may well be the single largest cost. Obviously, the only way to show cost effectiveness is to give examples of both new construction and rehab projects that saved a large percent of their energy consumption cost effectively.

Normally, the plural of anecdote is not data. But the point here is not to show that something is widespread - merely possible. For those purposes, multiple examples do constitute good evidence.

In cold dark Amsterdam, NDB (now ING) bank built an integrated, light, airy, lovely, sunlit, plant-filled building. It uses around 35,246 BTU per month[246], compared to a U.S. average consumption of 119,500 BTU per commercial square foot in 2002[247] Energy reductions alone saved the bank around $2.4 million U.S. dollars annually. The $700,000 additional investment the building cost over an average building its size in the Netherlands repaid costs within four months. When NDB first moved into the building they saw absenteeism drop by ten percent as an additional bonus.	69% saving
Anglia Polytechnic University (APU) Learning Resources Centre, 'The Queen's Building', 41,842 BTU per square foot[248]. Net capital saving of £240,750 – before the first savings in operation.	63% saving
Leeds City Office Park 39,306 BTU per square foot[249]: £437,000 capital investment provides energy cost reductions of £72,603 per year	66% saving
Enschede tax office (Netherlands) 35,185 BTU per square foot - at an additional capital cost of 421,972 NLG[250]: annual saving 67,097 NLG.	69|% saving
Sukkertoppen office building, owned by Employees Capital Pension Fund. retrofit, rented commercially to small computer companies and educational organizations[251]. 30,114 BTU per square foot; cost data proprietary, but successful commercial venture.	74% saving
Ridgehaven Office building renovation City of San Diego Environmental Services Department. 27,296 BTU per square foot: simple payback rate of 30%.[252].	76% saving
[253]Bloomington, Illinois Amtrak passenger station, insulation, outdoor shading, passive solar heating, - 2.4- kilowatt rooftop solar array, efficient lighting. Simple five year payback of about $100,000 in costs	75% saving
The Pennsylvania Department of Environmental Protection's Cambria Office less than 40,000 BTU per square foot[254]. Capital savings in climate control equipment paid for all or most of efficiency measures[255]. Costs/ft^2 within normal range for area[256]	65% saving
National Resources Defense council office on two floors of the already efficient American Association for the Advancement of Science in Washington D.C. - already included efficient air conditioning system, and low-e windows operable windows that saved more than half of climate control energy. Buildout combined daylighting with low energy electric lighting systems, to save 75% of normal lighting bills[257]. A stairway between the two floors reduces elevator use; energy star office equipment saves computer costs. Green materials were used in construction as well. "Green premium" on order of $10 per square foot; energy savings combined with productivity increases should yield a four year payback or less.	70% saving

Again this is data mining; the examples are well executed new buildings and rehab projects with large secondary energy savings, and good economic rates of return. This would be meaningless in showing a trend. As a means of demonstrating that something is possible, this is a valid methodology.

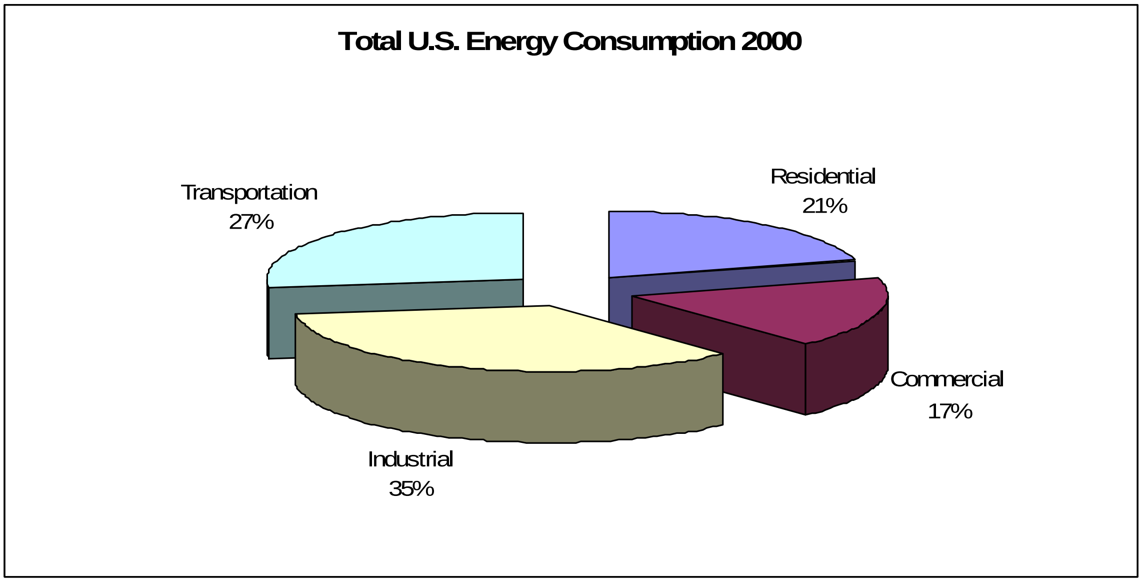
We have demonstrated we can save between two-thirds and three-quarters of the energy in both existing and new commercial buildings (compared to the current average) with a simple payback ranging from less than no time (energy saving techniques lower capital costs) to seven years. Longer payback periods typically do not include gains in productivity, which is the major economic benefit in both new construction and rehabilitation.

Therefore, it is a conservative assumption that average payback will be five years or less if productivity gains are included, probably a pessimistic one. Similarly, a seventy-percent or more savings at this payback rate is most likely pessimistic. Again, it is pessimistic not in terms of what is usually done (which it greatly exceeds), but in terms of what it is possible to do.

Given a 70% energy savings, a productivity gain at least equal in value to that savings, and a five year simple payback, and a 6.5% discount rate, this means we can pay ~2.84 times current cost for the remaining energy used and still break even.

All Together Now: Total Savings

Total U.S. energy usage in 2000 was around 98.942 quads divided as follows[258]:



Using the same information, we derive the following table with percentage consumption from each sector, along with the percent savings from the appropriate preceding chapters, along with the premium we can pay for renewables.

	Percent Total Consumption	Savings	Consumption Remaining	Multiple of current fossil fuel price savings from efficiency measures would let us pay for renewables.
Residential	20.73%	68.75%	6.48%	1.87x
Commercial	17.38%	70.00%	5.21%	2.83x
Industrial	35.05%	75.00%	8.76%	2.10x
Transportation	26.84%	77.07%	6.15%	5.00x
Total	**100.00%**	**73.39%**	**26.61%**	**2.79x**

So we can save ~73% of energy used on a per capita basis. After those savings, we can pay ~2.8 times what we currently spend for fossil fuels, and break even on total national energy bill.

But this is not the end of potential for efficiency gains. We also lose energy converting fuels into electricity, and then transmitting that electricity along power lines; around 38% of total primary energy consumption is used to generate electrical power[258].

Around 30% of electricity today comes from non-combustion sources[259]; that is from sources other than burning something. Nothing is burned to create hydroelectricity; it taps the energy of falling water. Geothermal energy uses the heat of the earth to boil water for steam. Wind, solar, wave, and tidal energy provide small amounts of non-combustion electricity. (So does nuclear power. But nuclear energy has its own problems.)

Burning fuel produces the rest - around 70%. This requires a bit less than three units of fuel to produce one unit of electricity. In the year 2000, according to the International Energy Agency, the U.S. produced about 36.7 BTUs of electricity for each 100 BTUs burned to generate it[239]. (This included line losses of around 10%[260], as well as thermal conversion losses.)

Given the efficiencies we are looking at, the total drop in electricity use, we should be able to supply all our electricity entirely from sources that don't involve combustion of fuel – hydroelectricity, wind and geothermal plus solar thermal. So after countervailing factors, (small additional amounts of electricity used in transportation, and additional line losses from sending power longer distances), we should have a net savings of an additional ~9.6% of remaining energy consumption[i]. Including that, we can save a total of 83% of energy use per capita, without lifestyle reductions or shrinking our economy.
.
Remember that, though our target date for a complete switch to renewable sources is 2040, we want to meet the energy needs of 2050 by that date. That is because we don't want to supply most energy from renewables in 2040, and then run short the next year.

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[i] We calculate this as follows. Current line losses, as mentioned, are about 10%. But if we are going generate electricity renewably without assuming breakthroughs – without assuming cheap solar cells, inexpensive fuel cells, inexpensive electrolysis, we will have ship electricity from where inexpensive renewable sources may be found – a lot of it a long distance from where consumed. So that we means we will need longer distance transmission lines, and greater losses from transmission – maybe as much as 10% greater (bringing total line losses to 20%).

Current losses are ~63% (current net conversion) of 70% (the percent of our electricity we generate from fossil fuel) of 38% (primary energy used to generate electricity) – equals ~16.76%. Instead we would lose ~20% of ~70% of ~38% - equals a ~5.3% loss. This is about an 11% gross saving.

However the 30% we currently generate from non-combustion sources will also have to be shipped further, doubling our 10% transmission loss there to 20%. So instead of 10% of 30% of 38% (~1%), we will lose 20% of 30% of 38% (~2%), another ~1%.

Lastly, about ~2% of total energy will be additional electricity used for transportation currently powered by fuel. This will be a tremendous savings over IC and jet engines; but we will still have a 20% transmission loss - an additional ~0.4%. Subtracting that 1% and .4% from the 11% gross saving still lets us save ~9.6% of total energy remaining.

These saving are economic, and environmental. A hydroelectric turbine does not convert the power of falling water to electricity with 100% efficiency (though it can come surprisingly close). Neither do wind generators, nor geothermal power stations.

The environmental differences are obvious; a solar thermal power plant emits no greenhouse gases in operation. The economic difference is important too. If you burn natural gas to produce electricity you could have used that same natural gas somewhere else – to heat homes, to drive high temperature industrial processes, to use as a raw feedstock. When we tap the power of the wind to generate electricity or pump water, that is the first stage at which the natural resource has been converted to an economic one. The opportunity costs are of a different order. (They are not zero of course; resources go into building a wind generator. But your operating input is not something that otherwise would have gone to a different economic purpose.)

What do we project energy consumption as in 2050 as? Up to 2010, we are looking at DOE projections that include per person economic growth. From 2010 forward we look only at population growth. (We explain why at the end of this chapter)

Projected energy consumption for 2010 is ~112 quads[261]. The middle (most probable) case U.S. population growth from 2010 to 2050 is projected to be slightly less than 35%[262]. So without increased efficiency, and (only for the moment) not considering economic growth, that means consumption is expected to be under ~152 quads of primary energy. With a bit less than factor a factor four increase in efficiency, the 73% reduction we talked of, this results in a consumption of ~41 quads in 2050, ~6.8 quads of which will be electricity. Not burning fuel to produce that electricity saves us 9.6% of the total energy consumption – an additional ~3.6 quads.

Sector	**Quads**
Residential	~9.85
Commercial	~7.93
Industrial	~13.32
Transportation	~9.64
Savings From Increased Efficiency in Electrical Production	(~3.88)
Total	**~36.86**
Absolute (as oppose to relative savings)	**~63%**

Note that a bit over one sixth of the total will be electrical.

Why deal only with population growth, and not per capita economic growth that exceeds it? We are looking at savings possible through technology available today. This means we assume no breakthroughs in renewables, no hydrogen path, and no inexpensive solar cells. In general the price per BTU of renewable energy has dropped faster than the economy has grown. (For example, the price of photovoltaic cells dropped from almost $500 per peak watt in 1965 to around $5.00 per peak watt in 2001[263].)

Per capita economic growth stems from two sources. One, which can be beneficial, is improvement in technology or business processes. Better technology, better workflow, and reductions in waste are all examples of this. Another comes from sweating workers more - lowering wages, making people work longer hours for no extra pay, making people work in more unpleasant or more dangerous working conditions. (For example, real U.S hourly wages for 80% of us peaked in 1972; they have fallen and risen since then, but never again reached the 1972 peak – nor, since 1980, even returned to the 1968 level again[264]. 100% of benefits from economic productivity increases have gone to capital and the top 20% of wage earners[i]. The only reason incomes for the rest of us have risen at all since 1972 is due to longer work hours.) Growth from this second source is not worth the price to the overwhelming majority of us whose hourly wage has been lowered.

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[i] The top 20% of households earned more than $84,000 in 2000.

So if we stick to growth from actual improvement in the way work is done, then we can count on renewable technology to automatically keep up with it. In short we want to demonstrate that the technology we have **now** can maintain the 2010 U.S. per capita GDP through 2050. If we show that, with a transition to essentially zero emission by 2040, then we have shown (by usual economic standards anyway) that normal renewable innovation rates will sustain economic growth over and above population increases.

(To be on the safe side though, you will note that we do have a section near the end of the book where we specifically consider R&D areas that would cover economic growth beyond that in population. It is speculative – but then again so are the innovations that will create such per capita growth. In that context we can consider things like cheap solar cells – because their uncertainty is no greater than the processes which will consume their power.)

Earth, Sun, Sky and Sea: Sources

I'll Let These Sparks Fly Out: Electricity

We have more potential to produce renewable electricity than any other form of renewable output (other of course than efficiency). As we will see in other sections, both wind and sun could provide enough renewable electricity to meet many times total world demand for all forms of power (not only electrical usage). Thus we will want to substitute electricity for other forms of energy whenever possible.

While efficiency and solar heat are the best ways to provide climate control and domestic hot water, these means may not always be practical. So long as we use it very thriftily, there is no reason renewable electricity rather than fossil fuels can't be used in these cases - via heat pumps, for example. Again, the preferred source for these purposes are solar energy, mid-temperature geothermal and ground-source heat pumps; but renewable electricity can provide backup, and last-ditch none-of-these-work alternatives. Because heat is cheaper to store than electricity, where this is necessary, PCM or other storage means could allow use of wind electricity without backup or standby energy.

In industry too, we can substitute electricity for much current fuel use. Often one for one substitution is impossible or at least highly inefficient. But almost always, when you look at the result you are aiming for, rather than merely focusing on the process, you can find an electrical means. For example, trying to design a resistance heater that would substitute for basic oxygen furnaces would be absurd. But electric arc furnaces process scrap metal far more effectively than coal fired furnaces - even when that electricity is produced by coal; if the electricity the savings are immense (which is why most scrap metal today is process in electric arc furnaces). Similarly, many of the efficiency means mentioned in the section on industry allow electrical substitution. Alternative cleaning processes such as super-critical carbon dioxide or ultrasonic chambers can substitute for high temperature cleaning processes. Mini-reactors can allow concentrated electrical processes to heat tiny areas substituting for huge fossil fuel driven furnaces. And, so forth.

Free as Running Water: Hydro-electricity

The U.S. consumed 2.84 quads of hydroelectricity in 2000[265], some imported from Canada. Thanks to global warming caused droughts, and competing uses, available hydroelectricity may not stay at that level. Also, hydroelectricity is extremely damaging ecologically, disrupting critical habitats and often endangered species. However, a lot of existing dams are used only for flood control and water supply; some of them could add turbines without affecting these existing uses or causing additional damage. Also, small hydro plants use canals and ditches rather than dams, and thus may do less environmental damage. This potential is almost untouched. We don't know what hydroelectric production in the U.S. will be at the end of this century. Given that the need for flood control and water supply won't go away, and the potential to add turbines to existing dams, plus small hydro potential we can guess that it won't be substantially less than we have now. Given the limiting climate and ecological factors needed we can guess it won't be substantially more. So a good tentative guess is that we can keep production about the same at a reasonable economic and ecological cost. But, we need to understand that there is a huge question mark; that is an extremely foggy number.

Most regions with hydroelectric power produce significantly less than needed just for their own consumption - even after the efficiency improvements recommended[266]. But the regions that produce the most hydroelectricity, the Pacific Contiguous and Rocky Mountain census areas, produce much more than their requirements after efficiency measures[266]. Hydroelectricity is among the most important renewable energy resources – because dams make it storable and dispatchable. Within limits we can store hydroelectricity and dispatch when we choose. (The limits are, of course, that dams are also important for flood control, and irrigation. We can’t let them get too full, nor waste water we need for other purposes.)

According to the California Energy Commission, the levelized production costs of hydroelectricity are about 6.04 cents per kWh.

Where the Hot Springs Blow: Geothermal Electricity

Something like 95% of the solid mass of the earth is at a temperature of 100 centigrade or more. So in a very hypothetical sense, we could provide all the electricity we need for thousands of years from this source. At the moment we have the technical ability to access a very tiny portion of that potential, and the ability to access a tiny portion of that tiny portion economically.

In the U.S., we could produce up to 22 gigawatts of capacity with today's technology[267]. However, probably only about 6.5 of those gigawatts could be produced economically. This translates into slightly less than .2 quads of electrical energy.

According to the World Bank, the levelized cost of geothermal electricity produced in large plants from plants runs from 4 to 6 cents per kWh[268]. The Public Renewables Partnership (a partnership of several DOE programs, several large utility associations, and the non-profit Center for Resource Solutions gives the price for binary plants (which can utilize lower temperature sources and are more environmentally sound) as around 5.8 cents per kWh[269]. The California Energy Commission, (which tends to be very careful, working as they do in a state Enron peeled like a banana) gives the cost as 7.37 cents per kWh[270], which we will use.

Restless Power of the Wind: Wind Electricity

Wind is an inexpensive source of electricity now - able to provide variable electricity at a levelized cost of ~5 cents per kWh[271].

Wind potential could provide virtually any amount of electricity we would need considering only class 5 and better wind power available year round[272]. Economically viable sources worldwide could supply many times world demand[273]; economically viable sources within the U.S. could supply several times U.S. demand[273].

Of course wind is a variable source (not intermittent – power curves from wind are fairly predictable – but variable). Further, most energy is consumed at a fair distance from areas where class 5 and higher winds blow all year round. (Constant high winds don't head most lists of preferred climates.) Even in those places the wind occasionally stops blowing.

The variable nature of wind is not as difficult to deal with as most people think. The problem with wind power without storage is that you need backups for when the wind does not blow - so you end up spending capital twice, once for the wind generator and once for the backup plant. But all power plants need some spinning and operating reserves. (Spinning reserves are reserves that are already on line or can come on line in less than a second – to compensate for failures where there is no notice. Operating reserves are off-line plants that can be brought on-line in a normal step by step manner for a planned or predicted reduction in production from another source.) There is a level of wind utilization at which operating and spinning reserves are no greater than those needed for any other source.

The DOE says that level is 10%. But studies, (and actual experience), suggests that that clever grid management can let you gain 20% of your power from wind and still not need a significant increase in spinning and operating reserves. If a large percent of your electricity is extremely reliable base generation - say hydroelectricity or geothermal energy, wind power without storage or extra backup may provide more than that[274].

But it turns out that wind could supply much higher percentages of a grid than previously realized if we used HVDC electric transmission lines to connect wind farms hundreds (or even thousands) of miles apart. Because wind tends to rise and fall at different locations at different times, low and no power periods grow shorter and less frequent. With sufficient interconnections, around a third of wind energy generated can compete with coal plants for baseload needs[275]. (Baseload is the demand for electricity a utility must meet all the time, as opposed to the additional loads the vary from hour to hour above that base.)

However we also need to consider than once you have all these interconnections, storage needs to turn a greater percent of power generated in into base or peak loads decreases. In March of 2006, Windtech International magazine published an article on Vehicle to Grid interconnection[276], which included a chart based on unpublished wind data from a study covering eight sites dispersed hundreds of kilometers apart[277]. It found that with such interconnected wind farms, most periods of low wind lasted three hours or fewer for the combination of interconnected farms (as opposed to a single farm). Thus the ability to store only a few hours worth of power would allow a much higher percent of power produced as firm or baseload capacity.

This still does not allow wind to meet demand above that consistent base; if you want to do that you would need to be able time shift some of your output by more than three hours. Ten hours of average production for the series of wind farms would seem a reasonable guess. At this point almost all the power produced could be used for base, load following, and even (to some extent) peak. That amount of reliability would let wind replace 80% or 90% of electrical use.

Average production for a wind generator represents about 30% maximum capacity. (That is: over the course of a year, a single generator will produce about 30% of the electricity it could create if it spun at maximum speed 24 hours per day.) So ten hours of average production represents three hours of peak production; and peak production is how capital expenditures for wind are measured. In other words, to calculate capital costs for the additional storage, we should price three hours of capacity compared to the power all the farms could produce if all the generators on all of them spun at maximum speed at the same time.

Heat of the Sun: Solar Thermal Electricity

Solar energy has even more potential than wind to produce electricity. Enough solar energy strikes the surface of the earth every 40 minutes to produce all power consumed for a year[278].

Solar thermal power plants currently produce electricity for ~11 cents per kWh[279], by using concentrating mirrors to produce heat to drive turbines. (The principle is the same as setting a bit of paper on fire with a magnifying glass.). Because heat is cheaper to store than electricity, the heat from the concentrators may be stored at $35 per kWht[280]. 16 hours storage makes the electricity fully dispatchable, allows plants to operate at about 65% of nameplate capacity, and (at the price mentioned) adds around 1 cent per kWh over the first twenty years of plant life. If you assume around a half cent per kWh additional O&M for the storage facility, this gives us a price ~12.5 cents per kWh – expensive, but less than hydrogen, flow batteries, or new nuclear plants for the same capability.

There is a major consortium who believes that the combination of simply mass producing the mirrors on a large scale, combined with using waste heat from the engines to produce water and air conditioning, would lower this price to between 3 and 5 cents per kWh[281]. Reliability is about 70%. (Solar thermal requires more storage than wind. An obvious cause is that night happens continuously 12 or so hours out of every 24. In addition, unlike wind, solar power from deserts does not provide access to widely differing sites. Extreme cloudy weather (especially multi-day extreme cloudy weather) will probably happen at the same time on differing sites.

Mixed Sources and Storage

Solar and wind electricity combined complement each other. Wind tends to peak in winter and at night. Solar energy tends to peak in the summer and during the day. Absolute still windless weather tends to be sunny. Heavy clouds tend to produce more wind. With a mixed grid of mainly solar thermal electricity (with thermal storage) and wind connected by long distance transmission lines, ten hours storage compared to average use will go even further. As with wind solar plants average only a small percentage of their peak output; so we can translate that ten hours average into three hours of peak for solar as well. (That is actually conservative. Solar electricity plants average more like 20% of peak than 30%.)

The least expensive way we know to store electricity is pumped storage - much less per kWh of capacity than flow batteries or flywheels. In a pumped storage plant, a reservoir is maintained at a significant elevation above a water source such as a lake or river. When excess power is available, water is pumped up to that reservoir. To recover that power, the water is simply dropped through a pipe into a hydroelectric generator then dumped back into that water source.

Conventional pumped storage is ecologically extremely damaging; in some cases it can dwarf even conventional hydro for in the destruction it causes. In North America the best conventional pumped storage sites are in use in any case. A more recent technique called modular pumped storage is both less ecologically harmful, and can be placed where conventional pumped storage can't. Modular pumped storage creates two artificial reservoirs an upper and a lower one. The lower reservoir is charged only once. Water is pumped between the two in a closed cycle. Operating water is only needed on a small scale to replace leakage and evaporation. Since such a system is not continuously draining rivers or lakes, it does not need to be near a major water source. You can place it anywhere you have sufficient differences in elevation, even in the desert. The price should be at high end of the Electricity Storage Association's estimate for a pumped storage cost range -- ~$150 per kWh of capacity[282].

So you would need about $450 worth of pumped storage per KW of peak wind and sun electricity. Those capital costs could add as much as 2 cents to each kWh, depending on how it was used in practice. O&M (excluding electricity costs) adds another quarter cent. In addition, you lose about 25% to 30% of each kWh you put into storage to friction, evaporation, and leakage. One third of power would go to base load without passing through storage. If you balanced amounts of wind and solar sources cleverly, a significant amount would also go directly into the grid to meet some peaking and load following needs. Also smart-grid technology would allow some of the load to follow production rather than requiring all of production to follow the load. If we had substantial all-electric and electric plug-in hybrid vehicles, a substantial portion of the power they used could probably be accepted on an as-available basis. Still, between half and 60% of production would probably need to come from storage. If we take the high figures (30% of 60%), that means we would lose 18% of our 5 cents per kWh electricity. We can round up to another 1 cent per kWh. So, total costs from storage would be around 3.25 cents per kWh.

Paying the Price: Costs of Transmitting, storing and Producing Electricity

This brings up another point hinted at earlier. Most of this power has to be generated fairly far from where it is consumed. There are various technical reasons wind farms need to be build far from cities - even when city wind speeds are suitable for turbines. If hydropower, geothermal, and solar thermal electricity are to mix with wind power to provide a reliable supply, we will need a few very long lines – some possibly up to 3,000 kilometers (1,864+ miles).

The longest DC lines in the world are around 1,700 or 1,800 kilometers. But most companies who have looked at the issue think that lines of up 5,000 kilometers are quite feasible if needed, let alone 3,000[283].

A 3,000 kilometer 3,000 Megawatt DC line will typically have an average 13% loss[283]. Most of the transmission lines would be less, so the overall average would be more like 11%. Wind, which is the vast majority of the proposed electricity grid, would mostly travel less than 1000 kilometers – with a fair percent of it traveling only via the local grid. (Not always of course; if we have such an extensive grid, and wind is blowing one place and not another, we will probably want to take advantage on occasion.) And a great deal of wind is much closer than 600 miles to where it is consumed. A 1,000 kilometer HVDC line typically suffers a 9% thermal and conversion loss. So we can average the power traveling up to 3,000 kilometers with the half derived from wind power traveling less than 1,000 kilometers – resulting at most in 10.36% loss. If you add in an additional 10% from normal AC transmission, conversion and distribution losses, the total is slightly less than 20%[i] - at most.

Minor grid improvements such as voltage regulators can reduce this. (For that matter there are small scale voltage regulators for homes and small business which can do the same thing[284].) Even before improvements, there are a lot of reasons losses don't have to be this high. But we will assume the 20% to be on the safe side.

Aside from power losses, what are the costs of the lines themselves, and of operations and management? The same source gives total levelized line costs and O&M of ~1 cent per kWh for a 15-17 cent per kWh total.

Let’s take another approach, to double check the costs of such an increased transmission network.

The electric utility industry, projecting a huge increase in demand, currently wants around 100 billion dollars in grid improvements[285].

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[i](Yes, having been asked this, the arithmetic is correct. Percentages multiply; they don’t add. Losing slightly more than 10%, followed by losing another 10% of **what remains** is a total loss of slightly less than 20%.

If, instead, we reduce electricity demand by slightly less than 80%, there is no justification for many of these requests. Large numbers of HVDC lines to transmit small amounts of power long distances would cost a great deal less than 110 billion dollars[286]. So if we really take a whole systems approach the transmissions costs of a renewable scenario are a great deal less expensive than the transmission costs of continuing on the same path.

Finally we still will need some backup. Depending on how much reliable geothermal and dam-based hydro-power is in the mix we will need between 1% and 5% of our electricity to come from fossil fuels - probably natural gas (which there is plenty of at this level of use.) Even 5% of our electricity via natural gas represents an acceptable emission level; and methane from existing dumps, sewage and other waste could displace some of this. Existing peaking natural gas generators could supply a large part of this; additional new one might add another cent per kWh to total costs.

Lastly we need to add on existing costs for utilities of normal transmission, distribution (other than power losses), general administration, meter reading and – well – everything else. These seem to average around 3 cents per kWh[287].

total before additional transmission costs		~.0825
20% line loss		~$0.040
Additional transmission levelized capital and O&M		~$0.010
Additional peaking natural gas generators + fuel		~0.0125
All other existing costs		~$0.030
Final cost per kWh for wind/solar/hydro/geothermal/ with no technical breakthroughs		**~$.165**

This compares to the existing average levelized cost of electricity – which according to the EIA statistics site in the pervious note was 8.14 cents per kWh in 2005. So we can provide renewable electricity for around twice the current market cost of fossil fuel electricity - with no technical breakthroughs. With efficiency measures in place that means total electric bills, including amortization of efficiency measure capital costs will be lower for the same service than at present.

The Hydrogen Path

At this point Amory Lovins is screaming at me[i]. "We don't need large numbers of transmissions lines. Yes, I agree with you that we can massively reduce demand even if I don't agree with your exact number. But for supply, why primarily rely on unevenly distributed sources like wind, and water and geothermal? The sun shines everywhere. Install photovoltaic cells on every rooftop, turn electricity not immediately needed into hydrogen, and put the hydrogen into fuel cells to produce electricity when the sun is not shining, and to run cars all the time. Or if that is too expensive, use steam reforming to create hydrogen from natural gas; then bury the carbon."

[i] I refer to the imaginary one in my head, of course. The real Amory is unlikely to ever read this, and probably does not scream a great deal

Sadly, compared to geothermal and existing hydro and wind, both solar photovoltaic generation, and hydrogen fuel cell storage are horribly expensive – even when the avoided cost of transmission lines is taken into account. I agree that if we had cheap solar cells, and the ability to electrolyze hydrogen inexpensively from the cheap electricity they would provide, and the ability to recover power economically from that hydrogen in reasonably priced fuel cells that would be preferable. You will agree in return, I presume, that if we had some eggs, we could have ham and eggs, if we had some ham.

In terms of steam reforming of natural gas: we certainly know how. But the cost is as least 50% higher than the cost of the natural gas alone. The system costs of a natural gas based hydrogen path will be high. And nature has already sequestered the carbon nicely for us. Leave the damn stuff in the ground and produce power from something else.

Before this book ends, I will suggest ways we might get to that hydrogen future (or something comparable) that does not require massive grid extension. The problem here is that it is one thing have confidence a technical problem is solvable. It is quite another to bet the future on making a breakthrough, however small it might seem, within a specific timeframe , with a quite literal drop dead deadline (as in a lot of people will drop dead if we don't make the deadline). The best we can do on this is structure our investments in such a manner, and order that the choice between a grid intensive and grid light path are delayed as long possible. In practice though time is short; we will probably end having to extend and improve our electricity grid. If the hydrogen future (or flow battery future) breakthrough happens we can still make use of such a grid to minimize the use of storage; storing electricity (more or less by definition) is more expensive than using it as generated.

Now to provide 100% renewable power would require more storage than the few hours specified above. But a mixed wind and solar grid that includes some hydro, geothermal, modest storage and long distance transmission can provide between 99% and 95% of our electricity. Even if we have to get 1% to 5% of remaining power from natural gas, that still reduces greenhouse emissions to an acceptable level.

Photovoltaics

Solar cells may be the flashiest source of renewable electricity. While they have some of the greatest long run potential, currently they also are one of the priciest. They can currently compete where grid connection is impractical or expensive, with peak power costs in certain very limited locations, as replacements for extremely expensive facings on some tall buildings. Without storage, they constitute a variable source (as much less expensive wind power does) for all on-grid connections; even at current prices the economically available potential is greater than zero.

Most experts think breakthroughs will happen soon in photovoltaics. If they do, solar cells on rooftops, south walls and shading parking lots and roadways could provide most or all of our electricity, reducing the need for huge wind farms and centralized solar thermal plants in a renewable scenario. Also because photovoltaic cells (unlike concentrating systems) can be reasonably productive in non-desert climates, you can get some of the same increase reliability from interconnections you do with wind plants. As with concentrating systems, you gain maximum benefit from a mixed grid with both wind and solar electricity.

Shades of Grey: Electricity and Environmental Questions

There are environmental questions about all these methods of generating renewable electricity, and of transmitting. We begin with wind energy.

One objection sometime made is that wind generators kill birds. It is true that badly located, designed, and sited turbines may kill endangered raptors; but this is easy to avoid.

Other than that - existing wind generators kill about 6,400 birds per year. If every bit of our current electricity demand (not reduced, but current) was met by wind about 1 million additional birds would die a year. In contrast, collisions with buildings kill 100 million birds a year; cell phone towers kill 40 million birds a year; human infrastructure and activities in general kill from one to four million birds a day in the United States[288]. Feral and outdoor cats kill at least hundreds of millions annually[289]. Next to efficiency, wind is the most environmentally benign energy source there is.

I will note that these objections are raised by the fossil fuel industry much more often than by environmentalists. In some cases people object that wind generators spoil their view; my reaction is "you want to burn more coal, give more miners black lung so as not to spoil your view? You want all of us to suffer more deaths from respiratory disease - including lung cancer so as not to spoil your view? You want more tornadoes, more hurricanes, more disease, more crop failures, more floods, and more droughts from global warming so as not to spoil your view? Get over yourself!"

There are slightly more serious objections to geothermal electricity. Hot water taken from sources can end up contaminating the freshwater table with salts and toxins. Huge amounts of cooling water are often used in water cooled geothermal plants. In modern plants, such as the Mokai Geothermal plant in New Zealand[290], these impacts are reduced to a negligible level:

> *…geothermal fluid is completely contained from production to reinjection, with the only emissions being negligible quantities of steam emitted by the steam traps and the non-condensable gases emitted above the air coolers.*
>
> *The plant has a relatively larger footprint but a much lower profile than a conventional condensing steam turbine with an underslung condenser. The air cooler structures have a significantly lower profile than wet cooling towers and have the advantage of never producing a visible plume. In addition to its low profile, the plant has no water or chemical consumption and no blow-down of contaminated cooling tower water…*

Normally greenhouse emissions from geothermal plants are considered to be about one sixth that of natural gas per unit of power. That might not be acceptable on a large scale, but as a small percentage of electricity production should prove no problem. In the U.S., where most feasible remaining untapped reserves are moderate temperature in any case, we will probably use close cycle air cooled binary technology almost exclusively, further reducing emissions.

A brief description of possible geothermal side affects and current mitigation technology can be found at the U.S. national park service web site[291].

Also, environmental effects may come from large scale HVDC transmission lines. These effects, if they exist, may not be minor. The question of what effect EMF from transmission lines have is controversial. The majority of studies have shown no effects. A minority, however, have shown links between exposure to powerline EMF and leukemia, brain tumors and other forms of cancer. WHO is concerned enough to classify EMF as a possible carcinogen.

The December, 2001 issue of Environmental Health Perspectives included a review of the literature on the subject[292]. Of those studies that showed effects, the most extreme seem to be in ranges increases in number of deaths from various cancer from low to high tens of people per million. One way to look at that is (according to the most pessimistic studies) that if we exposed 50 million people to greatly increased EMF, somewhere between zero and an additional <10,000 people per year would die. Any number above zero is quite horrible, of course.

In contrast, fine particle pollution from coal burning electric power plants we run now are, by themselves, responsible for at least 24,000 deaths per year in the U.S[293]. According to the same study, all fossil fuel based power plants particulates combined kill 30,000 per year. And this is particulates alone, without including NOX, Sulfur and other non-particulate air pollution, not to mention mining, mercury and global warming affects.

So even in the very unlikely worst case – high voltage transmission lines would still do a great deal less harm than the fossil fuel emissions they displace.

In addition, if such effects do exist, high voltage DC transmission line produce fields much more similar to the earth's natural field than AC lines do – meaning the body should be more adapted to them. So you would expect effects on the low rather than high end. Put it this way; reduce the number of large diesel trucks running through my neighborhood spewing toxins into the air, and as far as I'm concerned you may run a high voltage DC line past my house.

This brings to an important point to consider when weighing environmental effects. There is no kilowatt fairy, no BTU bunny. Everything we do has environmental affects. Solar cells are made with highly toxic metals. Fluorescent lights contain mercury (less than produced by coal to produce the electricity they displace though). I'm not saying it is the absolute optimum possible; it is a compilation, and I'm sure there are wonderful technologies out there I've overlooked. But without inexpensive electricity storage (something we do not yet have) any renewable scenario is going to require some additional high voltage lines.

"Aha!" say the primitivists. "High voltage lines aren't acceptable. Let's go low-tech instead, and live a simpler life." How far back exactly do you want to go? To wood lots for heating and cooking, with a population that will stabilize at between 8 and 12 billion? That won't leave you many forests or much land for growing food. "We can have solar panels for heat" chimes in the simple lifer; "we'll just live without electricity". And how do we make the glass and process the metal for your solar panel? Remember, we don't want to use fossil fuels or wood for that either. I'm not saying it is impossible to come up with a low tech way to support 12 billion people (depending upon how you define "low tech"). I'm betting, though, that any low tech answer will have a higher environmental impact than renewable electricity – even if renewable energy requires high voltage lines.

We need to also consider hydroelectric plants. These have the most serious consequences. Many people question whether they are even a sustainable source. There are ways to mitigate various problems. Fish friendly turbines are under development, as are improvements in small hydro. But fundamentally, pulling a large percent of moving water out of rivers, holding it in reservoirs, and then releasing it at our convenience does tremendous damage. It contributes to erosion, destroys fish and wildlife. The levees and dams that failed to protect New Orleans from hurricane Katrina also prevented the deposit of sediment that would have built up marshlands that had diminished the fury of hurricanes striking on previous occasions.

There are even questions about how carbon neutral hydroelectric dams are[294]. By flooding areas that were previously dry, dams may help convert CO2 to methane - a far more powerful greenhouse gas. Even where reservoirs are converted from existing lakes or wetlands, the powerful turbines may force dissolved methane out of the water that would otherwise have been converted by micro-organisms to CO2. How much occurs is not established fact, but that some of it occurs is unquestionable, especially if plant matter is left in place when the dam is built. The most important variable appears to be acres flooded per watt - meaning that high head hydro where existing plant matter is removed before construction is probably (but not certainly) low emissions. In short, we need (as *Nature* says repeatedly in discussing it), more data.

I will note that modular pumped storage avoids many of these problems. Recirculating the same water over and over again avoids destruction of rivers and lakes. And even if there is initially dissolved organic matter in the water that converts to methane, in a closed cycle this will be a one time occurrence. Once the existing organic matter is used up, there will be no significant source of new carbon to convert.

Hotter than the Sun: The Mandatory Section on Nuclear Electricity

Inexpensive sustained net-energy fusion would be wonderful if we had it; but we don't.

The last time we built nuclear power plants in the U.S. their capital costs averaged over $3,000 per KW in mid-80s dollars[295].

The nuclear industry insists that modern plants could be built more quickly and would cost much less; they promise their plants won't end up costing four to seven times budget as they have in the past.

The pebble bed reactor is one example often promoted of a new generation technology for producing less expensive, safer fission reactors. The consortium building a pebble bed reaction in South Africa has finally revealed the cost – just short of $9,800+ per KW in capital costs[296]; that cost has no chance of falling, but may yet increase.

We can build solar thermal with storage at two thirds of that price, fully dispatchable wind at one third – and not have to worry about uranium mining, waste transport and storage, and the liability issues (which in the U.S. are dealt with through the special privileges of the Price/Anderson act not given to any other power source).

One and One Still is One: Cogeneration

There is a well known way to increase the efficiency of electricity generation – combined heat and power or cogeneration. You can use waste heat from a power plant for lower temperature uses, such as industrial process heat or water heating or space conditioning. Or you can use waste heat from industrial processes to produce electricity. As a transitional strategy for say the next ten or fifteen years this would make sense in the U.S. But now that we have added up the numbers above, you can see once fossil fuels are phased out we won't be able to afford to use sparse biofuels to generate electricity. Using waste heat from industrial processes is more promising – so long as it does not increase the fuel used for those processes. In the latter case though, cogeneration becomes a variable process just like wind. Combined heat and power in such cases displaces wind and other variable sources, but does not provide either a base or load following source. And if you have an industrial process with enough high temperature waste heat to power an electrical turbine, you may be better off using that waste heat for another industrial process – possibly by co-locating another industrial plant near it. These limitations make co-generation an excellent means of reducing fossil fuel during the transition, but not a significant source of ways to eliminate it. The only exception would be if we have a breakthrough in cheap hydrogen production from electricity, but not in fuel cells. A combined cycle hydrogen burning turbine, where the waste heat is used for non-electrical purposes could match or exceed fuel cells in the hydrogen-use efficiency.

Warmth of the Sun: Active Solar Thermal for Low and Mid Temperature Heat

Electricity represents only about 18% of our end use consumption needs -although we can and must greatly increase this in a renewable scenario. A large portion of the rest may be supplied via active solar. Solar energy can supply space heat and hot water for residential use. (Single family residential cooling is on too small a scale for active solar to be economical, unless someone could integrate it into a solar heating unit without a great deal of additional cost). It can supply space heat, cooling and hot water in commercial buildings. (Commercial air conditioning is definitely done on a large enough scale to be supplied by solar thermal air conditioning.) Similarly the small portion of industrial consumption used for space conditioning could be supplied by solar thermal. Providing up 65% of climate control and hot water is considered normal today; but we are looking at fossil fuel free future where fuel is more expensive than at present. So our goal will be to see that active solar thermal will supply about 85% of all space heating, 85% of commercial and industrial space cooling, and 85% of hot water requirements below boiling temperature - beyond that provided by passive solar. (Note also that these are averages; the best technology can do better than this in California or Arizona, and worse in the Yukon. [Yes, you can get significant amounts of solar thermal energy in Alaska; just don't rely on it as your primary space or water heating source.])

Note that with seasonal storage, this works quite well in cloudy climates with short days. Yes you need more solar panels; but demand is higher, so they usually pay for themselves in almost as short a time as in sunnier climates with lower demand. Active solar can vary from low temperature low cost systems without moving parts (near passive systems) such as the solar wall[297], to sophisticated selectively coated flat plate systems.

While this is a worthwhile goal, and theoretically possible, it is not one we are likely to achieve. There are densely populated areas where buildings shade one another and buildings where walls are shaded and roofs have the wrong orientation for solar. These are especially discouraging in cold cloudy climates where you need a lot of heat, and don't get that much direct sunlight in any case. As we mentioned in the section on electricity, electric heat, is our backup plan - with ground source heat pumps used whenever possible. (A recent discovery is that ground source heat pumps can draw on space under streets; with cooperation from local governments these can be installed for entire neighborhoods during road repair.)

Now one last point before we add up the numbers on this. Because we incorporated passive solar already into our efficiency scenario, we have saved more in space heating and cooling than other areas. And because hot water uses comparatively low temperature heat, we were able to save more there as well. So it would be reasonable to lower the share of such use as a percent of total energy, thus reducing the amount of low temperature solar thermal we can use. (In other words we will assume less solar thermal than if the shares were the same, to avoid counting the same saving twice.)

Quadrillion BTU Energy in 2050 (not including the additional electricity storage losses)	~36.86

Commercial space heating as a percent of total energy 2000[298]	6.96%
Commercial water heating as a percent of total energy 2000[298]	1.04%
Commercial space cooling as a percent of total energy 2000[298]	2.63%
Residential space heating as percent of total energy 2000[299]	9.69%
Residential water heating as percent of total energy 2000[218]	3.58%
Industrial space conditioning as a percent of total energy 2000[169]	2.12%
Subtotal	26.02%
However, more intense efficiency savings are possible with space heating and cooling than other sectors due to the use of passive solar. So we reduce this total as a percent of total consumption by 20%	20.82%
Active solar can save about 85% of that at a price less than twice conventional low temperature applications	17.70%
Quadrillion BTU from active thermal solar in 2050	6.47

Shares of total energy are computed as follows. Share of each usage type as percent of the particular sector (in the sources referenced by endnotes in the table) is multiplied by each sectors share of all energy used[258].

Low temperature solar is almost competitive with natural gas now when supplying from 45%-65% of needs. At 2X the cost of fossil fuel we may be able to supply 85%. To the extent we can't, we can use un-stored, un-backed-up cheap wind electricity to drive heat pumps (ground source where practical, air-to-air where not). When temperatures drop too low for heat pumps to be practical we can rely on high efficiency resistance heating, powered by off-peak renewable electricity, and stored as heat.

The Sun is Burning: High Temperature Active Solar

The same concentrating solar mirrors that can drive electrical turbines can also provide heat for industrial processes. Reasonably priced rooftop parabolic collectors have been developed that can reach temperatures suitable for many industrial processes[300]. However the potential is more limited than with electricity. When it comes to electricity production you can locate plants to sunny climates (such as the clearest parts of the desert) and transmit the electricity where it is needed via high voltage lines. There are a lot of reasons for not relocating massive amounts of industry to the fragile desert ecosystems – for instance lack of water. (Industry needs lots of water.)

While evacuated tube collectors can produce low temperature heat on cloudy days, concentrating collectors produce high temperature heat only in direct sunlight. Also the practical maximum means these concentrators could only serve about 35% of the process heat and industrial boiler fuel market (though they might increase that a bit by acting as pre-heaters). It seems reasonable that we could provide 45% of that 35% - less in some areas of course, but more in others. That comes to nearly 16% of the industrial energy in our high efficiency scenario, or ~2 quads.

Fields of Fire: Land Based Biomass

Biomass may be produced from crops grown especially for that purpose and converted into biogas or liquid biofuel range from 1.5 to 4 times the price per BTU of comparable fossil fuels[301]; as an average say three times the cost. Biowaste as a fuel source ranges from one quarter the cost of comparable fossil fuel to 1.5 time that same cost[301]. You can make natural gas or syngas from biomass, convert it into charcoal as a coal replacement, or produce various liquid products (ethanol, methanol, biodiesel) to replace petroleum products.

How much land based biofuel could we use? We currently obtain a bit over 3% (~3.3 quads) of our energy from biomass in the United States[302]. Much of this is produced unsustainably. Some of it is not even biomass (waste plastic and such). But we discard a great deal more organic material than we use, and as already shown in the material intensity section, we know how to grow crops much more sustainably than we actually do. So it would be reasonable to assume we could continue to generate that sustainably rather than unsustainably, (without compromising the ability to use as much of it as needed for fertilizer or fiber purposes).

One example is corn. If we could use some of the stover from corn we produce anyway, either to produce additional ethanol or methanol or if we dried it and burned it directly as a coal substitute, we could obtain a small sustainable energy yield from such farms without increasing the land used or robbing it of fertility. (Removing between 40% and 50% of corn stover from a field costs it neither structure nor nutrients. In fact we have to take some of it. Too much corn stover on the soil is a nitrogen robber, and can lead to excess soil compaction.)

And corn stover is among the biomass least suited for fiber applications, so we are not competing with fiber either. (Though, stover is a good source for cellulosistic chemicals.) The enzymes required to produce ethanol from cellulose are still extremely expensive; but bio-methanol is around double the cost of fossil fuels, as is direct burning – which can be done comparatively cleanly in fluidized bed combustion plants. So we can extract 3.3 quads from existing cultivated cropland and biowaste.

Is there any way we can increase biomass from croplands? Fuel crops other than corn may be grown through rotational no-till organic methods just as crops for food, fiber and chemical may. In fact certain organic techniques (such as mixing crops) are easier if the product is harvested for fuel than for other purposes. There are a huge variety of crops suitable for energy purposes including switchgrass, hemp, elephant grass, leucana, Eucalyptus Grandis, alfalfa, hybrid poplar, coppice willow. Many of these are nitrogen fixers. Other are tree crops and can be use for soil conservation – mixed with other crops and thus NOT clear cut on harvest.

Of the 57 million acres that have been taken out of production, we already suggested using 17.7 million to produce fiber and chemical needs. Assuming that half should be left completely wild rather used for any agricultural purpose, that would still leave us with 10.8 million acres we could use for such purposes. (Again, as with kenaf and chemical crops, we don't necessarily have to dedicate land only to energy crops – though some areas may be suited to exactly that. We can increase the total crop lands by that amount and in many cases include fuel crops in rotation with other crops. The wider the variety of crops you include in a rotation the more resistance you have to disease and pests.)

Additionally, we are not utilizing most waste straw for fertilizer or fiber. In the short run we could probably generate up to 8 quads from that, giving us a 12.5 quad total. As a way of saving farms (thus making the biggest possible longer term contribution agricultural sustainability – preventing the loss of farmland) it may even be a wise choice. But energy really is not the optimum use for waste straw, given that some of it can help build soil structure, and the rest replace much of the wood used as building material. So we should not count on most of this being available for energy purposes in the long run.

What about unconventional sources? Ecologist David Tilman, at the University of Minnesota has discovered a way to get more net energy out of a hectare of mixed prairie grasses (the more variety the better) than best energy crops[303], about 28.4 GJ/HA on degraded land, about 42.6 GJ/HA on fertile ground. (This means that on eroded land they get about 50% more net energy per acre than corn ethanol, 75% more on good soil.) Part of this increased energy yield is due to the process suggested to convert biomass to energy - Fischer-Tropsch hydrocarbon synthesis - which produces diesel fuel, gasoline, and electricity. The diesel or gasoline is around 2¼ times more expensive than gasoline from fossil oil[304]. (It converts biomass with around 47% efficiency. If energy needed to grow, harvest and transport grasses also comes from this process, this nets 41% of the BTU's that were in the original biomass.) For diesel, which rail and trucking depend upon, this may be the best choice. Two alternatives to Fischer Tropsch could yield the same or better results less expensively - where the products could be used.

Conventional pyrolysis can convert biomass to methanol with around a 50% efficiency - sometimes better[305]. (You can gain another 5%-8% in the form of electricity generated from waste steam.) Methanol can substitute for gasoline, and many other liquid fuels at cost around double gasoline (per BTU). Methanol has a fuel value about half that of gasoline per gallon; many cars can't run on it; but we could put flex-fuel requirements on all new automobiles, so that we could phase in its use over the course of 13 years. Transport tankers and gas station storage tanks have to install special liners and new valves to handle it - again something that could be done over a 13 year period.

There are also environmental, health and safety concerns - all of which can be addressed. Methanol is toxic and dangerous - like gasoline. Unlike both MTBE and gasoline, it is a naturally occurring substance that many organisms have evolved to predate on. If an underground methanol tank leaks, it will seep into the water table where it will be diluted and broken down into less dangerous forms quickly[306] - nothing like the year that is the minimum for MTBE. In the case of surface spills, the same thing will happen even faster. That does not make spills trivial; like gasoline we want to keep the stuff out of the environment and especially out of our water supplies. If really heavy concentrations occur, then (again like) gasoline it can be cleaned up, though via different methods (high temperature steam oxidation, bioremediation or both). In terms of fire safety, pure methanol is indeed more dangerous to store - due to differences in vapors, colorlessness, and tastelessness. However, in practice, the maximum concentration usually advocated is 85% methanol and 15% gasoline (which can come from FT). This takes care of all those problems; so long as transport and storage have been modified to resist corrosion by methanol, the fire safety is equivalent to gasoline[307]. Note that methanol substitutes for gasoline[308]. While diesel engines can be modified to use methanol with efficiencies approaching or exceeding the best conventional diesels[309], maintenance and engine life to date have proven miserable compared to real diesel or biodiesel[310]. There is some work being done on making gasoline engines comparable in efficiency and reliability to diesel. If that was successful then methanol could replace diesel as well.

Biomass can also be converted to charcoal with around 50% efficiency; there may be waste gas not used up by the process to make electricity, as well as waste heat to be used for the same purpose. However it may be that process waste heat either from charcoal or methanol making will be needed for drying the grasses before conversion. Charcoal is much cheaper to make than other alternatives, but it also has more limited uses. The electricity coal and natural gas make can be better replaced by wind, sun and water. 5-7% of coal in the U.S. is used in industrially, over and above electricity making. There is some use of charcoal, as charcoal. Charcoal is an extraordinarily useful soil amendment, building soil structure permanently. And we can probably find some cases where charcoal can substitute for other fuels without compromising efficiency, though mostly people switch from coal to other fuels for process efficiency sake - since coal is the cheapest fossil fuel there is.

Overall the mix would be mostly methanol for gasoline, FT for diesel and gasoline to mix with the methanol, with some percent of charcoal production.

Is there any additional land we could use for bioproduction?

There are about 4 million hectares of land degraded by mining[311] we could produce fuel from by the Tilman method.

We also convert some grazing and rangeland. It is well known that Americans eat more meat that is good for us[312]. While I'm a great believer in small luxuries, could convert 15% of grazed land to energy production (concentrating on cattle land). The land currently devoted to growing grain to "finish" that beef could provide grain and legumes to replace the protein those cattle would have provided, plus. And it would not have to be a hardship, or even require vegetarian meals. Chile and beans , red beans and rice (with sausage if you wish) , split pea (with ham or bacon if you like), much Thai, Chinese, Vietnamese or Indian food, minestrone, Italian wedding soup, and bean burritos are all examples of luxury or comfort foods that get most of their protein from vegetables, but can still include a little meat or cheese for flavor. Eating a few meals like that a week, while still having the rest be heavily meat based would be no great hardship, unless you got tired of all that meat! 15% of range land is about 50.4 million hectares, and could be confined to overgrazed, eroded land, where we should probably stop grazing cattle in any case. This will probably reduce meat production by a great deal less than 15%.

However, there is one other major source for sustainable land based biomass – existing timberlands. If you remember, in the industrial section we suggested ways to reduce to one quarter the use of timberlands for paper, and also suggested ways to reduce wood demand to almost nothing, for a slightly below 93% per capita reduction in timber harvesting. Before the reduction this would have been 408 million acres[108] devoted to tree farming rather than wilderness. After the reduction, that would have meant a bit less then 31 million acres still in tree farms increasing to around 44 million acres by 2050 to match population growth.

That leaves 364 million acres that are either tree farms, or virgin timber scheduled for harvesting; we have made proposals to save all those acres. In the absence of technical breakthroughs in energy storage or cheap renewable electricity, we can use up to another 100 million acres of that for energy production, confining ourselves to short and medium rotation mono-cultures, and leaving 100% of old growth, and natural second growth forest and woodlands untouched.

Ok so how much energy does this add up to? The NDRC thinks we could get nearly 17 quads of energy from biomass[313]. However this assumes greatly increased per acre crop yields, and also use of all waste fiber not needed for soil building. However we have projected saving much more energy by replacing much of wood, and even some plastic and metal with the same waste fiber. Also it assumes greatly increased crop yields per acre - which may be done sustainably or may not. So, cutting this in half to 8.5 quad would be more reasonable.

As a double check a study by the University of Tennessee Biobased Energy Analysis Group projects about 15.5 quads with both increased yield, and massive conversion of existing grazing and timberland to biofuels, about 10 quad with almost no land conversion, but with greatly increased yield[314]. So a projection of 8.5 quads with significant conversion of land, but no increased yields is conservative.

Between crops, grazing land and timberland we are looking at potential of around 8.5 quads of energy from biomass. The only reason we can produce such a high amount of biomass sustainably is because we are phasing out a small portion of meat production, and because we have freed a great deal of land currently devoted to timber and paper production.

I would add that there are a wide variety of ways to process and use biofuels, and that obviously best practices should be adapted. In general corn based ethanol is a farm subsidy, not an energy program; a way of processing natural gas or coal through corn-fields into liquid fuel with either a net loss or a modest BTU boost from solar energy. The best way to convert biomass into usable fuel is FT, methanol, cellulosistic ethanol, biodiesel, and the creation of both charcoal and syngas. In all cases, electricity should be co-produced with the conversion of raw biomass to fuel. In all cases energy input should either be from the biomass itself, or from nearby renewable electricity without long distance transmission or fossil fuel backup.

While all this is technically possible in a very narrow sense there are social issue to consider. For example replacing some food crops with fuel crops may not need to increase hunger look at in the abstract; but in a globalized world market, reducing food production significantly anywhere increases food prices. Look how U.S. ethanol production from corn has increased food prices in both the U.S. and in Mexico. Fuel crops are also replacing food crops in nations in a number of poor nations, driving food prices up in areas where many people are already living on a dollar a day.

Further, in many cases fuel crops are actually increasing rather than reducing greenhouse emissions. In the U.S., extremely low to negative net energy corn ethanol is often distilled in coal powered processes. In Indonesia, palm and other fuel oil crops which do produce net energy also replace old growth rainforest, thus releasing far more emissions than the fossil fuel they replace.

To implement biofuels sustainably on a large scale would require a transformation of the entire international economy. In the absence of such change, we should probably be extremely modest in our use of them.

Putting it together: Grand Total

Including population growth, but not including per capita economic growth, after massive (nearly fivefold) efficiency improvements total 2050 energy demand is projected at around 36.86 quads. Total available potential supply equals ~37.7 quads, around 2% over requirements.

Electricity	
Hydroelectricity	2.84
Geothermal	0.20
Wind energy	As much as we can place
Natural gas + bio or waste gas for backup.	0.4-2.0
Solar thermal electric, photovoltaic, wave, electricity from biomass, other	As much as we can place
Additional wind & sun to make up transmission losses (omitted from total)	[1.36]
Land based biomass	*2.00-8.50*
Low temperature solar thermal	*6.47(or less)*
High temperature solar thermal	*1-2*
Total	**37.77**

As an additional margin of error, this scenario lowers our greenhouse gas production by more than 98-99% per capita - even with up to 5% of energy needs still being met directly by fossil fuel. If necessary we could provide a bit more from natural gas. Note that if we do manage to sustainably produce 8 quads of biofuels then we would need no fossil fuels.

As still another margin of error, this book was begun when oil was under $40 per barrel. To be conservative I assumed a $35 per barrel price. So, paybacks from efficiency measures in this book are now **very** conservative – meaning savings from efficiency would probably be greater than assumed.

Higher: The Mandatory Peak Oil Chapter

It is quite true that there is a finite amount of oil in the ground. We have to run out of it sometime, and before that happens production has to peak and decline.

The oil industry normally estimates that this will happen around 2030. Daniel Yegin puts that date closer to 2020. A number of analysts, including prominent ones in Bush's White House, and leading environmentalists think it may have already happened, or at least is likely to occur by 2010. There is at least some evidence that this view may be right.

The same efficiency measures and renewable alternatives that will solve global warming will phase out oil faster than the worse case peak oil projections require. U.S. domestic oil production peaked in the mid 70s. ~30 years later we still produce 40% of that peak. To solve global warming we need to phase out all fossil fuels almost completely – a 98% or better reduction over a thirty year period. We can't solve global warming without decreasing fossil fuel use faster than oil production drops - just as a side effect.

Don't Stop Thinking About Tomorrow: Research & Development

Mañana is now: R&D and Per Capita Economic Growth

So far we have dealt strictly with what we know how to do now. Current technology could allow us to phase out fossil fuels over the course of 30 years, along with drastically reducing timber harvesting, Portland cement manufacture, and other greenhouse emitting activities at essentially zero cost, while allowing normal economic growth through 2010, and keeping up with population growth thereafter.

There are a number of reasons we want to do better than this. To start with, we do want per capita economic growth, so long as it does not come about at apocalyptic costs, and genuinely benefits the people of this planet. For another, while a 30 year phase out gives us a decent chance avoiding the loss of our industrial civilization or worse, we would like better odds than that. (Think about how you would feel if as the result of a medical visit the doctor were to say in a cheery tone "congratulations – you have a 75% chance of surviving the year.") For a third, relying strictly on renewable and efficiency technology near the current price of fossil fuel requires us to make choices we'd rather not make – such as continued use of hydroelectricity, the use of a larger quantity of biomass than is strictly preferable, and the creation of a fairly extensive additional high voltage transmission network.

As I mentioned before, when we talk about economic growth beyond population, (per capita economic growth) it is reasonable to talk about breakthroughs that are not here yet; the technology to provide that growth, also, is not here yet. Imagine as a thought experiment that technological innovation ceased. You would continue to get per capita growth in developed nations for a while, based upon stuff "in the pipeline" that is not yet implemented. Past that, growth would stop, other than with population - assuming you did not simply force people to work longer or under harsher conditions. So if we are talking about growth all the way through 2050 it is reasonable to assume some technological innovation. Will it necessarily occur in the renewable energy sector? It always has in the past. Besides this kind of thing is a choice not a prediction. If we intelligently fund research and development in a large number of promising renewable sectors, we will get results - not in everything we fund, but in a high enough percentage to repay multiples of total investment. Here are some examples we might consider. This is not a research program, just a very incomplete list of projects worth further investigation.

The single most desirable breakthrough would be the development of inexpensive photovoltaic cells. This alone could bring about a hydrogen present – even without the fuel cell breakthrough usually paired with it. If we could bring down the price of PV down to the point where it produced power for a cent per kWh, (instead of the 25 cents of present), we could produce solar hydrogen for around $13 per mmbtu with existing commercial electroyzers – about 2.3 times the cost of natural gas – within the price we could afford for renewables in the efficiency scenario. This could displace biofuels for industrial, commercial and residential uses. How about transportation? Without inexpensive fuel cells hydrogen is not a particularly suitable transportation fuel. But since we are already looking at drastically reducing transportation energy demand, with a significant portion of that electricity we end up with no more than around 8 quads required for liquid transportation fuel – something we can produce from waste, agriculture and genuine tree thinning that does not take live healthy mature trees, and modest energy farming on existing timberlands - leaving most of our remaining forests untouched.

How hard would such a breakthrough be to make? After all we've been hoping for this for at least 30 years. Well there are never any guarantees. But there is one approach Barry Commoner suggested back in the 70's that a Danish consulting group recently revived. The theory is that the price of solar cells is a chicken/ egg problem. Because demand is low we never get large factories with full economies of scale to bring down the price of solar cells. Because the price is high demand stays low.

The usual suggestion for breaking the deadlock is demand pull – increasing orders to the point where large scale factories could be built. However, the Danish study suggests a large scale supply side approach – building a giant large scale PV factory accompanied by a large scale plant to manufacture solar grade silicon[315]. Currently PV factories buy computer grade silicon, or process computer chip scrap.

The cost would be well below a billion, with a high probability of success and huge potential payouts.

If it succeeded, we could eliminate the need for a huge network of high voltage transmission lines. With cheap enough solar cells you can produce cheap inexpensive electricity almost everywhere – from Southern California to Northern Massachusets. The few places where this is not the case, like Alaska, have low population densities and nearby access to wind, water, geothermal or biomass. With $0.01/kWh electricity, you can mix in large amounts of storage without overall electrical price being outrageous.

Is the building of such a pair of factories really likely to bring the price that low? Initially, the answer is no. Cells produced from such a factory are likely to produce electricity no cheaper than a nickel per kWh – about the same price as fossil fuel based electricity, but not cheap enough for a no fuel cell/cheap electrolyzer hydrogen future. But if solar cells really are a chicken/egg problem then the virtuous cycle does not end with the construction of a pair of factories. Once the demand is there, other manufacturers will compete for the new market, applying some of the research that has been completed but not applied to produce PV at a lower cost. And others will compete with them, and so forth. So we have a very good chance of getting $0.01 kWh electricity out of it.

Even if not, merely producing solar cells through true mass production, and providing a dedicated source of solar grade silicon, thus lowering solar electrical costs to ~five cents per kWh is worthwhile in itself. And frankly I think at least 2 cents to be likely, and 3 cents almost certain.

This does not mean there is no research left to do on PV. The European Commission suggests the following[316]:

1) *Low-cost and high-quality silicon feedstock;*
2) *Optimisation of crystalline silicon process technologies with particular emphasis on cost and efficiency of wafer cell production;*
3) *Thin-film technologies: highly efficient mass production plus an understanding of material limitations, aimed at reducing costs;*
4) *Innovative PV concepts for PV cells and modules which have a potential for large cost reductions (such as tandem and concentrator cells, new materials).*
5) *Research on reducing the cost of other new and innovative components and systems*

There is another path to a solar future besides PV, one that may be easier to reach. Solar thermal electricity runs 11 cents per kWh, and $40 per thermal equivalent of a kWh of storage.

However, the National Renewable Energy Laboratory believes they can lower storage cost from the current ~$40/kWht to around $15/kWht[280] - which would lower storage costs to about a cent per kWh over the lifetime of a plant. There is probably room to lower the cost of solar thermal electricity further as well. If we can do these two things, we can phase out hydropower and avoid most biomass use increase without needing a hydrogen path- though hydrogen remains desirable.

The most critical lack preventing a hydrogen present is not fuel cells but inexpensive electrolyzers. Currently Stuart Energy can provide 75% efficient electrolyzers for arund $400 per KW in 5 megawatt sizes and higher. If we could lower this to $100 per KW then hydrogen could be brought down to around double the price of natural gas even at 3 cents per kilowatt hour (probably attainable via wind in the near future). This is in part another chicken/egg problem. Demand for electrolyzers is not high. A well designed mass purchase program might by itself bring down prices to that level. If not, it would be well worth an R&D program.

What about fuel cells? I’m not as convinced of the centrality of fuel cells as many. We can use a combination of efficiency and other renewables to meet our needs without them. With the appropriate use of electric trains to substitute both for many auto and plane journeys, heavy rail for freight instead of trucks, electric autos, and non-hydrogen hyper car technology, we can run that part of transport requiring fuel on a comfortably sustainable amount of biofuel –so long as hydrogen or cheap renewable electricity is available for industry. (Otherwise we keep hydro for electricity, and end keeping an uncomfortably large portion of tree plantations continuing to operate as such, rather than converting them into forest.) Still having inexpensive fuel cells available would be highly desirable. They would help increase the efficiency of Hypercars, just as Amory Lovins suggests. Without cheap hydrogen they could still cut carbon emissions during the transition to a renewable society. With cheap hydrogen, that is cheap renewable electricity and cheap electrolyzers, they constitute an inexpensive source of massive amounts of reliable renewable electricity.

They are not as mature a technology as solar cells or electrolyzers, and I’m not completely convinced that fuel cells are a chicken/egg problem rather than something requiring more research. But such research would pay in a number of ways. For one thing, developing an inexpensive fuel cell would almost certainly develop an inexpensive PEM electrolyzer (the most efficient and currently the most expensive type of electrolyzer) because they are by definition the same problem. Extracting most of the available energy from hydrogen in the process of chemically converting it back water (rather than simply burning it) is a lot more difficult and complicated problem than using electrical energy to convert water into hydrogen and oxygen. If you can do the first inexpensively, you can do the second even more economically.

Hydrogen’s main potential value is not for transportation, though that is often suggested, but as one possible means of electricity storage, and as a source for high temperature industrial processes.

As we saw in earlier sections hydrogen is not the only potential means of storing electricity. Today's flow batteries offer lower costs than hydrogen as a means of electricity storage, and a higher round trip efficiency than hydrogen is ever likely to have. Research and development can lower the cost of hydrogen storage – but this is true for flow batteries as well. And even more than with fuel cells; research is definitely needed, it is not a simple chicken/egg problem. I contacted a leading flow battery manufacturer (VRB associates) to ask them how much larger batteries could lower the cost. They told me that they thought $225 per kWh was their current limit, that beyond that you run into diseconomies of scale. No doubt mass production could also bring costs down. But multi-megawatt batteries are not like automobiles. There are limits to how many you will ever produce in a year. In short to bring flow battery costs down will require major research investments, not merely demand pull – just as with fuel cells.

In terms of automobiles, lithium ion batteries for electrical vehicles are much closer to commercialization than fuel cells. It would not take much to bring them down to a reasonable price for auto use – making hybrid EVs or plug-in hybrids possible. A hybrid EV or plug-in hybrid relies entirely on stored grid power for short journeys, fuel for longer ones.

We also need greatly increased research into reversible chemical reactions for storing thermal energy – high temperature heat, low temperature heat and cold. A lot of efforts have focused on phase change, and they remain promising, but such reactions as metal hydrides and zeolites deserve more attention. Low quality natural zeolites may be as effective as high quality synthetic ones for storing thermal energy below the boiling point of water - which might make solar energy practical for close to 100% of low temperature needs.

In addition to solar energy, there is a tremendous untapped in potential in wind class 4 and below, probably accessible only via small wind. Right now small wind is much more expensive than utility scale wind farms (per kWh), but if the price can be brought down it has about 20 times of potential of wind farms – another possible path to a hydrogen future (which requires electricity cheaper than fossil fuels rather than merely competitive with them). So far efforts at small scale wind have focused either on conventional horizontal turbines, or on unconventional vertical ones – with neither resulting in the cost reductions we need. The Selsam wind turbine uses multiple horizontal style turbines on a tilted tower – getting some of the low capital costs of vertical wind, and some of the higher efficiency of horizontal ones[317]. (It has potential for utility scale wind too.) As in any R&D there are no guarantees, but basically we have a cost/output curve of which only the extreme ends have been tested. This turbine explores the whole area of the curve in between. It is at least possible that this will discover a "sweet spot" – a compromise with a lower cost per kWh hour than either extreme. Any R&D funding trying to lead to a renewable future should seriously consider this project.

Of course we should not just turn to small scale. Utility scale wind is already competitive with fossil fuels, and the potential, (though not as great as small wind) is more than we need. There is no reason to think we have come to end of the potential for lower large scale wind costs, and we need continuing research in this area as well. One possibility is gyromills (essentially tethered helicopters with wind generators attached) A gyromill can reach much higher than a tower, accessing high altitude rather than surface winds. Significant wind power can be tapped almost anywhere through this means. Unlike surface mills, gyromills can approach 80% of nameplate capacity. The power required to keep the mill in the air is a tiny portion of that generated. This has been demonstrated on a small scale. One major problem, stability, has been solved recently by adding more rotors – since unlike a helicopter, a gyromill does not actually need to travel. There is even one company who thinks gyromills are ready for commercial deployment, and could produce wind electricity at an unsubsidized cost of less two cents per kWh[318]. Though entrepreneurs are optimists by nature (at least in public), it sounds like financing a pilot project would be a worthwhile use of public funds, followed by encouraging deployment if the cost and output projections proved anywhere near accurate.

Although wind power is environmentally benign compared to any other means of generating electricity, this does not mean it can't be improved. We do need to continue to study bat, bird and insect protection.

Related to wind is wave power. It is not yet commercially priced, and the near term potential quantity is not nearly equal to that of wind or solar. But it has one advantage that makes it very promising indeed. Wave power is extremely reliable – not up to that of hydropower or geothermal, but very much greater than that of wind or solar without storage. Inexpensive wave power added to a renewable mix would significantly reduce the amount of expensive stored electricity needed. So bringing its price down is important even if it could supply only a small portion of total electricity needs.

We need a great deal more research in biomass as well. This includes: less expensive enzymes for less expensive production of cellulosistic ethanol, along with better and less expensive enzymes in general for biomass production, better gasification processes, better bio-refineries to co-produce chemical, pharmaceutical, food byproducts and energy production, integrated biomass production and processing facilities. We also need more research on more sustainable ways to generate biomass – low impact and especially low water; we need lower impact ways to process biomass as well.

Related to this, we need to find out if the high energy, resource, and land efficiency of biointensive agriculture can be duplicated or even approached without the high labor costs. Because of my background, my instinct is to look at robotics, cybernetic, computerization and data processing technology. But, as with no-till agriculture, the breakthroughs there are just as likely to occur via simple common sense questioning of assumptions. Approaching the problem from the other end, hydroponics is already an extremely water and labor efficient technology; we need research to lower its high capital and energy costs.

There is a related study that would be worth doing – a cultivatable and recoverable land survey. In many poor nations cultivatable land is simply held out of cultivation, to drive up the future price for purposes of real estate speculation. (In the rich nations this is not as common – the land already is valuable and there are usually short term ways to exploit land for which you have other long term plans.) Secondly, while a great deal of lost farmland is truly lost, some of it may have been eroded or damaged in other ways without having been permanently converted to other uses. There are well know ways to rebuild the soil on eroded land; sometimes even poisoned land can be recovered – and land that is too toxic to grow food on might still be suitable for energy biomass. Lastly a great deal of land in nations with hungry people is used to grown coffee and flowers and other non-food luxury crops – though in absolute terms the FAO figures do not seem to suggest they account for a large percent of world crop acreage[319].

We also need more investigation of kelp and algae and other ocean and water based biomass. Right now it is way too expensive to be a source for anything but chemicals, pharmaceuticals and luxury foods – products that sell at high prices per kilogram. But if the price could be lowered the sustainable potential is much greater than that for land based biomass. And to the extent that such material is grown in polluted water rather than fertilized it actually helps reduce eutrophication and clean the oceans of some of the damage we have done to them. Deliberate fertilization, as sometimes proposed, is probably not sound.

We need more research in high temperature solar applications for process heat. Dish concentrators can produce heat above 750 Fahrenheit degrees, but very expensively. If it could be done cheaply, that is another large portion of industrial needs that could be met by high temperature solar. Related to this, inexpensive long term storage of high temperature heat is an area that needs more funding.

While we already know how to make huge efficiency increases, the potential for improvements there is high also. We need more research on enzymes and catalysts that allow the huge number of chemicals involved in industrial production to take place at lower temperatures and for shorter times.

A great many production facilities include a few steps out of many that require energy or material intensive processes - ultra clean environments, highly toxic solvents, very high temperatures. More development of mini-reactors which isolate these steps from others in small tightly controlled environment could save huge amounts of energy, water and materials - especially in the chemical and electronics industries.

In these same industries (and many others) super-critical carbon dioxide might provide huge savings as well. It can substitute for toxic solvents in a great many contexts, and is much easier to keep ultra-pure than water – whose ultra-purification requires substantial energy.

Currently high strength carbon fibers are very expensive to produce in both money and environmental damage. Lowering both costs could allow them to widely substitute for steel and other metals – providing a huge energy and environmental savings.

We need to continue research into high temperature superconductors (of course) to lower transmission costs and risk for electricity. They are currently commercially competitive in certain limited instances; if their costs could be lowered and efficiency improved they have a great deal of potential.

Similarly we need more research into electroactive polymers, which might allow us to literally print lightbulbs, computer monitors and other electronics where nano-second response times are not required.

All of the above are comparatively short term. But we have seen in the past that “blue sky” research based on a large scale vision often pays off. So let’s include a couple of “big picture” long term projects just to show that they fit in as well.

One field we are already putting a great deal into is nanotech - and we should. We have every reason to expect this field to produce low cost solar cells, low cost environmentally sound electronics, low cost electrolyzers for hydrogen and possibly low cost fuel cells. However there is one aspect of nanotech we are not putting enough effort into – how dangerous the waste is and what needs to be done about it. The current and near future versions of nanotech, unlike portrayals in some of my favorite science fiction, mainly focuses not on bacteria and virus sized machines, but on how materials act when processed into very tiny fibers, crystals, tubes and other nanostructures. Carbon, silicon, glass and metals (just to name a few examples) behave in very different and often useful ways when formed into such structures, compared to their normal forms.

Now any manufacturing process produces some waste; nanotechnology usually results in scrap nanomaterial. We are talking about scrap carbon, glass, metal or silicon – all pretty harmless sounding stuff. And maybe it is just as harmless as it sounds. But just as common materials behave differently in useful ways, when formed into nanostructures, they may behave differently in harmful ways as well. The point is, we don’t know. Nanotech has so much potential; we do not want this infant industry to make the same mistake other high tech industries have, and smugly assume their waste products are harmless or that the problem of waste disposal will be solved without effort on their part. Test your material now; find out how harmless it really is; if it is not harmless find out how to turn into something that is. Apply the old business cliché and be proactive.

Is this a real concern? Well bear in mind we see many harmless materials turn dangerous even at the macro level when formed into ordinary small fibers. Cellulose and glass are among the least toxic non-food substances known. But when turned into cellulose fiber for insulation, and fiberglass for many purposes, you do not want to breathe them. Cellulose and fiberglass insulation are always sealed off from building air when properly installed. Workers who install the stuff wear masks and protect themselves in other ways, or they do if their employer cares about their health, or if they have the leverage to force their employer to care. Note that we have not stopped using either material. As a society we investigated what the dangers are, and know how to take appropriate precautions.

That I'm sure is all we need to do with nanotech - find out what the problems are. In some cases there probably won't be any. In others only simple fixes will be required. Some substances may require elaborate precautions or complex post processing. And isn't it better to know that in time not to kill a lot of people and ruin the reputation of an industry that could save us all? Spend the effort now to find out what problems it might create and how to solve them.

Another place I think we need to put some research money is into the space program. One possibility that requires trivial funding compared to the benefits is the space elevator or beanstalk. An elevator to space could get us there and back again a lot less expensively than space shuttles – if it worked. Admittedly that is a big if. There are many problems to be solved – developing the nanotubes to make that large a structure self-supporting, protecting against micro-meteors and space debris, protecting against differential winds, and corrosion from exposure to various levels of the atmosphere, find ways to ensure ultra-long fibers can be free of flaws. But some very serious people think it could be done.

And cheap access to space could provide a lot of benefits even with our 30 year time frame – solar energy that is reliable and predictable, cheap vacuum, a place to produce exotic materials without a biological environment to disrupt. What if it fails and you can't build a beanstalk? Well even then the research needed to make a serious attempt would probably give you nanotubes and a number of useful results. The potential spin-offs, even from failure, and the spectacular rewards of success might make this a project with a very good potential risk/reward ratio.

But I also think it is important to our growth as a species; it will help to make us better people. When I was very small and humankind made it into space for the first time, my late father wrote some verses on the subject. I still think it expresses something very important:

I can hear the planets ring!
I find joy in everything!
And there's no more room in living for tears!
I am glad for every breath!
Life was never meant for death!
And I want to live a million more years! I want to live a million more years!

The whole human race is my family.
I have brothers and sisters wherever I roam.
This little green globe is just too small for me!
So I count the great wide universe as my home!

We have lost that joy somewhere along the way, replaced it with an ecstasy of hate. I think it is time the human race make another attempt to become space people.

Now again, none of the above is a research agenda. It is simply some examples worth considering. A real research agenda would be laid out by experts in various fields to maximize results. But the principles, I think, are the ones a real research agenda would follow. Invest intelligently in a variety of promising approaches, and you will get good enough results from the successes to outweigh by many times what is lost to the failures. (It is rather like oil drilling, where the successful finds make up for the dry holes and the productive but uneconomic wells.) Mix short term practical projects with visionary blue sky possibilities – sometimes the low hanging fruit is as sweet as it looks; sometimes the wild and crazy big ideas produce the best results.

Hello Tomorrow: R&D II - Adapting to the Greenhouse

So far we have dealt with preventing global warming. But of course nearly one degree centigrade of it has already occurred. Even if we start comparatively soon, it is unlikely we will muster the political will anytime before 2010, and by the time we phase out fossil fuels, it is nearly certain that a second degree will have occurred. A feedback cycle may have already begun that will take us beyond that. And if the carbon lobby has its way we won't start anywhere near as soon as 2010.

I'm optimistic. I don't think the feedback cycles are so great as to be uncontrollable, and I think starting by 2010 will hold our losses down to a level our species and civilization can survive. But we will lose a lot, and we need work out how to adapt to it.

One of the big losses has already begun – water. We have less fresh water available where it is needed worldwide each year. Not of all this is due to global warming. We over tap aquifers, and recklessly contaminate freshwater sources with toxins. But we are also getting less snow pack in mountains, less rain where it would recharge aquifers in climates that need water most[i]. (We also get more rain in humid climates where there is no shortage of water. Of course some cities in rainy climates still depend on snow pack for fresh water. So, to take an example near where I live, Seattle may someday suffer a flood and a drought simultaneously.)

The material intensity section outlined some techniques to greatly increase production per liter of water. After all we have plenty of water for drinking, cooking and washing. (There are people without any of this of course, but they could be provided it at an absurdly low price. That anyone in the world goes without clean drinking, cooking or wash water is an example of hideous cruelty and injustice; for these purposes there is no shortage - only deprivation.) We may run short of water for agriculture and industry – even with a factor four productivity increase in its use.

There is a technique that is well known, and actually in fairly widespread commercial use - reverse osmosis desalination. It is very expensive, but a mature technology. It is very well suited to wind-power, since it essentially consists of pumping water through very fine filters which filter out the salt and let the water through. This might be a prime use for offshore wind – a market for the electricity right at the point of production. Similarly if wave power became practical, this would be an obvious application for it as well. (In fact most wave research assumes co-production of water and electricity, rather than producing either singly.)

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[i] Rainfall and snow pack have natural long term cycles. So we don't know how much of the current drop is due to global warming, and how much is due to the end of a peak.

Of course there is more research needed on reverse osmosis. While energy is one major cost of converting sea water into fresh water, it is not the only significant cost. Reverse osmosis filters are expensive, and don't last long. We need to improve this as much as possible, either by making the filters cheaper, making them last longer, or making them recyclable, or better yet, regeneratable. All of those at once would be nice of course. They have already improved a great deal. As energy efficiency improves for reverse osmosis, we not only save energy costs, but capital costs in the huge pumps they require as well.

Other adaptations are more development than research; we need better public health to make up for increased exposure to exotic disease; we need to restore wetlands, build up levees, and generally learn to prevent, mitigate and recover from the increased numbers of natural disasters .

One consequence we have already talked about of global warming is increased energy in the atmosphere. While in most respects this is bad news (very few climates will be improved by higher winds) it is good news for wind energy; many areas that are currently not suitable for wind power will become suitable as class 3 wind areas become class 4 wind areas, and class 4 wind areas class 5 wind areas. This is not an unmixed blessing even for the wind industry; you can't run a wind generator in a hurricane or even winds of above a certain the speed (what that speed is depending on the wind generator). Still, overall, commercially exploitable wind resources will increase.

If Tomorrow Never Comes: R&D III – Ignoring the Greenhouse

Much of the carbon lobby suggests that it would be less expensive and more humane to do nothing about reducing global warming - simply switch to coal (of which we have plenty) and adapt to the changes that would come.

Obviously I don't favor this approach, but I thought I'd be helpful to the other side, and put forward some specific proposals.

To start with in an unmitigated planet greenhouse you would have weather more than climate. It would tend to be much warmer on average, but would still get frosts and snowstorms unpredictably – some of them in places you currently don't get snow. You would get more droughts in dry climate, more floods in wet places (with an occasional switch just to keep things interesting). Insects would flourish on a warmer planet and pests of all types would migrate. And of course storms would be worse than at present, and the average wind speed would be significantly higher. This has interesting implications for agriculture. Finding crops that are simultaneously drought and flood resistant, adapted to high temperatures, but able to survive low temperatures, and that are usable by humans as sources of complete protein and moderately concentrated carbohydrates (comparable to grain or roots) makes for a fascinating challenge.

One possibility is to learn how to grow most of our crops indoors. Some parts of Scandinavia grow a large part of their fruits and vegetables in glass houses, but I don't know if any nation has ever tried to raise a significant amount of its grain and animals that way. For at least half a century, there have been proposals for geodesic and inflatable domes miles in diameter, but no one could ever come up with a good enough reason to build one; ignore global warming long enough and we may get one. I'm sure the people of this country won't mind having a quarter of it domed over. At any rate if we really intend to do nothing towards prevention, we need to investigate more seriously the cheapest way to deploy this well-known technology, and the cheapest way to climate condition these farm bubbles. We can research means to improve our hydroponics technology too, since hydroponics minimizes water consumption.

In case this fails, an alternative possibility is leaf protein. With a centrifuge you can extract protein from just about any kind of leaf on any kind plant. So we could simply plant "farms" with whatever kind of biomass we can get to grow and use wind powered centrifuges to extract the protein which we would then treat and store. Currently leaf protein is extremely expensive compared to meat; we need a way to bring the price down.

Also leaf protein is currently extracted from crops planted for just this purpose. An outdoor “farm” adapted to a greenhouse climate would consist of mixed plants. These would not be separate rows or beds or even in the more complex arrangements we find in permaculture and biointensive gardening. This would be a variety of species completely mixed; suitable for differing climates. The idea is that some varieties would flourish and others fail depending on what the weather that year was suited to grow. Any wild volunteers would be welcomed; in a planet greenhouse farm there would be no such thing as a weed.

Now leaf protein is already expensive compared to animal protein, since it requires more extensive processing than normal vegetable protein. Extracting the protein from mixed leaves of a semi-random variety will require some additional research.

If eating leaves does not appeal, there are other possibilities. Blue green algae – (spirulina) is both a protein and a carbohydrate source that can be produced in a wide variety of climates while requiring less water than conventional agriculture. It is still fairly expensive compared to normal animal and vegetable protein sources, and would require more research to bring those costs down.

There is one possible protein source that will actually increase on planet greenhouse – insects. We even know how to prepare them; there are organizations devoted to insect eating already in existence that have developed extensive recipes; some are reputed to be quite tasty. The trick here is harvesting. Most technology we have for dealing with insects involves killing or discouraging them. We need to learn how to capture them un-poisoned in large lots, if we really intend to live on unmitigated planet greenhouse. Possibly worms would be easier to do this with than flying insects; and snails are already well known as a gourmet treat. So that is good news for people who don’t want to live on leaves and pond-scum; we can eat bugs instead.

Ah, but there is one other thing we should consider. What if the same people who oppose doing anything to prevent the worst effects of global warming from happening don’t want to spend the money to learn to live with it? What a surprise that would be! Well there is still one area they would still desperately need to research.

If nothing is done to prevent the worst global warming, and no serious research is made in adapting to it, then you will eventually have the world food supply cut by at least one half, probably three quarters and possibly 90%. Of course the industrial infrastructure will also be seriously impacted. The remaining people will be pretty busy improvising adaptations without a lot of preparation via prior research. So you will not have a lot of people available with free time to dispose of the dead – no more than one per thousand corpses, probably as few as one per ten thousand corpses.

Now this will be a serious health hazard to the living, (presumably those who favor doing nothing to prevent global warming). In that case we need to develop techniques whereby one person may find and permanently dispose of a thousand or more widely scattered corpses per day unassisted. This may bring up thoughts of Soylent Green, but large scale exo-cannibalism is not actually a practical disposal method. Cannibalism tends to produce all sorts of exotic diseases to begin with. But eating corpses that have died of natural causes, especially when they are not fresh would be an extremely unsafe alternative. Because this is addressed to the carbon lobby, mentioning these practical considerations is important. I've never seen signs of ethical standards that would rule out their eating human flesh.

I do hope those who oppose mitigation of the global warming, and support simply adapting to it, find these suggestions helpful.

Objections

One thermodynamic criticism is often made of renewable sources – by anti-environmentalists, and even environmentalists such as George Monbiot. Renewable energy can never match the economy of concentrated hydrocarbons they argue; there may be a lot of it, but it is too sparsely distributed. This overlooks the fact that a great deal of effort in our society is spent to distribute them in non-concentrated, decentralized forms.

For example the electric grid is used to take the output of large electric plants and distribute them a few kilowatt-hours a time to multiple users. Similarly gas utilities distribute gas for heating and cooling. Filling stations distribute refined petroleum in the form of gasoline and diesel fuel to multiple cars and trucks. It would be a lot easier to produce energy in a distributed manner for distributed use, and concentrate it for the few (mostly industrial) cases where we need huge quantities of energy in a small space.

Renewable critics also point out how many square miles would have to be covered with solar cells to supply all our electricity, let alone all of our energy. There are a lot of reasons PV cells may not be presently able to supply a large percent of our energy - but lack of land to put them on is not one of them. Solar cells on rooftops, south walls, and parking lots alone could supply a lot more electricity than the U.S. uses. So could U.S. roads. There are some arguments worth considering against doing this (yet). Lack of environmentally sound places to put solar cells is not one of them.

In general land use arguments against renewables don't make sense. For one thing solar and wind don't actually use more land than many of our other sources. For instance, according to the DOE, a concentrating solar thermal plant would require less than 10% of the land consumed by the Grand Coulee Dam to produce the same amount of electricity[320] . Similarly, if land destroyed by mining is taken into consideration, CSP also uses around the same amount of land that coal plants do[321]. PV, even when not installed on rooftops and other existing human built structures consumes less land than CSP. Wind uses more land than solar, but uses it more lightly. Overall it does not seem that there is a reasonable land density argument to be made against solar and wind.

What about storage techniques such as pumped storage? Pumped storage to hold ten hours average consumption at today's rate would require less than 4,000 square miles compared to the 43,600 miles currently used to generate hydroelectricity, or the 92,600 consumed by all the dams in the NID inventory[322].

Another argument is that a lot of the proposals are already being carried out to some extent without solving the problem; that does not invalidate the fact that if carried through completely they can save or produce a great deal of energy. What we need to exceed is not our best current operating procedures, but our current average efficiency. If comprehensive adaptation of a widely used technique can raise that average high enough, then so much the better.

Answer at the End of the Line: Technical Conclusion

We could power the U.S., the most carbon intensive society on the planet, via carbon neutral techniques at a lower price than energy is provided now - allowing for population growth, and using existing technology. For economic growth over and above population increases, R&D potential in the field of alternate energy can more than match potential technical changes in other area.

Politics and Economics of the Transition

Two questions arise: if efficiency measures and renewable energy can replace fossil fuels at comparable prices, what is stopping us from doing it now, and what needs to change? A full answer would require a book in itself; in fact I've written it - the companion volume to this one *No Hair Shirts: Money and Politics in the Fight against Global Warming.* But it would be unfair to end without at least a hint of economic and political solutions to match the technical ones. For brevities sake, I'm simply going sketch a small part of the economic and political arguments – without proof, and without even much evidence. For such evidence, as well as a lot more detail on the political economy of both the problem and the solution read *No Hair Shirts*.

The conventional wisdom about things like global warming and air pollution is that a good part of it is caused by a lack of full social pricing. That is, coal plants owners hurt people other than the owners; and the owners don't have to pay for any of that damage. After all, if someone else is picking up certain expenses for you, you have no incentive to minimize those expenses, and in fact have every reason to incur more of those expenses if you can trade them for others which you do pay. Like a lot of conventional wisdom, this is quite true.

But a something else must be preventing a lot of the savings in this book from being realized; because a great many of the efficiency measures outline are less expensive than conventional alternatives, right now, and were less expensive even when oil was $35 per barrel. Lack of full social pricing, is not the reason savings with payback periods as short as two weeks are sometimes omitted.

In economic jargon, we would say that energy demand has low elasticity in response to price signals. Translated into English, this means that when the price of energy rises, demand drops but not by as much as you would reasonably expect.

Most economists who pay attention to energy economics do recognize that energy demand does in fact have low elasticity in response to price increases. And the reason for this in the short run is uncontroversial. While there are immediate things people can do to save a small percent of their consumption in response to price increases, major reductions require either capital investment or major sacrifices. For example, while we can turn down the thermostat up to a point, in sub-freezing weather we can only turn it down so far. If we want to save energy past that point we either make an investment in insulation, or take the risk of freezing to death.

What there is more argument about is why even in the very long elasticity seems too low. Why, when making capital investments, do investors overlook opportunities for incrementally tiny additional expenditures which have very high rates of return?

A number of reasons are suggested; for example there are split incentives – such as insulation in rental units. A renter has strong disincentives to insulate, because she may not be in the same unit to take advantage of the investments, and does not wish to simply make a present of a capital improvement to her landlord. A landlord paying for insulation will be saving the tenant money, not herself.

There is differential access to capital. For example a homeowner borrowing to insulate her attic is drawing down on a much more limited stock of credit than a utility borrowing to build a power plant or gas pipeline.

Most cost accounting systems (even ABC cost accounting systems which are still not the dominant accounting method) don't allocate flow costs such as energy properly – which means the people who actually control the costs won't necessarily get credit for any savings they produce. Essentially, we have split incentives within firms.

In all fairness there is a small minority who insist that there is no problem; they claim that a number of factors justify low investment in energy savings. One is that since energy is a comparatively small percentage of costs for most companies and individuals (even though high in absolute terms), high transaction costs for such savings lower their value. Another is a claim that energy efficiency techniques don't really provide equivalent services – that energy saving bulbs provide worse light, and that in general efficiency techniques make up in lowered quality what they save in energy. Lastly they point out that energy savings often translate into lower dollar savings than you would expect; energy bills include fixed costs that don't drop with energy consumption; so cutting energy use by half lowers energy bills by less than half.

However a large number of companies have instituted energy saving programs that pay back all costs (including additional administrative costs – the "transaction costs") many times over in a very short time – so for the most part the transaction cost argument does not wash.

Most of the time energy efficiency techniques improves rather than lowers quality. For example, it is true than many people find compact fluorescent bulbs provide worse quality light than incandescent. But the single biggest potential for efficiency in lighting is not in residential, but commercial buildings. And most commercial light already is fluorescent. Savings there are through using better grades of fluorescent bulbs, reflectors, dimmer switches to allow employees to adjust the brightness of ambient lighting to their own taste, the provision of desk lamps or other spot source employees can aim where they want, and the use of day-lighting – letting in natural sunlight. Every one of these steps is pretty universally agreed to improve lighting quality, and the human comfort compared to conventional fluorescents.

Lastly, fixed utility costs are real – but significant efficiency improvements still provide substantial payback, because electricity and fuel use charges are significant over and above fixed costs. Also many energy efficiency techniques provide more non-energy payback than energy payback. For example, better light in commercial buildings provides much more payback in productivity increases and reduced maintenance labor than in lighting energy.

For these reasons the majority of economists agree with engineers and energy experts, there are real energy saving opportunities being missed without justification. In the words of Amory Lovins, industry is leaving "$10,000 bills on the floor".

So what is the policy answer here? And what are the politics?

Well the usual suggestions are various forms of green taxes - driving energy prices up with carbon taxes, or the failed Kyoto style tradable permits. A price on carbon will have to be part of the solution, but in the face of demand inelasticity it cannot be the main approach. Raising prices and doing nothing else does not prevent leaving $10,000 bills on the floor; it just increases their number. Serious policy to solve global warming will have to include significant and public works components and regulatory components.

Public works are required because a lot choices required are NOT ones individuals can make. No amount of green taxes or regulation will provide light rail to transport people, or heavy rail to transport freight. A regulatory component is needed because we don't want to simply provide every kind of good and service publicly, but still face the problem of demand inelasticity – which leaves the only choice in such cases regulations that specify ends, while leaving means to individuals. If we seriously want to tackle the problem, significant regulation and public works will have to be part of the solution; paradoxically there the regulatory aspect may often prove the least coercive component.

At any rate regardless of what policy is used, phasing out U.S. fossil fuels will not be free. Oh the net cost will be zero; we will save more than we will spend. But, the expenditures will largely be capital expenditure, while the savings will be operational; we will have to invest money up front in order to gain a continuing flow of savings over many years – a lot of it public money.

How much money will this take? The New Apollo Alliance suggests spending $30 billion dollars per year the course of ten years on wind generators, solar roofs, and efficiency measures. But their goal is modest – focused mainly on oil. To almost completely phase out fossil fuels in the U.S. would probably cost around $150 billion dollar - $300 billion per year – for thirty years not ten. Now that is a lot of money; but aside from the fact that we would get it back, it is also something we can easily afford. For example, it is much less than we spend on the military each year. It is a tiny fraction of the cost of tax cuts we have given to millionaires and billionaires. It is less than a third of 2005 energy expenditures.

Five years into such a program, the annual value of energy saved will exceed annual public investment – though some of the savings will be a result of regulation and incentives rather than only public spending. Fifteen years from the beginning, total value of energy saved by public spending alone will exceed the cost of that public spending. Twenty years on, it will have paid back all costs including interest. And that assumes $35/barrel oil (which we will never see again) and no increases in other fossil fuel costs.

Now comes the hard part; politically given that conservatives are currently the dominant force in U.S. politics how are we going win this? $150 billion dollars a year in domestic public spending is not going to be popular with any conservative movement, nor are energy efficiency regulations.

Authors Michael Shellenberger and Ted Nordhaus, who helped found the Apollo Alliance give a hint as to how to approach this in their famous essay "*The Death of Environmentalism: Global warming politics in a post-environmental world*"[323]

Without agreeing with everything they say, I think they make one key point. The changes needed are too big to deal with as just an environmental view. But a lot of other movements to make this nation better are in a similar situation. Women's rights, ending racism, saving and expanding union rights, equality for GLBT and for the disabled all require changes that are too big for the individual movements to win by themselves. Further, none of these movements can win in an America moving ever further to the right. Every one of them requires stronger democracy, and strong state intervention on the side of the little guy against large private institutions. Most require significant amounts of public spending.

So this redefines the problem; it is not how the environmental movement gains support for technical and political solutions to global warming, but how some sort of alliance or coalition between labor, feminists, GLBT, anti-racists, the disability rights movement, and environmentalists combine agendas to win on broader progressive issues. In other words we need a progressive movement; a climate coalition will be able to make significant contributions to such a movement and make significant demands on it – but both the contributions and demands will be as one group among many other equal groups, not as a keystone. Climate disruption will not be THE central issue.

In "No Hair Shirts" I argue that the very size of this challenge gives us a shot at winning. People from every movement are realizing the need for some type of coalition. In that book, I compare it to baboon troops moving closer together in the face of predator pressure.

Appendixes

Hot Lies and Cold Facts: Global Warming Deniers vs. Climate Science

Powerful interests, cranks, and honest dupes continue to dispute the mainstream scientific consensus about global warming. Unfortunately we have to take the time to counter their propaganda - a victory for the carbon lobby. It is as though we were in the midst of trying to seriously improve public education, and suddenly had to stop and fight an attempt to remove the theory of evolution from biology text – oh wait…

Usually on catastrophic environmental issues, you consider the precautionary principle - weighing very small chances of catastrophe against great harm if they occur. Global warming is on the same scale, but with overwhelming rather than tiny odds of disaster if unchecked. It is rather as though a group of small children found a loaded gun - one with twelve chambers, eleven of which contain bullets. They decide to play Russian Roulette anyway; after all they might get lucky and pick the chamber without ammunition.

The greenhouse effect exists. As a bumper sticker says about the speed of light "186,000 miles per second; it's not just a good idea; it's the law." Most sunlight penetrating the earth's atmosphere to reach the surface does so in the form of visible short wave light. When it reaches the surface, much of it is converted into longer wavelength thermal energy - infrared. It tries to bounce back out into space again, but some of the longer wavelength energy cannot penetrate the carbon dioxide and other greenhouse gases in the atmosphere; thus solar energy is trapped and helps heat the planet. If greenhouse gases did not produce global warming the surface temperature of the planet would be too cold for humans to survive. The average surface temperature would slightly less than zero Fahrenheit degrees, instead of the nearly sixty Fahrenheit degrees it actually is[324]. The greenhouse effect is about as controversial as the round earth hypothesis.

Deniers seem confused about where the burden of proof lies. Basic meteorology tells us that increased levels of greenhouse gases lead to increased global warming. Fossil fuel use increases greenhouse gas levels in the atmosphere. All data available, including some of extremely high quality, shows that greenhouse gas levels and temperatures are rising. If deniers want to argue that warming is not occurring, or that something other than greenhouse gas level increases is the primary cause, the burden of proof is on them to suggest a plausible explanation and provide evidence for it. It is not the responsibility of mainstream science to take the time to demolish every evidence-free wild speculation they invent - although so far this has been done.

Not only the Intergovernmental Panel on Climate Change of the World Meteorological Organization and the United Nations Environmental Programme expressed consensus on the dangers of human caused global warming[325]. So has every scientific society in the U.S. with climate science expertise[325] including National Academy of Sciences, The American Meteorological Society, the American Geophysical Union, and American Association for the Advancement of Science. Further, between 1993 and 2003 the ISI database lists not one paper disputing global warming published in English language scientific peer reviewed literature[325]. (I'm sure a few have sneaked into obscure publications with careless editors.)

Global warming denial is a propaganda ploy, not a scientific position.

For example, deniers argue that an increase in greenhouse gases from fossil fuels will not significantly warm our climate. After all, atmospheric water vapor is directly responsible for far more of the greenhouse effect than carbon dioxide, methane, and other extraction and combustion products. Sadly, when such gases warm the air just a little, the atmosphere absorbs more water vapor - multiplying the effect into a significant one. In short, it is the other greenhouse gases that determine how much water vapor the atmosphere holds.

Deniers also claim that plants will absorb the extra carbon through normal processes of photosynthesis. Plants breathe carbon dioxide the way we breathe oxygen; increased carbon dioxide, in the absence of other changes does increase growth. Many commercial greenhouses use this principle. Unfortunately, exposure to temperatures they are not adapted to, more violent storms, and disruptions in water supplies, and increased insect populations higher average temperatures encourage, will destroy far more plant life than increased CO2 can encourage. There is also evidence that prolonged unbroken CO2 increases may limit the ability of most plants to use micronutrients, leading to an actual decrease in plant growth[326].

Let's compare theory to data. From the same NASA page cited earlier[324]:

> *According to the Intergovernmental Panel on Climate Change (IPCC), since the industrial revolution, carbon dioxide levels have increased 31 percent and methane levels have increased 151 percent. Paleoclimate readings taken from ice cores and fossil records show that these gases, two of the most abundant greenhouse gases, are at their highest levels in the past 420,000 years.*

So we've added significantly to the amount of carbon dioxide (and methane and NO2) in the atmosphere. Theory says this should have increased water vapor in the atmosphere and therefore temperature.

Citing NASA again[324]:

> *Temperature data gathered from many different sources all across the globe show that the surface temperature of the Earth, which includes the lower atmosphere and the surface of the ocean, has risen dramatically over the past century. The IPCC estimates the increase has been between 0.4°C and 0.8°C. Worldwide measurements of sea level show a rise of 0.1 to 0.2 meters over the last century. Readings gathered from glaciers reveal a steady recession of the world's continental glaciers. Taken together, all of these data suggest that over the last century the planet has experienced the largest increase in surface temperature in 1,000 years.*

Some deniers still fight a last ditch battle against admitting that warming is taking place - for example citing satellite data that seems to indicate less global warming than measured on the surface.

Satellite data measures different layers of the atmosphere than surface temperature; so you would expect results to be different than on the surface. Unlike surface data (that goes back to the 19th century), satellite results mostly cover the very short period from 1979 forward. That period includes both the Mount St. Helens volcanic eruption and ozone depletion - both of which could be expected to lower temperatures in the upper atmosphere. It also turns out there were measurement errors - including heating on the radiation sensor itself and satellite drift.

A new study by scientists from the National Center for Atmospheric Research and the Lawrence Livermore National Laboratory, supported by the U.S. Department of Energy and the National Oceanic and Atmospheric Administration, with contributions from the National Science Foundation corrected for all these factors[327]:

> *The group found a warming trend of 0.16°F per decade in the layer between about 1.5 and 7.5 miles high, compared to a trend of 0.02°F in the previously published UAH analysis. Both estimates have a margin of error of nearly 0.2°F (plus or minus).* [my interpolation: since the study covered 1979-1999 the total warming trend was 0.32°F - greater than the margin of error.] *According to the authors, the new results are a closer match with surface warming, as well as with four computer-model simulations of 20th-century climate produced by NCAR and Los Alamos National Laboratory.*
>
> *As a further check on the new satellite data set, the team examined regional patterns. Using a statistical technique, the group analyzed the 20th-century simulations and searched for an underlying "fingerprint" of climate change. For instance, the rates of warming in the satellite-monitored data vary by latitude from north to south. The authors found that the overall fingerprint of climate change in the models resembled this and other regional patterns found in the new satellite data set.*

In other words, allowing for the effects of ozone depletion and volcanic eruptions, and correcting for undisputed measurement errors, actual measurements approximate those predicted. Data confirms the theory.

Remember that if we were to decide that satellite data and standard meteorological records are unreliable, we would still have the glacier ice core results and measured increases in sea level[324] – plus measured warming of the oceans[328].

Deniers also like to claim the global warming (that they say isn't happening) is not human caused. In the past they argued that data show less warming than climate models predict. Currently, between cooling due to ozone destruction, and the corrected satellite data mentioned above, that dog not only won't hunt - it wants to lie very still in a corner and whine.

Instead they now argue that the peak of a long-term sun cycle[329], rather than greenhouse gases, causes rising temperatures. This long-term peak, however, is in magnetic flux - which has not been linked to temperature variations. Other deniers ascribe rising temperatures to the Milankovitch cycles - predictable variations in solar warming due to long term changes in earth's orbital distance from the sun. These cycles take place over many centuries, however, and cannot explain the size of the changes that took place within a single hundred years (the 20th century) - let alone the warming that occurred in the last two decades of that century. What about the shorter-term eleven-year and twenty-two year irradiance cycles - in which natural variations occur in the amount of solar energy reaching the earth's surface? According to the National Oceanic and Atmospheric Administration[330] "*... the trend in solar irradiance is estimated at ~0.09 W/m2 compared to 0.4 W/m2 from well-mixed greenhouse gases*". So, increases in greenhouse gas production explain at least four times as much of the warming trend as the irradiance cycle does - most analysts say much more.

Another denier position is that global warming will be mild and benign. Canada will grow oranges; Kansas will raise bananas; vineyards will cover England - and everyone will do the "Happy! Happy! Joy! Joy!" dance.

The overwhelming weight of the evidence goes against this rosy scenario. The Intergovernmental Panel on Climate Change projects that without drastic reductions in human caused greenhouse emissions, the Earth's average surface temperature will increase between 2.5° and 10.4°F (1.4°-5.8°C) between 1990 and 2100[331]. This may not seem like much. After all, night and daytime temperatures often differ by more than this range. Unfortunately this small average variation will cause much greater swings day to day. One way to understand the magnitude of such a change is the following quote from the Union of Concerned Scientists website[332]. "*Temperatures only 5°-9°F cooler than those today prevailed at the end of the last Ice Age, in which the Northeast United States was covered by more than 3,000 feet of ice.*"

The IPCC report puts it more cautiously[331]: "*The projected rate of warming is much larger than the observed changes during the 20th century and is very likely to be without precedent during at least the last 10,000 years, based on palaeoclimate data.*"

When it comes to the consequences the IPCC predicts[331]:[15]:

> *Higher maximum temperatures and more hot days, Higher minimum temperatures, fewer cold days and frost days, reduced diurnal temperature range over most land areas, increase of heat index over land areas, more intense precipitation events, increased summer continental drying over most mid-latitude continental land , associated risk of drought interiors, increase in tropical cyclone peak wind, increase in tropical cyclone mean and peak precipitation intensities*

This is expected to be worse in the global south, which will see more heat waves, more floods more droughts, more intense rain, more and stronger cyclones and topical storms. Food production there will drop precipitately; the greater number and intensity of cyclones, floods and storms, punctuated by the occasional drought, combined with decreased capability to deal with them will drastically enlarge the number of famines and global refugees. There will be more extinction, and more endangered species. This also means more species changing habitats - thus an increase in pests and the spread of disease (which will be encouraged to begin with by the warmer climate).

Growth in the more spectacular forms of poverty will increase the quieter forms that are just as deadly. Absolute hunger, and malnutrition, lack of access to clean water or to medical care will grow. Unchecked global warming will probably kill more in the poor nations than an unending major war would.

The same thing will happen on a smaller scale in the richer north; it too may expect more disease, more pests, and more extinction. If warming is not too severe, the rich nations may avoid famines and massive population displacement. But northern agriculture is not likely to flourish on planet greenhouse.

Aside from simple lower production, there are also questions of instability. Suppose, for example, that a wheat-growing region becomes suitable for banana production. One interesting question this raises is, will raising a luxury crop (bananas) instead of a staple (wheat) necessarily be equally profitable in a world where demand for staples vs. luxury food is increasing? More to the point - **when** does this hypothetical farmer make the switch? Temperatures will rise gradually but not steadily; there is no predicting exactly what year to plough up the wheat, and put in the banana trees. Worse, because of the instability mentioned, a year suitable for wheat may follow a year suitable for bananas. The poor farmer, aside from the usual problem of how well her crop will do, now has to decide what crop to plant. And of course she faces other problems from global warming - more storms, more high winds, more tornadoes and hurricanes if she plants in an area that suffers from them. She may yet face more droughts and floods. She will certainly face more insects, other crop pests, and more (and probably exotic) plant diseases.

I suspect a lot of global warming deniers have never talked to an actual farmer. I don't think they understand how much very small changes in climate from the optimum for a particular crop can affect yield. Farmers have enough problems weather and pest common to the areas they cultivate. Floods in areas that never flooded, heat waves on land which suffered only from frosts, attacks by entirely unfamiliar pests are not inconveniences to farmers – they are catastrophes. Deniers overlook, too, the role cold plays in the lifecycle of many plants. There are crops that only reproduce when subject to frosts, others that reproduce better in cold temperatures than hot ones. It has already been documented that higher night temperatures result in lower rice production[333], and possibly in lower production of other grains such as wheat and corn.

The suffering of the poorer countries will combine with direct effects to harm the rich nations. More refugees will drive down wages - either through immigration into the wealthy nations or by providing cheaper labor outside it. The diseases and pests are likely to travel northward and mingle with the newly flourishing native ones. Especially if combined with a growing refugee population, this will put additional strain on the health care system - so health care will be more expensive. Less food will be available; food prices will rise. Damage at home (and probably refugees from abroad) will combine to increase housing demand and costs. Without assuming more inequality, crime, and less social spending (all of which seem likely in a world that allows all this) even the rich part of planet greenhouse sounds like a miserable place to be poor, working class, or middle class compared to our current world.

History supplies a useful comparison. Fossil fuel burning and massive forest destruction, the two major contributors to both human caused air pollution and human caused global warming both escalated drastically around 1750 - the beginning of the industrial revolution. The consequences of escalating air pollution were felt from the start. We are only beginning to feel the consequences of global warming now. In 1995, the World Health Organization estimated that air pollution from fossil fuel killed more than 460,000 people annually[334]. A 1997 Lancet study suggested that number would rise to 700,000 a year by 2020[335]. This number is ~250 years after the industrial revolution, following decades of effort at mitigation. The carbon balance only altered enough to have major consequences for humans in the last few decades. Actual measurable harm began much more recently than that. We are in, essentially, the same position when it comes to global warming that we were with air pollution in 1750. Change occurs more rapidly than it did in the 18th century. If left unchecked we can expect greenhouse damage to escalate during this century as rapidly as damage from air pollution did in London between the 19th and 20th centuries. In 1873, 268 excess deaths were reported from a "pea-souper" in a period of a few days[336]. In 1954 the worst smog ever recorded in London killed around 4,000 people within one four day period[337]. A recent study suggests that current global warming killed around 160,000 people in 2000[338] due to increases in disease, heat waves, flooding, drought, hurricanes and tornadoes. By historical analogy (and not by scientific analysis) we could expect this to escalate to a bit less than 2.4 million annually by 2050 (if unchecked). This proves nothing - but provides a good sanity check on the previous numbers, showing that they make sense historically.

This leads to another point raised by global warming deniers. Global warming, which is not happening, and due to natural causes, and good for you, is too far advanced to do anything about. (Denier debating tactics resemble a story the Talmud tells. It seems that one family was accused of borrowing a jar from another, then taking it back cracked. The accused family offered three defenses: they never got the jar; it was already broken when they received it; and they returned it undamaged.) And it is not longer only deniers saying this. A number of climatologists and environmentalists are starting to panic, to fear that it is too late that we are doomed, doomed, doomed.

What they fear is that emissions must, just by virtue of how long change will take at this point rise well above the point where an irreversible feedback cycle begins, and that warming then continues regardless of what human beings do about emissions.

However leading climate scientists argue that the odds are still against catastrophe (though worse than we would like) if we start in time – by around 2010. Two facts give us this chance:

1) Climate change has thermal lag; it takes time after greenhouse gases are in the atmosphere for them to produce warming.
2) Many of the greenhouse gases other than CO2 – methane and so forth have much shorter lifespans in the atmosphere than carbon dioxide.

So if we start reducing emissions by 2010, we will still overshoot the safe level of 400 PPM, maybe even reaching 475 PPM of CO2 equivalent. If, at that time, we have been reducing emissions steadily since 2010, the drop in methane and other non-CO2 greenhouse gas may drop concentrations back to a safe level before the atmosphere reacts.

Malte Meinshausen, Reto Knutti and Dave Frame provide a useful analogy[339]: it would be as if we turned on our oven, and then just as the dial hit 475, noticed the cat had wandered inside. If we reacted quickly enough, and turned the oven off before it actually reached that temperature. the cat might survive. Right now climatologists think our odds are lot better than those of the cat in oven; around 75%. A one in four chance of disaster is not happy news of course; but people get those kind of odds in hospitals every day, and still survive.

Now it is true that significant global warming that has already occurred. But, IPCC documents show that if we drastically reduce greenhouse emissions, we probably still have time to prevent the worst consequences. Human beings are adaptable. If we can prevent the greenhouse effect escalating drastically, we will find a way to adjust to the changes that have already happened, or are too late to prevent. Worst case scenarios do not have to happen.

Readers who know something about global warming may wonder why, when looking at the consequences of not acting, I chose this particular scenario. It is after all, the mildest, most optimistic of the plausible "business as usual" projections. If Pollyanna, Pangloss, Anne of Green Gables, Mr. Micawber, and Rebecca of Sunnybrook Farm were climate scientists this is the example they would pick. Why not describe some of the more probable and horrible possibilities?

Because the least harm we can expect from unchecked global warming is enough reason to put enormous efforts into stopping it. The most optimistic plausible case is the equivalent of a major war, year after year for hundreds of years. I don't think that looking at worse possibilities than this gains us anything. Depression and terror aren't energizing; they don't help us fight better.

Imagine for a moment that you needed to walk on a two by four supported a few inches off the ground a distance of a several yards. Depending on your balance you might find this easy, difficult, or impossible. Now imagine that instead of a few inches off the ground it was set at a great height to bridge a chasm across jagged rocks. I don't know about you, but for me the challenge just got much harder. Now imagine trying to cross it while someone shouted over and over again: "If you fall you die. If you fall you die." Constant reminders of the stakes do not contribute to solving the problem.

I considered adding a second appendix titled "The Plural of Apocalypse" that dealt with genuine worst case scenarios. But I decided the demands of honesty are met by simply pointing out that these are real possibilities and (unfortunately) not simply wild speculation.

It is, after all, pretty clear that phasing out fossil fuels over the course of 30 years gives better than even odds. Further because the scenario I've outline phases in efficiency as existing infrastructure is retired emission reductions are slightly better than linear – meaning that we would probably reduce them by 70% or better within 20 years, and complete a total or near total phase out within thirty. That is actually better than most optimists currently think possible.

If that was not sufficient, we could phase in some of the carbon sequestration techniques that have been developed – powering them by wind generators, or other inexpensive forms of variable renewable energy as they are developed. Because we don't care what time of day or year carbon is sequestered as long as it is sequestered we would not need to worry about electricity storage issues; we could use the power as it came. Note that this is **not** a substitute for reducing emissions. (For one thing reducing emissions is much cheaper.) But once emissions are at (or near) zero this would be a way of reducing the damage that has been done. And if that is not fast enough, we can phase out fossil fuels much faster and more expensively either by retiring inefficient infrastructure fast or by phasing in expensive renewables. But we should take no longer than 30 years to reduce emissions to close to zero; there is even a good chance it will be enough.

In short we need to follow the first law of holes: when you are in one, stop digging.

How CyberTran May Replace Short Domestic Flights

We can replace a portion of domestic air travel with CyberTran. CyberTran, in addition to being a commuter transit vehicle, has a high-speed version that can reach 150 mph. A 150-mph train can match planes for travel speed on flights of up to 500 miles. (Various factors let a 150-mph train compete against much faster planes. Check in time at the airport; security, time in the airplane waiting for a runway before takeoff, time in the air before landing waiting for a landing strip, time after landing taxing to the terminal. In a connecting flight CyberTran loses the check and security in advantages; you are already checked in. But it retains the others and adds a certain security; if your flight is late, a CyberTran will still be available five minutes after you land; a connecting flight won't wait for you. And CyberTran is a lot less likely to be weather delayed than an airplane.)

What percent of infrastructure for U.S. domestic air service can CyberTran replace? The data is not available for a direct answer, but comparison to Europe, for which data is available, gives a good estimate. About 70% of European domestic flights are 621 miles or fewer[340]. Given that Europe has an excellent rail system, and has already switched some travel from plane to rail, and the U.S. has a generally poor rail system, it would not be unreasonable to assume that the percent for the U.S. is higher. It is conservative to assume that the U.S. percentage is the same. About 60% of U.S. flights are 400 miles or fewer[341]. So making the conservative assumption that 70% of U.S. flights are fewer than 621 miles, it is an equally conservative interpolation that 65% of U.S. Domestic flights are 500 miles or fewer.

Again it is estimated in Europe that only about half these miles could be replaced by rail, either because some are connecting flights, or because physical obstacles are in the way. But, as pointed out above, plane-to-plane connections are good candidates for CyberTran replacements. Mountains and bodies of water between two metropolitan areas 500 miles apart or fewer, both big enough to have airports with scheduled domestic airlines are likely to already be tunneled or bridged for auto traffic in the U.S. and thus available for CyberTran. So we could reasonably expect to replace 90% of these with CyberTran. And since we can credit such high speed rail for the ground traffic it will replace, we may count that as the next net savings for air travel.

Note that this refers to passenger miles, not routes. A fair number of short routes are between very minor airports, and carry very tiny numbers of passengers a day on a very few flights. Obviously, if fifty passengers a day fly three hundred miles from Podunk to Boondock, we are not going to build three hundred miles of track to save those flights. But, more or less by definition, most passenger miles on short flights will be over routes that have lots of passengers, where putting in track is worthwhile.

The Hawthorne Effect

In his excellent collection of energy saving examples "Cool Companies", Joseph J. Romm effectively compiles in one place data demolishing the whole idea of a "Hawthorne Effect".[342] (The Hawthorne Effect hypothesis claims that comfort, and physical working conditions have little affect on productivity; productivity increases stem from workers knowing manager are paying them attention.) He starts by quoting, Vivian Loftness head of Carnegie Mellon school of architecture on the bad results of this belief. "Executives constantly cite Hawthorne effect as clear disproof of any real linkage of productivity to the physical workplace - all that matters is management method. *This allows workers to be put into increasingly poorer work environments, smaller workstations, cheaper furniture, less work surface, less storage, no daylight or view, no control of air, temperature or light."*

According to Romm the "Hawthorne Effect" has never been replicated in any experiments. He cites two major reviews of the literature.

A 1967 study by U.S. Office of Education conducted new field research aimed at reproducing the Hawthorne Effect and also included a review of published education studies. The field research could not replicate the effect; nor did the literature review find any evidence[343]

In 1989, a more comprehensive review of the literature examined every journal article, unpublished paper or dissertation included in three major databases and previous Hawthorne reviews. This found 38 studies that included Hawthorne control groups in addition to normal control groups. The review found no evidence of an overall Hawthorne Effect. "Mean effect associated with Hawthorne manipulation was non-significant and such groups could essentially be regarded as no different from no-treatment controls[344]."

Omitting details, even the original two Hawthorne experiments do not support the conclusion drawn from them. In both experiments, there was greatly increased incentive for higher production, a promotion of small-group solidarity, and much greater feedback on performance than in the normal shop floor. In addition, in the second (and main) experiment, these workers had greatly increased control over their environment than on the normal shop floor. So these were actually experiments in feedback, incentive, and partial workers self-management!

Contrary to the usual descriptions, productivity did not constantly increase regardless of working conditions. Although the overall trend was steeply up, productivity fell almost as often as it rose. Modern statistical analysis shows zero correlation between "attention" and productivity in either Hawthorne experiment. However the second experiment's results do closely resemble a learning curve.

Given the studies cited that show that better lighting, ventilation and worker control of their own environment can improve productivity, the refutation of studies claiming that there is no such link, I think we can reasonably include productivity gains in the benefits of green building.

Accounting for Resource Flows

In recent decades business has begun to realize that so called standard accounting overlooks and misallocates costs, and costs them money. About 25% of accounting in the U.S. is now done via Activity Based Accounting; however ABC accounting is very sensitive to what drivers are used to allocate costs; energy, water and other flow costs still tend to be assigned to labor drivers – which perpetuates the problems we have covered. There are some further steps, which are still in their infancy.

One, which is not widely used, is RCA (Resource Consumption Accounting) which assigns costs to resources, not merely activities[345]. I don't know if the approach as a whole provides results superior enough to ABC accounting to be worth the additional effort. However, there is one area in which it which takes a vital step; it uses the solution of simultaneous equations to allocate costs. Whole systems thinking is always iterative, always requires simultaneous solutions, because optimizing parts separately almost never optimizes the whole. Accounting (other than projections forward) has always stuck to simple arithmetic for good reason; the resources to use anything more complex on a routine basis were not there. However with computers, the use of simultaneous solutions is no more difficult than simply double entry booking. Like ABC, there is extra data entry – which is where the question of effort vs. results has to be evaluated. But if you are using a system such as ABC where the data needs to be entered in any case, then it makes no sense to avoid computer time (but not human time) it would take to allocate properly.

More widely used, at least in larger EU companies is Environmental Management Accounting. EMA is not a case of corporations suddenly caring about more than their bottom line. It is based on the recognition that some environmental mistakes can cost companies money. The International Body UK, provides a decent explanation of this[346]. EMA is actually an ad-hoc collection of many techniques. However it almost always includes flow accounting, a measurement of the physical flow of materials and resources through the company – with cost allocation taking place only after knowing where the material is physically and who is responsible for it. It also includes better accounting for contingent liabilities, placing a value on the risk taken both of monetary liability and loss of reputation if a company is proven responsible for severe environmental damage. Better accounting is not a fundamental solution; but it can provide some marginal improvement, and has a role to play.

Note that green accounting tends to have very high transaction costs; it pays for itself in the narrow sense of increasing profits only in intensively polluting or resource intensive industries. For light and service industries more informal means, such as periodic green audits given better results for each dollar spent.

A strong example of how flow costs tend to get misallocated is the issue of occupational safety. Of course the primary "misallocation" here is a misallocation of power that leads to callousness and indifference to human suffering. Here I'm making a narrower point – that many costs *to the owner*, which you would expect to be tracked out of self interest, are hidden[347]. The paper cited gives examples of indirect costs which are often allocated to general overhead, rather than a specific accident:
Interruption in production immediately following the accident
Morale effects on coworkers
Personnel allocated to investigating and writing up the accident
Recruitment and training costs for replacement workers
Reduced quality of recruitment pool
Damage to equipment and materials (if not identified and allocated through routine accounting procedures)
Reduction in product quality following the accident
Reduced productivity of injured workers on light duty
Overhead cost of spare capacity maintained in order to absorb the cost of accidents
Not every firm will miss every one of these costs; but most will miss some. These are real dollar and cents costs to the owner. Estimates of how many of these costs are missed vary from a bit less than half to as high as 20 to 1. In other words, almost half the cost of worker injury being missed is the *low* estimate.

Phasing Out Other Greenhouse Forcings

Throughout this book we have concentrated on phasing out fossil fuels. But between a quarter and a third of human caused global warming is due to other greenhouse gases and the destruction of sinks. When examined closely we will see that most of either can be controlled by actions required to control fossil fuels or fit naturally with that actions we are taking to do so:

1) Methane. A great deal of methane is released into the atmosphere by coal mining which this book proposes phasing out or reducing drastically. (To the extent we continue to mine coal we can burn most of the methane released - reducing its impact.) Obviously natural gas production releases methane as well, since natural gas is methane. Much of the remaining methane is due to agriculture; no-till rotational cropping can reduce this is in row cropping. Intensively managed rotational grazing provides some reduction on the livestock side; carbon sequestration from soil building more than makes up for methane emissions; both livestock raising and row cropping become modest greenhouse gas sinks, rather than significant sources.
2) Nitrous oxide (N_2O) – mostly a product of artificial nitrogen fertilizer – whose use we propose eliminating (without lowering food or fiber production).
3) SF_6 - probably the highest impact greenhouse gas per gram of material; we described how to deal with it in the material impact subsection on computer monitors.
4) Perfluoro Compounds – can be dealt with an a manner similar to SF_6 the use of substitutes where possible, the capture and recycling where they must be used, and the development of replacements in the long run to let them be phased out.
5) Hydrofluorocarbons - used in refrigeration and air conditioning. They are being phased out in any case for the sake of the ozone layer. Although many advanced substitutes have been developed, probably ammonia and carbon dioxide are the best gases to use for these purposes in the long run. (Yes both greenhouse gases, but in the small quantity used in refrigeration and air conditioning will not be a problem compared to other refrigerants. Yes ammonia is poisonous – but ammonia water refrigerators contained it safely for decades; using ammonia safely as a refrigerant is a mature technology.)
6) NOx – not a greenhouse gas, but a sometime precursor of greenhouse gases. Produced from any type of combustion in the presence of nitrogen. Production of electricity completely from non-combustion sources, along with reductions in material intensity and greater industrial efficiency will reduce this a great deal. Methods specific to reducing NOx are dealt with to some extent in the pollution prevention section of the material intensity chapter.
7) Deforestation – we dealt with reducing this by ~60% overall in various sections of the material intensity chapter (Paper, "green" chemistry and biomass energy).
8) Cement production – we dealt with that in the material intensity chapter subsection on buildings.

9) Soil erosion – a fair amount of carbon is stored in healthy soil. No-till agriculture, and soil conservation tillage, can help turn agriculture from a carbon source to a carbon sink. We dealt with that in the material intensity section on food.

Timing: Can Emissions Reductions be Frontloaded?

Becoming carbon neutral over the course of thirty years is a vital goal; but reducing emission by only 33% during the first ten years may not be fast enough. Fortunately, because much of the infrastructure being replaced lasts much less than thirty years, the bulk of emissions reduction will occur towards the beginning. Renewable sources may be phased in a bit faster as well. And a few inexpensive additional steps may frontload the process further.

The First Ten Years

How much can we cut in the first ten years? (For the sake of the calculation, we assume a period from 2010 to the beginning of 2020.)

Transportation accounts for 27% of energy used. One third of the way into the transition we could cut a surprisingly large amount. Electric and Hypercars can be prototyped very rapidly once a decision is made to build commercial models; Electric and Hypercar factories are also faster to build than normal automobile plants. So you might actually have cars rolling off the factory floor within five years of deciding to start. Certainly regulators could insist that all new hybrids be plug-in hybrids. Possibly they would insist that plug-in hybrid efficiency was the minimum standard that would be accepted for any new car made or sold. Ideally that standard would increase to Plugin Electric Hypercars levels as quickly as possible.

CyberTran, and various Personal Rapid Transit (PRT) schemes have been alpha tested. You need to do competitive beta testing by setting up small commercial lines of each, to see which works best in day-to-day operations. During beta testing, you could simultaneously plan sign track locations in each major urban and suburban area, even obtaining easements and buying property, waiting until a system passed all real world tests to create final designs for each location. Still it would be four to six years before laying of track for major ultra-light rail systems could begin; once begun ultra-light rail can be constructed much faster than normal light rail. But most likely CyberTran (or some PRT if that proved better in practice) would be just beginning operation in year eight or nine of the transition. We would also have done a buyback of the worst fuel-hog junkers on the road, providing efficient automobiles to people who currently get 17 mpg or worse in things that barely run.

Autos have a twenty year life cycle; but they are usually down to traveling a few thousand miles a year or less by the end of thirteen years. So we would have replaced about 40% of the ones traveling the longest distances by the end of ten years. Many of those replacements would be electric cars that get eight times the mileage equivalent of conventional cars; some would be plugin hyper cars that get seven times the mileage. But even before this we would have begun phasing in plug-in hybrids which produce half conventional emissions.

When it comes to heavy trucks we can do even better. Freight trains need no Beta testing. And there is no reason to take 30 years to encourage a switch from truck to rail. Lay the tracks; put in the switchyards; build freight yards. Containers that can travel equally well by rail or truck are pretty routine, so if rail can get it most of the way, trucks can handle the first and last fifty miles. Put some of the 150 billion a year we have proposed allocating into this, and there is no reason we can't come close to eliminating long distance heavy trucking by the end of ten years. The same applies to savings in water transport as well; the potential is modest, but given that ships are one of great unregulated sources of air pollutants, there is no reason the modest savings there can't be phased in pretty quickly - paid for by air pollution reductions.

We can incorporate a modest portion of airline improvements too. We won't have CyberTran operating to replace short flights yet. But, there is no reason we can't put into place the operational efficiencies or the more advanced telecommuting.

Reductions in material intensity and energy use through the tenth year should lower the volume of freight shipped, and of fossil fuels pumped through pipelines by one third in the first ten years. In addition there is no reason the full 14% savings via operational efficiencies in pipelines should not be implemented within the first decade.

So we should end up with about a 39% per capita reduction in transportation emissions just from efficiency improvements. After allowing for population growth, that means total consumption would be down to 20 quads. Not bad for the first ten years of a thirty year program in a sector where a slow ramp up is unavoidable.

What about residential buildings, which account for about 21% of energy use? There is no reason adequate insulation and weather sealing should not be complete for every home in the U.S. in ten years. Windows and appliances will be replaced as they wear out; but lifespans imply that in ten years we will have replaced two thirds or more of these. New buildings will have to meet standards from day one. On average we should be over 70% through the efficiency cycle in residential buildings – which means per capita consumption in residences should be down 48%+. Allowing for population growth this means at the end of ten years, in 2020, residential consumption will be a bit over 13 quads.

Commercial buildings undergo full rehabs at least every 25 years. So a bit less than half of existing commercial buildings will have undergone full efficiency upgrades; 100% of new buildings will have to meet the new standards; so commercial buildings can be about 50% of the way through their possible savings in 10 years. Since total savings for commercial buildings is 70%, that means a reduction of 35% per capita; allowing for population growth, consumption will be 13.4~ quads.

However we could also develop about 50% of low temperature active solar potential by then, giving us another 3.3 quads – reducing combined consumption in commercial buildings to around 10.1 quads. (If some of the low temperature solar thermal proves impractical, we could put in additional wind without storage, and let the buildings use this "off-peak" wind energy to produce heat they would store in PCM, natural zeolites, or plain old thermal mass.)

Industrial equipment has an average lifespan of 20 years. In spite of the exceptions that are longer, the weighted average is much lower than that, because of the huge number with shorter lifespans. So when it comes to direct energy savings, there is no reason at least half should not be instituted within ten years. Changes in material intensity should be able to take place as fast or faster. So per capita industrial consumption should be reduced by 37.5 % over a ten year period; net industrial consumption should be less than 27 quads.

Total emissions in the three sectors combined will be about 70% of what was released in 2000. Energy consumption will be a bit higher than that of course, due to active solar.

But we can lower this a bit further. Around 35% of carbon equivalent emissions are generated from electricity production. (These, of course, are already included in sectorial reductions; we can't count them again.). But we could speed up decarbonization of our electrical grid -- massively deploying wind and solar and long distance transmission and storage, so that we phase out anther 25% or 30% of 2000 consumption. That would cut fossil fuel use for electricity production by more than half, and (if we phased out coal before phasing out other fossil fuels) about 60% of total electrical emissions. That would represent another ~10 quads over the savings from efficiency alone. That would bring total emissions reduction to around 40% - during the first ten years.

In addition we might get some reduction from carbon sequestration in the soil from "energy prairies", cultivation of glomalin in no-till agriculture, and the use of charcoal soil amendment. I'm very suspicious of counting soil sequestration in the long run; we don't know how long carbon in the soil stays in the soil. But if this works the way a lot of very smart people think it will, we could get another 2%

The Second Decade

How about the second ten years? CyberTran (or some electrified light or ultra-light rail system) will be complete; pre-efficiency standard autos will be 17 or older; most will be driven fewer than 1,200 miles a year. So transportation efficiency improvements will be 99%+ complete. The same will be true in residential buildings. 80% of existing commercial buildings will have finished their rehab cycle, and the remaining ones will have five years left at most; a short enough time to economically justify a premature rehab on grounds of energy savings and efficiency improvements, given higher energy prices at the time. Industry will similarly be through its 20 year equipment replacement cycle. Since this is an average, significant equipment will remain. But it is unlikely that this will represent a great deal of energy. Material intensity improvements should be complete – at least to the factor-four level we projected, though there are good reasons to support further ones. There is no reason 95% of efficiency improvements can't be in place.

What about supply? With only a few efficiency improvements remaining, all the supply improvements should be phased in as well. The saving from efficiency improvements will be more than enough to justify developing 100% of the renewable potential outlined. So we will have reduced fossil fuel consumption to about five quads or fewer at the end of 20 years. This is around a 94% reduction in absolute total. Since consumption will be small enough to consist entirely of natural gas, that should be better than 95% reduction in net emissions - especially since glomalin cultivation combined with low input farming should convert agriculture to a small carbon sink. Since population will be greater, the per capita reduction will be better than this.

The final five quads of fossil fuel consumption, or as much of it as necessary, could be eliminated over the remaining ten years, as additional efficiency savings and increased renewables reduce the need for natural gas.

Somewhere in this thirty year process we will get some sort of breakthrough. That is not speculation. It is certainly. While it is speculation to guess what that improvement will be, will either find cheaper renewable methods to generate some of this energy, cheaper methods to store this energy, or cheaper methods to save even more energy. Probably we will find all three. But note that even ignoring this we have the means to get off fossil fuel.

What about the Rest of the World?

So far this book has been extremely USAcentric – and for good reason. The United States is the most carbon intensive nation on this planet, and highly influential. Its ability to phase out fossil fuels strongly indicates the rest of the planet may as well; actually doing so instead of blocking international progress would influence many others.

However it is not quite as simple as “we can do it, so anyone could”. The U.S. may be a carbon intensive society, but we also have an unusually low population density compared to natural resource. We have more biomass available per person than Europe and most of Asia. If we believe the Stanford study, we have a quarter of the world’s wind resources. Still efficiency is pretty much a matter of access to capital and the sun shines everywhere. If the rich world provides capital for renewable developments to the poor ones, the same numbers add up for the world as for the U.S.

The U.S. in 2000 used around 100 quads to supply a population of ~282 million. World population in 2050 is projected to be ~9.25 billion. So if world GDP per capita in 2050 were to be equal to U.S. GDP per capita in 2000, and it squeezed five times the GDP from each unit of energy the U.S. did in 2000, world energy use would be around ~656 quads, ~22 terawatts, about 50% more than at present. Though rich nations, such as the U.S. could make absolute reductions in energy consumption, poor nations will need absolute increases if they are to stop being poor.

Efficiency increases means the world would get more benefit, more GDP from each energy unit used it afford to pay BTU for energy. Thus increases in potential efficiency mean the ability to pay more for clean renewable energy, and still get an increase in GDP, about 2.8 times more as we have already shown in the U.S. analysis.

For example, according to the Congressional Budget Office, on average the cost of electricity production in the U.S. is 8 cents per kWh, so with proper efficiency improvements, both it and the world could afford to pay 19.6 cents per kWh. Natural gas runs at minimum $6 per MCF, so efficiency increases would let the world pay the equivalent of $16.80 per MCF – and so on.

Let us start with low temperature heat, space heating, water heating, and air conditioning. With modern evacuated collectors, solar energy can provide heat at about the boiling point of water in almost any climate . With natural zeolites, which can store this indefinitely in very compact spaces there is no reason that almost any climate can't get much of its space, hot water, and air conditioning from solar energy at a price well below $16.80 per MCF equivalent. Buildings with roofs and south walls shaded by other buildings could get power from their neighbors. The only exceptions are climates in extreme latitudes, and climates with long lasting fogs. (Rain, clouds and morning fog won't prevent 100% solar low temperature power in these circumstances – just make it impractical.. Even in Alaska seasonal storage would make it possible to supply all climate control and hot water from the direct solar energy; just not feasible.) So, that is a bit over 7.33 TW right there. Let us allow for climates don't support this due to latitude or really extreme fog, subtract power to run the solar systems and say 7 TW. Bear in mind that we could provide 65% of that at prices competitive with 1998 natural gas, so nearly 100% at much higher prices is not unreasonable.

We might get about 3.4 terawatts of biomass from the following sources:

1) Energy crops included on expanded land base provided by inclusion of reserve land , as in the U.S.
2) Biodiverse energy plantations on overgrazed, strip mined or otherwise human damaged land. Almost any kind of crop can serve as an energy source. There are hardy perennials suited to most types of damaged land. There are grasses and herbaceous species that will grow in arid, cold climate, others that will grow in arid, warm climates, and a much wider variety that will grow in cold or warm wet climates. Once you reestablish soil, you may be able mix crops, get your biodiversity by combining multiple species in the same place rather than over time. Or you may use more conventional rotations – whatever suits your eco-system.
3) Replacement of timber farms with energy plantations as timber for buildings and paper is replaced by paper reduction, use of agricultural fiber for paper, and use of waste straw for building materials. Remember that up to half of straw and stove not only may but must be removed from the soil in sustainable agriculture.
4) Alternatively if the culture is already paper efficient, or if for some other reason waste straw and stover cannot be used as a manufacturing input, waste straw may itself be used as an energy source via gasification, F-T, or ultra-clean burning methods.

So biomass could produce a very important 15% of world-wide energy demand; it could provide hydrocarbon chemical stocks and gaseous and liquid fuels for processes that must have them. But again, for this not to be a disaster in practice would require an immense transformation in social context. Given a globalized market, extreme inequality both within and between nations, extreme corporate influence, and outright dictatorships in many nations in practice this would likely come at the expense of food production and the livelihoods of the poor, and often be a net emitter of greenhouse gases, and disrupt both natural and social ecologies in ways aside from greenhouse issues.

Fortunately, renewable electrical potential is far greater than any reasonable forecast for the poor nations as well as the rich. There is no significant demand for electricity that is not within 5,000 kilometers of a major potential dispatchable source – large amounts of geothermal or hydroelectric in rare cases, but mostly solar thermal and wind. (Remember, 5,000 kilometers is probably the practical limit for high voltage DC transmission.)

Take an especially knotty case – the United Kingdom. London has plenty of wind, but also is less than 2,400 kilometers from Tripoli as the crow flies. Transmission from North Africa to London via continental Europe and across the Chunnel would (of course) not be as the crow flies; but it could certainly be kept with that 5,000 kilometer limits.

Of course if Sky Windpower's gyromills prove practical, we could definitely get all we ever want. If they really can provide 2 cents per kWh electricity even more reliably than land based systems, total price for a 95% wind grid including storage could be provided at a cost comparable to fossil fuels today.

There are rare case where hydropower or geothermal may provide a significant percent of a nations electricity; in most nations there is at least enough of one, the other or both to complement wind power.

Miscellaneous Points on Sources, Style and Assumptions

1) There is no such thing as half a suspension bridge. Sometimes we have had to look forward to future chapters to calculate what is happening in current chapters. (If you remember high school algebra, you could think of this as solving simultaneous equations.)
2) I try to use gender neutral language whenever possible; but sometimes I find it unbearably awkward. When that happens I use “she”, “her” and “woman” as generic terms referring to both male and female humans.
3) Discount rates are a reflection of the fact that even an absolutely iron-clad guarantee of one hundred dollars a year for ten years is not worth the same as one thousand dollars today. (At a 6.5% discount rate, that cash flow is worth a bit less than $719.) By an odd coincidence, 6.5% is the discount rate used throughout this book[i].
4) A lot of the proposals are already being carried out to some extent; that does not invalidate the fact that if carried through completely they can save or produce a great deal of energy. What we need to exceed is not our best current operating procedures, but our current average efficiency. If comprehensive adaptation of a widely used technique can raise that average high enough, then so much the better.
5) If you are reading this in one of the rich nations other than the U.S. you may notice that a number of recommendations are routinely followed already where you live; the reality is that in many sectors the U.S. has fallen technologically behind the rest of the rich world.

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[i] Many bottom-up energy studies use extremely high discount rates - commonly 30% and up. This is because the people making these studies are focused on what the industries involved can be coaxed into doing either through simple persuasion, or through very mild tax incentives and regulations. There are various reasons industry demands such high rates of return on energy savings, which we will delve into after the technical sections.

It is tempting to go to the opposite extreme, and use the social discount rate, (the rate of growth in the economy). This is typically around 3 or 4 percent. After all, to the extent that capital as a whole (not individual firms, but all firms put together) earn a real rate of return greater than economic growth it must be extracted from somewhere else within the economy. I give an example on the next page that, for 80% of us, real wages have been frozen in the U.S. since 1968, while the per capita economy nearly doubled3. So using a social discount rate would make a great deal of sense.

But our definition of "zero cost" precludes this. We are going to bundle measures we predict to save less than our discount rate together with measures we predict to save more. We will start with savings exceeding our discount rate; then we will use that savings to pay for expensive renewable supplies - ending up with zero market cost compared to current trends or a bit less. With this kind of juggling we have to build in some risk premium as a margin of error. We will not end up with a return exceeding our discount rate by much; very small miscalculations could lead to yields that are lower. Mainstream social discounts hover around 5%. As a precaution, we will use a real discount rate of 6.5% - substantially higher than most variable mortgage rates as of the time of writing this book. It should be no lower than those rates even if they rise by the time it is published. Given that risks in energy saving investments are substantially lower in risk than private-mortgages backed bonds, that energy prices tend to keep up with inflation, and that greenhouse gas reducing investments have tremendous social benefits, this is still a conservative choice.

6) I use a variety of types of sources in this book; but I think if you pay attention to the type of information being documented you will find the sources appropriate. For example I get statistical information from large governmental or quasi-governmental agencies, or major think tanks, non-profits and academic and professional sources respected across the political spectrum. For cost averages (and comparable points), I sometimes use respected commercial sources or trade associations. For examples, and specific data points (such as the per square foot cost of a particular house) I will sometimes use general periodicals such as the NY Times.
7) I will occasionally cite advertising, partisan or viewpoint organizations or other highly biased, not necessarily respected sources in certain circumstances:
    a. For data where they would be the best source – for example price quotes from manufacturers or distributors
    b. Concessions that go against their bias, especially if reinforced by a respected source
    c. For quotation, when they make a point in an especially articulate or well reasoned way – though in such cases I always try to document the facts behind their argument from other sources.
8) Whenever possible I provide a URL to make cites easier to check, though of course a high percentage will have expired or become otherwise obsolete. When this happens Google is your friend. So are libraries.
9) I'm using a personal variation on end-of-manuscript Chicago style endnotes. Instead of dividing them into sections corresponding to chapters, and restarting numbering in each section, I simply number them consecutively from beginning to end. That way, when skipping past other notes to find the one you are searching for, it is always obvious approximately how far away your goal is.

End Notes

[1] Fossil fuel companies, auto industry, many oil producing nations, and a variety of right wing think tanks.

The leading journalist covering this is Ross Gelbspan. In 1995, he was briefly fooled by dishonest work from “global warming skeptics” Pat Michaels, S. Fred Singer and Richard Lindzen; when a look at the actual science showed him he had been lied to, he was angry enough to write the book “The Heat is On” to expose both their junk science, and the cranks and liars behind it He has probably been the leading journalist exposing the carbon lobby since then, and has essentially given up the rest of his career to focus fulltime on the global warming and the carbon lobby.

Ross Gelbspan, *The Heat Is on: The Climate Crisis, the Cover-Up, the Prescription* (New York: Perseus Book Group,1997). (Still an excellent source for history of the Carbon Lobby.)

Ross Gelbspan, *Boiling Point: How Politicians, Big Oil and Coal, Journalists and Activists Have Fueled the Climate Crisis - and What We Can Do to Avert Disaster* (New York: Perseus Book Group - Basic Books, 2004). (Focuses more on his view of solution – but also brings Carbon Lobby history up to date.)

Ross Gelbspan, "Snowed,". *Mother Jones* May/Jun 2005, The Foundation for National Progress, 10/Jun/2005 <http://www.motherjones.com/news/feature/2005/05/snowed.html>. (Part of excellent May 2005 issue of Mother Jones, which contains a good survey of the current state of the Carbon Lobby.)

Another good source for current state of the Carbon Lobby is the Union of Concerned Scientists. Union of Concerned Scientists, *Global Warming - Skeptic Organizations*. 2005, Union of Concerned Scientists, 30/Sep/2005 <http://www.ucsusa.org/global_warming/science/skeptic-organizations.html>.

To find out more about individual organizations, I recommend *SourceWatch* published online by The Center For Media and Democracy. You will that along with groups devoted primarily to global warming denial, much Carbon Lobby funding goes to general right wing groups that include it as one activity among many.

Center for Media and Democracy, *SourceWatch - SourceWatch*. SourceWatch Applies It's Standards to Itself - Reveals Own Funding Just as It Does Others, 2005, Center for Media and Democracy, 10/Jun/2005 <http://www.sourcewatch.org/index.php?title=SourceWatch>.

[2] Just about every public opinion survey by respectable sources shows about 75% of the public convinced that global warming is a real and serious problem, and about 25% convinced of the opposite or uncertain.

The Gallup poll for March 2005 shows nearly 80% of the population now believes human caused global warming is real.
Gallup Poll, *Environment: The Gallup Poll March 7-10 2005*. 01/07 2005, The Polling Report, 02/07/2005 << http://www.pollingreport.com/enviro.htm>>.

A series of public opinion polls regarding global warming compiled by the highly regarded Program on International Policy Attitudes:

"The Reality and Urgency of Global Warming," *Americans & the World*, Program on International Policy Attitudes - Jointly Established by the Center on Policy Attitudes (COPA) and the Center for International and Security Studies at Maryland (CISSM), School of Public Affairs, University of Maryland, 20/03 2005, 01/01/2005 <http://www.americans-world.org/digest/global_issues/global_warming/gw1.cfm>.

These include the following:

In September 2002, 74% said they "believe the theory that increased carbon dioxide and other gases released into the atmosphere will, if unchecked, lead to global warming and an increase in average temperatures" "Majorities Continue to Believe in Global Warming and Support Kyoto Treaty", *The Harris Poll*, Harris Interactive #56 , October-23-2002 <http://www.harrisinteractive.com/harris_poll/index.asp?PID=335> ((January 2, 2005)

--In March 2001, 64% said they "believe that emissions of gases like carbon dioxide are causing global temperature increases"; 23% did not (Time/CNN).

--In an August 2000 Harris poll, 72% said they "believe[d] the theory" of global warming, while 20% said they did not--up from December 1997 when in response to the same question 67% said they believed it and 21% said they did not.

--In a July 1999 NBC News/Wall Street Journal poll, only 11% took the position that "concern about global climate change is unwarranted."

--In a September 1998 Wirthlin poll, 74% embraced the belief that "global warming is real" even when the belief was defined in terms of global warming having "catastrophic consequences," while just 22% said they did not believe in it.

--An October 1997 Ohio State University survey asked about "the idea that the world's temperature may have been going up slowly over the last 100 years" and found that 77% thought "this has probably been happening," while 20% thought "it probably hasn't been happening." Likewise, 74% thought the world's average temperature would go up in the future, while 22% thought it would not.

The Pew Research Center for People and the Press, *Americans Support Action on Global Warming: Progress Seen On AIDS, Jobs, Crime and the Deficit.* 21/11 1997, 02/07/2005 <http://people-press.org/reports/display.php3?ReportID=100>.

[3]Jennifer O'Connor, *Survey on Actual Service Lives for North American Buildings*, Oct 2004). Sep 2004. *Presented at Woodframe Housing Durability and Disaster Issues Conference*, 16/Jun/2006 <http://www.northernrockies.org/Departments/Fire/Wood_Buildings/Wood%2520Buildings%2520Service_Life_E.pdf>.

A good indicator is that the Australian government thinks that most Australian homes (which have to meet tougher standards than U.S. ones do) have a lifespan of around 50 years.

Chris Reardon, *Your Home Technical Manual - Design for Lifestyle and the Future - 3.0 Materials Use Introduction*. 1/Mar/2004, Commonwealth of Australia/Joint Initiative of the Australian Government and the Design and Construction Industries, 9/Jan/2005 <http://www.greenhouse.gov.au/yourhome/technical/fs30.htm>.

[4] The Old House Web, *Schedule of Normal Life*. 1995, 1/Jan/2005 <http://www.oldhouseweb.net/stories/Detailed/267.shtml>.

[5]Hawkins, Dominique M., *Saving Wood Windows*. 24/Sep 2004, *State of New Jersey Department of Environmental Protection Division of Parks & Forestry Natural & Historic Resources Historic Preservation Office*, 2/Jan/2005 <http://www.state.nj.us/dep/hpo/4sustain/windowsave.pdf>.

[6]The Minnesota Green Affordable Housing Guide, published by University of Minnesota College of Architecture and Landscape Architecture cites a 25 year lifespan

Regents of the University of Minnesota, *The Minnesota Green Affordable Housing Guide - Components: Cladding (Siding)*, 30/June 2004, 2004 Regents of the University of Minnesota, 09/Jan/2005 <http://www.greenhousing.umn.edu/comp_cladding.html>.

So does the Commonwealth of Massachusetts Historical Commission
Carol DiNinno and Ann Lattinville, "Technical Assistance Tips: Vinyl Siding,". *Preservation Advocate*, no. Spring 2003 (2003), Commonwealth of Massachusetts Historical Commission, 06/Jul/2005 <http://www.sec.state.ma.us/mhc/mhcpdf/pasp03.pdf>. P5.

Jim Cory, "Siding Replacement", *Remodeling Magazine*, no. November 2002 November 2002: 2002 Cost vs. Value Report, Hanley Wood, 10/Mar/2004 <http://www.remodeling.hw.net/pages/remodelingonline/Story.nsp?story_id=1000027503&ID=newsreal&scategory=Computers&type=break>.

Note that many "authoritative" sources give longer, life spans, based upon exaggerated manufacturers claims, rather than real life experience. For instance, one of the sources most commonly cited for lifespans is the September 2002, **Baseline Measures for Improving Housing Durability**, published by the U.S. Department of Housing and Urban Development

Robert E. Chapman and Christine A. Izzo, *Baseline Measures for Improving Housing Durability*, NISTIR 6870. September 2002. *US. Department of Commerce National Institute of Standards and Technology Building and Fire Research Laboratory/U.S. Department of Housing and Urban Development Office of Policy Development and Research*, 06/Jul/2005 <http://fire.nist.gov/bfrlpubs/build02/PDF/b02159.pdf>.

If you look at footnote 26 at the bottom of page 38 of that article, it turns out that average (as opposed to minimum) lifetimes are based on "Life Expectancy of Housing Components" published by Ahluwalia, Gopal, and Angela Shackford. in the August 1993 Housing Economics pp. 5-9 – based on surveys of manufacturers, trade industry associations and researchers. Given that at least two thirds of the sources would tend to be biased towards optimism, I would expect lifespans from such a source to be wildly exaggerated. Let's test this by focusing in on one example – vinyl siding.

The 50 year average estimated lifespan for vinyl siding is widely cited. The Housing Economics is not the sole source of course. The Vinyl Institute promotes this figure as much as possible. But does it make sense compared to environmental and remodeling sources?

Most vinyl siding offers a 50+ year warranty. That appears devastating until you look at what kind of warranty is offered. Many of the warranties are prorated. Those that are not usually have a kicker: they are invalidated or become prorated when the home is sold. Because most people do not stay in the same house for 25 year, the vast majority of these warranties will expose the seller to no significant liability past after a couple of decade. (I know there are exceptions. But, looking at it from the point of view of how much money a warranty will cost the issuer, the exceptions are not significant.

Let's look at one vinyl siding warranty (http://www.mastic.com/warrantyvs.asp) a warranty for Mastic Vinyl Siding from Alcoa, downloaded February 2, 2005 – one that advertises itself as non-pro-rated, transferable. That sounds good – except that as soon as it is transferred it becomes very heavily prorated indeed.

For a second owner, by the time 14 years have passed the warranty covers only 20% of the original cost of the siding. Bear in mind that decently installed, well maintained vinyl siding will last 25-30 years. So imagine every most (non-original owners have problems and try to collect on the warranty 20 years from now. That means the manufacturer will have to pay out 20% of siding sales price in 20 years. But having to pay a dollar twenty years from now does not cost the same as having to pay it now. Using a discount rate of 6.5% that 20% 20 years from now is worth only 3.5% of the current sales dollar. In other words, the manufacturer (knowing that most homes will be occupied by a second (or third or fourth owner)) needs only add 3.5% to the selling price to cover the cost of this 50 year warranty. Actually that is overstating; in practice by the time the home has passed through a number of hands, a lot of people won't even think of checking to see whether there is a warranty out on siding 20+ years old. What about siding that goes bad sooner? Well remember this particular warranty hits that 20% mark after 14 years. Even badly installed and maintained siding tends to last for 15. But if the siding was improperly installed or poorly maintained that invalidates the warranty in any case. In other words offering a 50 year warranty under those particular terms is a worthwhile investment in marketing terms, even if the siding does not in fact last 50 years. So the existence of such a warranty does not tell you very much.

Also by the time the manufacturers face a significant number of people trying to collect on the warranty, whoever made the recommendation to offer it will be working for a different company or retired.

Fundamentally vinyl (as it is normally installed) just is not sturdy enough to last more than 30 years in the conditions house siding normally faces. It becomes brittle with age, and also brittle in extremely cold (and sometimes in extremely hot) weather. You can harmlessly bounce a hammer off newly installed vinyl siding; try it ten years later and you will shatter your vinyl. The same thing is true in really cold weather. Hit vinyl siding with a snow-blower or lawnmower and it won't hold up very well. As it grows older, you can damage vinyl siding by leaning a ladder against it to repair a roof or a window. Top quality vinyl siding, perfectly installed and maintained might well last fifty years or longer. But that is not the average case – especially the perfect installation and maintenance.

[7]Robin Suttell, "Intelligent and Integrated Buildings: Technologies and Current Market Conditions Break Down Conventional Barriers,". *Buildings Magazine* November 2002, Statmats Business Media, 5/Jan/2005 <http://www.buildings.com/Articles/detail.asp?ArticleID=1095>.

[8]OUS Capital Construction, *The Oregon University System Sustainable Renewal Program for Failing Assets*. 19/Jul 2004, 02/Jan/2005 <<http://www.ous.edu/board/dockets/ddoc040716-DM.pdf>>.

[9]. Engelbert Westkämper, director of the Institute of Manufacturing and Factory Operation at the University of Stuttgart says "... A factory building normally lasts 30 years, but it doesn't stay the same for 30 years. Machines and systems have an average life span of ten years; in some cases only five years..."

"Prof. Engelbert Westkämper, 56, is a leading expert in the field of manufacturing engineering. Since 1995 he has served as Director of the Fraunhofer Institute for Production Engineering and Automation in Stuttgart, Germany and as Director of the Institute of Manufacturing and Factory Operation at the University of Stuttgart. A mechanical engineer, Westkämper also has a hands-on industrial background, including positions as Manager of Manufacturing Engineering and Technology at MBB in Munich and as Manager of Production Engineering at AEG in Frankfurt. He was also responsible for manufacturing technology at Airbus in Hamburg and Bremen.

"Visualizing Tomorrow's Industrial Environments: Interview with Engelbert Westkämper,". *Siemens Webzine*, no. Pictures of the Future - Fall 2002 (2002), Siemen, 02/Jan/2005 <http://w4.siemens.de/FuI/en/archiv/pof/heft2_02/artikel08/>.

The OECD gives the average service life for capital equipment (weighted by value) as 15 years - not the same as in the U.S., but indicative.

Paul Schreyer, *Capital Stocks, Capital Services, and Multi-Factor Prodductivity Measures. Economic Studies*, Draft. 3/Nov 2003, OECD Statistics Directorate, 3/Jan/2005 <http://www.oecd.org/dataoecd/30/46/29877839.pdf>. P10.

According to the Deutsche Bundesbank , U.S. capital equipment generally lasted about 25 years in 1987, and the rate of depreciation has risen drastically every one of the 18 years that followed (meaning lifespan has fallen).

Ulf von Kalckreuth and Jurgen Schröder, *Monetary Transmission in the New Economy: Service Life of Capital, Transmission Channels and the Speed of Adjustment*, Discussion Paper 16/02. 16/June 2002, Economic Research Centre of the Deutsche Bundesbank,p2, 03/Jan/2005 <http://www.bundesbank.de/download/volkswirtschaft/dkp/2002/200216dkp.pdf>.

Some U.S. economists calculate an average 5.9% depreciation rate for U.S. physical capital, which is consistent with a 20 year lifespan:

M. Ishaq Nadiri and Ingmar R. Prucha, "Estimation of the Depreciation Rate of Physical and R&D Capital in the U.S. Total Manufacturing Sector,". *Economic Inquiry* XXXIV January 1996: 43-56, Western Economic Association International, 03/Jan/2005 <http://www.econ.nyu.edu/user/nadiri/pub86.PDF>.

[10]Region 2 United States Environmental Protection Agency, *Life Cycle of Old Computers - Problem Continued*. 15/October 2002, U.S. EPA, 3/July/2005 <http://www.epa.gov/region02/r3/problem.htm>.

[11] “The generally accepted standard for the normal effective lifespan of a coke oven is 25 to 30 years.”

Office Technology Assessment, "Technology and Raw Materials Problems - Chapter 7," *Technology and Steel Industry Competitiveness*, June 1980), NTIS Order #PB80-208200. 1996, 223. *Office Technology Assessment*, Princeton University, 02/Jan/2005 <http://www.wws.princeton.edu/cgi-bin/byteserv.prl/~ota/disk3/1980/8019/801909.PDF>.

[12]American Society Civil Engineers, *ASCE Report Card for America’s Future: 2003 Progress Report And Update to the 2001 Progress Report*. September 2003, 1, ASCE, 10/Jan/2005 <http://www.asce.org/reportcard/pdf/fullreport03.pdf>.

The EPA sponsored a study that focused on water infrastructure, and concluded the ASCE was too generous.

American Water Works Service Co. Inc. Engineering Department, *Deteriorating Buried Infrastructure Management Challenges and Strategies*. May 2002. *Environmental Protection Agency*, 10/Jan/2005 <http://www.epa.gov/safewater/tcr/pdf/infrastructure.pdf>.

[13]S. Lu, *VEHICLE SURVIVABILITY AND TRAVEL MILEAGE SCHEDULES*, DOT HS 809 952. Jan 2006, : NHTSA’s National Center for Statistics and Analysis NCSA, 12/Jan/2007 <http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/Rpts/2006/809952.pdf>.

Florida Department of Highway Safety and Motor Vehicles, *How to Buy a Used Car*. 21/May 2004, 3/July/2005 <http://www.hsmv.state.fl.us/dmv/usedcar.html>.

[14] Freightline Custom Chassis, *Commericial Bus Chassis: Frequently Asked Questions*. 03/Jan/2005 <http://www.freightlinerchassis.com/cb_default.asp?page=cb_faqs&nav=mb>.

2nd source:
Research and Special Programs Administration John A. Volpe National Transportation Systems Center, *Transit Security Design Considerations: Final Report*. November 2004, 7-8. *Federal Transit Authority of the U.S. Department of Transportation*, 05/Jul/2005 <http://transit-safety.volpe.dot.gov/security/SecurityInitiatives/DesignConsiderations/CD/ftasesc.pdf>.

[15] We have to combine two figures here, average number of miles traveled annually by heavy trucks, and engine life in miles. The Department of Transportation suggests that heavy trucks average 47,022 miles annually in the U.S.

Stacey C. Davis and Susan W. Diegel, *TRANSPORTATION ENERGY DATA BOOK: - Edition 23*, ORNL-697(Edition 23 of ORNL-5198). October 2003, Chapter 5: Heavy Vehicles and Characteristics, Page 5-7, Table 5-Truck Statistics by Size - 1997. *Oak Ridge National Laboratory for the U.S. Department of Energy Office of Planning, Budget Formulation and Analysis Energy Efficiency and Renewable Energy*, 24/Feb/2003 <http://www-cta.ornl.gov/data/tedb23/Full_Doc_TEDB23.pdf>.

The Pacific Northwest National Laboratory suggest that a heavy truck, on average, needs a major overhaul at between 400,000 and one million miles. (A truck that is used a lot, but run at a low mileage, spending a lot of time idling or in stop and go traffic, or turning around in narrow streets and parking lots will wear out in a lot fewer miles, so the range makes sense.) Therefore if we assume that million miles, divide the 47,022 miles traveled annually into it and calculate a 21 year life span, we are projecting an optimistic length of time between major overhauls for an "average" heavy truck.

PNNL, "Need For Transportation Technologies Heads Into Overdrive,". *PNNL Breakthroughs Magazine: Science, Technology, Innovation* Fall 2002, Pacific Northwest National U.S. Department of Energy Multiprogram National Laboratory - Richland WA, 3/Jan/2005 <http://www.pnl.gov/breakthroughs/fall02/special.stm>.

[16]"When Should Part-Life Engines Be Built?" *Engine Yearbook 2005*. 2005. Aviation Industry Press Ltd., London, 11/Jan/2005 < http://www.aviation-industry.com/atem/newpages/eyb2003pdfs/E2005_TES.pdf>.P30.

[17] "Commercial Aero-Engine MRO Outlook - a New Dawn?" *Engine Yearbook 2005*. 2005. *Aviation Industry Press Ltd*, 11/Jan/2005 <http://www.aviation-industry.com/atem/newpages/eyb2003pdfs/E2005_aerostrat.pdf>.p4.

[18]Charles River Associates for Diesel Technology Forum, *Diesel Technology and the American Economy*, Report D02378-00. October 2000, 12/Jan/2005 <http://www.dieselforum.org/enews/downloads/DTF-Economic-Study.PDF>. p2.

For rail transport in general the same figure seems to be 12 years (ibid 14:Volpe above)

[19] "Locomotive engines are expected to last for at least 40 years, which places greater emphasis on durability. This low turnover rate also limits the penetration rate of new technologies; however, locomotives undergo many overhauls, providing opportunities for modifications throughout their lives."

Frank Stodolsky, Railroad and Locomotive Technology Roadmap, ANL/ESD/02-6. December 2002. Center for Transportation Research, Energy Systems Division - Argonne National Laboratory, 11/Jan/2005 <http://www.transportation.anl.gov/pdfs/RR/261.pdf>.p13.

[20]Yes, this is a press release – a press release boasting about an extraordinary example of product life – with no claim that it represents typical results. The estimate is likely to be high rather than low; and higher numbers are less favorable to the case we are making.

Torben Klingenberg, *Press Release: Heading for 30 000 Operating Hours with HFO GenSets*. October 2003. *MAN B&W Diesel A/S*, 17/Jan/2005 <http://www.manbw.com/files/news/filesof3003/CP_ships_pr_nov.pdf>.

[21]As previously noted, the following press release is more likely to give a high than a low lifespan estimate.

Vesa Tompuri, "Wärtsilä's New Medium-Speed Diesel Engine Has the Lowest Emissions on the Market," *WATTSON:Wärtsilä's Investor Magazine*. 2004. *Sanoma Magazines Custom Publishing Division for*

Wärtsilä Corporation, 13/Jan/2005 <http://www.wartsila.com/Wartsila/docs/en/investors/English_lowres.pdf>.p13.

2nd source: a 1999 study was pessimistic about reducing greenhouse gas emissions in ships, because they have lifespans of 20 years or more.

Bronson Consulting Group CPCS Transcom Ltd. for Marine Sub-Group of the Transportation Table on Climate Change, *Marine Summary:Transportation &Climate Change : Assessment of Opportunities to Reduce GHG Emissions in the Marine Transportation Industry*. July 1999, 18/Nov/2003 <http://www.tc.gc.ca/programs/environment/climatechange/subgroups1/marine/Exec_Summary/English/Marine.htm>.

[22]"..Only one percent of total material flow ends up in, and is still being used within, products six months after their sale..."
Paul Hawken, Amory Lovins, and L.Hunter Lovins, *Natural Capitalism: Creating the Next Industrial Revolution* (Boston: Little, Brown and Company/Back Bay, 2000). p81. Page citations are to the Back Bay paperback edition. Along with Barry Commoner, Amory Lovins is one of the key popularizers of the idea that increased efficiency and more use of renewables could supply most of our energy.

[23] Friedrich Bio Schmidt-Bleek, "Energy," *Factor 10 Manifesto*, Jan 2000). May 2000. *Factor 10 Institute*, 2/Feb/2004 <http://www.factor10-institute.org/pdf/F10Manif.pdf>.p5.

[24]David Malin Roodman and Nicholas Lenssen, *Worldwatch Paper #124: A Building Revolution: How Ecology and Health Concerns Are Transforming Construction*. Single Page Summary of Book, March 1995, Worldwatch Institute, 22/Aug/2005 <http://www.worldwatch.org/pubs/paper/124>.
(note one page summary, not entire 67 page paper)

[25] California Institute of Earth Art and Architecture, *Nader Khalili*. Jan 2004, California Institute of Earth Art and Architecture, 23/Aug/2005 <http://www.calearth.org/khalili.htm>.

[26]California Institute of Earth Art and Architecture, *CalEarth Forum*. July 2005, California Institute of Earth Art and Architecture, 23/Aug/2005 <http://www.calearth.org/>.

[27]Ernst von Weizsacker, Amory B. Lovins, and L. Hunter Lovins, *Factor Four - Doubling Wealth, Halving Resource Use - The New Report to the Club of Rome* (London: Earthscan, 1997).

Wayne Trusty and Jamie Meil, *The Environmental Implications of Building New Versus Renovating an Existing Structure*. Jan 2001. *ATHENA™ Sustainable Materials Institute*, 23/Aug/2005 <http://www.athenasmi.ca/papers/down_papers/SB2000_paper.pdf>.

[28]Ernst von Weizsacker, Amory B. Lovins, and L. Hunter Lovins, *Factor Four - Doubling Wealth, Halving Resource Use - The New Report to the Club of Rome* (London: Earthscan, 1997).

Wayne Trusty and Jamie Meil, *The Environmental Implications of Building New Versus Renovating an Existing Structure*. Jan 2001. *ATHENA™ Sustainable Materials Institute*, 23/Aug/2005 <http://www.athenasmi.ca/papers/down_papers/SB2000_paper.pdf>.

[29] Amazon Nails, *Information Guide to Straw Bale Building for Self-Builders and the Construction Industry*, 2001). 2003. *Amazon Nails*, 23/Dec/2003 <http://www.strawbalefutures.org.uk/pdf/strawbaleguide.pdf>.p2.

[30]Canadian Architect, "Measures of Sustainability - Embodied Energy," *Measures of Sustainability*, 2002, Canadian Architect, 02/Feb/2003

<http://www.cdnarchitect.com/asf/perspectives_sustainibility/measures_of_sustainablity/measures_of_sustainablity_embodied.htm>.

[31] Amazon Nails, *Information Guide to Straw Bale Building for Self-Builders and the Construction Industry*, 2001). 2003. *Amazon Nails*, 23/Dec/2003 <http://www.strawbalefutures.org.uk/pdf/strawbaleguide.pdf>.p2.

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International Network for Bamboo and Rattan, *International Network for Bamboo and Rattan (INBAR) | Bamboo and Rattan Facts*. 2005, International Network for Bamboo and Rattan, 26/Oct/2005 <http://www.inbar.int/facts.htm>.

International Fund for Agricultural Development, *Agricultural Research Grants | Programme for Development and Diffusion of Technologies for Smallholder Bamboo- and Rattan-Based Producers – Phase II*. 2005, International Fund for Agricultural Development, 26/Oct/2005 <http://www.ifad.org/grants/tags/518.htm>.

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Carol A. Miles, Chuhe Chen, and Tamera Flores, *Washington State University Bamboo Research Report 2000 - On-Farm Bamboo Production in the Pacific Northwest*, 2000). May 2001. *Extension Agricultural Systems Program, Washington State University Research and Extension Center*, 23/Aug/2005 <http://agsyst.wsu.edu/BambooReport2000.pdf>.

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[37]Laura Soullière Harrison, "National Park Service: Architecture in the Parks (Old Faithful Inn)," *Architecture in the Parks: Excerpts from a National Historic Landmark Theme Study*, Nov 1986). 26/Feb 2001. *National Park Service - Department of the Interior*, 23/Aug/2005 <http://www.cr.nps.gov/history/online_books/harrison/harrison3.htm>.

Chateau at the Oregon Caves, *Oregon Caves Outfitters - An In-Depth Description of the Chateau*. 2003, Chateau at the Oregon Caves, 23/Aug/2005 <http://www.oregoncavesoutfitters.com/AbouttheChateau.asp>.

[38]Jamie Meil et al., *CORRIM: Phase I Final Report - Module J: Environmental Impacts of a Single Family Building Shell - From Harvest to Construction (Review Draft)*. 23/Aug 2004. *Consortium for Research on Renewable Industrial Materials (CORRIM)*, 23/Aug/2005 <http://www.corrim.org/reports/final_report_2004/Module%2520J_%2520August%252023.pdf>.

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[43] Rastra Found., *What is RASTRA®*. 16/Mar 2005, Rastra Found., 4/Sep/2005 <http://rastra.net/rastracom/web-site/wi_ra.htm>.pp1-2.

[44] Wooden pagodas the height of small skyscrapers have been documented historically.
China Internet Information Center, "Introduction," *China Through a Lens*, 25/Sep 2002, China Internet Information Center - Authorized Government Portal Site to China, 4/Sep/2005 < http://www.china.org.cn/english/TR-e/43461.htm>.

Edwin Karmiol, *Mysteries of Japanese Pagodas Unlocked*. 17/Aug 2002, Asia Times, 4/Sep/2005 <http://www.atimes.com/atimes/Japan/DH17Dh01.html>.

Bamboo is used as scaffolding in building skyscrapers today.
Mark Landler, "Foreign Desk: Hong Kong Journal; For Raising Skyscrapers, Bamboo Does Nicely (Abstract),". *NY Times*, no. Late Edition - Final 27/Mar 2002: Section A, Page 4, Column 3, 23/Aug/2005 <http://query.nytimes.com/gst/abstract.html?res=FB0917F9385F0C748EDDAA0894DA404482>.

Now there was one huge problem with traditional pagodas. While they were sturdy, and wonderfully insect and earthquake resistant, when exposed to fire they went up like, well, tinder. Fortunately, today there are all sorts of fire barriers you can wrap wood in. In point of fact, protected wood, guarded by a multi-hour graded fire barrier can be more fire safe than steel - because wood does not have the huge thermal conductivity steel has; it simply does not have the capability of growing as hot. How far beyond seven stories wood (and possibly bamboo construction) can grow safely is hard to guess. But seven stories is probably not the limit.

[45]Michelle Clark Hucal, "Recycled Roofing,". *Environmental Design and Construction*, no. Cool Roofing - May 2003 Supplement 1/May 2003, BNP Media, 5/Sep/2005 <http://www.edcmag.com/CDA/ArticleInformation/features/BNP__Features__Item/0,4120,97795,00.html >.

[46] Ibid 22 "Chapter 7, Muda, Service and Flow" pp.139-141.

[47]Wuppertal Institute for Climate, Environment and Energy, *Material Intensity of Materials, Fuels, Transport Services*, Version 2;28.10.2003. May 2004. *Wuppertal Institute for Climate, Environment and Energy*, Wuppertal Institute for Climate, Environment and Energy, 5/Sep/2005 <http://www.wupperinst.org/Projekte/mipsonline/download/MIT_v2.pdf>.p3(clay),p8(cement).

American Clay Enterprises, *American Clay Finishes™ Clay Veneer Plaster Product Specifications*. 18/Dec 2003. *American Clay Enterprises*, 5/Sep/2005 <http://www.americanclay.com/pdfs/ProductSpecs.pdf>.

Athena Swentzell Steen and Bill Steen, *Artistry in Clay & Lime*. 3/Jun 2005, The Canelo Project, 5/Sep/2005 < http://www.caneloproject.com/pages/workshops/clayartistry.html>.

[48]Michael Clar, *Buckeye Development, LLC - Pembrook Woods Low Impact Development*. Feb 2000, Buckeye Development, LLC, 5/Sep/2005 <http://www.buckeyedevelopment.net/lowimpactdevelopment.htm>.

[49]U.S. Department of Housing and Urban Development Partnership for Advancing Technology in Housing, *Affordability and Value Through Housing Technology Program and Services Guide*. 20/Jun 2002. *U.S. Department of Housing and Urban Development Partnership for Advancing Technology in Housing*, 5/Sep/2005 <http://www.huduser.org/publications/pdf/guidetoserv.pdf>.p3.

[50]The Aluminum Association, Inc., *Aluminum Association | Climate Change*. 2004, Environment and Climate Change - Conservation, Preservation, and Recycling, The Aluminum Association, Inc., 5/Sep/2005 <http://www.aluminum.org/Content/NavigationMenu/The_Industry/Government_Policy/Climate_Change/Climate_Change.htm>.

[51] Alex Wilson, "Insulation Materials: Environmental Comparisons,". *Environmental Building News* 4, no. 1 Jan/Feb 1995, BuildingGreen.Com, 5/Sep/2005 <http://www.buildinggreen.com/auth/article.cfm?fileName=040101a.xml>.

More recent data from the United States National Institute of Standards and Technology suggests essentially the same thing.
Barbara C. Lippiatt, BEES 2.0 -Building for Environmental and Economic Sustainability Technical Manual and User Guide, Jun/2000). June 2000. Office of Applied Economics, Building and Fire Research Laboratory, National Institute of Standards and Technology, 5/Sep/2005 <http://museum.nist.gov/exhibits/timeline/PDF/BEES.PDF>.pp 62,65.

A contractor for the EPA analyzed the same BEES database and came to the opposite conclusion:
United States Environmental Protection Agency Office of Research and Development, Framework for Responsible Environmental Decision Making (FRED): Using Life Cycle Assessment to Evaluate Preferability of Products, Oct 2000), EPA/600/R-00/095. June 2001. United States Environmental Protection Agency Office of Research and Development, 5/Sep/2005 <http://www.lcacenter.org/library/pdf/fred.pdf>.pB-5.

Their conclusion does not seem to match the data. Where BEES database, as added up in manual site shows cellulose requiring about one fifth the energy input (for manufacturing and raw materials combined) as fiberglass, the FRED example shows cellulose requiring more than **20 times** the energy per kilogram. Since this varies from every other analysis ever done to be believed it would have to more specific as to where the difference came from.

For example the Minnesota Building Database shows about one tenth the global warming impact for cellulose as fiberglass
University of Minnesota College of Architecture and Landscape Architecture Center for Sustainable Building Research, "Minnesota Building Materials Database - Generic Fiberglass Batt," *Minnesota Building Materials Database*, 26/May 2004, University of Minnesota College of Architecture and Landscape Architecture Center for Sustainable Building Research, 5/Sep/2005 <http://www.buildingmaterials.umn.edu/07211_batt_bees.html>.

University of Minnesota College of Architecture and Landscape Architecture Center for Sustainable Building Research, "Minnesota Building Materials Database - Blown Cellulose," *Minnesota Building Materials Database*, 26/May 2004, University of Minnesota College of Architecture and Landscape Architecture Center for Sustainable Building Research, 5/Sep/2005 <http://www.buildingmaterials.umn.edu/07210_blown_bees.html>.

[52] Food and Agriculture Organization of the United Nations (FAO)., "Food Balance Sheet," *FAOSTAT Online Database 2004. Commodity Balances Database - Production*. Aug 2004, Food and Agriculture Organization of the United Nations (FAO)., 10/Sep/2005 <http://faostat.fao.org/faostat/servlet/XteServlet3?OutputLanguage=english&Areas=ALL&Items=2901&Years=2001&Years=2000&Domain=FBS&ItemTypes=FBS&language=EN&Codes=ShowCodes>.

[53]Economic Research Unit United States Department of Agriculture, *ERS/USDA Briefing Room - Global Food Security: Questions and Answers*. 11/May 2005, Economic Research Unit United States Department of Agriculture, 10/Sep/2005 <http://www.ers.usda.gov/Briefing/GlobalFoodSecurity/questions/>.

[54]Institute of Medicine of the National Academies, *Dietary Reference Intakes: Macronutrients*. May 2005, National Academy of Sciences, 10/Sep/2005 <http://www.iom.edu/Object.File/Master/7/300/0.pdf>.p4.

[55] U.S. Census Bureau, "World Population: Total Midyear Population," *Intenational Data Base*, 30/April 2004, U.S. Census Bureau, 25/May/2004 <http://www.census.gov/ipc/www/worldpop.html>.

[56] Brian Halweil, "Can Organic Farming Feed Us All?". *World Watch Magazine* 19, no. 3 May/Jun 2006*The Organic Center*, Worldwatch Institute, Jan-03-2007 <http://www.organic-center.org/reportfiles/EP193A.Halweil.pdf>.

[57] Food and Agriculture Organization of the United Nations (FAO)., *FAOSTAT Online Database 2004 - Crops Primary*. Aug 2004, Food and Agriculture Organization of the United Nations (FAO)., 10/Sep/2005 <http://faostat.fao.org/faostat/servlet/XteServlet3?Areas=231&Items=%3E1714&Elements=31&Years=2000&Format=Table&Xaxis=Countries&Yaxis=Items&Aggregate=&Calculate=&Domain=SUA&ItemTypes=Production.Crops.Primary&language=EN>.

U.S. Grain harvest in 2000 in hectares equal	58,497,083
U.S. agricultural harvest from cropland in 2000 equals	136,057,883

So ~43% of total cropland harvested in 2000 was grain.

World Resources Institute, "Meat Consumption: Grain Fed to Livestock as a Percent of Total Grain Consumed," *EarthTrends Environmental Portal - Environmental Information Database*, 2004, World Resources Institute, 10/Sep/2005 <http://earthtrends.wri.org/searchable_db/results.cfm?years=1999-2000,2000-2001,2001-2002,2002-2003,2003-2004&variable_ID=348&theme=8&cID=190&ccID=0>.
From 60% to 65% of U.S. grain is fed to animals,
So around 27% of U.S. cropland used to grow food for animals

[58] Food and Agriculture Organization of the United Nations (FAO)., *FAOSTAT Online Database 2003 - Crops Primary*. Aug 2004, Food and Agriculture Organization of the United Nations (FAO)., 10/Sep/2005 <http://faostat.fao.org/faostat/servlet/XteServlet3?Areas=862&Items=%3E1714&Elements=31&Years=2000&Format=Table&Xaxis=Years&Yaxis=Countries&Aggregate=&Calculate=&Domain=SUA&ItemTypes=Production.Crops.Primary&language=EN>.

Total Crops Worldwide 2000 (Ha)	1,348,840,594
Total Crops World Wide Grain (Ha)	674,247,980

So ~50% of harvested primary crop acreage used for grain in 2000

World Resources Institute, "Meat Consumption: Grain Fed to Livestock as a Percent of Total Grain Consumed," *EarthTrends Environmental Portal - Environmental Information Database*, 2004, World Resources Institute, 10/Sep/2005 < http://earthtrends.wri.org/searchable_db/results.cfm?years=1999-2000,2000-2001,2001-2002,2002-2003,2003-2004&variable_ID=348&theme=8&cID=190&ccID=0 >.
Around 37% of grain crops worldwide fed to animals.
~37% of ~50%=~18.5% of total cropland worldwide used to grow grain for animals.

[59]Joel Salatin, a grass-fed beef pioneer and author makes the point from a stockman's viewpoint:

Roughly speaking, land that will produce 100 bushel-per-acre corn, will produce 400 cow-day[s] forage (one cow day is what one cow will eat in one day--cow-days are to graziers what inches are to carpenters and board-feet are to lumberjacks). If 100 bushels (average 60 pounds per bushel, weight 6,000 pounds), that will produce about 857 pounds of beef.

At 400 cow-days we can carry 600 stocker calves (400-800 lb.) gaining at least 1.5 pounds per day, yielding 900 lbs. (600 X 1.5 = 900) of beef per acre.

…..... The point is to move the stock to mimic grazing patterns of native herbivores…

... Under good controlled grazing, we allow the grass to recuperate through its "blaze of growth" period before being regrazed.… …By keeping 98% of the farm at rest and in the fast growth period, not letting the forage get grazed too early or too late after growth slows down, we can see tremendous increases in forage growth…

…. Most parasites lose strength dramatically after being denied a host for three weeks. Since most paddock shifts occur at least three weeks apart…, this depletes parasite virility and reduces the need for wormers..

.... Because the animals lounge in different paddocks every day, they spread their manure more evenly over the pasture…

Joel Salatin, "Joel Salatin Introduces Livestock Grazing... 'Salad Bar Beef,". *Acres USA - A Voice for Eco-Agriculture* March 1996*Eco-Friendly Foods*, 10/Sep/2005 <http://www.ecofriendly.com/index.cfm?section=4&page=20>.

[60]Cutler J. Cleveland and Charles A. S. Hall, "Climate Change Human Driving Forces, Biophysical Basis, and Likely Impacts," *Climate Change - Socioeconomic Dimensions and Consequences of Mitigation*, ed. Pentti Vartia, 2000). Oct 1999. *Fortum*, Boston Univerisity, 11/Sep/2005 <http://www.bu.edu/cees/research/workingp/pdfs/9910.pdf>.p9.

[61]Jimmy Henning et al., *Rotational Grazing*, 2000), ID-143. 2000. *Cooperative Extension Service - University of Kentucky, Department of Agriculture*, 13/Sep/2005 <http://www.ca.uky.edu/agc/pubs/id/id143/id143.pdf>.

State of Illinois Department of Agriculture IIllinois Sustainable Agriculture Committee, "S/A 98-18 Sustainable Beef Production - Management Intensive Grazing Vs Corn Silage Program for Beef Stocker Calves.," *Sustainable Agriculture Grant Review Committee C2000 Sustainable Agriculture Grant Projects - ON-FARM RESEARCH AND DEMONSTRATION*. Oct 2001. *State of Illinois Department of Agriculture IIllinois Sustainable Agriculture Committee*, State of Illinois Department of Agriculture IIllinois Sustainable Agriculture Committee, 13/Sep/2005 <http://www.agr.state.il.us/C2000/fy00/FY00Report.pdf>.pp6-17
(*Note: total beef production over the three year period was about one third the per acre production from corn.. However this was an experimental program grazing basically two forages - alfalfa /orchard grass during warm weather, and small grain cereal rye during cool. A more experienced grazer with a wider variety of forages could expect better results - especially if drough resistant varieties were used. Also the cattle tested were largely bred as feedlot animals. Forage animals in pasture compared to feedlot breeds on grain would be a better test. However, even with the lower production per acre, cost per pound of beef, and especially labor per pound of beef was lower with grass raised.)

Center for Integrated Agricultural Systems of the University of Wisconsin's College of Agricultural and Life Sciences, *CIAS: Management Intensive Rotational Grazing's Sense..and Dollars*. April 1996, Center for Integrated Agricultural Systems of the University of Wisconsin's College of Agricultural and Life Sciences, 13/Sep/2005

<http://www.cias.wisc.edu/archives/2000/01/04/dairy_grazing_can_provide_good_financial_return/index.php>.
(The milk per acre is slightly lower, but labor costs are MUCH lower, as are feed costs and capital costs. So even with no price premium the farmer would make higher profits.)

Also, Ibid 59

[62]Richard Cowan, "U.S. Group Blasts Creekstone Mad Cow Testing Plan,". *Reuters Via Forbes.Com* 19/Apr 2004, Forbes, 14/May/2004 <http://www.forbes.com/markets/newswire/2004/04/19/rtr1336959.html>.

[63]Donald Lobb, "No-Till Success Hinges on Developing a Complete Crop Production 'System,'". *Sustainable Farming*, no. Winter 94 (1994)*Ecological Agriculture Projects, McGill University (Macdonald Campus)*, Resource Efficient Agricultural Production - Canada (REAP-CANADA), 17/Sep/2005 <http://www.eap.mcgill.ca/MagRack/SF/Winter%2094%20I.htm>.

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[65]Preston Sullivan, *Conservation Tillage*, Jul-2003). *Appropriate Technology Transfer For Rural Areas*. Aug 2003. *National Center for Appropriate Technology*, 26/May/2004 <http://attra.ncat.org/attra-pub/PDF/consertill.pdf>.Pp2-3.

Corliss Karasov, "No-Till Farming on Comeback Trail,". *Environmental Health Perspectives* 110, no. 2 Feb 2002, 1/Jun/2004 <http://www.greennature.com/article833.html>.

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[67] Emma Marris, "Black is the New Green,". *Nature* 442, no. 10 Aug 2006, Charcoal Sequestering Carbon in Soil, Nature Publishing Group, Jan-03-2007 <http://www.bestenergies.com/downloads/naturemag_200604.pdf>.

[68]Greg Gunthorp and Lei Gunthorp, *Grassfarmer.Com - PASTURED PIGS ON THE GUNTHORP FARM*. 24/Feb 2004, American Farmland Trust, 13/Sep/2005 <http://grassfarmer.com/pigs/gun1.html>.

Sustainable Agriculture Network, *Profitable Pork:Strategies for Hog Producers*. *Livestock Alternatives*. Jul 2003. *Sustainable Agriculture Network*, Sustainable Agriculture Research and Education Program, 31/May/2004 <http://www.sare.org/publications/hogs/profpork.pdf>.

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[70]Hempopotamus, *All About Hemp*. 2004, Industrial Hemp, Hempopotamus, 22/Jun/2004 <http://www.hemphouse.com/docs/hempinfo.html>.

[71]John Jeavons, "Cultivating Our Garden: Biointensive Farming Uses Less Water, Land, Machinery, and Fertilizer - and More Human Labor,". *In Context*, no. 42/Fall 1995 - A Good Harvest (1995), Context Institute, 17/Sep/2005 < http://www.context.org/ICLIB/IC42/Jeavons.htm>.p34.

[72] United States Environmental Protection Agency, *How We Use Water In These United States*. 18/March 2003, United States Environmental Protection Agency, 06/Jul/2005 <http://www.epa.gov/watrhome/you/chap1.html>.

[73]Micro-irrigation system (drip + sprinkler) about 5.7% of total irrigated acreage
Various gravity forms (at 50%) are about 43.9% of total irrigated acreage
Other sprinklers irrigate about 51.2% of total irrigated acreage
United States Department of Agriculture National Agricultural Statistics Department, *2003 Farm & Ranch Irrigation Survey (2002 Census of Agriculture| Volume 3, Special Studies, Part 1)*. Nov 2004. *United States Department of Agriculture National Agricultural Statistics Department*, 28/Oct/2005 <http://www.nass.usda.gov/census/census02/fris/fris03.pdf>.p8.
Table 4. Land Irrigated by Method of Water Distribution: 2003 and 1998

Micro irrigation systems average around 82.5% irrigation efficiency
Gravity irrigation systems average around 50% irrigation efficiency
Other sprinkler average around 70% irrigation efficiency

Michael D. Dukes, *Types and Efficiency of Florida Irrigation Systems*, (Note: Data Used Was from National Sources). Dec 2002. *University of Florida - Agricultural and Biological Engineering Dept*, 28/Oct/2005 <http://www.agen.ufl.edu/~mdukes/publications/Types_and_Efficiency_of_Florida_Irrigation_Systems.pdf>..p8.

So applying the efficiency numbers from the second source to the acreage in the first, we can calculate that current average irrigation efficiency is around 62%. If that average efficiency was upgrade to micro-irrigation levels we would reduce water use for irrigation nationally by an average of one third.

[74]I. Broner, *Irrigation: Tailwater Recovery for Surface Irrigation. Crop Series*, 4.709. 1998. *Colorado State University Cooperative Extension*, 17/Sep/2005 <http://www.ext.colostate.edu/pubs/crops/04709.PDF>.

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[78]Eric Williams, "Energy Intensity of Computer Manufacturing: Hybrid Assessment Combining Process and Economic Input-Output Methods,". *Environmental Science & Technology* 38, no. 22 15/Nov 2004, American Chemical Society, 18/Sep/2005 <http://www.it-environment.org/publications/hybrid%20PC%20LCA%20abstract.pdf or full version(paid) http://pubs.acs.org/cgi-bin/article.cgi/esthag/2004/38/i22/pdf/es035152j.pdf>.pp6166 – 6174.

[79]EECO - A Transico Company, *EECO-Greenä SILVER-THROUGH-HOLE DOUBLE-SIDED PRINTED CIRCUIT BOARDS PRODUCT OVERVIEW DESIGN CONSIDERATIONS FAQ's*. Dec 2003, EECO - A Transico Company, 22/May/2004 < http://www.eecoswitch.com/PDF%20Files/STH%20FAQs.PDF>.

[80]Sumitomo Bakelite Co. Ltd., *Products That Provide Environmental Solutions*. Jan 2004. *Sumitomo Bakelite Co. Ltd.*, 4/Jun/2004 <http://www.sumibe.co.jp/english/kankyou/pdf/rc2003_E06.pdf>.

[81] Jonathan G. Overly, Lori E. Kincaid, and Jack R. Geibig, "Chapter 3: LIFE-CYCLE IMPACT ASSESSMENT," *Desktop Computer Displays: A Life-Cycle Assessment*, EPA-744-R-01-004a. Dec 2001. *Environmental Protection Agency*, 18/Mar/2005 <http://www.epa.gov/dfe/pubs/comp-dic/lca/Ch3.pdf>.pp3-30.
Table 3-10. Baseline life-cycle impact category indicators

[82]Sharp Corporation, *Sharp Environmental Report 2002,* April 2001 - March 2002. December 2002. *Sharp Corporation*, 20/Mar/2005 <http://sharp-world.com/corporate/eco/report/2002pdf/report_2002.pdf>.p9.

[83]Richard T. Carson and Nadja Marinova, *Running on Air*, Sep-1999). *Institute on Global Conflict and Cooperation IGCC Policy Briefs*, ISSN 1089-8352 Policy Brief Number 13. 21/Feb 2005. *Institute on Global Conflict and Cooperation (IGCC)*, 18/Mar/2005 <http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1088&context=igcc>.

[84]Keirsten Scanlon, *Poison PCs and Toxic TVs:California's Biggest Environmental Crisis That You've Never Heard of*. Jun 2001. *Silicon Valley Toxics Coalition; Californians Against Waste; Materials for the Future*, 6/Jun/2004 <http://www.cawrecycles.org/Ewaste/PPCs%20and%20TTVs/ppc-ttv.pdf>.
Citing: the Electronic Product Recovery and Recycling Baseline Report, published in May, 1999 by the US National Safety Council

[85]Friedrich Bio Schmidt-Bleek, *MIPSBOOK or The Fossil Makers -Factor 10 and More*, ed. Reuben(Trans) Deumling, 1994), ISBN 3-7643-2959-9. *Birkhäuser: Basel, Boston, Berlin*, Wuppertal Institute for Climate, Environment, Energy, 3/Aug/2004 < http://prog2000.casaccia.enea.it/nuovo/documenti/427.doc>.

[86] "Steel Producers Target Canned Foods,". *Packaging World Magazine* July 1995*Packaging World Magazine Online*, Summit Publishing, 9/Jun/2004 < http://www.packworld.com/articles/Features/1064.html>.

Note: this is an article favoring steel cans over foil packs for coffee. I analyzed information from this article so as to make to make sure I was not being over-optimistic. So again I repeat - this is information from steel can makers - people who favor steel cans over foil packs.

Modern steel cans for coffee weigh 17 pounds vs. 3 pounds for a steel brick. This is still an 80%+ reduction.

Here are the invalid arguments:

1) The most popular can quantity is 13 pounds not 17 pounds. Right, but a 13 pound can holds fewer servings than a 3 pound brick. A 17 pound can remains the correct comparison. If you insist on using 13 pound cans as a comparison then you have to take a fraction of the weight of a second 13 pound can and allocate it - which would result in a less favorable result for steel than a single 17 pound can.
2) The second argument is one from recycling. About 64% of steel cans are recycled, whereas foil pack currently are not. The problem with this is that recycling a steel can does not cut its impact in half. It would not even if the steel cans were simple rinsed out and had a new lid put on them. But in fact that is not how steel cans are recycled. They are melted down and used as sources to make new steel from. That new steel does have about 1/2 the material intensity of steel from raw ore, but then the energy and impacts of shaping the steel and making the cans are about the same. So long as the foil pack is not recycled we end up with about a 65% reduction - still significant. However we are not looking just at current practices, but at what practices we need to adapt. So we could theoretically recycle close to 100% of steel cans (those cans being used in households to hold nails and such making up for those not recycled). So that ends up as only a 60% reduction using foil wrap - still better than coffee cans. But if

we are looking at this, it is not impossible to recycle this kind of wrap. If you reduce the variety of plastic, using only one metal and one plastic, as we shall see later on it is possible to separate out the metal and plastic. Or you can use the combination to make plastic lumber. So if you recycle both you end up with an 80% net reduction again.

[87]Association of Cities and Regions for Recycling, *Good Practices Guide on Waste Plastics Recycling: A Guide by and For Local and Regional Authorities - 2004*, ed. Jean-Pierre Hannequart. Feb 2004. *Association of Cities and Regions for Recycling*, 10/May/2005 <http://www.ecvm.org/img/db/ACRRReport.pdf>.p83.

[88]Azom.com Pty Ltd, *Aluminium Packaging (Focus on Europe)*. 2002, Azom.Com Pty Ltd, 9/Jun/2004 <http://www.azom.com/details.asp?ArticleID=1396#_Advantages_of_Aluminium>.

[89]Environment and Plastics Industry Council (EPIC), *Plastics and Source Reduction*. Sep 2001. *Environment and Plastics Industry Council (EPIC)*, 9/Jun/2004 < http://www.cpia.ca/epic/docs/factsheets/Source%20Reduction.PDF>.

[90]Flexible Packaging Association, *Examples of Source Reduction*. Flexible Packaging Association, 9/Jun/2004 <http://www.flexpack.org/enviro/09srexamples.htm>.

[91]Envirowise, *Retail Supply Chain Distributes Cost Savings from Improved Packaging - A Case Study from the Book Industry*. *Envirowise Case Studies*, CS332. Mar 2002. *Envirowise*, 14/May/2004 <http://www.envirowise.gov.uk/envirowisev3.nsf/0/EAE528C70CD5852480256CE5004C7095/$File/CS332.pdf>.

[92]Envirowise, *Packaging Rethink Boosts Profits: A Good Practice Case Study At Harman Pro Audio Manufacturing*. *Environmental Technology Best Practice Programme*, GC275 Final Results. Oct 2000. *Envirowise*, 14/May/2004 < http://www.envirowise.gov.uk/envirowisev3.nsf/0/17A681225D041DE080256CE5004C71EC/$File/GC275.pdf>.

[93]Figures for 1999, but without packaging, and with a total for 1998(not 1999) that excludes building paper: Peter J. Ince and Irene Durbak, "Pulpwood Supply and Demand: Development in the South, Little Growth Elsewhere,". *Journal of Forestry* 100, no. 2 1/Mar 2002, Society of American Foresters, 18/Sep/2005 <http://www.fpl.fs.fed.us/documnts/pdf2002/ince02b.pdf>.pp20-21.

Totals for 1998 and 1999 paperboard – which is the bulk of paper products not including building paper. James L. Howard, U.S. Timber Production, Trade, Consumption, and Price Statistics 1965-1999, FPL-RP-595. April 2001. United States Department of Agriculture Forest Service Forest Products Laboratory, 18/Sep/2005 <http://www.fpl.fs.fed.us/documnts/fplrp/fplrp595.pdf>.p71.
Table 45—Paperboard production, imports, exports, and consumption, 1965–1999

Using the growth consumption between 1998 and 1999 from the above I was able to take the 1998 total from the first source and estimate the 1999 total consumption. Given 1999 total consumption and every other category, 1999 packaging may then be calculated by subtraction.

[94]Mark J Lytle, "Library Without Books,". *The Guardian (Guardian Unlimited)* 22/Apr 2004, 11/Jun/2004 < http://www.guardian.co.uk/online/story/0,3605,1197495,00.html>.

[95]Reuters, *Let's Make Reading Better!* 9/Feb 2004, IT supplement of The Tribune, The Tribune of India, 20/Sep/2005 <http://www.tribuneindia.com/2004/20040209/login/main3.htm>.

[96]Advertising accounts for around 65% of daily revenues, circulation for 35%, while newsprint accounts for about one third of total costs. Allowing for profit (so that one third of revenues does not equal one third of

costs), this means printing a typical daily U.S. newspaper costs well over half, and perhaps as much as 90% of the subscription price.

"Newspaper," *Microsoft® Encarta® Online Encyclopedia.* 2004, 11/Jun/2004 < http://encarta.msn.com/text_761564853___62/Newspaper.html>.

[97]Lyad Atuan et al., *Life-Cycle Assessment of Desktop Computer Display*. Mar 2004. *None - Term Project in Masters Level Class*, 6/Jun/2004 <http://s93889521.onlinehome.us/docs/mie415.pdf>.

(Please note that this is only student project in a masters program. However it tracks quite closely to the EPA result for CRT and LED monitors, using differing sources. So it is not an unreasonable source for the saving for e-ink – especially since we are not talking about a big difference in any case.)

[98] 2002 paper consumption was 21.4 kg per person
Clare Walker, *Melbourne Central Green Office 2002 Performance Report.* Jul 2003. *BP Australia*, 11/Jun/2004 <http://www.bp.com.au/environmental_social/green_office_2002_report.pdf>.p6.

According to the 2001 report, the 1997 bench was 55 kg per person. So that was indeed a 61% reduction. Also there were layoffs and hours per person increased - so this may understate the saving.
Kerryn Schrank, *Melbourne Central Green Office 2001 Performance Report*. Aug 2002. *BP Australia*, 11/Jun/2004 <http://www.bp.com.au/environmental_social/green_office_2001_report.pdf>.p4.

[99]Brad Wallace, "Paper Reduction Program Saves Money And The Environment," *Knowledge Bank Articles*, 28/Sep 2004, Innovative Management Systems, 20/Sep/2004 <http://www.solutions.ca/Knowledge_Bank/Articles/article.asp?doc_id=158>.

[100]Abigail J. Sellen and Richard Harper, *The Myth of the Paperless Office* (Cambridge MA USA: MIT Press, 2001).

[101]David Stewart, "Ensuring Effective Insurance Thanks to Paperless Office,". *SiliconRepublic.Com - Ireland's Technology News Service* 19/Apr 2004*Case Studies*, Silcon Republic - Dublin, 11/Jun/2004 <http://www.siliconrepublic.com/news/news.nv?uid=lipowg&sid=C5mmenoD&storyid=single3087>.

[102] Mike Martin, "Paperless Office: Case Studies Show How and Why,". *Computer Bits* 14, no. 1 Jan 2004, Bitwise Productions Portland Oregon, 14/Jun/2004 < http://www.computerbits.com/archive/2004/0100/paperless.html (if no longer good cache at: http://66.102.7.104/search?q=cache:IrULwCmYYXYJ:www.computerbits.com/archive/2004/0100/paperless.html)>.

[103] KP Products, *About The Kenaf Plant*. 14/Jan 2005, KP Products, 20/Sep/2005 < http://www.visionpaper.com/kenaf2.html>.

[104]Jame A. Rydelius, *Growing Eucalyptus for Pulp and Energy. Mechanization in Short Rotation, Intensive Culture Forestry Conference, Mobile, AL, March 1-3, 1994*. Mar 1994, Short Rotation Woody Crops Operations Working Group (Established by DOE ORNL, USDA and EPRI), 14/Jun/2004 < http://www.woodycrops.org/mechconf/rydeliu.html>.

[105] Gene Stevenson, *90 Years' Results Say Yes to Winter Legumes, Crop Rotations*. 9/Feb 1989, College of Agriculture: Auburn University Alabama Agricultural Experiment Station, 15/Jun/2004 < http://www.ag.auburn.edu/aaes/webpress/1989/rotations.htm>.

[106]Charles Mitchell, Wayne Reeves, and Dennis Delany, "Breaking Records: Sensible Management Helps Alabama's Long Term Experiments Net Record Yields,". *Online Highlights: A Magazine of Research from the Alabama Agricultural Research Station at Auburn University* 48, no. 3 Fall 2001, College of

Agriculture: Auburn University Alabama Agricultural Experiment Station, 15/Jun/2004 < http://www.ag.auburn.edu/aaes/communications/highlightsonline/fall01/fall-mitchell.html>.

[107] Jane N. Abramovitz and Ashley T. Mattoon, *Paper Cuts:: Recovering the Paper Landscape*, ed. Jane A. Peterson, WorldWatch Paper 149. Dec 1999. *Worldwatch Institute*, 16/Jun/2004 <http://www.worldwatch.org/pubs/download/EWP149/>.p21.
Figure 5

[108]David R. Darr, *U.S. Forest Resources*. 28/Sep 2000, U.S. Forest Service, 15/Jun/2004 <http://biology.usgs.gov/s+t/noframe/m1103.htm>.

[109] Jim Motavalli, "Beyond Wood | Tree-Free and Chlorine-Free Papers Offer Sound Alternatives to Forest Destruction,". *E, The Environmental Magazine* IX, no. 1 Jan-Feb 1998, Earth Action Network, Inc., 1/Oct/2005 <http://www.emagazine.com/view/?41>.

[110]U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS);Iowa State University's Center for Survey Statistics and Methodology, *2002 Annual Natural Resources Inventory: Land Use*. April 2004. *U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS);Iowa State University's Center for Survey Statistics and Methodology*, 15/Jun/2004 <http://www.nrcs.usda.gov/technical/land/nri02/landuse.pdf>.p2.

[111]Thomas A. Rymsza, "Firm Profile: Vision Paper,". *Journal of Industrial Ecology* 7, no. 3-4 May 2004, Massachusetts Institute of Technology and Yale University, 16/Jun/2004 <http://www.visionpaper.com/speeches_papers/jiec_7_3-4_215_0.pdf>.p217.

[112] Ibid 107 p49.

[113]European Commission, *Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques in the Pulp and Paper Industry*. Dec 2001. *European Commission*, 20/Sep/2005 <ftp://ftp.jrc.es/pub/eippcb/doc/ppm_bref_1201.pdf>.

[114]"In 2003 the U.S. paper recovery rate achieved an all-time high of 50.3%. Paper recovery has increased steadily from 33.5% in 1990, to its present level of 50.3%." (Note that not all of the 50.3% recovered can be used. So, the actual recycling rate is less than 50%.)

American Forest and Paper Association, "Recycling," *Environment and Recycling*, 2005, American Forest and Paper Association, 21/Jun/2005 <http://www.afandpa.org/Content/NavigationMenu/Environment_and_Recycling/Recycling/Recycling.htm >.

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Table 2-2 - CEPI – European Paper and Board and Recovered Statistic by Country in 2000 – 1000 tonnes

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127 Ibid 125 p100.

128 Ibid 125 p79.

129 Ibid 125 p78.

130 Ibid 124 p265.
Section 4.3.3

131 Ibid 124 pp267-268.
Section 4.3.4

132 Ibid 125 p79.

133 Ibid 125 p80.

134 Ibid 125 p.85.

135 Ibid 124 p446.
Section 5.1

[136] Ibid 124 p353.
Section 4.6.21.3

[137] Ibid 124 p370.
Section 4.7.8

[138] Ibid 124 p371.
Section 4.7.9

[139]Ibid 125 p81.

[140]Ibid 125 p82.

[141]Ibid 125 p82.

[142] Ibid 125 p93.

[143] Ibid 124 p368.
Section 4.7.7

[144]Hempopotamus, *All About Hemp*. 2004, Industrial Hemp, Hempopotamus, 22/Jun/2004 <http://www.hemphouse.com/docs/hempinfo.html>.

[145]John A. Dearien, Struthers Richard D., and Kent D. McCarthy, *CyberTran: A Systems Analysis Solution to the High Cost and Low Passenger Appeal of Conventional Rail Transportation Systems*. Nov 2001, CyberTran International, Inc, 22/Jun/2004 <http://www.cybertran.com/ctpaper.pdf>.

[146] Ibid 145 P.5 (Note the cost per seat in examples given is five to ten times less. But once you include greater utilization from computation or routes on the one tenth the cost becomes a conservative estimate.)

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Page 2-14 Table 2.11 Passenger Travel and Energy Use in the United States, 2000

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[149] Ibid 148 p 5.
[150]Zipcar, Inc, *Get a Zipcard*. 2005, Zipcar, Inc, 23/Sep/2005 <http://www.zipcar.com/apply/>.

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Table 8.5: Demographic Statistics from the 1969, 1977, 1983, 1990, 1995 NPTS and 2001 NHTS

[155] Ibid 15 p2-7.
Table 2.5 - Transportation Energy Use by Mode, 2000–2001

[156] Ibid 147
Table 2.11 Passenger Travel and Energy Use in the United States, 2000

[157]Ibid 15
Table 2.14 - Intercity Freight Movement and Energy Use in the United States, 2001

[158] For number of class I freight cars and locomotives
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Ibid 15 for number of trucks

[159] Ibid 158 p669.
No.1053.Highway Mileage —Functional Systems and Urban/Rural:2000

[160] Ibid 158

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Joe Sharkey, "Rail Projects Are Sign of a Quiet Revolution in Short-Haul Trips," *EcoCity Cleveland - Transportation Choices*, 4/Jun 2002, New York Times Inc., 23/Sep/2005 < http://www.ecocitycleveland.org/transportation/rail/nytimes_rail_article.html>.

70% of European domestic flights are 621 miles or under
Caroline Dr. Lucas, *The Future of Aviation: The Government's Consultation Document on Air Transport Policy - Submission from Dr Caroline Lucas, MEP, Green Party, and Member of the European Parliament's Transport Committee*. 2001. *European Parliment*, Green Party UK, 23/Sep/2005 < http://archive.greenparty.org.uk/reports/2001/aviation/av_fut_mep_resp.pdf>.

Since Europe has much better long distance passenger rail infrastructure than the U.S., it would be reasonable to assume that at least 60% of U.S. domestic flights are same length. Thus 500 miles is a reasonable interpolation between the two data points. Even if the second is thrown out, it is a conservative extrapolation of the first data point alone.

[163]Conrad Schneider, *Power Plant Emissions: Particulate Matter-Related Health Damages and the Benefits of Alternative Emission Reduction Scenarios*. Jun 2004. *Clean Air Task Force* Abt Associates Inc, 24/Aug/2004 <http://cta.policy.net/dirtypower/docs/abt_powerplant_whitepaper.pdf>.

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[165]Martin Patel et al., "Chapter 14 Life-Cycle Assessment of Bio-Based Polymers and Natural Fiber Composites," *Biopolymers, Volume 10, General Aspects and Special Applications. Biopolymers, 10 Volumes with Index*, ed. Alexander Steinbüchel. April 2003. *Wiley*, 11/Jun/2004 <http://www.chem.uu.nl/nws/www/general/personal/Biopoly.pdf>.p409.
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[170]Arvind C. Thekdi, "Guest Column: Energy Savings in Industry Through Use of Insulation and Refractories,". *Energy Matters* May/Jun 2000: Best Practices, U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Industrial Technologies Program, 25/Sep/2005 <http://www.eere.energy.gov/industry/bestpractices/may2000_guest.htm>.

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Note that this is talking commercial boilers – used for space and hot water heating. But the same principals apply to industrial boilers; a boiler operates much less efficiently when used at less than capacity. So multiple boilers turned on as needed, so that all running boiler operate near maximum efficiency are more efficient than one big boiler running at less than maximum efficiency most of the time. Note there are two major limits to this. One is cost: many small boilers cost more that a few big ones. The second is that warming up and cooling down a boiler also costs energy. If you have too many boilers and spend a lot of time turning them on and off, you will waste more energy than you save. But the optimum is fairly easy to calculate on a plant by plant basis, and we are nowhere near it.

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(Note: recommendation 3 in table 3-3 appears to have a multi-century payback because a period was substituted for a comma. The same number appears in table 3-2 in the document http://www.delta-institute.org/publications/boilers/Table3-2.pdf with comma in the proper place.)

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[178] Ibid 22 p115.
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[179] U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Industrial Technologies Program, *Energy Tips: Reduce Pumping Costs Through Optimum Pipe Sizing: Motor Tip Sheet # 1*, DOE/GO-10099-879. Dec 1999. *U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Industrial Technologies Program*, 16/Aug/2004 <http://www.energystar.gov/ia/business/industry/motor1.pdf>.

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[186]Office of Industrial Technologies - Energy Efficiency and Renewable Energy • U.S. Department of Energy, *Weldcomputer® Resistance Welder Adaptive Control: Sophisticated Welding Control System Saves Energy, Improves Quality, and is Affordable for General Industrial Use. Inventions and Innovation Success Story*, I-OT-588. Jan 2002, Fice of Industrial Technologies - Energy Efficiency and Renewable Energy • U.S. Department of Energy, 4/Sep/2005 <http://www.eere.energy.gov/inventions/pdfs/weldcomp.pdf>.

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[192]Ross A. Leventhal, "Sustainable in Seattle,". *Architecture Week*, no. 101 5/Jun 2002: Environment, Artifice Inc., 6/Sep/2004 <http://www.architectureweek.com/2002/0605/environment_2-2.html>.pE2.2.

[193]"Journeys-to-work using public transportation continued to take twice as long as private transportation, though there is only a slight difference in travel distance."
Ibid 147 p11-15.

[194]Ibid 147 p11-12.

[195] John A. Dearien (Junior), "Ultralight Rail and Energy Use," in *Encyclopedia of Energy*, ed. Cutler J. Cleveland (Elsevier Publishing, March 2004), 255-66.

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Page v. - Battery cycles are over 2,000 cycles with almost no loss of capacity with deep discharge, even better with shallow discharge in actual use. So we can conservatively estimate 1,000 cycles, which would last longer than the lifetime of the car.

Page vi - NiMH cost can reach $320 per kWh capacity in volumes of 100,000 or more. (Remember that an automobile needs more than one)

So battery cost, interest, and electricity at 14 cents per kWh will still cost less than $2.50 per gallon gas.

[198]Rocky Mountain Institute, "The Hypercar® Concept," *Transportation*, 2004, Rocky Mountain Institute, 19/Aug/2004 <http://www.rmi.org/sitepages/pid386.php>.

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[200] CalCars - The California Cars Initiative - 100 MPG Hybrids, *Plug-In Hybrids: State Of Play, History & Players*. 17/Mar 2006, 17/Mar/2006 <http://www.calcars.org/history.html>.

[201]Hanne Siikavirta et al., "Effects of E-Commerce on Greenhouse Gas Emissions: A Case Study of Grocery Home Delivery in Finland,". *Journal of Industrial Ecology* 6, no. 2 - E-commerce, the Internet,

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[203]Gerrit Knaap et al., *Government Policy and Urban Sprawl.* 2000. *Illinois Department of Natural Resources*, University of Illinois at Urbana-Champaign, 29/Jun/2005 <http://dnr.state.il.us/orep/c2000/balancedgrowth/pdfs/government.pdf>.

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<http://www.mtc.ca.gov/maps_and_data/datamart/survey/APS_report_volume_1.pdf>.p7.
(Note statistics are bay area statistics only.)

Inbound International travel 26%-30% primarily for business purposes. So 26% remains a conservative estimate at international level.
Bureau of Transportation Statistics, *BTS - U.S. International Travel and Transportation Trends - Overseas Travel Trends.* 2004, Inbound Overseas Travel;, Bureau of Transportation Statistics, 23/Sep/2005 <http://www.bts.gov/publications/us_international_travel_and_transportation_trends/overtrends.html>.

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[207]D. Dimitriu et al., *Aviation and the Global Atmosphere -(Chapter 8) Air Transport Operations and Relations to Emissions - Executive Summary*. Apr 1999, GRID-Arendal Official United Nations Environment Programme (UNEP) Centre, 19/Aug/2004 <http://www.grida.no/climate/ipcc/aviation/119.htm>.

[208]Boeing World Headquarters, *Boeing 787-3 Dreamliner Facts*. 2003, Boeing Company, 21/Aug/2004 <http://www.boeing.com/commercial/7e7/facts_sr.html>.

[209]William R. Moomaw et al., *Climate Change 2001 - Mitigation -Working Group III: Mitigation - 3.4.4.8 Waterborne Transport.* 2001, Intergovernmental Panel on Climate Change, 19/Aug/2005 <http://www.grida.no/climate/ipcc_tar/wg3/103.htm>.

[210]U.S. Army Corp of Engineers | Rock Island District | Mississippi Valley Division, *Transportation Mode Comparison - Energy Environment- Efficiency*. Jan 2002. *U.S. Army Corp of Engineers | Rock Island District | Mississippi Valley Division*, 26/Sep/2005 <http://www2.mvr.usace.army.mil/UMR-IWWSNS/documents/tr-comp.pdf>.p1.

[211]I'm conservatively estimating compressor change potential to be only a 1% savings though more probably between 2% and 4% of compressor energy could be saved in the U.S. through such means.

Compresser efficiency can vary from 50% to over 90% in natural gas pipelines.
Southwest Research Institute (SwRI), *18-Services for the Pipeline Industry Brochure.* 2005, Southwest Research Institute (SwRI), 27/Sep/2005 <http://www.swri.edu/3pubs/brochure/d18/pipeline/pipeline.htm>.

We have an aging fleet of compressors 20-50 years old. While most the efficient gas compressors are about 91%, new electric compressor 92-95% efficient. (Note: these percents are comparisons to the thermodynamic limit, not to a theormodynamically impossible 100% efficiency. And yes, the gas used to generate the electricity for the electric compressors is taken into consideration; it is like hybrid cars; in some cases using heat to generate electricity to produce mechanical power can be more efficient that using heat directly to generate mechanical power).

Michael Crowley and Prem Bansal, *Development of an Integrated Electric Motor Compression System.* 3/Oct 2004, Gas Machinery Research Council | DOE NETL Research Review, 27/Sep/2005 <http://www.gmrc.org/gmrc/2004finalpapers/Development%20of%20an%20Integrated%20Electric%20Motor%20Driven%20Compressor.pdf>.

Although older less efficient compressors were more rugged and lasted up to 50 years, more typically a pipeline compressor lasts 30 years. Most U.S. compressors are under 90% efficiency, and almost none are above 91%. So even if the "compressor fleet" was new we could expect just about every compressor to be replaced over the next 30 years with one that is a percent or two more efficient. But in fact, as documented above we have a lot of old compressors, which are probably more in 75%-80% efficiency range. They will need to be replaced soon; replacing them with the most efficient compressors will save a lot more than a few percent. So actually 4% savings from compressor improvements would still be a conservative estimate. 1% leaves a huge margin of error.

[212]Phil Ferber et al., *Gas Pipeline Optimization*. *31st Annual Meeting - October 20-22, 1999 | St. Louis, Missouri.* Oct 1999, Pipeline Simulation Interest Group, 27/Sep/2005 <http://www.psig.org/papers/1990/9905.pdf>.p16.

This documents a 13.26% savings from just better (and very simple) software control. That cumulated with a 1% savings from improved compressors gives you better that 14% savings. And that does not even consider leaks: better controls can detect leaks more quickly and pinpoint them more accurately. More modern compressors cause fewer leaks to begin with. (Compressors are a major cause of leaks.) So that gives you an additional margin of error in an already very conservative estimate.

[213]Jürgen Schnieders, *CEPHEUS - Measurement Results from More Than 100 Dwelling Units in Passive Houses.* May 2003. *Passive House Institute*, 23/Dec/2003 <http://www.passiv.de/07_eng/news/CEPHEUS_ECEEE.pdf>.

(Note: he documented an 80% reduction compared to German standards. But Germans use about half the energy per capita as the U.S.

States Census Bureau, "Section 19 - Energy and Utilities," *Statistical Abstract of the United States 2002.* December 2002. *United States Census Bureau*
<http://www.census.gov/prod/2003pubs/02statab/energy.pdf>.p847
Table No. 1350. Energy Consumption and Production by Country: 1990 and 2000

So this is a 90% savings, compared to U.S. standards. Actually it is a bit more, because the 80% savings compares to tougher requirements for new German homes, not average use.

[214]U.S. Department of Energy - Energy Information Administration, "2001 Consumption and Expenditures Tables - Space-Heating Expenditures Tables," *A Look at Residential Energy Consumption in 2001.*

23/October 2003, 23/Dec/2003
<ftp://ftp.eia.doe.gov/pub/consumption/residential/2001ce_tables/spaceheat_expend.pdf>

Table CE2-9e. Space-Heating Energy Expenditures in U.S. Households by Northeast Census Region, 2001 - Preliminary Data

Table CE2-12e. Space-Heating Energy Expenditures in U.S. Households by West Census Region, 2001 - Preliminary Data

U.S. Department of Energy - Energy Information Administration, "2001 Consumption and Expenditures Tables - Electric Air-Conditioning Expenditures Tables," *A Look at Residential Energy Consumption in 2001*. 23/October 2003, 23/Dec/2003
<ftp://ftp.eia.doe.gov/pub/consumption/residential/2001ce_tables/ac_expend.pdf>.

Table CE3-9e. Electric Air-Conditioning Energy Expenditures in U.S. Households by Northeast Census Region, 2001 - Preliminary Data

Table CE3-12e. Electric Air-Conditioning Energy Expenditures in U.S. Households by West Census Region, 2001 - Preliminary Data

[215]Joe Wiehagen and Craig Drumhelle, *Strategies for Energy Efficient Remodeling | Seer 2003 |Case Study Report*, 2004). 30/Mar 2004. *National Renewable Energy Laboratory*, 1/Oct/2005
<http://www.toolbase.org/docs/MainNav/Remodeling/4564_SEERCaseStudyReport.pdf>.

[216] Agence France-Presse, *Thai Architect Hits on Blueprint for Sustainable Living in the Tropics*. 28/September 2003, Terra Daily, 06/Jul/2005
<http://www.terradaily.com/2003/030928033742.6azaxajn.html>.

Maria Cheng and Julian Gearing, "Green Seeds,". *Asia Week* 27-18 11/May 2001, Asia Week, 05/Jul/2005
<http://www.asiaweek.com/asiaweek/magazine/nations/0,8782,108626,00.html>.

[217]And according to Amory Lovins this was larger than he needed.
Paul Hawken, Amory Lovins, and L.Hunter Lovins, *Natural Capitalism: Creating the Next Industrial Revolution* (Boston: Little, Brown and Company/Back Bay, 2000).
Chapter 5:Building Blocks. p103.

[218]U.S. Department of Energy - Energy Information Administration, "2001 Consumption and Expenditures Tables - Total Energy Consumption," *A Look at Residential Energy Consumption in 2001*. 23/October 2003, 23/Dec/2003
<ftp://ftp.eia.doe.gov/pub/consumption/residential/2001ce_tables/enduse_consump.pdf>.

Table CE1-9c. Total Energy Consumption in U.S. Households by Northeast Census Region, 2001 - Preliminary Data

U.S. Department of Energy - Energy Information Administration, "2001 Consumption and Expenditures Tables - Water-Heating Consumption Tables," *A Look at Residential Energy Consumption in 2001*. 23/October 2003, 23/Dec/2003
<ftp://ftp.eia.doe.gov/pub/consumption/residential/2001ce_tables/waterheat_consump.pdf>.

Table CE4-9c. Water-Heating Energy Consumption in U.S. Households by Northeast Census Region, 2001 - Preliminary

[219]U.S. Department of Energy - Energy Information Administration, "2001 Consumption and Expenditures Tables - Water-Heating Expenditures," *A Look at Residential Energy Consumption in 2001*. 23/October

2003, 23/Dec/2003
<ftp://ftp.eia.doe.gov/pub/consumption/residential/2001ce_tables/waterheat_expend.pdf>

Table CE4-9e. Water-Heating Energy Expenditures in U.S. Households by Northeast Census Region, 2001 - Preliminary Data

Table CE4-10e. Water-Heating Energy Expenditures in U.S. Households by Midwest Census Region, 2001 - Preliminary Data

[220]U.S. Department of Labor Bureau of Labor Statistics, "Table 8. Region of Residence: Average Annual Expenditures and Characteristics," *Consumer Expenditure Survey 2002*. 13/Nov 2003. *U.S. Department of Labor Bureau of Labor Statistics,* 06/Jul/2005 < http://www.bls.gov/cex/2002/Standard/region.pdf>.

Table 8. Region of residence: Average annual expenditures and characteristics, Consumer Expenditure Survey, 2002

[221]Whedon 0.5 GPM Ultra SaverAerator - US$3.50
Energy Federation Incorporated, *EFI Internet Division Residential Catalogue | Bath Faucet Aerators*. July 2005, Energy Federation Incorporated, 13/Jul/2005
<http://www.energyfederation.org/consumer/default.php/cPath/27_52>.

similar product to above for $2.15
Conserv-A-Store, *Conserv-A-Store :: Recycling Supplies, Solar Lighting, Electrical, Plumbing & Water Conservation Products-Economical & Eco-Friendly! Part Number: 01-0104*. July 2005, Conserv-A-Store, 13/Jul/2005 <http://www.conservastore.com/productdetail.php?p=23>.

[222]Conserv-A-Store, *Conserv-A-Store :: Recycling Supplies, Solar Lighting, Electrical, Plumbing & Water Conservation Products-Economical & Eco-Friendly!*. July 2005, Conserv-A-Store, 13/Jul/2005
<http://www.conservastore.com/index_plumbing.htm>.

[223]According to the Handyman Club the Stepflow Kick Pedal should be discounted to $129
Tom Sweeney, *Handyman Club of America - Hands Free - Pedal Valve Makes Sink Faucets Convenient and Clean*. February 1999, Handyman Club of America (Publishers of Handy Magazine), 13/Jul/2005
<http://www.handymanclub.com/document.asp?cID=57&dID=777>.

And here it is on-line for $120.00 with shipping and such probably around $129 .
Professional Piercing Information Systems, *Products: Step-Flow Operated Sink Valve*. 16/June 2005, Professional Piercing Information Systems, 13/Jul/2005 <http://www.propiercing.com/products.html>.

[224]Priced at $27.00 without shipping at sustainable village. Assuming six bucks in shipping charges total of $60. Since sustainable village ships this only to developing nations, I've given the URL of manufacturer who should be able to tell where we in the U.S. can actually buy it.

Sustainable Village, *Sustainable Village - Products - Aqua Helix*. 2005, Sustainable Village, 13/Jul/2005
<http://www.thesustainablevillage.com/servlet/display/product/detail/22602>.

Jet Blast Industrial Services, *Aqua Helix Home*. 18/Feb 1999, Jet Blast Industrial Services, 13/Jul/2005
<http://www.jetblast.net/ahhome.html>.

[225]Microphor LF-210 $539.00
Dean Petrich, *Toilet Prices*. 16/July 2005, Ultra-Low Water-Flush toilets, Aqua Alternatives, 20/Jul/2005
<http://www.enviroalternatives.com/toiletprices.html#ULTRA-LOW%20WATER-FLUSH>.

[226]WaterFilm Energy Inc., *GFX 40% Off.* GFX Heat Exchanger, 25/May 2005, WaterFilm Energy Inc., 20/Jul/2005 < http://www.gfxtechnology.com/sale.html>.

Carmine Dr. Vasile, *International Data on Successfully Demonstrated Energy Efficiency Projects - Residential Waste Water Heat-Recovery System: GFX.* April 2000, Centre for the Analysis and Dissemination of Demonstrated Energy Technologies, 20/Jul/2005 <http://gfxtechnology.com/CADDET.PDF>.

Note where showers are not the main hot water consumer in the household storage recovery systems are available in the same price range:

National Association of Home Builders Research Center, *Drainwater Heat Recovery.* 2004, National Association of Home Builders Research Center, 08/Aug/2005 <http://www.toolbase.org/tertiaryT.asp?DocumentID=2134&CategoryID=1402>.

[227]EnergyStar Dishwasher product rating - in this case 85% better than average new model (so divide by 185).
(Note: this does not quite double efficiency of what is currently for sale, which means it is probably double or better that currently in use - but we will use EnergyStar rating as conservative estimate of savings)

Energy Star Program of the EPA and DOE, *Energy Star Qualified Dishwashers*, List of Energy Star Dishwashers with Efficiency Ratings. 14/June 2004, Energy Start Program of the EPA and DOE, 10/Jul/2005 <http://www.energystar.gov/ia/products/prod_lists/dishwash_prod_list.pdf>.p1

[228]Average Energystar & regular appliance prices 2000

The NPD Group, Inc., *NPD INTELECT REPORTS SIGNIFICANT GROWTH FOR ENERGY-EFFICIENT APPLIANCES.* Average Appliance Prices: Energystar Vs. Non-Energystar, 18/October 2000, The NPD Group, Inc., 10/Jul/2005 < http://www.npd.com/press/releases/press_001018.htm>.

(Note: A market survey is a legitimate source for pricing information).

[229]ASKO, *D3350*. 204, ASKO, 05/Jul/2005 <http://www.asko.se/ASKO/brandsite/main.cfm?moduleID=10&productID=2814#>.

[230]Universal Appliance and Kitchen Center, *24" ASKO Dishwasher, D3121*. Quote July 10 for Asko D3121, July 2005, Universal Appliance and Kitchen Center, 10/Jul/2005 <http://store.universal-akb.net/24asdid3.html>. (Note this was for a particular day – the key is that you can get a dishwasher that consumes around 250 kWh per year for around $333 more than a non-Energy Star model.)

[231]Liz Madison, *Kitchen Tools, Kitchen Electrics, Cookware, Tableware - LizMadison.Com -GWL11*. GWL11 Clothes Washer, July 2005, Liz Madison, 10/Ju <http://www.lizmadison.com/housewares/Product.asp_X_SKU_Y_GWL11_Z_REF_Y_SHLIZ>.

No doubt the particular page will have expired by the time you read this. The main point is that you can get a washing machine that saves nearly 80% of the energy a non-Energy Star model would use for about $220 more.

[232]Energy Star Program of the EPA and DOE, *ENERGY STAR® Qualified Clothes Washers*, ENERGY STAR® Qualified Clothes Washers with Effiiciencies and Projected Yearly KWh Consumption. 21/June 2004. *Energy Star Program of the EPA and DOE*, 11/Jul/2005 <http://www.energystar.gov/ia/products/prod_lists/clotheswash_prod_list.pdf>.

(Again this rates against average new available, so efficiency compared to installed home clothes washers is probably slightly better.)

[233]Mark Hutchinson, *Trickle Irrigation: Using and Conserving Water in the Home Garden - University of Maine Cooperative Extension Bulletin #2280*. April 2005, University of Maine Cooperative Extension, 13/Jul/2005 < http://www.umext.maine.edu/onlinepubs/htmpubs/2160.htm>.

[234]William B. DeOreo, David M. Lewis, and Peter W. Mayer, *Seattle Home Water Conservation Study: The Impacts of High Efficiency Plumbing Fixture Retrofits in Single-Family Homes*. December 2000. *Aquacraft, Inc. Water Engineering and Management*, 08/Aug/2005 <http://www.cuwcc.org/Uploads/product/Seattle-Final-Report.pdf>.p54.

[235]Madison Gas & Electric Company, *Water Heaters*. Feb/25 2005. *Madison Gas and Electric Company*, Madison Gas and Electric Company, 08/Aug/2005 <http://www.mge.com/images/PDF/Brochures/Residential/WaterHeaters.pdf>.p3.

[236]Low Energy Systems, Inc, *Infinion with Battery Spark Ignition*. August 2005, Low Energy Systems, Inc, 08/Aug/2005 <http://www.tanklesswaterheaters.com/infinion2.html>.

[237] U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, "Energy Savers: Compact Fluorescent Lamps," *Energy Savers: A Consumer Guide to Renewable Energy and Energy Efficiency,* 21/June 2004, 19/Aug/2005 <http://www.eere.energy.gov/consumerinfo/factsheets/ef2.html>.

[238]Fisher & Paykel, *Washers*. August 2005, Fisher & Paykel, 19/Aug/2005 <http://usa.fisherpaykel.com/laundry/washers/washers.cfm>.

[239]Secondary (end use) consumption is 4 kWh per load for the electric dryer, plus .23 kWh per load plus .22 therms per load for the gas dryer. If you convert therms to kWh at 100% efficiency this comes out the gas dryer actually using 67% more energy than an electric dryer.

Energy Star Program of the EPA and DOE, "About the HES Appliance Module," *The Home Energy Saver*, Table 3: Other Appliances and Miscellaneous Energy Usages, 06/June 2001, Energy Star Program of the EPA and DOE, 20/Aug/2005 < http://homeenergysaver.lbl.gov/hes/aboutapps.html>.

However, on average heat driven power plants convert only 36.47% of heat energy into electricity.

International Energy Agency, *Electricity Information 2002 Edition*, Electricity Information, vol. 2002 Edition, no. ISBN 9264197931 (Paris: OECD - Organisation for Economic Co-operation and Development, 2002).p.II.706
Part II Table 9 United State Electricity Production From Combustible Fuels in Electricity Plants"

So dividing the electricity consumption in both gas and electric dryers by 36.47, and then converting both to therms or both to kWh as you please, you end up with a 35.47% savings.

[240]California Energy Commission, "Dryers," *Consumer Energy Center - Inside Your Home*, August 2005, California Energy Commission, 20/Aug/2005 <http://www.consumerenergycenter.org/homeandwork/homes/inside/appliances/dryers.html>.

[241]Amory B. Lovins and William D. Browning, *Negawatts for Buildings*, Jul/1992). 15/Nov 2000. *Urban Land Institute*, 21/Jan/2004 <http://www.rmi.org/images/other/GDS-Negawatts4Bldgs.pdf>.pp4-5

[242] Sarah Goorskey, Andy Smith, and Katherine Wang, *Home Energy Briefs #7 - Electronics*, 2004). 3/Dec 2004. *Rocky Mountain Institute,* 20/Aug/2005 <http://www.rmi.org/images/other/Energy/E04-17_HEB7Electronics.pdf>.p3.

[243]Mark Palmer and Alicia Mariscal, *Green Buildings and Worker Productivity: A Review of the Literature*, Aug 2001). Aug 2001. *San Francisco Department of the Environment*, 22/Aug/2005 <http://www.sfenvironment.com/aboutus/innovative/greenbldg/gb_productivity.pdf>.

[244]Gregory H. Kats, *Green Building Costs and Financial Benefits*. October 2003. *Massachusetts Technology Collaborative State Development Agency for Renewable Energy and the Innovation Economy*., 23/Jan/2004 < http://www.mtpc.org/RenewableEnergy/green_buildings/GreenBuildingspaper.pdf>.p6.

[245]Gregory H. Kats et al., *The Costs and Financial Benefits of Green Buildings: A Report to California's Sustainable Building Task Force*, Oct 2003). Oct 2003. *California Sustainable Building Task Force*, 29/Jan/2004 < http://www.usgbc.org/Docs/News/News477.pdf>.p ix.

[246]William Browning, *NMB Bank Headquarters: The Impressive Performance of a Green Building*, June 1992). 24/Feb 2003. *The Urban Land Institute*, Rocky Mountain Institute, 22/Aug/2005 <http://www.rmi.org/images/other/GDS/D92-21_NMBBankHQ.pdf>.p24.

[247]U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, *2004 Buildings Energy Databook*, Jan 2005). Jan 2005. *U.S. Department of Energy Office of Energy Efficiency and Renewable Energy*, 22/Aug/2005 <http://buildingsdatabook.eren.doe.gov/docs/2004bedb-0105.pdf>.p1-9.
Table 1.3.4 - Commercial Delivered and Primary Energy Consumption Intensities, by Year

[248] http://erg.ucd.ie/EC2000/EC2000_PDFs/dossier_1011.pdf
Commission of the European Communities, *Energy Consumption and Cost Effectiveness of EC2000 Buildings*, Jan 2000). *Energy Comfort 2000*, European Commission Thermie Project to Reduce Energy and Improve Comfort and Environment, Information Dossier Number 10/11. January 2004. *Commission of the European Communities*, Energy Research Group - University College, 22/Aug/2005 <http://erg.ucd.ie/EC2000/EC2000_PDFs/dossier_1011.pdf>.pp1-2.

[249]

Ibid 248 pp2-3.

[250]Ibid 248 pp3-4.

[251]Energy Research Group - University College, *Case Study Module C - Sukkertoppen - Copenhagen DK. Mid Career Education: Solar Energy in European Office Buildings*. Nov 1997. *Energy Research Group - University College*, 22/Aug/2005 <http://erg.ucd.ie/mid_career/pdfs/case_study_C.pdf>.p15.

[252] Joseph J. Romm, *Cool Companies: How the Best Businesses Boost Profits and Productivity by Cutting Greenhouse Gas Emissions* (Washington D.C. & Covelo CA: Island Press, 1999).p51.
Chapter 3: Buildings.

[253] Joseph J. Romm, *Cool Companies: Proven Results - Cool Buildings*. 2005, Romm,Joseph J., 22/Aug/2005 <http://www.cool-companies.com/proven/buildings.cfm>.

[254]Green Building Council, *USGBC - LEED Case Study - Energy - DEP Cambria*. 2003, Green Building Council, 22/Aug/2005 <http://leedcasestudies.usgbc.org/energy.cfm?ProjectID=47>.

[255]Green Building Council, *USGBC - LEED Case Study - Finance - DEP Cambria*. 2003, Green Building Council, 22/Aug/2005 <http://leedcasestudies.usgbc.org/finance.cfm?ProjectID=47>.

[256]U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, *Department of Environmental Protection, Cambria Office Building, Ebensberg Pennsylvania - Highlighting High Performance*, Nov 2001), DOE/GO-102001-1353. Jan 2002. *U.S. Department of Energy Office of Energy Efficiency and Renewable Energy*, 22/Aug/2005 <http://www.eere.energy.gov/buildings/info/documents/pdfs/29941.pdf>.p3.

[257]Buy Recycled Business Alliance, *Natural Resources Defense Council*, 2004). 17/Sep 2004. *Buy Recycled Business Alliance*, 22/Aug/2005 <http://www.brba-epp.org/brba-epp.org/pdfs/Natural%20Resou%E2%80%A6ces%20Defense%20C.pdf>.p2.

[258]United States Department of Energy, Energy Information Administration, "Table 2.1a Energy Consumption by Sector, 1949-2002," *Annual Energy Review*, 2004, United States Department of Energy, Energy Information Administration, 20/Aug/2004 <http://www.eia.doe.gov/emeu/aer/txt/ptb0201a.html>. Table 2.1a Energy Consumption by Sector, 1949-2002 (Trillion Btu)

[259]States Census Bureau, "Section 19 - Energy and Utilities," *Statistical Abstract of the United States 2002*. December 2002. *United States Census Bureau* <http://www.census.gov/prod/2003pubs/02statab/energy.pdf>.p572.
Energy and Utilities - Table No.892. Electric Power Industry
Capability,and Consumption of Fuels:1990 to 2000 [Net generation for calendar years; capability as of December 31]

[260]Los Alamos National Laboratory, *Los Alamos--Energy Security Overview*. 2003, Los Alamos National Laboratory, 31/Aug/2004 <http://www.lanl.gov/energy/overview.html>.

[261]United States Department of Energy, Energy Information Administration, *Annual Energy Outlook 2004 with Projections to 2025*, DOE/EIA-0383(2004. January 2004, Table 2. Energy Consumption by Sector and Source, United States Department of Energy, Energy Information Administration, 21/Aug/2004 <http://www.eia.doe.gov/oiaf/aeo/excel/aeotab_2.xls>.

Table 2. Energy Consumption by Sector and Source (Quadrillion Btu per Year, Unless Otherwise Noted)

[262] U.S. Census Bureau, *Table 1a. Projected Population of the United States, by Race and Hispanic Origin: 2000 to 2050*. 18/March 2004, 16/March/2005 <http://www.census.gov/ipc/www/usinterimproj/>.

[263] Brian A. Toal, "Renewables:Future Shock,". *Oil & Gas Investor* October 2001, Chemical Week Associates Inc., *National Renewable Energy Laboratory,* 2/Jul/2005 <http://www.nrel.gov/docs/gen/fy02/31353.pdf>. p2

[264] *U.S. Bureau of Labor Statistics Series Reports*. 2/Jul/2005 <http://data.bls.gov/cgi-bin/srgate>. Series CEU0500000049 [Employment, Hours, and Earnings from the Current Employment Statistics survey (National)] All Years, Not Seasonally Adjusted, Super Sector - Total Private, Industry -Total Private, Data Type - AVERAGE HOURLY EARNINGS, 1982 DOLLARS

“Production and nonsupervisory workers account for about 80 percent of all employment measured by the CES survey.”

Bureau of Labor Statistics, "Planned Changes to the Current Employment Survey," *Employment, Hours, and Earnings from the Current Employment Statistics Survey (National)*, 18/April 2005, 12/06/2005 <http://www.bls.gov/ces/cesww.htm>.

[265] Stacey C. Davis and Susan W. Diegel, *TRANSPORTATION ENERGY DATA BOOK: - Edition 22*, ORNL-6967 (Edition 22 of ORNL-5198). Sep 2002. *Center for Transportation Analysis Science and Technology Division of the Oak Ridge National Laboratory for the U.S. DOE*, 23/Sep/2005 <http://www-cta.ornl.gov/cta/Publications/pdf/ORNL-6967.pdf>. p563. Energy and Utilities - Table No. 877. Energy Supply and Disposition by Type of Fuel: 1960 to 2000
[In quadrillion British thermal units (Btu). For Btu conversion factors, see source]

[266]Hydroelectricity:

United States Department of Energy, Energy Information Administration, *Table E2. Existing Capacity at U.S. Electric Utilities by Census Division, State, and Prime Mover, 2000*. 24/Sep 2002, United States Department of Energy, Energy Information Administration, 22/Aug/2004 <http://www.eia.doe.gov/cneaf/electricity/ipp/html1/ippv1te2p1.html>.

Estimates for power consumption by State:
United States Department of Energy, Energy Information Administration, *State Energy Data 2000: Consumption Estimates for Power Consumption by State*. 2003, United States Department of Energy, Energy Information Administration, 22/Aug/2004 <http://www.eia.doe.gov/emeu/states/sep_use/total/csv/use_all_btu.csv>.

[267] Geothermal Energy Association, *Geothermal Electric Production Potential*. 2004, Geothermal Energy Association, 22/Aug/2004 <http://www.geo-energy.org/UsResources.htm>.

[268]World Bank, *Geothermal Energy: Assessment*. 7/Sep 2000, World Bank, 22/Aug/2004 <http://www.worldbank.org/html/fpd/energy/geothermal/assessment.htm>.

[269]Roger Hill, *Public Renewables Partnership, About PRP - Geothermal:Geothermal Costs*. 10/Jun 2004, The Public Renewables Partnership, 22/Aug/2004 <http://www.repartners.org/geothermal/geocosts.htm>.

[270]California Energy Commission, *Levelized Cost of Electricity Production*<. Jan 2004, California Energy Commission, 7/Jun/2004 <http://www.energy.ca.gov/electricity/levelized_cost.html>.

[271]Federal Energy Regulatory Commission, *Staff Briefing Paper: ASSESSING THE STATE OF WIND ENERGY IN WHOLESALE ELECTRICITY MARKETS*, ADO0 13 000. Nov 2004. *Federal Energy Regulatory Commission*, 1/Oct/2005 < http://www.ferc.gov/legal/maj-ord-reg/land-docs/11-04-wind-report.pdf>.p11.

New Mexico Energy, Minerals, and Natural Resources Departments - Energy Conservation and Management Division, *Wind Energy*. 1/Nov 2005, New Mexico Energy, Minerals, and Natural Resources Departments - Energy Conservation and Management Division, 1/Oct/2005 <http://www.emnrd.state.nm.us/emnrd/ecmd/Wind/wind.htm>.

U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, *Wind and Hydropower Technologies Program: Wind Energy Research*. 30/Aug 2005, U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 1/Oct/2005 <http://www.eere.energy.gov/windandhydro/wind_research.html>.

[272]Renewable Resource Data Center, *Wind Energy Resource Atlas of the United States - Map 2-14 Summer Wind Resource Estimates in the Contiguous United States*. Feb 2002, U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 27/Sep/2005 < Http://rredc.nrel.gov/wind/pubs/atlas/maps/chap2/2-14m.html>.

[273] Cristina L. Archer and Mark Z. Jacobson, "Evaluation of Global Wind Power,". *Journal of Geophysical Research - Atmospheres* 110, no. D12 30-Jun 2005, American Geophysical Union, 20-Jan-2008 <http://www.stanford.edu/group/efmh/winds/2004jd005462.pdf>, D12110 DOI:10.1029/2004JD005462.

[274] Julie Osborn et al., *A Sensitivity Analysis of the Treatment of Wind Energy in the Aeo99 Version of NEMS*, LBNL-44070 / TP-28529. Jan 2001. *Ernest Orlando Lawrence Berkeley National Laboratory - University of California; National Renewable Energy Laboratory*, 12/Jun/2004 <http://enduse.lbl.gov/info/LBNL-44070.pdf>.

[275] Cristina L. Archer and Mark Z. Jacobson, "Supplying Baseload Power and Reducing Transmission Requirements by Interconnecting Wind Farms,". *JOURNAL OF APPLIED METEOROLOGY AND CLIMATOLOGY* 46, no. 11 Nov 2007: 1701-17, American Meteorological Society, 18/Jan/2008 <http://www.stanford.edu/group/efmh/winds/aj07_jamc.pdf>.

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[276]Willet Kempton and Amardeep Dhanju, "Electric Vehicles with V2G Storage for Large-Scale Wind Power,". *Windtech International* Mar 2006, (accessed 27/Dec/2004) <http://www.udel.edu/V2G/docs/KemptonDhanju06-V2G-Wind.pdf>. Figure 2.

[277]]Cristina L. Archer and Mark Z. Jacobson, "Spatial and Temporal Distributions of U.S. Winds and Wind Power at 80 m Derived from Measurements,". *JOURNAL OF GEOPHYSICAL RESEARCH* 108, no. D9 16/May 2003, (accessed 27/Dec/2006) <http://www.stanford.edu/group/efmh/winds/2002JD002076.pdf>.Previously unpublished data in the V2G article had been compiled for this study.

[278] Ken Zweibel, James Mason, and Vasilis Fthenakis, "A Solar Grand Plan,". *Scientific American* Jan 2008, By 2050 Solar Power Could End U.S. Dependence on Foreign Oil and Slash Greenhouse Gas Emissions, 18/Jan/2008 <http://www.sciam.com/article.cfm?id=a-solar-grand-plan>.

[279]Otis Port, "Power From The Sunbaked Desert | Solar Generators May Be a Hot Source of Plentiful Electricity,". *Business Week* 12/Sep 2005: SCIENCE & TECHNOLOGY, The McGraw-Hill Companies Inc, 14/Oct/2005 <http://www.businessweek.com/magazine/content/05_37/b3950067_mz018.htm>.

[280]National Renewable Energy Laboratory (NREL), *NREL: Concentrating Solar Power Research - Parabolic-Trough Thermal Energy Storage Technology*. National Renewable Energy Laboratory (NREL), 26/Mar/2005 <http://www.nrel.gov/csp/thermal_storage_tech.html>.

[281]Gerhard Knies, *Deserts as Sustainable Powerhouses and Inexhaustible Waterworks for the World*, Sep-2006). Sep 2006. *Trans-Mediterranean Renewable Energy Cooperation - (Formed by The Club of Rome, The Hamburg Climate Protection Foundation, and the National Energy Research Center of Jordan)*, 3/Jan/2007 <http://www.trecers.net/downloads/GCREADER.pdf>.

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[283]Alessandro Clerici and Andrea Longhi, *Competitive Electricity Transmission as an Alternative to Pipeline Gas Transport for Electricity Delivery. 17th World Energy Council Congress, Houston, Texas, USA, 13-18 September 1998*. Sep 1998. *World Energy Council*, 23/Aug/2004 <http://www.worldenergy.org/wec-geis/publications/default/tech_papers/17th_congress/2_2_08.asp>.

Also: American Wind Energy Association, *FAQ: Cost of Wind Energy*. 2000, American Wind Energy Association, 22/Aug/2004 <http://www.awea.org/faq/cost.html>.

Also:Shimon Awerbuch, "Determining the Real Cost: Why Renewable Power is More Cost-Competitive Than Previously Believed,". *Renewable Energy World*, no. March-April 2003 Mar 2003, James & James, 27/Sep/2005 <http://www.earthscan.co.uk/news/article/mps/UAN/71/v/3/sp/332149698573342662256>.

[284]Energy Ideas Clearinghouse, *Product Technology & Review | Home Voltage Regulator (HVR)™, Enterprise Voltage Regulator (EVR)™*. 2004. *Washington State University Extension Energy Program (Manages Energy Ideas Clearinghuse for Northwest Energy Efficiency Alliance in Portland Oregon)*, 26/Mar/2005 <http://www.nwalliance.org/resources/documents/PTR/EI_PTR200407Microplanet.pdf>.

[285]"The scale of deploying the technology, and doing the detailed systems engineering to make it work as a seamless network, will require significant levels of investment, estimated at $100 billion over a decade."

T.J. Glauthier, Testimony of T.J. Glauthier President & CEO, Electricity Innovation Institute Affiliate of EPRI (Electric Power Research Institute) House Committee on Energy and Commerce Hearing on

“Blackout 2003: How Did It Happen and Why?” Sep 2003, Electric Power Research Institute (EPRI), 27/Sep/2005 <http://www.epri.com/corporate/discover_epri/news/testimony_TJ-090403.pdf>.p5.

If they really mean what they say in the study, they are talking about a number closer to $200 billion per decade plus:

“..investment deficit is now on the order of $20 billion per year and must be accounted for over and above the investment levels of the 1990s if service demands are to be confidently met.”

Electric Power Research Institute (EPRI), *Electricity Sector Framework for the Future | Volume I | Achieving the 21st Century Transformation*. 6/Aug 2003, Electric Power Research Institute (EPRI), 27/Sep/2005 <http://www.epri.com/corporate/esff/ESFF_volume1.pdf>.p16.

So this is $100 billion every five years, plus however many years of “deficit” they propose to make up for.

[286]Eric Hirst and Brendan Kirby, *Transmission Planning and the Need for New Capacity. National Transmisson Grid Study - Issue Studies*, Issue 4. May 2002, U.S. Department of Energy, 27/Sep/2005 <http://www.eh.doe.gov/ntgs/issuepapers/ISSUE_4.PDF>.pD-19.
Table 3. Typical costs, thermal capacities, and corridor widths of transmission lines
(Note: The table was reformatted by me to fit this document, some of the units converted, and a computed column added to the end.)

Voltage (kV)	**Capital cost $/mile**	**Capacity (MW)**	**Cost (Million $/GW-Mile)**	**Width (feet)**	**Cost for 3000 KM (1865 mile) Line**
230	480,000	350	1.37	100	895,200,000
345	900,000	900	1	125	1,678,500,000
500	1,200,000	2000	0.6	175	2,238,000,000
765	1,800,000	4000	0.45	200	3,357,000,000

[287]

Generation, Distribution and various administrative, sales and miscellaneous expenses ran around 36.5% of total expenses in 2005.
Energy Information Administration, *Revenue and Expense Statistics for Major U.S. Investor-Owned Electric Utilities* (Electric Power Annual with data for 2005) - Published October 2006. <http://www.eia.doe.gov/cneaf/electricity/epa/epat8p1.html>

Electricity costs per kWh in 2005 averaged 8.14 cents per kWh.
Table 7.4. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, 1994 through 2005 - (Electric Power Annual with data for 2005) - Published October 2006 <http://www.eia.doe.gov/cneaf/electricity/epa/epat7p4.html>

Hence 2.9697 or ~3.0 cents per kWh
[288]Mick Sagrillo, "Advice from an Expert -Putting Wind Power's Effect on Birds in Perspective," *Frequently Asked Questions*, 2003, American Wind Energy Association, 24/Jun/2005 < http://www.awea.org/faq/sagrillo/swbirds.html>.

[289]John S. Coleman, Stanley A. Temple, and Scott R. Craven, *Cats and Wildlife - A Conservation Dilemma*. 1997, U.S. Department of Agriculture, University of Wisconsin-Extension, Cooperative Extension, 24/Jun/2005 <http://wildlife.wisc.edu/extension/catfly3.htm>.

[290] Power Technology, *Power Technology - Mokai Geothermal Power Plantl, New Zealand*. 26/Aug 2003, SPG Media Limited/SPG Media Group, 23/Aug/2004 <http://www.power-technology.com/projects/mokai/>.

[291] National Park Service - U.S. Department of the Interior - Geologic Resources Division, *Geothermal Energy Overview. NPS Western Energy Summit Jan 21 - 23*. Jan 2003, National Park Service - U.S. Department of the Interior - Geologic Resources Division, 24/Aug/2004 <http://www2.nature.nps.gov/geology/adjacent_minerals/EnergySummit/Geothermal/geothermal%20factsheet.pdf>.p2.

[292] Anders Ahlbom et al., "Review of the Epidemiologic Literature on EMF and Health,". *Environmental Health Perspectives* 109, no. SUPPLEMENT 6 Dec 2001, ICNIRP (International Commission for Non-Ionizing Radiation Protection) Standing Committee on Epidemiology, National Institute of Environmental Health Sciences of the U.S. Department of Health and Human Services, 24/Aug/2004 <http://www.icnirp.de/documents/epireview1.pdf ; http://ehp.niehs.nih.gov/members/2001/suppl-6/911-933ahlbom/ahlbom-full.html>.pp911-933.

[293] Ibid 163 p6-2. - Table 6.1

[294] Jim Giles, "Methane quashes green credentials of hydropower", *Nature*, November 30 2006,444:7119. p.524

[295] American Society of Civil Engineers, *2001 Report Card for America's Infrastructure - Report Card ASCE - Energy*. 2001, American Society of Civil Engineers, 8/May/2003 <http://www.asce.org/reportcard/index.cfm?reaction=factsheet&page=12>.

[296] Steve Thomas, "Government Needs to Take a Brave Decision Now | Crunch Time for Pebble Bed Plan,". *Cape Times* 18/Sep 2003: Insight, The Cape Times & Independent Online (Pty) Ltd, 10/Apr/2005 <http://www.capetimes.co.za/index.php?fSectionId=332&fArticleId=238104>.

[297] U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, *Combustion Success Story: Solarwall© Air Preheating System | Elegantly Simple System Uses Solar Energy to Heat Ventilation Air or Preheat Combustion Air. Office of Industrial Technology Inventions & Innovations Program*, I-CO-563. December 2001, U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 5/Sep/2004 <http://www.eere.energy.gov/inventions/pdfs/conserval.pdf>.

[298] United States Department of Energy, Energy Information Administration, *Preliminary CBECS End-Use Estimates - Preliminary End-Use Energy Consumption Estimates for Commercial Buildings in 1999 Based on Data from the 1999 Commercial Buildings Energy Survey*. 1999, United States Department of Energy, Energy Information Administration, 25/Aug/2004 <http://www.eia.doe.gov/emeu/cbecs/enduse_consumption/intro.html>.
Detailed Tables - Table 1. End-Use Consumption for Natural Gas, Electricity, and Fuel Oil, 1999 (Preliminary Estimates)

[299] These are preliminary numbers released in late 2003, and may change slightly by the time you read this.

U.S. Department of Energy - Energy Information Administration, "2001 Consumption and Expenditures Tables – Total Energy Consumption" *A Look at Residential Energy Consumption in 2001.* 23/October 2003, 23/Dec/2003 <ftp://ftp.eia.doe.gov/pub/consumption/residential/2001ce_tables/enduse_consump.pdf>.
Table CE1-9c. Total Energy Consumption in U.S. Households by Northeast Census Region, 2001 - Preliminary Data
Table CE1-10c. Total Energy Consumption in U.S. Households by Midwest Census Region, 2001 - Preliminary Data
Table CE1-11c. Total Energy Consumption in U.S. Households by South Census Region, 2001 - Preliminary Data
Table CE1-12c. Total Energy Consumption in U.S. Households by West Census Region, 2001 - Preliminary Data

U.S. Department of Energy - Energy Information Administration, "2001 Consumption and Expenditures Tables - Space-Heating Energy Consumption," *A Look at Residential Energy Consumption in 2001*. 23/October 2003, 23/Dec/2003
<ftp://ftp.eia.doe.gov/pub/consumption/residential/2001ce_tables/spaceheat_consump.pdf>.
Table CE2-9c. Space-Heating Energy Consumption in U.S. Households by Northeast Census Region, 2001 -Preliminary Data
Table CE2-10c. Space-Heating Energy Consumption in U.S. Households by Midwest Census Region, 2001 - Preliminary Data
Table CE2-11c. Space-Heating Energy Consumption in U.S. Households by South Census Region, 2001 - Preliminary Data
Table CE2-12c. Space-Heating Energy Consumption in U.S. Households by West Census Region, 2001 - Preliminary Data

U.S. Department of Energy - Energy Information Administration, "2001 Consumption and Expenditures Tables - Electric Air-Conditioning Consumption Tables," *A Look at Residential Energy Consumption in 2001*. 23/October 2003, 23/Dec/2003
<ftp://ftp.eia.doe.gov/pub/consumption/residential/2001ce_tables/ac_consump.pdf>.
Table CE3-9c. Electric Air-Conditioning Energy Consumption in U.S. Households by Northeast Census Region, 2001 - Preliminary Data
Table CE3-10c. Electric Air-Conditioning Energy Consumption in U.S. Households by Midwest Census Region, 2001 - Preliminary Data
Table CE3-11c. Electric Air-Conditioning Energy Consumption in U.S. Households by South Census Region, - Preliminary Data
Table CE3-12c. Electric Air-Conditioning Energy Consumption in U.S. Households by West Census Region, - Preliminary Data

[300]Solargenix Energy LLC, *Solargenix Energy - Formerly Duke Solar Energy - The Natural Power For Good.* 2005, Solargenix Energy LLC, 28/Mar/2005 <http://www.solargenix.com/powerRoof.cfm>.

[301]Rober C. Brown, Colletti, Joe, and Arne Hallam, "Factors Influencing the Adoption of Biomass Energy Systems: An Evaluation for Iowa," Fifth World Congress of Chemical Engineering, San Diego, CA, July 14-18, 1996 (Ames Iowa USA: Iowa State University, 1996), Obsolete URL (http://webbook2.ameslab.gov/Summary%20Biomass.doc).

[302] Donal L. Klass, "Biomass for Renewable Energy And Fuels," *Encyclopedia of Energy*. 2004. *Elsevier, Inc*, Biomass Energy Research Association (BERA) Washington D.C., 28/Sep/2005 <http://www.bera1.org/cyclopediaofEnergy.pdf>.p196.

[303] David Tilman, Jason Hill, and Clarence Lehman, "Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass,". *Science* 314, no. 5805 8/Dec 2006, American Association for the Advancement of Science, 01/01/2007
<http://www.ce.cmu.edu/~gdrg/readings/2006/12/12/Tilman_CNegativeBiofuelsFromLowInputHighDiversityGrasslandBiomass.pdf>.

[304]Biopact [Summarizing Report from German Energy Agency], *Bioenergy Pact Between Europe and Africa: German Energy Agency: Biomass-to-Liquids Can Meet up to 35% of Germany's Fuel Needs by 2030*. 15/December 2006, Biopact, 28/Dec/2006 <http://biopact.com/2006/12/german-energy-agency-biomass-to.html [summary of orginal report in German: http://www.dena.de/fileadmin/user_upload/Download/Dokumente/Publikationen/mobilitaet/BtL_Realisierungsstudie.pdf]>.

Note that this price assumes biomass imported by ship or rail into German - so probably more than with biomass grown within 50 miles.. The price given is \$3.98/ gallon, which is for refined product. At the pump price tends to be 42% higher than refined product - so at the pump price of \$5.65 (including taxes), around 2.2 X current price of \$2.50/gallon.

[305] Stefan Unnasch and Louis Browning, *Fuel Cycle Energy Conversion Efficiency Analysis Status Report*. 25/May 2000. *California Energy Commission Transportation Technology and Fuels Office* ARCADIS Geraghty & Miller, Inc, 01/03/2007 <http://www.arb.ca.gov/msprog/zevprog/2000review/efficiency.doc>.p7.Table 6.
three specific cases:
It was considered feasible to produce Methanol with nearly 53% thermal efficiency back in 1981:
L.K. Mudge et al., *Investigations on Catalyzed Steam Gasification of Biomass. Appendix B: Feasibility Study of Methanol Production Via Catalytic Gasification of 2000 Tons of Wood Per Day*, Jan-1981), On-Line Abstract. 2001. *U.S. Department of Energy*, 03-Jan-2007 <http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=6711590>.

More recently, non-bleeding-edge technology was considered able to convert biomass into methanol which had 57% of the original BTU content. If the plant generated its own electricity that would reduce thermal efficiency to 475-49%. However, this is not the proper accounting of net energy, because even with combined heat and power, methanol combustion is not an efficient way to generate electricity. If efficiently generated electricity had been used, provided by (say) a 55% efficient combined cycle turbine that managed to place some waste heat, the range would have more like 50% - 52%, even more if the electricity was provided by wind.
Nycomb Synergetics and Ecotraffic R&D AB, *Biomass-Derived Alcohols for Automotive and Industrial Uses*, Apr 1999). May 1999, European Union Program Altener and the Swedish National Board for Industrial and Technical Development, Jan-03-2007 <http://www.nykomb.se/pdf/methanol.pdf>.

Lastly, Mitsubishi recently demonstrated bleeding edge technology extracted 65% of energy from biomass in the form of methanol in a pilot project. They claim that, on a large scale, 75% would be possible. Obviously this should be taken with great circulatory system threatening sacks of salt. Also, Mitsubishi says nothing about cost. But it certainly is indicative that Methanol conversion efficiency limit is well above 50%.

Mitsubishi Power Sysems, *New Product New Technology: Biomass Gasification Methanol Synthesis System*. 29/Sep 2005, Mitsubishi Power Sysems, Jan-03-2007 <http://www.mhi.co.jp/power/e_power/techno/biomass/index.html>.
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[307] John A. Volpe National Transportation Systems Center of the U.S. Department of Transportation Research and Special Programs Administration, *CLEAN AIR PROGRAM SUMMARY OF ASSESSMENT OF THE SAFETY, HEALTH, ENVIRONMENTALAND SYSTEM RISKS OF ALTERNATIVE FUELS - Aug 1995 Final Report*, Aug 1995), FTA-MA-90-7007-95-1 ;DOT-VNTSC-FTA-95-5. Mar 1999. *Federal Transit Administration*, 01/03/2007 <http://transit-safety.volpe.dot.gov/Publications/CleanAir/Alt_Fuel/alt_fuel.pdf>.p3-5.
[308]B.H. West et al., *Federal Methanol Fleet Project Final Report*, Mar-1993), ORNL/TM -12278. 2003. *Oak Ridge Natonal Laboratory;U.S. Department of Energy Office of Transportation Systems*, Jan-03-2007 <http://www.ornl.gov/info/reports/1993/3445603700029.pdf>.
An important note on maintenance: if you look at the chapter on this subject, especially the summary tables on page 21, you will see that engine wear, and maintenance were if fact worse than with gasoline, but not a great deal worse. Given that these were retrofits rather than designed from scratch for M85, had original parts ripped out and replaced, there is little doubt that a built-from-scratch methanol car would have had reliability comparable to gasoline.

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[314]Burton C. English et al., *25% Renewable Energy for the United States By 2025: Agricultural and Economic Impacts*, Nov 2006). Nov 2006, 4.1 Renewable Production. *The University of Tennessee Department of Agricultural Economics Biobased Energy Economics Analysis Group*, 03/Jan/2007 <http://www.agpolicy.org/ppap/REPORT%2025x25.pdf>. p31.Table 11.

[315]KPMG Bureau voor Economische Argumentatie; Steins Bisschop Meijburg & Co Advocaten, *Solar Energy: From Perennial Promise to Competitive Alternative - Final Report*, Project Number: 2562. Aug 1999. *Greenpeace - Nederlands*, 24/Sep/2004 <http://archive.greenpeace.org/~climate/renewables/reports/kpmg8.pdf>.

[316] European Commission, *EUROPA - Research - Energy - - R&D Topics*. Jul 2005, European Commission, 28/Sep/2005 < http://europa.eu.int/comm/research/energy/nn/nn_rt/nn_rt_pv/article_1108_en.htm>.

[317]Doug Selsam, *The Selsam SUPERTURBINE*. Sep 2005, Superturbine Inc., 28/Sep/2005 <http://www.speakerfactory.net/wind.htm>.

California Energy Commission, *Notice of Awards EISG Program, Solicitation 02-01*. 19/Feb 2003, California Energy Commission, 18/Sep/2004 <http://www.energy.ca.gov/contracts/smallgrant/2003-02-21_awards_02-02.html>.

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United Nations Food and Agriculture Organization of the United Nations Statistical Service, *FAOSTAT Database Results*. 2004, United Nations Food and Agriculture Organization of the United Nations Statistical Service, 13/Jul/2005 <http://faostat.fao.org/faostat/servlet/XteServlet3?Areas=862&Items=656&Items=15&Elements=31&Year

s=2004&Format=Table&Xaxis=Years&Yaxis=Countries&Aggregate=&Calculate=&Domain=SUA&ItemTypes=Production.Crops.Primary&language=EN>.

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http://www.eere.energy.gov/solar/cfm/faqs/third_level.cfm/name=Concentrating%20Solar%20Power/cat=ALL#Q84

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Ibid 320

According to an in depth 1984 study, CSP uses slightly more land than coa.
Byron A. Miller and Martin J. Pasqualetti, "Land Requirements for the Solar and Coal Options," *The Geographical Journal* 150, no. 2 (Jul 1984): 192-212.

Given that solar energy has made a lot of progress since 1984, it seems likely that Miller and Pasqualetti were right when their study was complete, and the DOE is correct today.

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Brevia: Page 1291

327National Center for Atmospheric Research, *New Look at Satellite Data Supports Global Warming Trend*. 1/May 2003, National Center for Atmospheric Research, 10/Jun/2004 <http://www.ucar.edu/communications/newsreleases/2003/wigley2.html>.

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Output? 27/May 2005, National Oceanic and Atmospheric Administration, 1/Oct/2005 < http://lwf.ncdc.noaa.gov/oa/climate/globalwarming.html#Q10>.

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[339]Dave Frame, Reto Knutti, and Malte Meinshausen, *RealClimate - Can 2°C Warming Be Avoided?* Climate Science from Climate Scientists, 31/Jan 2006, Real Climate, 12/Feb/2006 <http://www.realclimate.org/index.php?p=246#more-246>.
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