

Healthy Solutions for the Low Carbon Economy

Guidelines for Investors, Insurers and Policy Makers



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HEALTHY SOLUTIONS FOR THE LOW CARBON ECONOMY

INTRODUCTORY MATERIAL

The Climate Clarion: Underestimating the Rate of Climate Change

In 1896, a Swedish scientist named Svante Arrhenius calculated that rising atmospheric carbon dioxide (CO₂) levels would warm the globe, projecting that doubling CO₂ would increase temperatures 5°C at the equator and 6°C at the poles. Then in 1938, the British meteorologist, G.S. Callender, calculated that higher atmospheric levels of CO₂ had already caused warming in Europe and North America.

More than a half century later, the Intergovernmental Panel on Climate Change (IPCC, Houghton et al. 1990) calculated that a 60-80% reduction in greenhouse gas (GHG) emissions below 1990 levels was needed to stabilize the atmospheric concentrations. Writing in *Geophysical Research Letters*, Matthews and Caldeira (2008) argue that "...to hold climate constant at a given global temperature requires near-zero future carbon emissions."

Now after almost two decades of increasing fossil fuel combustion and continuing deforestation, atmospheric levels are rising faster than all scenarios projected and are approaching 385 parts per million (ppm) – far outside the 180-280 ppm envelope in which they have persisted for over 600,000 years (Simon et al. 2005; Solomon et al. 2007; Parry et al. 2007).

- At 180 ppm, ice caps were large and the average global temperature was 10°C (~50°F).
- At 280 ppm, ice caps were of moderate size and the global average temperature was 15°C (59°F).
- Approaching 385 ppm, we are moving toward small ice caps and rising sea levels; perhaps even a surprise "cold reversal," due to the discharge of Greenland and West Antarctica outlet glaciers.

But why are observations ahead of model projections?

First, CO₂ is rising faster than the highest IPCC scenario, and the rate of increase is 1.9 ppm/yr vs. 1.5 ppm/yr for the previous 30 year period.

Second, carbon "sinks" are decreasing, with ocean pH 30% down from the pre-industrial era (Lovejoy 2008), plus deforestation and enhanced soil respiration (Piao et al. 2008). The diminished sinks account for 18% of the increased rate in atmospheric CO₂ concentrations (Leimann 2008).

Models based only on rising CO₂ levels underestimate the full effect of GHGs plus black soot and aerosols. The combined global warming potential (GWP) of all heat-trapping gases is nearing 460 ppm of "CO₂-equivalent" concentrations (IPCC 2007a). Subtracting

for the cooling impact of sulfate aerosols and adding: A. the warming impact of black soot, which: 1) traps heat (0.9 Watts per square meter; CO₂ being 1.66 W/m²) (Ramanathan and Carmichael 2008) and 2) settles into snow and ice (decreasing reflectivity or albedo), and B. rising water vapor (the air holds 6% more H₂O for each 1°C it warms). Together A + B add up to a yet-to-be calculated GWP – but perhaps substantially above the 385 ppm mark of CO₂ alone.

Moreover, the world ocean has absorbed twenty-two times the amount of heat as has the atmosphere over the last half century (Levitus et al. 2005; Barnett et al. 2005). The rise in heat-trapping GHGs – along with decreased albedo (reflectivity) from melting sea ice and black carbon deposits (Ramanathan et al. 2007) – may help explain why observed changes in ocean temperatures, ice cover and wind patterns are substantially ahead of model projections.

The sensitivity of climate to increases in GHGs is also difficult to calculate (Roe & Baker 2007) and the climate system exhibits a lag in response to changes in forcing factors. Earth is now absorbing more incoming solar energy than it is emitting back into space from the build up of GHGs, and the imbalance is projected to result in an additional warming of 0.6°C (1.1°F) without any further change in the GHG concentrations (Hansen et al. 2005).

Climate models also do not adequately model threshold and non-linear changes, thereby systematically underestimating the potential for such “phase-state” changes. Accelerating changes in Earth’s ice cover present the greatest concern for surprises, as reflected in sea level rise, storm surges, storm intensity (Emanuel 2005; Webster et al. 2005), and Earth’s albedo; posing risks to the overall stability of the climate system (Epstein & McCarthy 2004; Alley et al. 2005; Meehl & Washington 2005; Overpeck et al. 2006).

With growing climate instability – increasing rates of change in ice cover, wider swings of variability and major weather outliers – the potential for surprises, nonlinearities, and discontinuities in climate may be increasing, posing threats for the manageability of the costs of inaction.

Climate Change and Health

Climate change has multiple direct and indirect consequences for human health, and for the health of Earths’ life-support systems (Epstein 2005; IPCC 2007b).

- Heat waves affect humans directly and are projected to take an increasing toll in developed and underdeveloped nations (IPCC 2007b).
- Excess CO₂ boosts ragweed pollen production, with implications for allergies and asthma (Ziska & Caulfield 2000; Rogers et al. 2006).
- Excess CO₂ promotes the growth of poison ivy and the chemical within it (uruschiol) that acts as the irritant (Ziska et al. 2007a).
- Climate change is associated with increases in heat wave intensity, breadth and duration, all made worse by warmer nights and higher heat indices.

- Warming expands the potential range of infectious diseases and disease vectors.
- Extreme weather events often create conditions conducive to “clusters” of mosquito-, rodent- and water-borne diseases (Epstein 1999).
- Warming and extreme weather favor the spread of insect pests and diseases among forests, crops, livestock, wildlife and coastal marine life: Earth’s life-support systems (Epstein & Mills 2005).
- In U.S. and European forests the spread of pine bark beetles is adding to the risk of wildfires, which affect air quality, habitat, watersheds and carbon stores.
 - Absent sustained killing frosts (<20°F for 10 days), bark beetles -- from Arizona to Alaska -- are overwintering, moving to higher altitudes and latitudes, and getting in more generations each year.
 - At the same time, repeated droughts weaken host defenses by drying the resin that normally drowns the beetles as they try to bore through the bark.
- Ocean life (corals, shellfish, and calcareous algae) is threatened by warming and by the acidification directly caused by the ocean uptake CO₂ (Caldeira & Wickett 2003; Sabine et al. 2004).

The Stern Review (2006) projections, echoed by those of the IPCC 2007, were for the growing potential of non-linear impacts (e.g., forest diebacks, widespread crop failures, coral reef collapse); estimating annual losses of 5-20% of world output (~\$35 trillion; thus \$1.75 to \$7 trillion/yr damages annually).

Climate Change and Food Security

Climate change also poses a number of risks for food security and nutritional health worldwide. Issues affecting food supplies include:

- Warming winters and altered growing seasons.
- Alterations in precipitation regimes.
- Extreme weather events: droughts, heavy rains and sequential extremes.
- Pests, pathogens and weeds, affected by the warming and extremes.
- Changes in migratory patterns of seed distributors and pollinators.
- Threats to genetic diversity of livestock and ability of certain breeds to adapt to climate change and to resist pests and disease.

Growing of crops for biofuels is now adding additional pressure on land, displacing that currently under production for food, feed and fiber crops.

Energy Generation and Water

A major part of the increased demand for water comes from that used to cool power plants. Power plants draw 39 billion gallons of clean drinking water from aquifers daily, equivalent to the daily drinking water requirements of 62 billion people, about 10 times the Earth's population (Brown 2005).

- Nuclear plants consume the most water: 0.62 gallons per kWh.

- Coal-fired plants consume 0.49 gallons per kWh.
- Combined cycle natural gas power plants consume 0.25 gallons per kWh.

The Energy Challenge

The world rate of energy use in 2005 was 16.3 trillion watts (terawatts or TW), and that figure is projected to double by 2050 (IEA 2002; EPA 2005; EIA 2005). Approximately ~1/3 (5.6 TW) of the global energy is used to generate electricity, though 2/3 of that (3.5 TW) is lost as waste heat. The remaining 10.7 TW is used for fuel for vehicles and building heat. But ultimately all the heat from engines, light bulbs, home furnaces, etc. is emitted; i.e., all 16.3 TW of heat is added to the environment (Hochbaum et al. 2008).

The International Energy Agency, an affiliate of the Organization for Economic Cooperation and Development, estimates that by 2030, ~\$20 trillion will be needed in new infrastructure to meet world demands (IEA 2007; NPC 2007).

Freshwater aquifers, already overdrawn and underfed, are threatened by patterns of use and climate change. In the U.S. electricity production accounts for 39% of domestic withdrawals, roughly equal that of agriculture. In the U.S. southwest severe drought threatens the cooling water for over 24 of the nation's 104 nuclear energy reactors (Hightower 2008).

An Excellent Summary from a Prominent Writer

This year, the world is expected to burn through some thirty-one billion barrels of oil, six billion tons of coal, and a hundred trillion cubic feet of natural gas. The combustion of these fossil fuels will produce four hundred quadrillion B.T.U.s [“quads” of British Thermal Units] of energy. It will also yield around thirty billion tons of carbon dioxide. Next year, global consumption of fossil fuels is expected to grow by about two per cent, meaning that emissions will rise by more than half a billion tons, and the following year consumption is expected to grow by yet another two per cent.

The article also points out that Over the past ten years, forests covering a hundred and fifty million acres in the United States and Canada have died from warming-related beetle infestations.

-- Elizabeth Kolbert, “The island in the wind.”
The New Yorker July 7 & 14, 2008, pp 68-77.

Liquid fuels

In 2007 the global consumption was 86 million barrels of oil equivalent (mboe) -- 40,000 gallons a second -- and this is projected to go up to ~118 mboe in 2030. Oil from tar sands (bitumen) and shale oil, plus biofuels, coal-to-liquid and gas-to-liquid are projected

to jump from 2.4 mboe (in 2005) to 10.5 mboe in 2030 (i.e., only 8 % of the total liquid fuels requirements).

Decreasing the demand for liquid fuels is paramount. This can be done by a) shifting modes of transport; b) changing types of engines (plug-in hybrids), and c) smart growth; all aimed at reducing vehicular miles travelled (VMTs).

Definitions

1 joule (J) is the amount of energy needed to lift 1 kilogram 10 cm.

1 watt (W) of power = 1 joule per second.

The flow of 1 kilowatt for 1 hour transfers 1 kilowatt-hour (kWh) of energy.

A 5-7 kW solar unit can power a medium-sized house

One megawatt = 1,000 KW and can power 1,000 air conditioners.

1,000 watts = 1 kilowatt

1,000 kilowatts = 1 megawatt

1,000 megawatts = 1 terawatt

1 gallon of gas produced 19.4 lbs of CO₂ (by removing O₂ from the air)
Molecular weight of C = 12; molecular weight of O = 16)

Thus, a 10 gal tank produces ~200 lbs CO₂

And, 10 fill-ups produces ~1 ton CO₂

Meanwhile, 100,000 trillion joules per second or 100,000 TW reach the earth's surface. And the global rate of conversion of sunlight via plant photosynthesis is about 200 TW, 100 TW of which is the "net primary productivity" that fuels the rest of life on Earth (J. Holdren, pers. comm. Feb. 2008). In addition 370 TW of wind energy are available.

Over 85% of this power comes from the combustion of fossil fuels: just over one third from oil; one quarter from coal; one quarter from natural gas.

The U.S. depends on imported oil for over half of the 21 million barrels used daily, and the costs for these imports grew from \$45 billion in 1998 to \$400 billion in 2007. Oil imports are the largest contributor to the U.S.'s negative trade balance and the decreasing value of the U.S. dollar.

Carbon emissions today total about 7 GtC/yr from fossil fuel combustion and deforestation. An additional 2-3 GtC equivalent (GtCO₂e) in emissions are composed of methane, CFCs and nitrous oxide. Measured as total carbon dioxide equivalents (CO₂ is

almost four times as heavy as C per molecule) the figure is about 40 Gt of CO₂e per year. Within the next decade over 1100 new coal-fired power plants are planned to meet growing energy needs.

In February of 2008 the USDOE withdrew from the FutureGen CO₂ capture and storage (CCS) project – an alliance of over a dozen fossil fuel companies – slated for Mattoon, Ill. because of the doubling of cost projections early on in the project (Tollefson 2008a). Meanwhile plans for coal-fired utility plants in the U.S. are being scrapped in favor of plants using natural gas, due to health, environmental and economic concerns (Tollefson 2008b), and several prominent Wall Street banks have taken the lead.

The Vulnerability of Cities

Pavement and other impermeable surfaces, inadequate vegetation, minimal soil moisture, air pollution (with ozone and “CO₂ domes”), along with heat generated by energy use combine to produce the “urban heat island effect,” which raises inner-city temperatures up to 10°F (6°C) above surrounding rural areas.

Warmer temperatures and higher ambient levels (levels 400 to over 700 ppm in some cities), boost ragweed pollen production (Ziska et al; 2007b; George et al. 2007), contributing to morbidity and mortality from air pollution, and add to the health impacts of heat waves. Diesel particles add an unfortunate synergy, providing delivery vehicles for clusters of pollen and fungal spores. Meanwhile, more ground-level ozone forms during heat waves, harming lung tissue and adding to urban heating.

“Smart growth,” with green buildings, rooftop gardens, biking lanes, walking paths, open space, mixed-use development, light-rail trains and hybrid buses can decrease VMTs and transform cities into healthier environments. These measures will reduce vulnerability to the health effects of heat waves while stimulating enterprises for innovative technologies (Frumkin et al. 2004).

Smart growth is a major undertaking, but is an essential part of the societal transformations needed to stabilize the climate and secure a healthier future.

Energy Sector Vulnerabilities

Climate change itself poses new challenges and risks for the energy sector. In addition to those listed in the box below, avalanches after melting and heavy precipitation can knock out power (as it did in Alaska in early July 2008); and bark beetle infestations and other tree pests can lead to line disruption from falling dead trees (as has occurred in New England from the fungi-injecting caterpillars and moths destroying oak trees in the region) (Baxter 2008).

These vulnerabilities support the conclusion that an intelligent, resilient and clean grid is necessary for adapting to and to mitigating climate change.

VULNERABILITIES IN THE ENERGY SECTOR



Image: Photodisc

- Heat waves generate blackouts.
- Sequential storms disrupt offshore oil rigs, pipelines, refineries and distribution systems.
- Diminished river flows reduce hydroelectric capacity and impede barge transport.
- Melting tundra undermines pipelines and power transmission lines.
- Warmed inland waters shut down power plant cooling systems.
- Lightning claims rise with warming.

Each stage in the life cycle of oil, including exploration, extraction, transport, refining and combustion, carries hazards for human health and the environment. More intense storms, thawing permafrost and dried riverbeds, make every stage more precarious.

--Epstein & Mills. Climate Change Futures 2005

TECHNOLOGIES FOR EARLY ADOPTION

Smart Grids

The centralized energy infrastructure today is composed of energy generation, transmission, regional distribution, storage and utilization. While over 50% of funds flowing into the energy sector support the elements of grids apart from generation, these other components are currently inefficient and are composed of outdated technologies. Modernization of the utility grid to increase efficiency, embed feedbacks and cybernetic self-regulation, can reduce demand and waste (Mazza 2005; Leonard 2006; Anderson 2007). Increased grid efficiency and reducing demand can also allow expanded use of

small units of distributed generation and more regional generation, with renewable sources (Aitken 2004; Wiser & Bolinger 2006).

Smart Technologies

- Demand response programs that shave peak loads, reducing the need for expensive and polluting peak power plants.
- Electronics and control software that monitor power flows in real time, to run existing lines much closer to capacity without compromising reliability.
- Sensors and meters that indicate precisely where power is needed and is being used, so utilities can expand distribution only where and when needed.
- Sensors and software to remotely monitor expensive equipment, to know when it needs replacement.
- Improved storage (fly-wheels, hydro, organic batteries) for intermittent sources.

-- U.S. Department of Energy

Demonstration Project

The Pacific Northwest GridWise™ of the U.S. Department of Energy Pacific Northwest Laboratory estimates that digital technologies could save customers 10% on their bills and \$70 billion over 20 years, obviating the need to build 30 large coal-fired plants.

- A year-long "smart grid" demonstration project by GridWise™, involving 112 homeowners on the Olympic Peninsula, Washington, showed that consumers saved 10% on utility bills and cut power use 15% during peak hours.
- Homeowners were given new electric meters that received signals from the local utility when power prices were high, and thermostats and computer software to curtail power use at these times. They could also set preferences by computer and remotely change preferences while away from home.
- A spokesperson from IBM, which participated in the study, said that nationwide use of this method could save \$120 billion in power plants and transmission lines that would not have to be built.

--U.S. DOE Pacific Northwest National Laboratory: "Smart grid" saves \$120 billion in power use in U.S." <http://www.chinaview.cn> (1 Jan 2008).

To maximize resilience, multiple sources (hybrids) of energy generation can be employed and distributed and regional generation with renewables can be integrated with central generation.

Creating smart grids can reduce the need to build power plants, especially highly wasteful peak production power plants, and reduce greenhouse gas emissions over all.

Measures to Create Smart Grids

- Change from analogue to digital transmission and technologies.
- Computerized devices for optimized use, monitoring and metering.
- Cyber (feedback)-technologies to deliver preferential power to critical areas
 - Within buildings (e.g., refrigeration and air conditioning)
 - Across cities (e.g., hospitals and nursing homes).
- Distributed generation with renewable sources.
- Co-generation
 - Combined heat capture and use (e.g., for hot water)
 - Utilizes the 2/3 of power plant energy lost as heat (Casten & Downes 2007).
- Improved storage technologies, including batteries (MIT 2007), hydropower reserves, and compressed air (Juvonen 2007).
- Energy efficient refrigerators, washers and dryers.
- Informed consumers.

Batteries at a Glance I

- Battery cells are comprised of electrolytes and negative and positive electrodes, between which electrons flow spontaneously when an external circuit is attached. A battery is a collection of cells and the following lists some of those that are rechargeable.
- Lead-acid are the oldest type of batteries used in automobiles. Lead is a neurotoxin, but lead-acid batteries can be recycled easily because lead has value as scrap metal.
- Nickel-Cadmium (Ni-Cd) cells are commonly used in vehicles and can be recharged over a thousand times. But cadmium is a potent toxin.
- Nickel-Metal Hydride cells (Ni-MH) are a new generation of batteries that can replace Ni-Cd in electronic and hybrid vehicles, having higher energy density w/o the most dangerous heavy metals. But they cannot be charged as many times as Ni-Cd batteries.

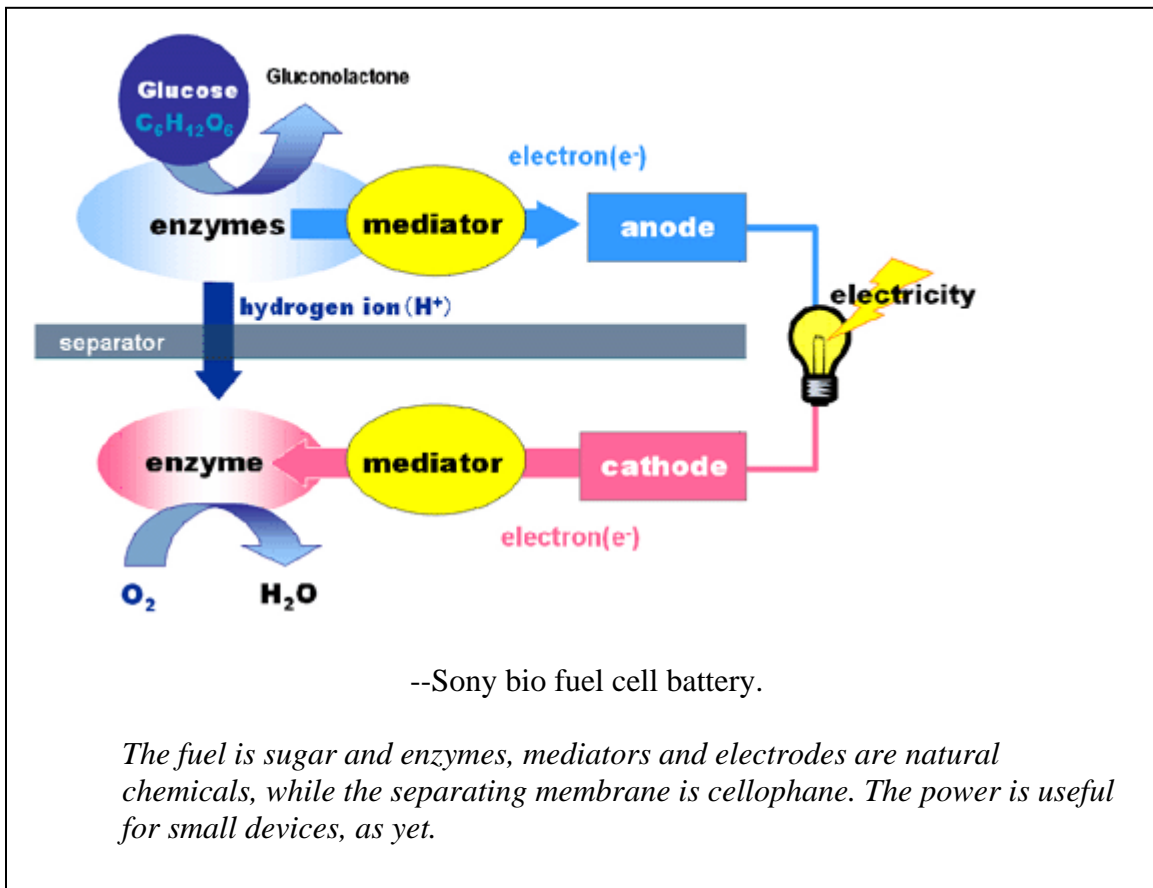
Batteries at a Glance II

- Nickel-Zinc cells are less expensive than Ni-MH, are lighter, better performers than lead acid, and are low maintenance. They are claimed to provide the lowest environmental health risk of any rechargeable battery for they contain no heavy metals.
- Lithium-ion (Li-ion) batteries are used in laptops and, recently, in hybrid vehicles. They are expensive, but smaller, lighter batteries provide five times more energy than lead-acid the others and they can be recharged up to 1000 times. The cobalt component is limited; but lithium can be extracted with solar energy in unlimited quantities from sea water.
- Lithium-Organic batteries use “green chemistry” – organic plant polymers and iron complexes (e.g., as in hemoglobin) – for all the components. Those in development have similar characteristics to Li-Ion batteries, but they will be much cheaper and safer to produce, and could become the batteries of the future. (See below for bio fuel cell.)
- Lithium-Oxygen: Metal-air technologies are used in fuel cells. But while Li provides eight times the energy of zinc, there are hurdles to overcome: Li_2O_2 clogs electrodes.
- Nanotechnologies increase battery power and capacity, decrease costs and materials, and “nano-painting” electrodes with thin carbon layers optimizes conductivity. But risks to human cells and genetic makeup from manufacture and disposal need to be assessed.
- Sodium sulfur batteries can take vehicles twice as far as lead-acid batteries w/o recharging, but require very high temperatures and have waste-disposal hazards.
- Improper handling and disposal of Li-containing batteries can cause explosions. “Lithium anodes are flammable, burn vigorously and react violently with water,” And cathode materials can be highly toxic and irritate the eyes, skin and lungs (MOD 2003). The health consequences of disposing large quantities of lithium batteries have not been adequately evaluated.

--See ENVOCARE 2006: <http://www.envocare.co.uk/batteries.htm>

--Armand & Tarascon, Nature 2008.

Organically-derived materials are being used in LEDs, transistors, solar cells and batteries. Below is a diagram of a small fuel cell battery powered by separating hydrogen from glucose.



Green Buildings

Buildings represent approximately 40% of overall energy use. Of the total energy consumption and CO₂ emissions coming from buildings, 80-85% is for heating, cooling, ventilation and hot water (Vattenfall 2007). Measures to green all new buildings and retrofit existing structures will have multiple health and economic co-benefits. Manufacturing materials for green buildings – e.g., insulation, appropriate windows, and sustainable wood products – generates new industries and jobs.

Research at the Lawrence Berkeley National Laboratory projects that improvements in indoor environmental quality in green buildings offer hundreds of billions of dollars in savings in health, productivity and energy benefits. It is, however, possible that some of the financial benefits listed may only be partially realized, and research to assess the magnitude of improvements in health and work performance within existing green buildings is needed.

Improving ventilation and air quality reduces respiratory illnesses. A Carnegie Mellon review (2005) found an average reduction of 51% in buildings with improved air quality. Another review of the literature by Lawrence Berkeley National Laboratory (Fisk & Rosenfeld 1997; Fisk 2000) estimated that improved ventilation and better indoor air

quality would reduce respiratory illnesses by 9-20% in the general population, resulting in 16-37 million fewer cases of colds and influenza, with annual savings of \$6-14 billion.

For new buildings, siting, orientation and maximum use of passive solar lighting (Edwards & Torcellini 2002) are the first steps in green design (USDOE 2000; NEFa 2001), and daylighting has many positive health and productivity benefits for the occupants (NEFa 2001; Figueiro 2004; EERE 2004; HMG 1999, 2003; Hobstetter 2007) and helps regulate circadian rhythms which influence depression (e.g., seasonal affective disorder) and sleep (Pauley 2004).

- ❖ Lisa Heschong and colleagues (HMG 1999) studied daylighting in schools and retail buildings; but the results remain controversial. Follow up studies by Heschong (HMG 2001) found no health benefits, though better view to outdoors was associated with improved performance HMG 2003). A National Academy of Sciences review of green schools (NAS/NRC 2006) found that the evidence of better performance from more daylight was limited and inconclusive.
- ❖ Other factors influencing indoor air quality and performance in schools (CARB 2004; Shaughnessy et al. 2006; Wargocki & Wyon 2007) and offices (Wargocki et al. 2000; Fisk et al. 2005) include the rate of ventilation (outdoor air supply), and better temperature control (Seppanen et al. 2005). Performance in both math and reading tests increased with ventilation, and reaction times and memorization increased with the number of air exchanges.

Green Chemistry in Action

Through innovation, green chemical processes can have significant impacts on reducing carbon output and increasing energy efficiency. One successful example of green chemistry in practice is that of Buckman Laboratories in Memphis, TN. Buckman introduced a line of enzymes for use in the paper manufacturing and recycling industry. The use of the enzyme allowed one mill to eliminate the use of virgin pulp, reduced the refining and drying time in production by 13% and also increased the strength of the paper product. The result was large energy and cost savings for the industry, as well as a decrease in the amount of virgin material being used (Hoekstra 2005).

--- Amy Cannon, BeyondBenign, 2008

Green buildings with green surroundings provide a confluence of potential benefits by utilizing clean energy and efficiency measures, with woods derived from sustainable forestry practices, and materials and chemicals derived from “green chemistry” (which avoids petrol-based carcinogens for materials and furniture (Kats 2003; Kats 2006; Brown et al. 2007). Bio-based feedstocks are now being used to produce solvents, plastics, lubricants and fragrances (Raguauskas et al. 2007).

LEED Standards

The Leadership in Energy and Environmental Design (LEED) certification of the Washington, D.C.-based U.S. Green Building Council promotes clean, healthy design that also increases profitability (Xynergy 2000; USGBC 2007). Ratings are based primarily on a) recycling, b) energy and water efficiencies, and c) air quality, and range from basic to platinum. High efficiency green buildings can be cost-neutral by reducing the equipment needed to power and manage it. Wall Street's launch of Sustainable Mortgage Backed Securities is projected to help take green new buildings to 70%-90% market penetration in 5-10 years (Capital Markets Partnership 2007).

Retrofits for existing buildings are being planned for close to 1000 buildings in the U.S., equaling ½ billion square feet. LEED-EB (existing building) standards have been developed. The USGBC estimates the savings will be 90 cents per foot, with payback periods from 2 to 2 ½ years (Cortese 2008). Wide scale retrofitting of existing building stock will require additional financial instruments and government incentives.

Distributed Generation

Distributed generation – power produced near the point of use – with solar, wind, geothermal heat pumps (Anon 2007) and fuel cells can be fed into existing grids, and can generate income for the producers. Cogeneration for industries and regional energy generators amplifies this application by using heat that is otherwise lost. Geothermal supplies air conditioning, increasingly critical with intensification of heat waves.

Hybrids, using multiple “insurance” sources of generation (in stationary and mobile systems), add resilience and reliability.

Advantages of Distributed Generation

- Fuel flexibility
- Reduced transmission and distribution line losses
- Enhanced power quality and reliability
- Greater end-user control
- Back-up for peak and surges
- Deferral of investments and siting controversies associated with power generation, transmission and distribution expansions
- Income for the generators (with “net metering” regulations).

Stand-alone energy systems, with solar and wind power – augmented with human power (e.g., bicycle-driven) and stored in improved batteries (sodium sulfur, lithium ion or biologically-based) can pump water, irrigate fields, power clinics, light homes, cook food and drive development. Energy is essential to meeting the Millennium Development Goals (Wilkinson et al. 2007; Haines et al. 2007).

Distributed Generation in Action

- ❖ Close to 40 million Chinese homes get their hot water from rooftop solar-thermal water heaters.
- ❖ In Iceland, 90% of the homes are heated (and cooled) with geothermal energy, virtually eliminating the use of coal.
- ❖ The Philippines derives 25% of its electricity from geothermal power plants.

-- Brown, L.E. Plan B 3.0: Mobilizing to Save Civilization, 2008

Concentrated Solar Thermal Arrays

Solar thermal energy can be used to heat hot water for residential and commercial buildings. “Water Pyramids” (30m diameter; 9m height; ground area ~650 m²) utilize solar energy to purify and desalinate water (<http://www.aaws.nl/home.htm#>).

Large arrays of parabolic mirrors can also be used to concentrate the sun’s energy (70 times) and heat liquids that boil water to steam run turbines to generate electricity (Kearney & Mehos 2007; Sandia 2007). Large concentrated solar power (CSP) arrays can then be focused on “power towers” that store the heat for use when the sun isn’t shining (Lavelle 2007).

The cost of CSP arrays is roughly half the cost of PV.

Concentrated Solar Power (CSP) arrays in desert locations can meet peak power by producing it during the hottest part of the day, when demand and costs are greatest. New models focus mirrors on “power towers,” that store energy as hot fluids up to 12 hours. CSP projects are being built or planned in Algeria, China, Egypt, Israel, Mexico, Morocco, the U.S. Southwest, South Africa and Spain. Three large arrays can generate as much electricity as a nuclear plant and can be constructed in two years, rather than the decade or more to build a nuclear plant (Wald 2008b).

Joint efforts between the U.S. and Germany have a goal of developing 5,000 MW of power by 2010 and the Central Station Solar Task Force of the Western States Governors found that, with federal and state policy support, 4 GWs of CSP plants could be deployed in the Southwest U.S. by 2015. With up to 12 hours of thermal storage utilizing molten salt, they calculate that CSP could generate 80 GWs by 2030 (Kearney & Mehos 2007). California is estimated to have the capacity to generate six times the state’s utility requirements (Lavelle 2007).

With efficiencies of PV increasing and costs falling, PV and CSP can contribute to central, regional and distributed generation systems to feed into grids (Chaudhari et al. 2004; Denholm et al. 2007).

The Solar Grand Plan

The Vision

- 69% of U.S. electricity needs could come from solar alone by 2050.
- The projection is based on a 1% increase in energy use per year.
- Posits modest increases in thin-film PV efficiency (from 10% to 14%)
- Minimal use of natural gas.
- Storage can be achieved with compressed air and molten salt.
- Transmission can be facilitated by transforming the grid with DC transmission lines.

Land use

- The U.S. has about ¼ million square miles in the Southwest suitable for PV and CSP.
- Almost 2/3 of the grid could be generated with 30,000 square miles of PV, 16,000 square miles of concentrated solar power (CSP).
- The land required to produce 1 GW of solar energy in the U.S. Southwest is “less than that needed for a coal-fired plant, when factoring in land for coal mining”.

Energy

- The amount of energy will supply 344 million plug-in hybrid vehicles.

Three phases:

- I. 2011-2020, primed with federal subsidies.
- II. 2020-2050 to achieve the 69% goal.
- III. Projecting forward, the authors estimate that renewable energy could generate 100% of the grid and over 90% of all the nation’s energy needs by the end of this century.

Estimated costs: \$10 billion/y for 40 years = \$400 billion.

-- Zweibel, Mason & Fthenakis. SciAm, Jan 2008

A Grand Wind plan

- 1.5 million wind turbines (2 MW each) in the U.S. is feasible by 2020
- This would supply 3 TWs or 40% of the world’s electricity needs
- The turbines could be produced in reopened automobile assembly plants

-- L.E. Brown. Plan B 3.0: Mobilizing to Save Civilization, 2008

Hydropower

About one quarter of human-made reservoirs are currently being tapped for hydropower. Melting glacier water is another source; one that is rapidly disappearing in the Andes, African highlands and in Asia. Large dams for hydropower have been associated with the spread of diseases (e.g., malaria, schistosomiasis). In addition, decaying organic material from reservoirs releases an estimated 1GT/yr of CO₂ annually and about 70 million tons of methane, though these figures are disputed by the hydropower industry (Adam 2007).

Other issues that require research include: fish mortalities associated with turbines; alterations in habitats: and water availability and quality. The U.S. Department of Energy is now supporting research into environmentally-friendly hydropower technologies, including new turbine designs (Sale et al. 2003).

Transportation

Climate change is projected to have significant impacts on transportation, affecting the way U.S. transportation professionals plan, design, construct, operate, and maintain infrastructure. Today's decisions related to the redesign and retrofitting of existing or the location and design of new transportation infrastructure will affect how well transport systems adapt to climate change far into the future (NRC 2008).

Rationalizing transport includes changing:

1. Modes of travel, transit and transport (e.g., buses and bikes for cars);
2. The amount of transport;
3. The types of vehicles;
4. Vehicular efficiency; and
5. The fuel used.

The average number of commute miles driven per year ranges between 4,500 and 5,600 miles (NRC 2008). All the above measures will minimize combustion of all transport fuels, reduce air pollution and the urban heat island effect, and encourage exercise. Decreased vehicular miles traveled (VMTs, S. Bernstein, Personal communication, 2007), with improved public transport, plug-in hybrids, better batteries, and electric cars can help meet transportation needs, while light-rail transport can be used widely to reduce road traffic and energy use. Ride sharing, congestion fees and – the hardest long-term project – smart urban growth will all cut down on inner city traffic and gridlock that now occur in so many major cities worldwide.

Total effects of public transportation reduce energy use in the U.S. by the equivalent of 4.2 billion gallons of gasoline.

Diesel and biodiesel-run engines are more efficient than gasoline-powered vehicles, reducing CO₂ emissions. But more energy goes into refining diesel than gasoline, the

carbon content of diesel is greater than gasoline, and diesel combustion releases NO_xs – a powerful greenhouse gas and precursor of ground-level ozone.

Plug-in hybrids are vehicles with a hybrid of power generation modalities: e.g., a gasoline internal combustion engine combined with an electric motor. The plug-in capability means that an efficient battery can store electricity derived from the grid and provide even greater power via the electric power; thus minimizing the use of liquid fuels for the internal combustion engine.

Plug-in hybrids for cars, buses, trains and airplanes can move us toward cleaner, healthier environments. But to achieve the maximum potential for changes in vehicles, a clean grid is necessary to plug into. Moreover, “smart growth” and reorganization of urban transport systems are necessary to minimize vehicular miles traveled.

Public Transport

“Transit reduces U.S. travel by an estimated 102.2 billion vehicle miles traveled (VMT) each year. This is equal to 3.4 percent of the annual VMT in the U.S. in 2007.

"By reducing vehicle miles traveled, public transportation reduces energy use in the transportation sector and emissions. The total energy saved, less the energy used by public transportation and adding fuel savings from reduced congestion, is equivalent to 4.2 billion gallons of gasoline. The total effects reduce greenhouse gas emissions from automobile travel by 37 million metric tons. This consists of 30.1 million metric tonnes reduced from secondary effects and a net savings of 6.9 million metric tonnes from primary effects and the effects of transit induced congestion reduction. To put the CO₂ reductions in perspective, to achieve parallel savings by planting new forests, one would have to plant a forest larger than the state of Indiana."

-- American Public Transportation Association 2008

Case Study: The Cambridge Energy Alliance

- Five-year, \$100 million massive energy efficiency project in Cambridge, Massachusetts
- Scope: All sectors involved – commercial, industrial, government, universities, hospitals and non-profits, housing and residents
- Goal of reducing peak demand by 50 MW and fossil fuel use by 5% over 5 years; major reductions in GHG emissions

- Best way for city, companies and consumers to stabilize energy costs and reduce pressure on the grid
- Significant number of new jobs and economic development

What is Massive Energy Efficiency Implementation?

- High penetration rates in Commercial, Industrial, Government & Residential Sectors
- Critical mass for financing; reducing marketing and transaction costs
- Emphasis on retrofitting existing buildings; engage new construction as well
- Use all measures: lighting, HVAC and control systems, appliance standards and building practices
- Install Distributed Generation (Renewable Energy and Combined Heat & Power Facilities) wherever possible; emphasize demand response to reduce peak electricity use
- High profile campaigns involving government, private sector and citizen leadership

The Financing

- Assembling \$70 million revolving line of finance
 - \$15 million in public funding (ISO-NE, other)
 - \$5 million in private equity or subordinated debt financing
 - \$50 million in private project financing debt
- \$50 million in private debt raised from pension and annuity providers, life insurance companies
- Low risk debt, attractive interest rates
- Because savings are paid into revolving line, approximately \$100+ million in energy efficiency implementation will result over 5 years

Governance

- Cambridge is closely partnering with a 501(c)(3) – Cambridge Energy Alliance
- The nonprofit serves as a City-sponsored ESCO (Energy Service Company), reaching out to aggregate demand from all sectors

- The nonprofit is:
 - Leading public outreach and marketing campaign
 - Raising debt financing through efficiency finance specialists
 - Combining all available public revenue sources (FCM, efficiency incentives, RGGI funding, carbon offsets, etc.)
 - Issuing efficiency solicitations, i.e., for C&I, schools, hospitals, housing, residents

- All efficiency services will be delivered by private energy service companies, contractors and engineering firms

High Profile Campaign

- Massachusetts Governor and Cambridge Officials announced on March 29, 2007
- Cambridge, Harvard, MIT, Chamber of Commerce, and other key representatives on Organizing Committee
- Seeks to involve all large Cambridge employers, hospitals, universities, schools, housing providers and small and medium size businesses
- Peer Pressure (decals and graphics to denote participants) and Media Attention
- SmartPower organizing messaging, graphics, radio spots and public advertising
- Religious leaders are involved; additional community partners engaged in outreach

--Rob Pratt, Amy Panek, Cambridge Energy Alliance

Sustainable Agriculture

Agriculture with low- and no-tillage can provide another wedge of avoided carbon emissions (Kern & Johnson 1993; Reicosky 1999; So et al. 1999; Smith et al. 1998; Lal & Bruce 1999; Lal 2000; Holland 2004). Soils, including those in all croplands, pastures and forests, totaling 8.5 billion hectares (1Ha = 2.4 acres), hold about 1,100 to 1,600 GtC (FAO2007b). But while carbon is added to soils annually, an equal or greater amount is lost from erosion, forest clearing and overgrazing of pasture lands 425 GtC.

David Pimentel (pers. comm., 2007) estimate that 230 million tons of carbon are added to soils each year, but an equal amount (or greater) is lost annually due to erosion, forest removal, and overgrazing of pasture lands.

Soil has the remarkable property of being either a source or a sink of CO₂, depending on how it is managed. Crops contribute carbon to the soil in the form of residues, roots and litter left behind after cultivation (So et al. 1999). However, traditional tillage releases

more carbon from soil degradation into the atmosphere than is removed by the previous year's crop (Reicosky 1999).

Conservation or no-tillage is an alternative cultivation practice that minimizes soil disruption, turning soil into a carbon sink, maintains soil fertility, and reduces erosion. This practice has become fairly common in the U.S., primarily for erosion control; but most parts of the world practice traditional tillage. There are a variety of ecological and public health benefits from conservation tillage, in addition to climate mitigation, including improved food security, greater biodiversity on agricultural lands, and reduced flooding and agricultural run-off.

Diverse fields of crops, interspersed with trees – as wind-breakers and habitat for herbivore-consuming birds – store more carbon than do monocultures. Diverse fields also provide better protection against weather-related damage and more resistance to crop pests and blights (IFOAM 2004). Organic agriculture eliminates pesticides and minimizes fossil-fuel derived fertilizers, and locally grown food decreases the “food miles” that generate GHG emissions.

The synthesis of ammonia to produce inorganic fertilizers is the single largest cause of human-driven doubling of the natural nitrogen cycle (Smil et al. 2000). Nitrogen in waterways contributes to harmful algal blooms (HABs), exacerbating the over 150 “dead zones” in rivers, estuaries and coastal marine waters worldwide (Naylor et al. 2005; Thorne 2007). HABs and dead zones have health implications for humans and fisheries (Cederberg & Stadig 2003; Townsend et al. 2003; Walker et al. 2005; Steinfeld et al. 2006; Ogino et al. 2007).

Slow-release and ammonium fertilizers, off-season straw on fields, and fields left fallow are practices that preserve soils and productivity, while minimizing fossil fuel inputs.

Livestock Rearing Practices

The animal agriculture sector includes farm animal-rearing; grain production; production and use of fertilizers, pesticides, and herbicides; animal waste; on-farm energy expenditures; and off-the-farm transport of meat, eggs, and dairy products. The U.N. Food and Agriculture Organization estimates that the livestock sector is responsible for 18% of annual GHG emissions, measured in CO₂-equivalent, globally (Steinfeld et al. 2006; Nierenberg 2007; Koneswaran and Nierenberg 2008). The total CO₂ emissions are summarized in the box below.

Deforestation is the largest contributor of CO₂ emissions, and growing grains for feed and creating grazing land are two of the main drivers of forest clearing (Steinfeld et al. 2006). For cattle the equation is starkest: six to ten lbs (2.7-4.5 kilograms) of grain (and enormous quantities of water) are needed to produce 1 lb (1 kg) of beef (Smil 2000; Smil 2001). For hogs and chickens, the ratios are two to three to one.

FAO Summary of CO₂Emissions from Animal Agriculture

Sector	Estimated annual CO ₂ emissions in tons
Deforestation	2.4 billion
Desertification of pastures	100 million
On-farm fossil fuel use	90 million
Fossil fuel for fertilizer manufacture	41 million
Releases from cultivated soils	28 million
Processing animal products	Several tens of million tons
Transporting feed & animal products	0.8 million tons
Total	~2.7 billion tons

--Koneswaran & Nierenberg 2008

■ 2.7GtCO₂ = ~0.7 GtC

■ Figures do not include other GHGs, chiefly methane and nitrous oxide

Healthy and environmentally-friendly measures to reduce livestock sector emissions include:

- Free-range and pasture-based production
- Better waste management (see below), and methane capture and use (USDA 2005; Aillery et al. 2005)
- Shift to organically grown beef
 - This practice may emit up to 40% less GHG emissions and consume 85% less energy than conventionally produced beef (Cederberg & Stadig 2003; Clancy 2006; Fanelli 2007; Ogino et al. 2007)
- Enhanced local production
- Changes in consumption patterns

Reduced meat consumption is recommended to mitigate greenhouse gas emissions and to reduce heart disease, some types of cancer, and obesity (McMichael et al. 2007). The measures depicted above are beneficial for soils, water and air quality, biodiversity, nutrition, and public health.

Municipal Solid Waste Management

Municipal solid waste (MSW) management is currently very inefficient (as is municipal water management) regarding GHG emissions and potential mitigation options. In 2000 annual emissions from MSW were estimated to be 0.47 GtC/yr, rising to 0.99 GtC/yr by 2054 (EPA 2002, 2005; Covanta/Trinity 2007). Increased use of recycling, energy recovery and landfill gas collection have the potential to reduce GHG emissions by 1 GtC/yr.

The international community, including the U.K.'s Department of Environment and Rural Affairs (DEFRA) and the USEPA, have adopted a waste management hierarchy as a model for sustainability and best GHG practices. The elements include:

- Source reduction
 - Recycling
 - Combustion of waste for energy
 - Land filling, with and without landfill gas recovery.
- EPA 2002, 2006; IPCC 2006; Simmons et al. 2006; FAO 2005b.

The USEPA illustration below identifies the preferred management options in descending order (URL sites listed in citations):



Source reduction and recycling minimize the use of natural resources and in the process save and avoid GHG generation. The European Union, USEPA and IPCC have also concluded that combustion with energy recovery (aka energy-from-waste or waste-to-energy) is preferred over landfilling.

Landfilling is the least desirable option and if necessary, should be equipped with bottom and top liners and a landfill gas collection system with either a flare or engine for energy recovery for the full anaerobic digestion process that is estimated to be 100 years.

Anaerobic Digesters

One technical mitigation strategy being adopted by some large-scale producers is the use of anaerobic digesters to isolate the methane from farm animal manure and use it to power generators on-site or sell the energy to local electric companies (Storck 2007; AAIS 2007). The EPA estimates that anaerobic digestion systems are feasible at approximately 7,000 pig and dairy operations in the U.S. and, through the AgStar program and the Methane to Markets Partnership, provides technical assistance and financial incentives to encourage the use of these systems both domestically and globally (EPA 2007; AAIS 2007).

According to the EPA, existing systems provide enough renewable energy to power more than 20,000 average U.S. homes and have reduced annual methane emissions by about 1.5 million tons of CO₂-equivalent.

Despite their benefits for mitigating GHG emissions, anaerobic digesters are not entirely risk-free. An article in the American Association of Insurance Services' magazine Viewpoint notes that methane from manure piped into a tank for storage essentially renders the operation "a flammable gas compressor station like that found in the natural gas industry" that, for underwriting purposes, "should be treated similarly to that of a hazardous petrochemical manufacturing plant" (AAIS 2007).

TECHNOLOGIES WARRANTING FURTHER STUDY

Coal-to-Liquid Synfuels

Development of synthetic fuels ("synfuels") from coal – coal-to-liquid – continue all the life cycle hazards of coal and can amplify the health problems caused by combustion by-products (Williams et al. 2006). Conversion of coal into gas by Integrated Gasification Combined Cycle (IGCC) coal gasification by the Fisher-Tropsch process is energy-intensive and, though the combustion by-products may be less than those emitted from burning coal directly, continues the upstream life cycle costs of coal.

Phasing out coal

Note: There are approximately 110,000 FTE employees in the U.S. mining industry. If coal is phased out rapidly, retraining displaced workers for new industries – to manufacture solar thermal arrays and wind turbines, for example – could replace the lost livelihoods and revitalize economically-depressed communities. The phase out of coal mining will require a new industrial policy to expand the relevant enterprises.

Life Cycle Analysis: Biofuels Carbon Debts

Life-cycle analytical tools include the Argonne National Lab GREET model (greenhouse gases, regulated emissions, and energy use). When land use change is added, the conversion of forests, peatlands, savannas and grasslands to "biofuel farms" in Brazil, Southeast Asia and the U.S. adds significantly to the net "carbon deficits." The land clearing is done primarily via fires, with rapid carbon release, followed by prolonged release via microbial decomposition. Including these emissions in the calculations of the net carbon benefits/losses, corn-to-ethanol emits nearly twice as much GHGs as gasoline, and lignocellulosic biofuels from switchgrass increases the net emissions 50%. The time to repay this "biofuels carbon debt" ranges from 17 years (for sugarcane) to 93 years (corn-ethanol on U.S. grasslands) and 423 years (for palm biodiesel) (Searchinger et al. 2008; Fargione et al. 2008).

Using Genetically Modified Organisms

Plants and microorganisms are being genetically modified to improve the breakdown of lignin and cellulose. While the direct health effects of genetically modified organisms (GMOs) (when used as foods) undoubtedly warrant continued study, the environmental risks of GMOs are the chief concern. Recent findings regarding the stability of DNA should give the biotechnology industry pause, as released organisms will spread.

(For food crops, those containing pesticides or those that induce pesticide-resistance (i.e., impacting interactions among species) may be more important to regulate than those that increase tolerance to drought or increased salinity.)

- ❖ In August 2001 Belgian scientists reported “mysterious” rearrangements of DNA within Monsanto Co. Roundup Ready GMO soybeans (Windels et al. 2001). In the 1930s geneticist Barbara McClintock, examining the chromosomes of corn kernels with only a microscope, observed such “jumping genes” or transposons (Comfort 2001). Other studies demonstrate that “epigenetic” messengers – chemicals outside the genome -- express some genes and suppress others, throughout cell differentiation and morphological development (Wu et al. 2001). Genetically modifying organisms is based on the potentially untoward assumption that the genome is static and acts alone.
- ❖ Regarding the ecological impacts, inserted genes conferring resistance to pesticides can jump to weeds, rendering them resistant (Wolfenbarger & Phifer 2000). There is field evidence indicating that pesticide-generating genes can harm pollinators like butterflies. And inserted genes that generate pesticides, like *Bacillus thuringiensis israeliensis* (Bti) toxin, can create sufficient evolutionary pressure to induce Bti-resistance in the leaf-eaters. (Applying Bti intermittently, as is done in organic farming, minimizes this risk.)

Releasing GMOs into the wild that produce pesticides or impart pesticide resistance may hold unintended ecological consequences; for genetic engineering involves the “evolution” of new organisms at rates that may surpass nature’s ability for co-evolution -- of the community of predators, competitors and cooperating organisms that help keep opportunistic, pioneering pests and pathogens in check. To borrow a phrase that Williams College marine ecologist Dr. James T. Carlton coined regarding the global transport of invasive species, we are playing “ecological roulette” at the most fundamental scale.

There are alternative methods for safely increasing agricultural production. Large-scale experiments in China, involving thousands of acres, demonstrate that interspersing naturally rice blast-resistant rice with disease-sensitive strains (i.e., biodiversity vs. monocropping) has dramatic effects. Mixing strains increased the yield of glutinous plants 89% over that in monoculture plots. Mixing also reduced

grain loss due to disease to 1%, compared to the 20% losses in the monocultures (Zhu et al. 2000) meeting all the claims of GMOs. Biologically diverse systems, in general, supplied with adequate nutrients, are proving to be more productive, resilient and resistant than simplified ones.

Algae

Algae grown in ponds or in nutrient-rich waste water lagoons, using CO₂ from the air or from power plants, offers another source of biodiesel and ethanol. Algal productivity (biomass per acre) is several orders of magnitude greater than yields for crops. Algal processing can transform oils into biodiesel, while the residues can be used to generate ethanol. Algal growth also maximizes water use and this promising process obviates the significant use of agricultural land for biofuels (Goldman & Ryther 1977).

Algae can be used for biodiesel and ethanol; it could also form the feedstocks for “green chemistry” products, including plastics, paints, pesticides and others, currently derived from fossil fuels.

Nuclear Fission

Nuclear energy is seeking a revival (Motavalli 2007; Ansolabehere et al. 2007). But replacing carbon pollution with radioactive waste carries many hazards (Hughes 2006a; Fleming 2006). Plant safety may be “containable” with new “pebble” technologies. But security is an emerging issue for transport, use and temporary storage, and the safety of long-term storage from earthquakes is proving extremely difficult to ensure (Makhijani 2007). The July 2007 earthquake in Kashiwazaki, Japan on 16 July 2007 raises the stakes regarding plant safety and safe storage (Cristoffels 2007).

Health Concerns

The evidence that ionizing radiation in the nuclear fuel cycle causes cancer and other illnesses in exposed workers and communities is well-established. Studies of uranium miners (Roscoe, et al., 1995; Pinkerton, et al., 2004; BEIR VI, 1999) have documented increased lung cancer from radon exposure in the mines and Navajo miners in the U.S. and African mineworkers in Namibia get greater radiation exposures than their white counterparts.

There is at least one study (Cragle et al., 1988) which found statistically significant increased leukemia deaths in nuclear fuel processing workers. Numerous studies of nuclear industry workers in both commercial power facilities and weapons plants have documented increased mortality from lung cancer, multiple myeloma and other cancers (Cardis et al., 2007). Likewise, there have been several studies of communities around nuclear facilities in the U.S. and U.K. that have reported increased adult leukemia, childhood leukemia and other childhood cancers (Morris et al., 1996; Beral et al., 1993). Finally, a French study identified increased leukemia in young people exposed to

radiation through various routes around a nuclear fuel reprocessing plant (Pobel & Viel 1997).

Workers and communities are exposed to ionizing radiation during dismantlement and transportation of radioactive materials and at other points in the life cycle of nuclear power plants, but no studies of these populations have been published to date.

Temporary Storage

A nuclear reactor generates about 20 tons of radioactive waste annually, writes Mathew Wald in the NYTimes (2008b). The waste in the U.S. is in temporary storage at 122 sites in 39 states, and if and when a long-term repository is opened, the backlog would take decades to clear.

Permanent Storage

Long-term storage remains the most intractable issue. Meeting a wedge with nuclear energy would generate radioactive waste that would fill the capacity of one “Yucca Mountain” (the proposed site in Nevada) every 5-10 years until mid-century. Meanwhile, Yucca Mountain will cost an estimated \$77 billion and securing it remains a challenge: on May 21, 2007 the U.S. Geological Survey reported the existence of a previously undetected fault running through it; reporting that there are 10 known faults within a 20-mile radius of Yucca Mountain, and Solitario Canyon west of the planned site could produce a 6.5 magnitude earthquake.

Costs are also an issue with nuclear.

Nuclear power plants	~\$6-\$12 billion
Coal-fired plant	~\$2 billion
Gas-fired plant	~\$1.6 billion
Wind-farms	• steel, concrete and labor costs < coal-fired plants ~\$1.8 Billion off-shore. <\$1 Billion on-land

Federal subsidies to expand nuclear significantly would have to increase substantially. Security is also a significant problem for power plants, transported radioactive materials and for temporarily-stored radioactive materials. International tension is high today. Climate change and water, food and energy shortages (CNA 2007) may exacerbate the conflicts, making security against attacks on facilities and “loose nukes” and “dirty bombs” a problem for some time. This issue alone, not amenable to international treaties, may be a deciding factor in comprehensive plans to scale up nuclear as a solution to meet stabilization wedges.

Finally, timing is an issue, for scaling up nuclear energy cannot easily be done in a short-time frame.

Key Elements of a Low Carbon Economy

I. Smart grids: Robust, resilient, ‘self-healing’ and cleanly-powered grids

- a. Interconnected distributed, regional and central generation
- b. Combined heat and power generation (‘co-gen’) at all scales
- c. Maximal use of renewables: solar, wind, ground heat pumps and geothermal
- d. Improved storage for intermittent sources: wind, solar, hydro
- e. “Sensory” technologies to monitor and decrease use of energy
- f. Identified critical areas: within buildings and across the grid
- g. Peak load pricing
- h. Decoupling utility profits from use

II. Healthy Cities Programs and Measures to Minimize Use of Liquid Fuels

- a. Green buildings
- b. Rooftop gardens
- c. Tree-lined streets
- d. Walking paths
- e. Biking lanes
- f. Open space
- g. Expanded public transport
- h. Smart growth
- i. Intercity light-rails
- j. Plug-in hybrid vehicles: cars, trucks, buses, planes
 - i. For transport and power generation

III. Fortified Natural Systems

- a. Forest preservation
- b. Local, no-tillage and diverse, organic agriculture
- c. Wetlands, barrier island and coral reef preservation

IV. Green, non fossil fuel-based, chemistry