Healthy Solutions for the Low Carbon Economy

Guidelines for Investors, Insurers and Policy Makers






A Project of:
The Center for Health and the Global Environment
Harvard Medical School

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WELLS FARGO

GLOBAL ROUNDTABLE ON CLIMATE CHANGE
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

Funded by:
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Cover Images: (first row, left to right) Vicente Barcelo Varona/Dreamstime.com; Dimitar Marinov/Dreamstime.com; Brian Lindley, No-Till on the

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Overview

Reducing greenhouse gas emissions 80% (or more) below 1990 levels with the aim of stabilizing the climate will require rapidly scaling up a comprehensive set of measures, primed with a coordinated mix of financial and policy instruments.

This report examines the suite of energy choices available – the "stabilization wedges" – through the health and environmental lens. It is intended to complement assessments of their technological and economic feasibilities. The methodologies advanced are: 1. Assessing the net energy balance; and 2. Conducting a life cycle analysis of the potential health, ecological and economic consequences of proposed technologies and practices. Exploring the potential consequences of new technologies can help separate safe solutions to scale up today, from those warranting further research before widespread adoption.

This report draws on precautionary tales passed down by the insurance sector; namely the "long tails" of decades of health, liability and insurance costs from asbestos, tobacco, lead and industrial toxins. The potential risks of mercury released during accidents and disposal of compact fluorescent light bulbs (*vs.* light-emitting diodes) is a current demonstration of the potential economic ramifications of inadequately assessing health and safety concerns.

This report describes the potential side effects of using oil sands, shale oil and biomass to produce liquid fuels for transport; coal combustion with CO_2 capture and storage; and nuclear fission. It also provides a positive vision of intelligent grids, green buildings, smart growth and hybrids of clean power generation technologies in mobile and stationary systems.

While broad in scope, these guidelines are not exhaustive, given the accelerating pace of innovation and the need to control emissions of all greenhouse gases.

The report pinpoints key private sector financial instruments and addresses the financial architecture needed to enable large-scale shifts in private investments. It highlights the need for a substantial global fund for adaptation and mitigation.

Image: Cyril Hou/Dreamstime.com

We hope these guidelines help investors, insurers and policymakers make well-informed decisions regarding our future energy system. Weaning society from fossil fuels is the highest priority, given their manifold health, ecological and social costs. We believe that comprehensive, bold, yet careful, planning can support a path that optimizes adaptation and mitigation, maximizes co-benefits and minimizes the unintended consequences for health and the global environment.

To Scale up Now

Smart, Cleanly Powered Grids
Healthy Cities Programs
Measures to Minimize Liquid Fuels:
- Enhanced public transport
- Walking and biking
- Plug-in hybrid electric vehicles
- Smart urban growth

For Further Study

Oil Sands and Shale Oil
Biofuels
Coal with CO_2 Capture and Storage
Geoengineering
Nuclear Fission
Nanoscience
Current, Wave and Tidal Energy

Key Points

The Precautionary Principle

Every action has consequences. Adopting the precautionary principle means avoiding (or minimizing) risky practices, particularly when the consequences could be great.

Pilot Programs for Proposed Technologies to Include

EIO: Energy In and Out balance = net energy, water use and greenhouse gas (GHG) emissions

LCA+: Life Cycle Analysis plus exploration of alternatives

Criteria for Energy Options

Meet multiple goals

Enhance adaptation and mitigation

Maximize health, environmental and economic co-benefits

Minimize unintended consequences

Power

Solar, wind and ground source heat pumps for distributed generation

Solar, wind, geothermnal and hydropower for utility grid base-loads

Combined heat and power ('co-gen') at all scales

Natural gas for back-up distributed power, and regional and central generation

Stand-alone solar and wind systems where grids are inadequate

Solar thermal desalination

Ecological Design

Hybrids – diverse means of power generation – for mobile and stationary systems

- Provide insurance and resilience
- Build in strength and flexibility
- Minimize the potential unintended consequences of over-using any one technology

Complementary systems – with distributed, regional and central generation – provide resilience

Mimicking photosynthesis for photovoltaics, linked with fuel cells, is a central challenge for the clean energy transformation

Smart Grids - Diverse, Robust, Utility Systems

Digital, direct current transmission to enable sensors

Sensors and systems to optimize efficiency, manage peak loads and critical functions, and enable clean distributed generation

Efficient appliances

Modernized storage capability for intermittent sources

Financial and Policy Instruments

Private sector

Shift assets under management

Alter lending guidelines

Amortize and lease measures with high upfront costs

Reduce insurance premiums for builders of green buildings and hybrid vehicle owners

Revise insurance policies for Directors and Officers

Public sector

"Decouple" utility revenues from energy use to incentivize efficiency measures

Dismantle bureaucratic obstacles to innovation

Provide tax incentives and "feebates" for consumers and producers

Switch subsidies from fossil fuels to renewables

Switch farm subsidies from corn to wind

International Financial Architecture

Realign rewards and regulations to support the Clean Energy Transformation

Establish a substantial Global Fund for Adaptation and Mitigation

Build the institutional foundation: e.g., via the Global Environment Facility/United Nations Framework Convention on Climate Change

Restructure operating rules of trade and debt to drive sustainable development

Phases

I. 2009-2010: Comprehensive planning
II. 2011-2020: Large susidies for infrastructure
III. 2021-2050: Ramp up implementation
IV. 2051-2100: Complete clean energy transformation

Introduction

As the pace of climate change quickens, the world is suddenly faced with food, fuel and financial crises. Systemic measures, beginning with a comprehensive change in energy systems, will be needed to address the underlying drivers.

In the coming decades, world energy use will rise as oil supplies peak and ultimately decline. In 2005, the world used energy at a rate of 16.3 trillion watts (terawatts or TW). A watt is a *rate* equal to one unit of energy (a joule) per second (J. Holdren, pers. comm. 2008). By 2050, energy demands are projected to double (EIA 2005). These estimates do not include increased demands due to water stress and prolonged heat waves.

Oil is the primary source of energy: the world consumes 86 million barrels daily or **40,000 gallons a second** (EIA 2007).

To meet growing needs, the petroleum industry estimates that $20 trillion will be invested in new energy infrastructure over the next 25 years (IEA 2007).

Meanwhile, 89,000 TW of sunlight reach Earth's surface and utilizing 600 TW is a practical target. Additionally, 50 TW of wind energy are available on land and 3 TW are practically available (Lewis 2004).

This report explores avenues, as well as financial and policy instruments, for redirecting investments into a renewable, reliable and robust energy infrastructure – a prerequisite for coping with climate change, controlling fuel and food prices, sustaining healthy economies, and stabilizing the climate.

CLIMATE CHANGE AND HEALTH, ENERGY, TRANSPORT AND WATER

Climate change threatens human health and well-being, natural and managed ecosystems, economies and global political stability (Epstein and Mills 2005; IPCC 2007b; CNA 2007). Climate change also threatens the energy sector.

Storms can: 1. Disrupt oil rigs, pipelines and refineries (25% of Gulf of Mexico oil and gas production is still

The intensity of hurricanes has increased and poor nations and communities can experience the after effects for years following storms. Image: Bill Haber/AP

down three years following Katrina); and 2. Interrupt transmission (as did a massive snowstorm in China in Jan/Feb 2008). Heat waves can 3. Cause power outages (e.g., almost half the U.S. lost power in the summer of 2003); and 4. Shut down nuclear power plants (as occurred in France, summer of 2003). Meanwhile, 5. Thawing tundra is undermining arctic pipelines; and 6. Shrinking montane glaciers threaten hydropower in developed and developing nations.

Prolonged U.S. Southwest drought is affecting the cooling water for over 24 of the nation's 104 nuclear energy reactors (Hightower 2008).

Climate change threatens the transport sector, posing new challenges for planning, design, construction, operation and maintenance of infrastructure. Today's decisions regarding retrofitting of existing – and placement of new transportation – infrastructure will affect how well the systems adapt to a changing climate far into the future.

With freshwater aquifers overdrawn and underfed in many regions, water supplies will be further compromised by disappearing montane glaciers and dwindling snowpack (Barnett *et al.* 2008). Today, 1.7 billon people live in "water-stressed" nations and the number may reach 5 billion by 2025 (IPCC 2007a).

Meanwhile, lack of energy or **energy poverty** hinders development. Developing economies need consistent energy supplies to power their development and cope with more volatile weather. Where utility grids are inadequate, stand-alone power generators – using solar, wind, human and bicycle-assisted power – can be used to pump, decontaminate and desalinate water, irrigate land, power clinics, light homes and run small businesses. Clean, distributed energy is necessary for meeting the Millennium Development Goals (Wilkinson *et al.* 2007; *Haines et al.* 2007).

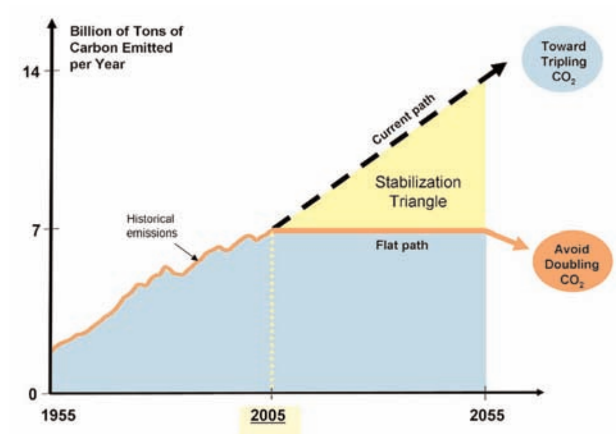
"Electricity cuts plague 35 nations [and] outages are stifling a boom in Africa," warned the *Wall Street Journal* this spring (Childress 2008).

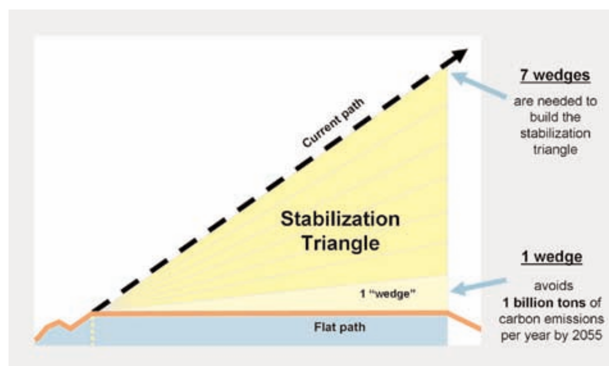
THE STABILIZATION WEDGES

A set of energy solutions, called the "stabilization wedges," was developed by Steve Pacala and Robert Socolow of Princeton University (2004), and provides a template for developing comprehensive energy plans. Fifteen energy choices were depicted and several others have since been proposed. Each wedge would avoid 1 billion tons (a gigaton or Gt) of carbon *emissions* annually by mid-century, by reducing CO_2 and CO_2-equivalent (CO_2-e) emissions.

A caveat: By 2004 calculations, seven wedges would offset projected increases in emissions by 2054. But stabilizing or reducing *concentrations* of GHGs will require increasing the number of wedges implemented or doubling the size of each wedge, or both.

Analyses of the wedges, to date, focus on technological and economic feasibilities. But some options may prove unsustainable due to serious health and environmental damages. Some may inadvertently enhance global warming. It is therefore incumbent upon us to assess the net energy gain (including water and material inputs), and explore the potential side effects of each step in the life cycle of new technologies. Meanwhile, we can identify measures with health, environmental and economic co-benefits in which we can invest, insure and enable through sound public policies.





These images depict the "wedge" concept and the magnitude of measures required to "bend the curve" on greenhouse gas emissions. Image based on "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies" by Steve Pacala and Rob Socolow, Science, August 13, 2004, V. 305, p. 968.

THE LIST OF ENERGY OPTIONS

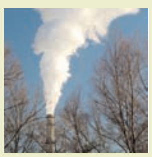
AS DEPICTED BY PACALA AND SOCOLOW, *SCIENCE* 2004; 305:968-971.

Efficiency

1. Double fuel economy for 2 billion cars from 30 to 60 mpg
2. Halve vehicular miles traveled for 2 billion cars: urban design, mass transit, telecommuting
3. Cut carbon emissions by one-fourth from buildings and appliances
4. Double coal-power output with advanced high-temperature materials

Fuel shift

5. Replace 1400 GW of coal-fired power with natural gas plants

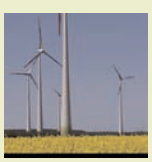


CO_2 capture and storage (CCS)

6. CCS for 800 GW worth of coal or 1600 GW natural gas: average plant = 1 GW
7. Capture CO_2 at plants producing H_2 from coal or natural gas
8. CCS at synfuels plants producing 30 million barrels a day from coal

Nuclear fission

9. Add 700 GW: twice the current capacity



Renewable electricity and fuels

10. Add 2 million 1MW-peak windmills: 50 times current capacity
11. Wind-derived H_2 for fuel-cells in hybrid cars: add 4 million 1 MW-peak windmills to make H_2 or 100 times current capacity
12. Add 2000 GW-peak photovoltaics (PV): 700 times current capacity
13. Add 100 times the current ethanol: one-sixth of world cropland

Forests and agricultural soils

14. Eliminate deforestation; reforestation and afforestation: 300 Mha of new trees or twice current rate
15. Conservation tillage for all cropland: 10 times the current usage

Images: Halina Przeszlo, Bram Janssens, Fritz Langmann, Mamahoohooba, Elena Elisseeva, Rockford Royko/Dreamstime.com

Technologies for Early Adoption

TECHNOLOGIES FOR EARLY ADOPTION

CONSERVATION AND ENERGY EFFICIENCY

Conservation and energy efficiency are the obvious measures for early and widespread adoption. Conserving energy, water and materials by altering our behavior involves individuals and the groups to which we belong: families, neighborhoods, places of education, worship and work. This "behavioral wedge" can be pivotal for achieving savings *and* for sending signals into the marketplace. This shift is already underway and private and public sector incentives are needed to reinforce it.

Conservation and energy efficiency cut across all the wedges, and reducing overall energy demands can enable deployment of more small- and intermediate-scale power generators. Greater efficiency in industrial processes, buildings, transport and waste disposal will reduce demand and save money. These measures are the ubiquitous "low-hanging fruit" (McKinsey 2007b).

INDUSTRIAL EFFICIENCY

Industry accounts for one third of total CO_2e emissions, with steel- and cement-production being the most energy-intensive and GHG-emitting sectors (Worrell *et al.* 2004; Bittner 2004). Material substitution (e.g., fly ash and steel blast furnace slag for concrete), and product replacement (e.g., reusable cloth for petroleum-based disposable plastic bags), decreases energy use and waste. Life cycle analyses of industrial processes, including upstream supply chains and downstream marketing and transport, can identify elements for improving efficiency, resource use, occupational health and safety, and consumer protection.

GREEN CHEMISTRY

Green chemistry principles guide industrial chemists and molecular designers to create materials and products that maximize the use of biodegradable feedstocks and minimize waste (Anastas and Warner 1998). Green chemistry employs plant extracts as chemical platforms and avoids petrochemicals, many of which are persistent, hormone-disrupters and carcinogens.

The chemical sector consumes about 20% of the total fuel used by U.S. industry (Worrell *et al.* 2000) and fossil fuels are used for energy and for the products. Making ethylene, for example, is one of the most energy-intensive processes and is a platform chemical for plastics and medicines. Circumventing ethylene could, therefore, reduce energy use and shift dependence from petroleum for feedstocks.

Deriving plant platforms from highly productive algal ponds would obviate land displacement.

SMART GRIDS

Apart from power generation, utility grids consist of transmission, distribution, storage and use. Over 50% of investments in U.S. utilities will go to upgrade these elements of our energy system. Intelligent technologies include movement sensors to turn on lights, and computer-controlled meters and sensors to identify and power critical functions within buildings (e.g., heating and refrigeration), and within cities (e.g., hospitals and nursing homes). Monitoring and feedbacks, made possible with digital transmission, are components of smart, self-healing grids that can cope better with stresses while stimulating innovation, jobs and enterprises.

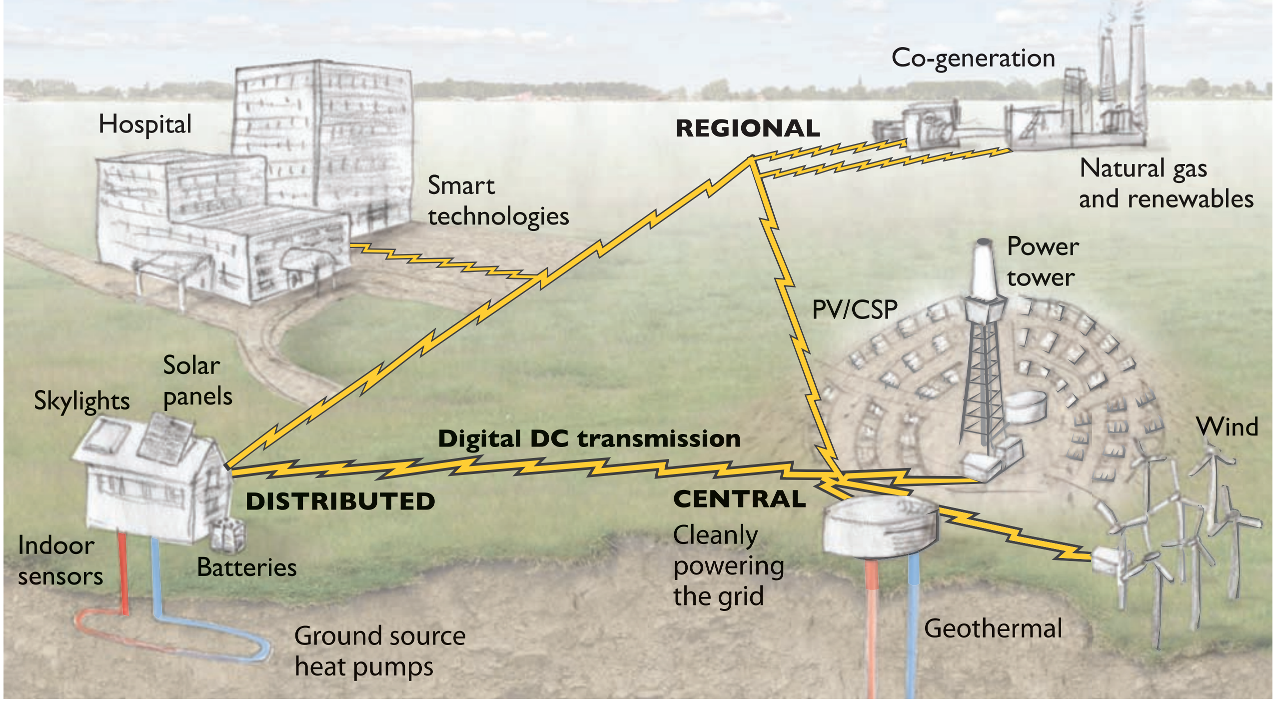
A year-long Pacific Northwest Laboratory demonstration project on the Olympic Peninsula, Washington realized significant savings by using: 1. Electric meters to identify times with high prices and high use of coal; 2. Thermostats and computer software to curtail use during these periods; and 3. Remote devices to adjust the preferences. The U.S. Department of Energy estimates that digital monitoring and control technologies could save consumers $70-$120 billion over the next 20 years and obviate the need to build 30 large coal-fired plants.

GREEN BUILDINGS

Green buildings include natural daylighting, argon-containing, tinted windows that keep heat in during winter and deflect it in summer, renewable energy sources and green environs. Green buildings provide energy savings and employ products derived from green chemistry and sustainable forestry (e.g., fast-growing woods and grasses like bamboo). The Leadership in Energy and Environmental Design (LEED) certification of the U.S. Green Building Council (USGBC) includes efficiency in construction, recycling, operating energy

Smart, cleanly-powered grid

Interconnected grid with: **1.** Distributed, regional, and central generation; **2.** Hybrids (multiple means) of power generation at each scale; **3.** Smart sensors in buildings for efficient use; **4.** Smart technologies to designate critical areas during power losses; **5.** New generation batteries and other storage technologies.



This illustration depicts the hybridization of power generation measures, the multiple scales of generation and the smart technologies and storage needed to provide clean, robust and reliable power grids. PV = photovoltaic; CSP = concentrated solar power arrays (discussed below). Graphic: David M. Butler, The Boston Globe

and water efficiency, improved air quality, and profitability. Green buildings can be cost-neutral or cost-saving by reducing the size of equipment powering and managing the buildings.

In the U.S., retrofits are planned for almost 1,000 existing buildings (a half billion square feet), using LEED standards. Estimated payback periods range from 2 to 2.5 years.

Studies at the Lawrence Berkeley National Laboratory project that improvements in indoor air quality in green buildings offer tens of billions of dollars in savings.

A caveat: Some of the financial benefits listed (see box) may only be partially realized; further research is needed to assess the health and work performance benefits of green buildings.

Estimated Savings from Green Buildings in the U.S. (In 1996 $US)

Respiratory disease	$6 to $14 billion
Allergies and asthma	$1 to $4 billion
Sick building syndrome	$10 to $30 billion
Worker performance	$20 to $160 billion
Total Energy Savings	$70 billion

Fisk 2000

Schools with Natural Light

20% faster on math tests
26% faster on reading tests

Kats 2006

Stores with Natural Light

40% more sales

Kellert *et al.* 2008

Hospitals with Better Lighting and Ventilation

Improved patient outcomes and reduced hospital stays

Frumkin 2008

GREEN ROOFS

Rooftop gardens, with a diversity of plants and bases to capture rain water, have many benefits. Green roofs: 1. Cool buildings; 2. Draw down CO_2, toxic chemicals, smog and heavy metals; 3. Absorb noise and shield rooftops from damaging UVB rays; 4. Attract birds that control insect herbivores; 5. Provide useful water; 6. Decrease the urban heat island effect; 7. Create enterprises and jobs; and 8. Make life more pleasant. The cost- and energy-savings more than make up for the upfront costs.

DISTRIBUTED GENERATION

Distributed generation – on-site power or that produced near the point of use – can provide both baseline and back-up power for peak use and surges. Distributed generation (DG) can be fed into grids and, with "net metering" and "feed-in tariffs," provide income for local suppliers. DG can utilize solar, small wind turbines, natural gas and, in most areas of the globe, ground source energy. Fuel cells can generate and store power, and hybrids of energy production modes increase reliability.

Combined heat and power: Many industries require steam in their operations. Generating steam heat and power simultaneously can: a) displace power from the grid; b) be sold to other facilities; or c) be fed into the grid to avoid the need for additional generation. The elegance of this solution has motivated its use at smaller and smaller scales, and residential combined heat and power units are now becoming available. Casten (2007) estimates that recycling waste energy can reduce the fossil fuel burned to generate electricity by one quarter.

Rooftop gardens cool buildings, beautify cities and reduce the urban heat island effect. Image: Cook + Fox Architects LLP

The Bank of America building in mid-town Manhattan, designed by Cook+Fox Architects, will save water, energy and expenses, and provides pleasing and healthy working conditions. Image: dbox for Cook+Fox Architects LLP

SOLAR POWER

The sun provides more energy to the earth in one hour than all the energy consumed by humans in a single year (Zweibel *et al.* 2008). In addition to the solar energy stored in fossil fuels and plants, solar energy can be harnessed via: 1. Direct daylighting and heating buildings; 2. Heating water; 3. Reflecting and concentrating sunlight with parabolic mirror arrays; and 4. Photovoltaic cells.

Almost 40 million Chinese homes derive hot water from rooftop solar-thermal heaters (Brown 2008).

SOLAR DESALINATION

Persistent drought in major agricultural regions, along with mounting demands on aquifers and surface water, threaten agriculture, hydropower and health in many areas (IPCC 2007b). Desalinated seawater in the Middle East (using oil for power) irrigates land and nourishes populations. Direct solar thermal evaporation and condensation – and PV- and wind-driven electricity – can provide communities and regions with freshwater (Morgan *et al.* 1998; Bourouni *et al.* 2001; Shannon *et al.* 2008).

Mimicking Photosynthesis

In living plants, incoming wave packets of light (photons) excite electrons to jump up ladder rungs (quantum levels), releasing energy as they fall back to intermediate steps. Chlorophyll contains other components that capture, transfer, convert and store the energy. In photovoltaic (PV) systems, photons excite electrons to become energetic electric charge carriers in external wires. Nanotechnologies – with components measuring billionths of a meter – increase the surface area of components, and have the potential to dramatically increase efficiency and reduce costs. (Their benefits and risks are discussed below.)

The need for freshwater may become a driver for rapid deployment of clean energy.

In Mexico, water impoundment in lakes is being studied as a means to ameliorate sea level rise. Solar desalination of sea water to irrigate parched lands could play a contributing role.

GROUND SOURCE HEAT PUMPS

Ground source heat pumps supply buildings with heat and air conditioning by tapping into solar (heat) energy stored in the ground. (Geothermal energy refers to heat from hot springs, geysers, volcanic hot spots and hot rocks deep inside the earth.) Ground source heat pumps benefit from near-constant underground temperatures of ~55°F down to 150-200 feet, exploiting the differential between that and above-ground temperatures. The pumps operate to heat and cool, performing the latter by efficiently drawing heat out of buildings. (This naturally-derived air conditioning can help cope with heat waves.) Depending on site characteristics, ground source heat pumps can be shallow, closed or open loops, or deep standing column wells. They can be installed almost everywhere.

Due to drilling and construction costs, ground source heat pumps have payback periods of ~seven years; after that, minimal electricity (e.g., from wind or solar) is needed to drive fluids through the underground loops.

90% of Icelandic homes are heated and cooled with ground source energy (Brown 2008).

HIGH CAP/LOW OP TECHNOLOGIES

Technologies with high up-front capital expenditures and minimal operating costs ("High Cap/Low Op") can be facilitated with creative financial instruments, whereby intermediate companies purchase them, amortize the costs and lease them to individuals and businesses.

WIND POWER

Wind energy – an alternative with competitive costs today – can be used for distributed power generation and for central power for grids. There is great potential for wind power on land and in coastal waters (Kempton *et al.* 2007). Use of just 12% of the land suitable for wind power in the U.S. could generate about 1 TW (Lewis 2004). Off-shore winds have a higher potential; but distance from shore (i.e., grids) matters, and the costs are twice those for on-shore wind farms.

Wind energy is plentiful on-land and off-shore. Wind turbines can produce power near the point of use and wind farms can produce significant portions of power for national grids. Image: Elena Elisseeva/Dreamstime.com

Globally, 1.5 million 2 MW turbines could produce 3 TW by 2020, one fifth of energy used worldwide today (Brown 2008).

Computer simulations at the Massachusetts Institute of Technology suggest that very large wind turbine farms could affect local weather conditions and general circulation patterns. Given this potential, the precautionary principle suggests distributing wind farms geographically.

CONCERN FOR BIRDS

Studies of modern turbines (with large, slow-moving blades) in the Netherlands demonstrate very low mortalities, with a higher risk of collision for local birds passing turbines (0.16%) than for migratory birds (0.01%) (Drewitt and Langston 2006). Most studies of bird collisions have found similarly low collision rates; but flight patterns can be altered, especially for water birds (Krijgsveld and Dirksen 2006).

Comparisons of bird mortalities from cell phone tower guide wires and buildings, and due to climate change itself, indicate that the losses from wind turbines are orders of magnitude lower than from these other factors.

The effect of wind turbines on birds is therefore projected to be small relative to the benefits of reducing fossil fuels; though siting with respect to avian flyways warrants on-going monitoring and research.

Avian Mortalities

U.S. bird deaths from current wind turbines	10,000-40,000/yr
U.S. bird deaths from communication towers	5-50 million/yr
Estimated bird deaths with 2,500,000 turbines worldwide	2.5-10 million/yr
Estimated bird deaths from household cats (77 million, U.S.)	100s of millions
Worldwide bird deaths from avian flu	200 million/yr

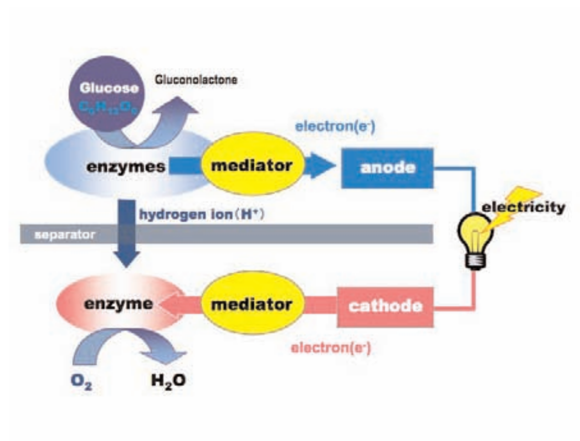
Sources: American Bird Conservancy April 2006; M. Z. Jacobsen, pers. comm. 2007; San Jose Mercury News April 2006; World Health Organization 2002

FUEL CELLS

Fuel cells, consisting of two electrodes separated by a membrane, were first developed in 1839. They generate electricity by stripping electrons from hydrogen molecules, which then flow spontaneously through external circuits. Because fuel cells produce electricity electrochemically – not by combustion – they are silent, clean and easily scalable (stackable). Fuel cells emit only hot water that can be used directly or for space heating – giving them twice the efficiency of fossil fuel generators. A 5-to-7 KW fuel cell prototype – the size of a refrigerator freezer – can power a 2,000 square foot home.

Green Chemistry in Action

Organically-derived materials can be used to manufacture solar cells, light-emitting diodes (LEDs), transistors and batteries. The diagram below depicts a small fuel cell (that functions as a battery), with hydrogen derived from sugar. Using photosynthetic-like processes and wind power to split H_2O and link the derived H_2 with fuel cells is a central challenge for providing and storing energy derived from intermittent power sources (Kanan and Nocera 2008).



A fuel cell battery using glucose, natural enzymes, mediators and electrodes, separated by a cellophane membrane. Image: Courtesy of Sony

The Cambridge Energy Alliance

The CEA is a five-year, $100 million energy efficiency project in Cambridge, MA. Its goals are to reduce peak demand by 50 MW, decrease fossil fuel use 5% and achieve major reductions in GHGs. The program entails:

- High penetration rates in business, government and residential sectors
- Changing lighting, HVAC (heating, ventilation and air conditioning), control systems, appliances and building practices
- Installing on-site generation with renewables and co-gen wherever possible
- Demand-side management (efficiencies) to reduce peak electricity use
- Assemble a $70 million revolving line of finance
  - $15 million in public funding
  - $5 million in private equity or subordinated debt financing
  - $50 million in private project financing debt
- High profile campaigns involving government, private sector and citizen leaders
- Project includes the City of Cambridge, the Chamber of Commerce, Harvard University, MIT, religious leaders and community partners

The CEA will help Cambridge, corporations and consumers stabilize energy costs, reduce pressure on the regional grid and create new jobs and economic development.
–Rob Pratt, Amy Panek, CEA 2008

Fuel cells, the most reliable of all generators, are being used in hospitals and international banking institutions.

But, separating hydrogen from water, methane, propane, ethanol or gasoline requires energy. Thus, using cleanly-derived electricity to split water (hydrolysis) is necessary for developing the non-fossil-fuel-based hydrogen economy.

HEALTHY CITIES PROGRAMS

Cities concentrate air pollutants, and locally-trapped ozone (and probably CO_2) enhance the urban heat island effect whereby inner cities heat up to 10°F above surrounding rural areas. Healthy cities with green buildings, rooftop gardens, walking paths, biking lanes, tree-lined streets, open space, congestion control and improved public transport can decrease vehicular miles traveled, promote exercise, save money and create jobs. "Smart growth" or mixed-use development combines commercial, service sector and residential housing to reduce commutes and promote community cohesion. Smart urban and peri-urban growth requires long-term, integrated planning.

TRANSPORTATION

Most discussions of GHG emissions reductions from the transport sector focus on changing fuel types and improving vehicular efficiency (CAFÉ or corporate averaged fuel efficiency) standards. But there are health-promoting and job-creating measures that decrease vehicle miles traveled (VMTs), and therefore demand for liquid fuels. They include:

1. Changing modes of travel (e.g., from cars to bikes, buses and trains)

Air Pollution and Climate Change: "Nasty Synergies" from Fossil Fuels

1. Increasing CO_2 boosts ragweed pollen production and pollen grain allergenicity
2. Fine diesel particles help deliver pollen grains deep into the lungs
3. Heat waves accelerate the formation of photochemical smog, another respiratory irritant
4. Climate change is extending spring and fall allergy seasons
5. Floods foster fungi (mold) and fires transiently affect air quality

Epstein and Mills 2005

Urban landscapes can be transformed into hubs with housing, commercial and employment opportunities in close proximity, to promote exercise and reduce travel. Images: Steve Price, Urban Advantage, http://www.urban-advantage.com/

2. Converting whole fleets of vehicles (e.g., from large to small plug-in hybrids)
3. Inter-city light-rails to reduce highway traffic and short-haul air transport
4. Smart growth to reduce transit and transport.

In the U.S., mass transit reduces road travel by approximately 100 billion VMTs yearly, or 3.4% of the 2007 VMTs. This could be greatly expanded.

Electric cars, developed in Belgium in 1899, dominated the market in the early 1900s. By 1920, however, cheap oil and the internal combustion engine displaced them. The Tesla Roadster is the primary electric vehicle available today, and plug-in hybrid and other electric vehicles will soon be available.

Shipping: CO_2 emissions from shipping, with 70,000 vessels carrying over 90% of world trade, are more than twice those from aviation. Marine transport releases 600-800 million tons of CO_2 per year, or ~5% of the global total. Neither shipping nor aviation is covered under the Kyoto Protocol.

To reduce GHG emissions from transport, plug-in hybrid electric cars, buses, trucks, trains and ships must plug into a clean grid.

POWERING GRIDS WITH CLEAN ENERGY

With the advent of plug-in hybrid electric vehicles (PHEVs), powering utility grids cleanly becomes the overriding challenge. Deep underground 'hot rock' geothermal energy is a relatively untapped resource, and, as solar and wind are intermittent sources, there is a great need for improved means of storing energy.

New storage methodologies include: 1. Hot water and molten salt "power towers" for concentrated solar power (CSP) arrays; 2. Compressed air for wind and solar; and 3. New generation batteries (discussed in supporting materials, online). Impoundments can provide storage and back-up hydropower.

Meanwhile, as two-thirds of energy from power plants is lost as heat, capturing the heat, boiling water and running turbines – combined heat and power or co-generation ('co-gen') – can dramatically increase efficiency at all scales of power generation.

Electric and plug-in hybrid vehicles are a key part of reducing our dependence on and combustion of liquid fuels. Image: Tesla Motors, Inc.

CONCENTRATED SOLAR POWER

Large arrays of parabolic mirrors can concentrate solar energy 70-fold, heating liquids that boil water to run turbines and generate electricity. The arrays can also be focused on "power towers" that store energy as hot fluids (e.g., molten salt) up to 12 hours. Three large arrays generate as much electricity as a nuclear plant, and can be constructed in two years, while a decade or more is needed to build nuclear plants. CSP arrays cost roughly half that of PV systems, though twice that of coal-fired plants. CSP projects are under construction or planned in Algeria, Canada, China, Egypt, Israel, Mexico, Morocco, the U.S. Southwest, South Africa and Spain.

Employing hybrids of multiple means of power generation is applicable for stationary and mobile systems. Complementary means of generating power can support reliable, robust grids and facilitate integrated resource-planning. An "ecosystem-based" approach to design avoids "monocultures" of technologies, while diverse measures can avert unintended consequences of over-using any one technology.

And while it is unrealistic to think all our energy needs can be met soon without some use of fossil fuels, natural gas is the cleanest burning and can serve to power back-up generators and for regional and central power plants. With adequate investments and international funds, nations such as China and India can transition rapidly from coal to natural gas, just as did Europe and – to some extent – the U.S. in the 20th century.

A "Solar Grand Plan" has been proposed by Zweibel and colleagues (2008) to cover two-thirds of the U.S. utility demands by 2050 with photovoltaic, solar thermal arrays and direct current transmission lines.

CSP arrays and PV farms in the U.S. Southwest, wind farms in the Great Plains and geothermal in the West could generate most of the nation's electricity by mid-century. CSP and PV in North African deserts, geothermal energy in Iceland and hydropower on the continent, connected by long-range transmission lines, could constitute a European "super grid."

SUSTAINABLE FORESTRY

The condition of the world's forests constitute some 20% of the greenhouse problem. Logging, land-clear-

THE SOLAR GRAND PLAN

This plan aims to meet 69% of U.S. electricity needs by 2050 with solar energy, accounting for a 1% increase in energy needs per year and a modest increase in thin-film PV efficiency (not including nanotechnology). The plan includes energy storage achieved with molten salt and compressed air. Its implementation would require rewiring the nation with direct current (DC) transmission lines. Direct current is unidirectional electricity produced by solar cells and batteries; alternating current (AC) varies cyclically in direction and magnitude.

In the U.S. Southwest, 250,000 square miles are suitable for solar development. This plan calls for 30,000 square miles for PV and 16,000 square miles for 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 after taking into account land needed for coal mining.

Implementation in Stages

I. 2011-2020: Subsidies to begin building the infrastructure
II. 2020-2050: Scale up to achieve the 69% goal
III. By 2100 renewable energy could generate 100% of grid power and over 90% of the nation's energy

Cost Estimates

$10 billion/yr or $400 billion spread over 40 years

Zweibel, Mason and Fthenakis Scientific American, Jan 2008

Forests cool the earth, maintain hydrological cycles, provide essential habitat, produce oxygen and absorb CO_2. We vastly underestimate the ratio of plant-to-animal biomass needed to sustain life on Earth. Image: António Nunes/Dreamstime.com

ing, droughts, forest pests, mounting demands for meat and declines in fisheries, are placing enormous pressures on tropical, temperate and boreal forests. The quest for biofuels is the latest threat to these essential biological resources. Every second, one acre of forest is felled, equaling 32 million acres (or 50,000 square miles) annually (FAO 2007). Forests, wetlands, soils and coral reefs constitute the primary stores of carbon on the surface of the earth.

Forest pests are a growing threat associated with global warming. From Arizona to Alaska, pine bark beetles have exacted a heavy toll on North American forests, by overwintering, moving up in altitude and latitude, and increasing their annual generations.

Bark beetle infestations in British Columbia, Canada, have turned vast pine forests into carbon sources rather than carbon sinks (Kurz 2008).

Approximately 2,300 square miles in Colorado have vast stands of dead trees, setting the stage for destructive wildfires. Pine bark beetle infestations contributed to California's lethal fires in 2006, 2007 and 2008.

An additional wedge of avoided CO_2e emissions can be derived by properly managing and skillfully nurturing the world's forests. Forest preservation, reforestation and afforestation (planting trees on previously un-forested land) contribute to climate adaptation, as forests absorb floodwaters and maintain regional hydrological cycles. Moreover, intact, diverse, healthy forests generate oxygen, draw down CO_2, and are essential habitat offering nourishment and protection. Protective policies for U.S. forests include: 1. Extending timber rotations; 2. Banning steep mountain-slope logging; and 3. Prohibiting new roads and off-road recreational vehicles.

Financial instruments to reward avoided deforestation and tree planting include "Debt-for-nature swaps" that offer payments to local foresters in lieu of debt-repayment to international banks (Lovejoy 1984), and well-monitored and verified carbon credits and carbon offsets. The United Nations Development Programme and World Bank initiative, *Reducing Emissions from Deforestation and Degradation* (or REDD), will require adequate funding.

By paying land-holders to preserve and plant trees, Costa Rica increased its forest cover from 20% in the early 1990s to 50% in 2007 (Arias 2007).

But climate stabilization is needed to protect and preserve healthy terrestrial habitat.

SUSTAINABLE AGRICULTURE

Soils store 1,100 to 1,600 GtC (FAO 2007) and, while carbon is added to soils annually, an equal or greater amount is lost from erosion, forest clearing and overgrazing (D. Pimentel, pers. comm. 2008).

Soils can be carbon sources or sinks, depending on how they are managed and nurtured. Crop residues, roots and litter store carbon; conservation tillage leaves them to minimize soil disruption, absorb floodwaters, maintain soil fertility, and reduce run-off and erosion. Conservation tillage (or no-till agriculture) can improve crop yields, preserve micro-nutrients, sustain plant and animal biodiversity, and mitigate climate

Image: Courtesy of Brian Lindley, No-Till on the Plains, Inc.

change by holding stored carbon.

Diverse fields of crops, interspersed with trees and shrubs, store more carbon than do large open fields and monocultures. High-diversity grasslands generate approximately two and a half times the energy yields as do monocultures, measured over a decade (Tilman *et al.* 2001). Poly-culture practices provide resilience to weather-related damage and crop pests (Zhu *et al.* 2000; Mitchell *et al.* 2002), and organic agriculture eliminates pesticides and minimizes fertilizers (both fossil fuel-derived), while locally-grown food decreases the "food miles" that generate greenhouse gas emissions. With targeted policies and incentives to enable investments in land conservation and low-carbon agricultural practices, these measures, along with no-till agriculture, can provide an additional wedge of avoided carbon emissions.

LESS INTENSIVE LIVESTOCK REARING

Energy inputs and GHG emissions from animal agriculture stem from: 1. Animal-rearing; 2. Growing feed; 3. Fertilizers, pesticides and herbicide production; 4. Animal waste, including methane; 5. On-the-farm fuel use; 6. Processing and packaging; and 7. Off-the-farm transport of meat and dairy products. Together these steps account for almost 20% of GHG emissions worldwide. (Material adapted from Koneswaran and Nierenberg 2008, unless otherwise indicated.)

The bulk of the loss stems from land-clearing. Of the 2.7 $GtCO_2$ emitted by livestock rearing, 2.4 $GtCO_2$ (or 1 GtC) is released from deforestation to create grazing pasture and fields to grow grain for feed. Eight-to-ten pounds of grain (and thousands of liters of water) are needed to produce one pound of beef. For hogs and chickens, the ratios for grain-to-meat are two-to-three to one, respectively.

Concentrated animal feeding operations, or CAFOs, release CO_2 and methane into the air and nitrates into ground water (Townsend *et al.* 2003). Nitrates have health ("blue baby syndrome") and environmental consequences (eutrophication, "red tides" and "dead zones"). The air pollutants from CAFOs have been shown to increase asthma rates in children attending schools nearby (Mirabelli *et al.* 2006; Sigurdarson and Kline 2006), and intensive, industrialized farming requires high levels of antibiotics to prevent disease and promote growth, practices that encourage the emergence of antibiotic-resistant bacteria (Pew 2008).

Image: Tadija Savic/Dreamstime.com

Industrial livestock production has grown twice as fast as have mixed farms, and six times the rate of grazing systems. Globally, industrial systems account for an estimated two-thirds of poultry meat production, one-half of egg production, and two-fifths of pork production.

Healthy practices include: 1. Free-range and pasture-based production; 2. Local production; 3. Improved waste management; 4. Methane capture and use; and 5. Changes in consumption patterns. U.S. residents consume 200 lbs of meat (including fish) annually and Chinese counterparts now consume 110 lbs per person per year. Reducing red meat consumption is recommended to save energy, water and land, and reduce obesity, heart disease and some types of cancer.

IMPROVED MUNICIPAL SOLID WASTE MANAGEMENT

Municipal sold waste (MSW) management is currently highly inefficient (as is municipal water management). In 2000, annual emissions from MSW were estimated to be 0.47 GtC/yr, and they are projected to double (0.99 GtC/yr) by 2054 (EPA 2002, 2005; Covanta and Trinity 2007). Increased use of recycling, energy recovery and energy generation (via landfill gas collection) have the potential to reduce GHG emissions more than 1 GtC/yr, thus comprising an additional stabilization wedge.

Low Tech/High Opportunity Measures

Innovative low tech solutions can be implemented in a variety of settings. They include:

Bicycles

Bicycle-driven systems augmenting solar- and wind-powered systems

Stairmaster- and bicycle-driven generators in health clubs and homes

Stairmaster-like kick- and hand-pumps for irrigation and small enterprises (http://www.kickstart.org/home/index.html)

Knee-mounted generators that turn "walks into watts" (Donelan *et al.* 2008)

Powering vehicles with vegetablle oil (http://www.trishdalton.com/greasecar/grease-car.htm)

Solar-powered desalination and water decontamination (http://www.aaws.nl/home.htm#)

WaterPyramids are structures, placed over salty and/or contaminated bodies of water, which heat up in the sun. The water evaporates and condenses into water pure enough to be used for IV solutions; so pure, that minerals must be added for use in irrigation to ensure nutrient-rich crops. Image: Martijn Nitzsche, Aqua- Aero WaterSystems BV, Sibanor, The Gambia

Technologies Warranting Further Study

TECHNOLOGIES WARRANTING FURTHER STUDY

This section addresses fossil-based fuels, biomass, nanoscience, geoengineering, nuclear fission, and wave, tidal and ocean current energy. The health and environmental concerns raised are intended as guides to developing a research agenda involving the public health community, scientists and engineers.

LIQUID FUELS FOR TRANSPORT

Liquid fuels are needed for vehicles and the U.S. uses one quarter of the world's oil: 22 million barrels per day or approximately **10,000 gallons a second**. Half is imported. Over the past decade, the price per barrel has risen over ten-fold, as it did in the 1970s, and U.S. expenses for imported oil have risen from $45 billion in 1998 to over $400 billion in 2007 (EIA 2007). As a result of the price hikes, many nations are experiencing extreme hardship, much as they did in the 1970s, and food and fuel have become security issues (Hoyos and Blas 2008).

While the benefits of the energy from fossil fuels are self-evident, oil, coal and natural gas affect human and ecosystem health, have widened social inequities and fostered international conflict. The life cycle costs include the damages from exploration, extraction, mining, refining and transport; spills and leaks disrupt forest and coastal marine habitat, and combustion causes acid rain, air pollution and climate change.

SHALE OIL AND OIL SANDS

Extracting liquid fuel from oil ("tar") sands and shale to extend supplies of liquid fuels past "peak oil" (King and Fritsch 2008) consumes enormous quantities of energy and water. Exploitation of the Athabasca Oil Sands fields in Alberta, Canada impacts the surrounding environment and regional water supplies that are already under pressure. The Colorado Plateau, holding the largest deposits of shale oil in the world, is already a water-poor region and is projected to become more so.

Shale oil does not contain oil. Instead, kerogen must be mined, transported and heated to 450^{0}C (850^{0}F), and hydrogen added to liquefy the output (Youngquist 1998). For each barrel of oil derived, 2-to-4.5 barrels of heavily-contaminated wastewater is discharged, releasing toxins and heavy metals into soils, and surface and ground water (Griffiths *et al.* 2006). This process emits three times as much CO_2 as does the processing of conventional petroleum (Woynillowicz *et al.* 2005).

BIOFUELS

Biomass (e.g., dung, wood, crop residues) is used directly for cooking in developing nations. Meeting this essential energy need creates indoor air pollution and particulate levels that often reach 20 times the U.S. standards (WHO 2002). This is a major cause of respiratory disease and early mortality in women and children in developing countries.

For most of the biofuels under mass production, energy gains are questionable. With CO_2 uptake by plants equal to the CO_2 emitted during their combustion, the energy, water and material inputs outweigh the energy derived. When one considers land-use changes involved, the energy balance for first generation biofuels becomes overwhelmingly negative.

The **energy balance** includes that used in: 1. Growing crops; 2. Manufacturing (and dispensing) fertilizers, pesticides and herbicides (derived from oil and natural gas); 3. Running farm machinery; 4. Irrigating land; 5. Grinding and transporting crops; 6. Fermentation and distillation; 7. Processing; 8. Packaging, 9. Transport; and 10. Marketing (Pimentel and Patzek 2005). Corn, in particular, requires large amounts of fertilizers and pesticides. The amounts of fossil fuel inputs *exceeding* the energy derived are the following:

Soybean-to-biodiesel requires 27% more fossil energy input than is gained.

Corn-to-ethanol: 29%.

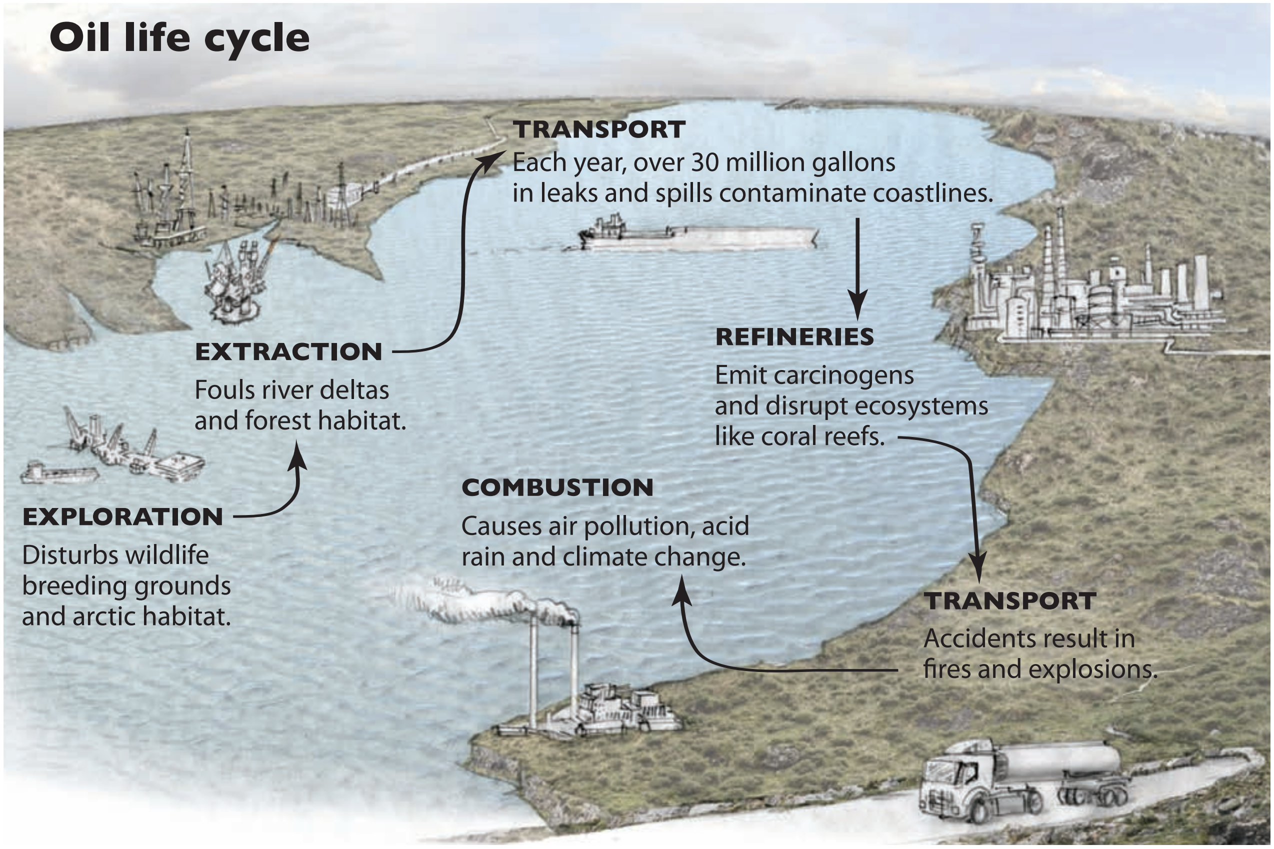
Switchgrass: 45%.

Woody biomass: 57%.

Sunflower: 118%.

Pimentel and Patzek 2005

"… if 100% of U.S. corn were used [for bioethanol]," explains Cornell scientist David Pimentel, "it would replace only 7% of total U.S. petroleum use."



This diagram illustrates the multiple impacts of our dependence on oil, save for the social disparities and international conflicts to which it contributes. See http://chge.med.harvard.edu/publications/documents/oilfullreport.pdf. Graphic: David M. Butler, The Boston Globe

When the conversion of forests, peatlands, savannas and grasslands to "biofuel farms" is included, corn-to-ethanol emits nearly twice the levels of GHGs as gasoline; cellulosic ethanol derived from switchgrasses increases net emissions by 50%.

Globally, deriving a wedge from [first generation] biofuels would mean devoting one sixth of cropland to crops for ethanol (Pacala and Socolow 2004).

BIODIESEL

The yields from palm plantations are eight times greater than those from soybean; but palm trees take eight years to mature. In 2006, 85% of palm oil came from Indonesia and Malaysia, and, in 2005, Malaysia produced almost 16 million long tons [1 long ton = 2240 pounds] of crude palm oil, earning $14.1 billion in export revenues (Unmacht 2006).

But fires to clear land for palm plantations are removing rainforests and peat wetlands, destroying primate habitat, and releasing large stores of carbon and heat-trapping black soot (Ramanathan and Carmichael 2008). These emissions have catapulted Indonesia into third place, after China and the U.S., on the list of global greenhouse gas emitters.

In the U.S., soybean biodiesel refineries are fouling rivers with oily by-products containing glycerin and methanol. In 2008, the discharge from one Mississippi plant killed 25,000 fish and eliminated the population of an endangered species of mussels (Goodman 2008).

LAND USE CHANGES

In Brazil, sugar plantations have begun to push soybean plantations deeper into the Amazon. In the U.S. in 2007, increased corn acreage led to a 19% drop in soybean acreage, boosting prices for this food and feed staple (Bradsher 2008). Higher crop prices, in turn, increase forest- and grassland-clearing to grow the food and feed.

The pressures on land stem from: 1. The rising costs of fuel; 2. Persistent drought in food-growing regions; 3. Industrial zones displacing (and contaminating) cropland; 4. The growing demand for meat; 5. Depletion of soils and water; and 6. Dwindling fisheries. The quest for biofuels unleashed the current wave of escalating costs.

SOCIAL FERMENT

In January 2007, subsidized U.S. corn-for-ethanol sent residents of Mexico City, heavy consumers of corn tortillas, into the streets. According to the U.N. Food and Agricultural Organization and the World Bank, 36 nations are experiencing food insecurity. In the past year and a half food riots have occurred in Egypt, Haiti, Indonesia, Guinea, Mauritania, Mexico, Morocco, Pakistan, Senegal, Uzbekistan and Yemen, while Asian countries have erected quotas or bans on exports and instituted price controls (Bradsher 2008).

ALTERNATIVE AND SECOND GENERATION BIOFUELS

Using **switchgrass** to produce "cellulosic" ethanol (with enzymes produced by microbes to break down cell walls) is proposed as an alternative to using those displacing food crops. Some argue that 40 million acres of abandoned farmland and 20-30 million acres of idle lands, roadway edges and powerline rights-of-way could be restored to forest or high-diversity prairie, which could provide relatively low carbon biofuel; leaving lakes, rivers, ground water and wildlife habitat cleaner and healthier (D. Tilman, pers. comm. 2008).

On the other hand, only a small percentage of U.S. prairie grasslands remain intact and are still diverse: an acre often contains about 100 different species of native grasses, legumes, and other flowering perennials. Monocrops of switchgrass would diminish biodiversity (altering soils and increasing vulnerability to pests and blights), and harvesting would compete with other uses of the grasses, including the grazing (and overgrazing) of 100 million head of cattle, 7 million sheep and 4 million horses.

Introducing genetically modified grasses to facilitate the breakdown of cellulose and lignin into ethanol adds more layers of ecological uncertainty (Wolfenberger and Phifer 2000), for genetically modified organisms are neither permanently stable nor containable.

Farm waste, landfill methane, landfill garbage gasification, cooking grease and wood pellets do not displace food, feed or fiber crops.

ALGAE AND WEEDS

Algae grown in waste water ponds draws down atmospheric CO_2 (or that emitted from a power plant) and can be converted to biodiesel; and with the residues refined into ethanol. The biomass yields are on the order of 100 times those for a field of crops. Some companies have surpassed the 15,000 gallon per acre accepted benchmark, and one company claims to produce 180,000 gallons of biodiesel a year from each acre of algae, equaling 4,000 barrels at $25 per barrel or $.59 per gallon. The next leading feedstock – palm oil – yeilds 635 gallons per acre per year (Siegel 2008).

Invasive weeds, such as kudzu and jatropha (a roadside African weed that is highly toxic to humans and livestock), can generate biofuels and have obvious co-benefits; though there is concern for further inadvertent spread. The U.S. Food and Drug Administration is studying the use of kudzu to generate ethanol (L. Ziska, pers. comm. 2008).

HEALTH AND ENVIRONMENTAL CONCERNS

But burning all organic matter produces CO_2. In addition, burning ethanol and methanol emits fine particles and volatile organic compounds, including acetaldehyde and formaldehyde, precursors of ground-level ozone or photochemical smog.

Additionally, burning alcohol/gasoline mixtures releases aromatics, including polycyclic aromatic hydrocarbons (PAHs). Combustion of biodiesel also emits aromatics, and more NOxs and particulates than does the burning of gasoline.

Ozone, that increases during heat waves, damages lung tissue, can trigger and initiate cases of childhood asthma, and is a local heat-trapping gas, which enhances the urban heat island effect. The production of VOCs, particulates, oxides of nitrogen, and aromatics from ethanol/gasoline mixtures and biodiesels must be adequately assessed by public health researchers.

Another concern is the health impacts of intensified farming. The consequences of monocultures include:

1. Nitrogen-containing fertilizer run-off, associated with harmful algal blooms and "dead zones" (at its peak, the Gulf of Mexico dead zone spans over 8,000 square miles, about the size of the state of New Jersey (Roach 2005)); 2. Nitrogen-contamination of groundwater (Townsend *et al.* 2003); 3. Depletion of groundwater (especially from sugar plantations); 4. Decreased soil fertility and nutritional quality of produce; and 5. Displacement of food crops and subsequent deforestation.

An additional concern is the health of agricultural systems associated with a changing climate.

Climate Change and Crop Security

Worldwide, some 42% of growing and stored crops (worth approximately $300 billion) are lost annually due to pests, pathogens and weeds (Rosenzweig *et al.* 2001).

Warmer winters, more extreme weather events, and changes in the timing and intensity of precipitation will affect yields.

Warming and extremes are conducive to pest and pathogen invasions: warming allows the overwintering of insect pests and expands their potential range, while floods foster fungi (the primary affliction of crops), and droughts encourage aphids, whiteflies and locust.

Rodent populations can 'explode' when heavy rains, following droughts, drive them from their burrows and provide them with fresh food sources.

CO_2 stimulates the growth of agricultural weeds.

Changes in carbon to nitrogen (C:N) ratios encourage leaf-eating pests to consume more biomass to obtain the nitrogen they need to grow.

Increased pests, pathogens and weeds, in turn, will require greater use of insecticides, fungicides and herbicides, the residues of which can be carcinogenic, neurotoxic, and harmful to reproductive health.

Warming and more weather extremes, plus more pests, pathogens and weeds, can have "non-linear" effects on agricultural yields (i.e., widespread loss).

There are implications for biofuel and food security, thus human health and political stability.

Expropriating biological productivity on the earth's surface to derive power may be no more sustainable than extracting and burning fossil fuels.

COAL WITH CO_2 CAPTURE AND STORAGE

Coal accounts for 25% of global energy consumption, but generates 39% of the CO_2 emissions. Coal burning produces one and a half times the CO_2 emissions as does oil and twice that from burning natural gas (for an equal amount of energy produced). Coal consumption has grown 30% since 2002, twice as fast as any other energy source. Two-thirds of this is "steam coal," used to produce electricity; one-third is "coking coal," used primarily for making steel and concrete. Converting coal-to-liquid produces high levels of CO_2 emissions (Krauss 2008).

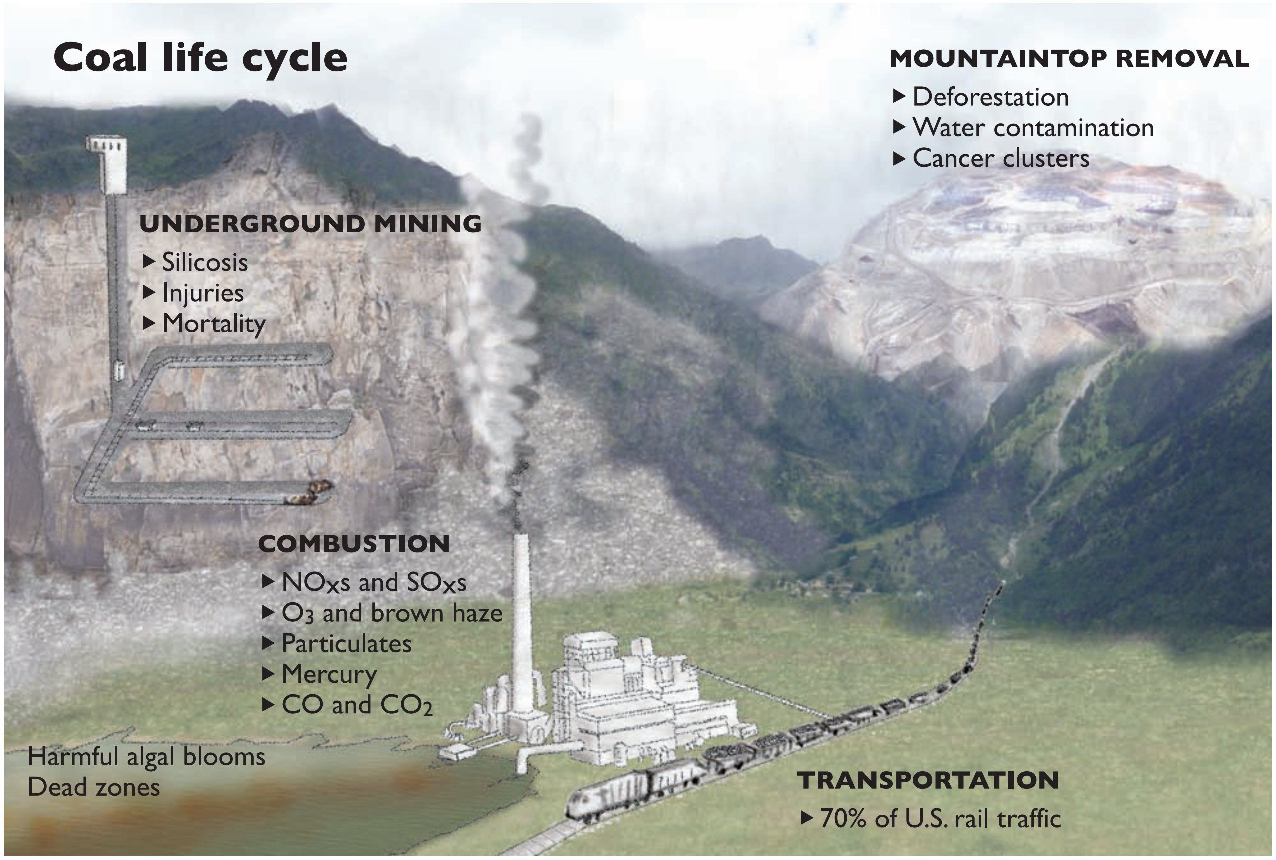
The total recoverable reserves of coal worldwide are estimated at approximately 1 trillion short tons [1 short ton = 2,000 lbs] (EIA 2007). Two-thirds of this is found in four countries: U.S. 27%; Russia 17%; China 13% and India 10%. With 268 billion tons underground, the coal industry estimates the U.S. has enough to last 200 years (at current consumption levels). Coal is mined in 27 states in the U.S. and coal-fired plants provide just over 50% of the electricity.

China, however, is the chief consumer of coal, burning more than the U.S., the European Union and Japan combined.

With worldwide demand and oil insecurity growing, the price of coal doubled (from March 2007 to March 2008): from $41 to $85 per ton (Krauss 2008). By 2050, the coal industry projects that U.S. demands will double from the current 1.13 billion short tons (2005). Land and transport would be further stressed: the bulk of new mining would come from mountain-top removal and, today, 70% of U.S. rail traffic is devoted to the transport of coal.

HEALTH AND ENVIRONMENTAL CONCERNS

Burning coal with CO_2 capture and storage (CCS) in terrestrial sites, and in the ocean or in deep ocean sediments (House *et al.* 2006), are proposed methods of deriving "clean coal." But significant obstacles lie in the way, including the energy penalty of 40% (i.e., the



This graphic illustrates the life cycle costs of coal, including the health and ecological consequences of mining and combustion. NO_xs from burning coal are a major contributor to eutrophication, 'HABs' and dead zones. Graphic: David M. Butler, The Boston Globe

additional energy required beyond that needed for traditional coal-fired plants). The life cycle costs include: 1. The impacts of mining accidents, chronic illness, death and disability; 2. Mercury, NO_xs and particulate emissions; 3. Mountain-top removal; and 4. The effects of storing large amounts of CO_2.

Coal-burning releases particulates, nitrates, sulfates and, in the U.S. alone, approximately 48 tons of the neurotoxin mercury each year (EPA 2004). Fine particle pollution from U.S. power plants, principally coal plants, cuts short the lives of nearly 24,000 people each year, including 2,800 from lung cancer. It is responsible for 38,200 non-fatal heart attacks and tens of thousands of emergency room visits, hospitalizations, and lost work days (ABT 2004). Pollution from coal-fired plants in the U.S. Northeast is linked to over 43,000 asthma attacks, 300,000 episodes of upper respiratory illness, and 100 premature deaths annually (Levy and Spengler 2000; HEI 2007). The risk of death for people living within 30 miles of coal-fired plants is three-to-four times that of people living at a distance.

Additional energy penalties would accrue from filtering and storing all these pollutants.

Coal Life Cycle Hazards

Underground mining

In the 1990s over 15,000 former U.S. miners died from coal workers' pneumoconiosis (black lung disease) (NIOSH 2008)

Accidents and fatalities: 3,800 - 6,000 deaths annually in China (Yardley 2008)

Strip mining/mountain top removal

Less expensive than underground mining; one plant can produce 200 tons of coal/day

The impacts include:
Stream-bed silting

Water contamination with carcinogens and heavy metals associated with cancer clusters

Coal waste disposal and slurry impoundments

Degraded valleys

The safety (and insurability) of storing the billion tons of CO_2 generated each year into the foreseeable future, is unknown; though storing CO_2 in liquid and solid forms may reduce the hazards. But all local experiments must be assessed cautiously, for scaling up CCS to the volumes needed to generate a wedge could have unforeseen consequences.

On August 12, 1986, at 9:30 PM, a cloudy mist of naturally occurring CO_2 rose suddenly from Lake Nyos, Cameroon, sweeping into adjacent valleys, killing1,700 people, thousands of cattle, and birds and wild animals (Kling *et al.* 2005).

CHANGING PRIORITIES AND SHIFTING ASSETS

In February, 2008 the U.S. Department of Energy withdrew from the FutureGen CCS project in Matoon, Ill., involving an alliance of over a dozen fossil fuel companies, due to escalating cost projections. With European plans for coal and CCS also on hold, Norway's pilot to bury CO_2 from natural gas exploration is the lone large-scale experiment.

CO_2 Capture and Storage

A Special IPCC Report on Carbon Dioxide Capture and Storage (Metz *et al.* 2005) lists the following concerns for CCS in underground terrestrial sites:

Storing CO_2 underground can acidify saline aquifers and can leach heavy metals, such as arsenic and lead, into ground water.

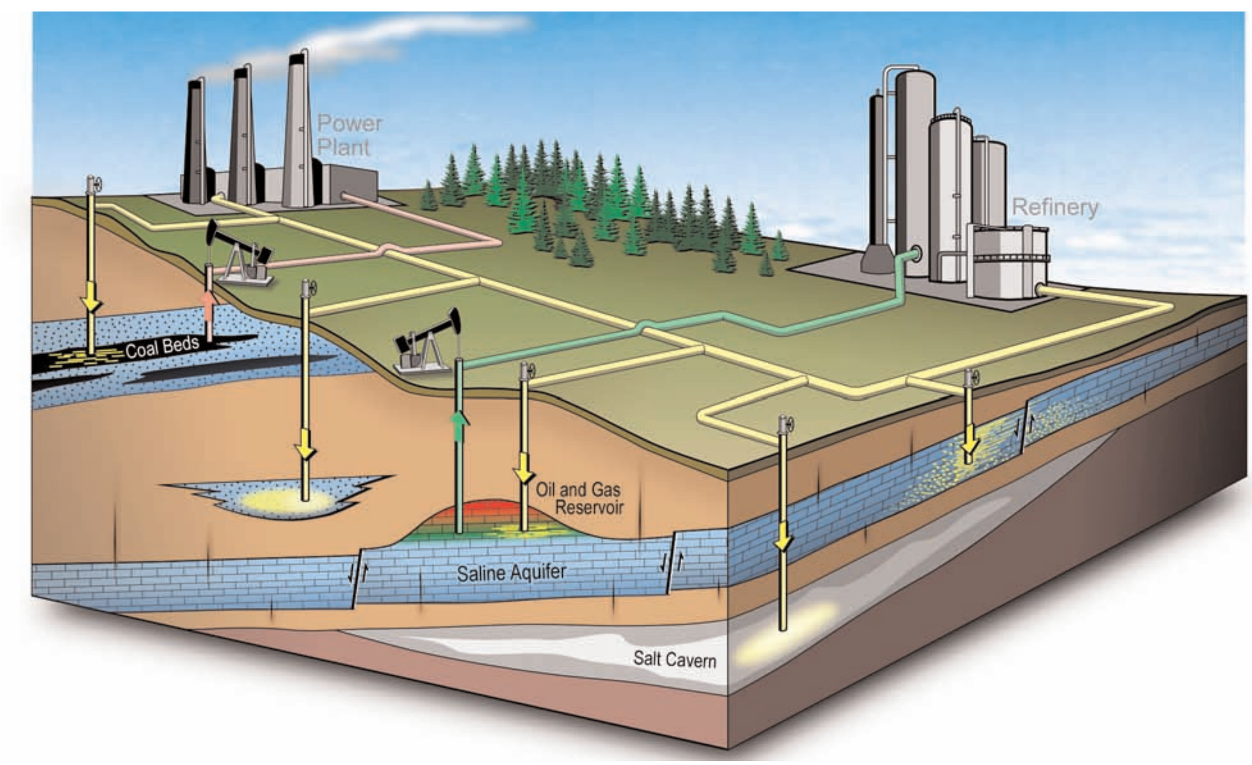
Increased pressures may cause leaks and releases from previously drilled (often unmapped) pathways.

Large amounts of concentrated CO_2 are toxic to plants and animals.The 2006 Mammoth Mountain, California release left dead stands of trees (KNBC 2006).

Microbial communities may be altered, with release of other gases.

AND

Acidification increases fluid-rock interactions that enhance calcite dissolution and solubility, and can lead to fractures in limestone ($CaCO_3$) and subsequent releases of CO_2 in high concentrations (Renard *et al.* 2005).



This illustration depicts several proposed storage sites for CO_2. Coal beds, oil fields and saline aquifers are the primary candidates. Image: Alberta Geological Society

In the U.S., several state governors and environmental groups led major banks (JPMorgan Chase, Citigroup, Morgan Stanly and Bank of America, followers of the Carbon Principles) to reassess risks and withdraw project financing for coal-fired utility plants in favor of gas-fired plants; siting health, environmental and economic concerns (Ball 2008). In 2007, over 50 proposed coal-fired plants were delayed or canceled due to concerns over GHG emissions (Krauss 2008).

GEOENGINEERING CLIMATE STABILITY

Iron released into the sea stimulates algae to proliferate and (via photosynthesis) draw down CO_2. Priming this "ocean biological pump" with iron filings is proposed as a means to: 1. Earn carbon credits; and 2. Help stabilize the climate.

Experiments to-date, however, measure CO_2 that drops below the upper layers of the ocean (the photic zone down to 600 feet in the open ocean). Whether long-term storage can be achieved is unknown, and the risks of these experiments include 1. Greater ocean acidification; 2. More harmful algal blooms; and 3. Chemical reduction of some gases to strong heat-trapping gases, such as methane and nitrous oxide.

CO_2 uptake has already dropped ocean pH 30% below pre-industrial levels (Caldeira and Wickett 2003; Orr *et al.* 2005; Lovejoy 2008), threatening shell fish (thus food webs) and coral reefs, via calcium depletion. This "osteoporosis" retards growth of organisms and may reduce the capacity of coral to rebound from warming-induced bleaching.

Other proposed geoengineering methods include: 1. Sending mirrors into space; 2. Seeding clouds; and 3. Repeatedly injecting massive amounts of sulfur into the stratosphere to reflect incoming sunlight.

Sulfates, however, remain in the atmosphere for days, while the residence time for CO_2 is approximately100 years. This measure could also delay recovery of the Antarctic ozone hole 30 to 70 years (Tilmes *et al.* 2008).

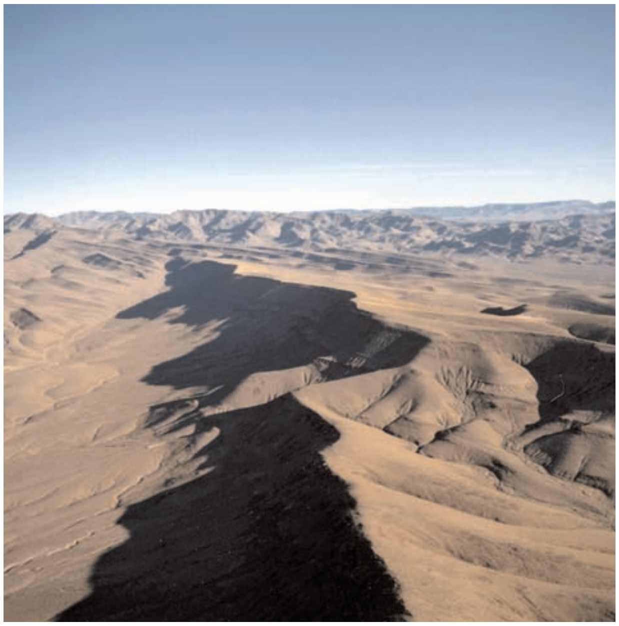
NUCLEAR FISSION

Nuclear fission is a non carbon-based method for generating power. The highest concentrations of nuclear power plants (each on the order of 0.5 to 1 GW) are in the U.S., Europe and Japan. Deriving a wedge from nuclear energy would require adding 700 GW of nuclear power or about twice that currently deployed (Pacala and Socolow 2004).

Meanwhile, mining, transport, milling, construction of facilities and disposal of fissile material all require large inputs of energy that are presently carbon-based. Additionally, there are significant health, safety, storage and security concerns, as well as the issues of costs and timing.

HEALTH CONCERNS

Uranium oxide is yellow; thus the life cycle, from mining to use and disposal, is known as the "Yellow Cake Road." Well-documented health hazards are associated with all stages. Uranium miners experience increased lung cancer rates from radon exposure; nuclear fuel processors have increased death rates from leukemia; workers in nuclear power facilities and nuclear weapons facilities have increased mortality from all cancers (lung, multiple myeloma, and others); and communities adjacent to nuclear facilities in the U.S. and U.K. have increased rates of leukemia and other childhood cancers (Cragle *et al.* 1988; Morris and Knorr 1996; Beral *et al.* 1993; Pobel and Viel 1997; Cardis *et al.* 2007).



Yucca Mt., southern Nevada, 100 miles NW of Las Vegas. The USGS has identified ten seismic faults within a 20 mile radius around the site. Image: Department of Energy, U.S. Government

SAFETY

Advanced "pebble" technologies eliminate the risk of runaway fission reactions. But hazards remain. The 6.8 magnitude earthquake striking the Kashiwazaki, Japan nuclear plant, the largest in the world, in July 2007, released radiation into the sea (NIRS 2007). The public can also be exposed via accidents during transport of radioactive materials. Climate change poses additional risks from heat waves (cooling water) and accelerated sea level rise for nuclear plants near the coast, including all 13 in the U.K.

Storms and weather volatility present additional threats to overly centralized power systems.

STORAGE

A nuclear reactor generates about 20 tons of radioactive waste annually (Wald 2008a). In the U.S., the waste is in temporary storage at 122 sites in 39 states. If a long-term repository is opened, it would take decades to clear the backlog.

Securing safe, long-term storage presents the greatest hurdle. By 2017, the date projected for opening the Yucca Mountain, Nevada site, U.S. taxpayers will have spent tens of billions of dollars (estimates run to $54 billion) to study, prepare and operate the site (Loux 1998). The 1982 National Waste Policy Act, as amended in 1987, limits the quantity of spent fuel that can be placed in the first repository to 70,000 metric tonnes [1 tonne = 2,200 pounds] of heavy metal … "until such time as a second repository is in operation" (Peterson 2003). The U.S. Geological Survey (USGS) reports 10 known faults within a 20-mile radius of Yucca Mountain. Solitario Canyon, west of the planned site, could generate a 6.5 magnitude earthquake.

On May 21, 2007 the USGS reported finding a previously undetected fault running through Yucca Mountain (AP 2007).

Meeting a wedge with nuclear energy would generate a volume of radioactive waste that would fill one "Yucca Mountain" every 5-10 years until mid-century (Keystone 2007). The larger number is based on the Congressional Bill proposing to double the amount of stored material allowed. Neither number includes burying decommissioned plants.

Regulatory criteria for Yucca Mountain require, among other things, that the groundwater below the Armagosa Valley near Yucca Mountain be protected

Relative Costs for Construction of Power Plants (500 MW to 1 GW)

Nuclear: $6-$12 billion

Coal-fired plant: ~$2 billion

Gas-fired plant: ~$1.6 billion (requires less steel, concrete and labor than coal-fired plants.)

Windfarm: ~$1.8 billion off-shore; < $1billion on-land

Note: Nuclear fusion, the process found in stars (combining, not splitting, atomic elements), has not been demonstrated to work at room temperatures or to be controllable. It is, as yet, entirely experimental.

Cost Overruns are Common in the Nuclear Industry

The estimated cost of the U.S. Department of Energy's Supercolliding Super Conductor project in Texas rose from $5.9 billion (late 1980s) to $11 billion (when it was canceled in 1993).

The Fuels and Materials Examination Facility at the Hanford site, Washington ran 39% over budget.

The waste vitrification plant (temporarily encasing waste in glass) at the U.S. Department of Energy's Savannah River site, South Carolina, was 62% over budget and 6.5 years behind schedule.

Loux 1998

for at least 10,000 years (Peterson 2003). Ensuring the safe storage of radioactive waste for tens-to-hundreds of thousands of years remains a serious obstacle to expanding nuclear energy.

SECURITY

With international tensions high, and likely to remain so as climate change exacerbates conflicts over resources, security is a significant problem for nuclear power plants as well as for transported and temporarily-stored radioactive materials. The risks include attacks, and "loose nukes" and "dirty bombs" from stolen fissile material. "Peak uranium" presents additional concerns, for reprocessed spent radioactive material is more liable to abuse than is uranium.

The security issues above are, for the most part, not amenable to international treaties, and may become decisive factors in assessing the risks of expanding nuclear fission.

COSTS AND TIMING

Costs and timing are also significant issues, given the urgency of displacing carbon-based power generators. Nuclear power plants take 8-12 years to construct, and the projected costs of constructing a new generation nuclear power plant recently rose from $6 billion to $12 billion (Smith 2008). Considerable time and subsidies would be needed to derive a stabilization wedge from nuclear fission.

NANOSCIENCE

Nanotechnologies, with components measuring billionths of a meter (100,000 times thinner than a human hair), can, by increasing active surface areas, dramatically increase efficiencies and reduce costs (Carts-Powell 2006; Lenatti 2006). One solar technology based on nanocomponents (plastic polymers) promises a 75% reduction in costs; but little is known of its performance, durability and safety.

Composition matters: The emerging discipline of distilling or engineering useful technologies from naturally-occurring materials and organisms holds great promise. Self-assembling peptides have been shown to promote tissue healing, while nanovesicles for drug encapsulation aid drug-delivery and nanofibers can act as scaffolds for growing new tissues (Lee *et al.* 2005).

The "spinach chip": An MIT team has demonstrated a plant photosynthetic energy-harvesting molecular machine that directly converts photons into electricity (Zhang *et al.* 2004).

Memristor: This spring, Strukov *et al.* (2008) reported finding the predicted fourth type of circuitry: memristor, a contraction of 'memory resistor'. Memristor microchips, unlike capacitors, resistors and inductors, can communicate in terms intermediate between ON and OFF (or 0s and 1s). These nanocells hold the promise of extending for years 'Moore's Law,' whereby computer capacity doubles every 18 months.

HEALTH AND SAFETY CONCERNS

Nanocrystallites, quantum dots and nanotubes can be carbon-coated to reduce the risks of particle release during use. And many products have been used for decades that are technically nanotechnologies. But the use of these new materials must be tempered by careful evaluation of health and safety concerns, due to their small size and ability to interact with biological and other materials.

Size matters: Nanomaterials 20 microns (millionths of a meter; composed of many nanoparticles) are similar in size to asbestos fibers, and, as indicated in a study in mice (Poland *et al.* 2008), could lead to tissue and genetic damage via skin and respiratory inhalation. The same study showed that smaller particles, 5 microns, do not initiate inflammation.

The insurance industry is concerned with risks that include: 1. Spills in production facilities; 2. Chronic illnesses in workers; 3. Product recalls and liability from discovery of untoward effects; and 4. Potential release from disposed products (EPA 2006; Weisner 2006; Dunphy *et al.* 2006; Lloyds 2007).

Private investment in nanotech reached $11.8 billion in 2006. But, of the $1 billion in the U.S. National Nanotechnology Initiative, only 0.6% ($6 million) is allocated to studying the health and environmental risks.

WAVE, CURRENT AND TIDAL ENERGY

Wave, current and tidal energy are relatively new technologies. While wave and tidal power are unlikely to meet more than local needs, ocean currents offer enormous potential. Estimates for the Gulf Stream off the U.S. Southeast are 30-50 GW of zero-carbon base-load power (W. Kempton, pers. comm. 2008). It will be crucial to choose appropriate areas to pilot these technologies and to monitor physical properties, fisheries, reptile and marine mammal migration, and shipping safety.

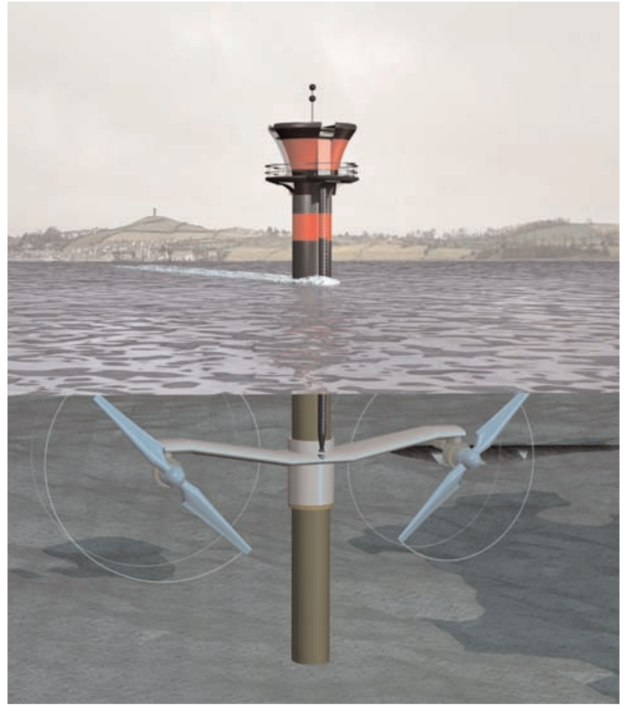
Private Initiatives, Public Policies

Sound public policies are necessary to enable large shifts of private sector funds into clean tech/green energy. But some financial instruments can be employed today, even in the absence of clear market signals. Most of the "low hanging fruit" are cost-saving (McKinsey 2007b).

Creative financial instruments are needed to turn High Cap/Low Op options into "no-regrets" solutions that generate profitable enterprises. Intermediary financial units and firms can purchase technologies with high capital expenditures ("Cap Ex"), and lease them to individuals and businesses; the costs amortized over the pay-back periods (e.g., approximately 7 years for ground source heat pumps).

Financial institutions such as banks, other institutional investors, brokerage houses, rating agencies and regulators can help shift investments into promising sources of *real* (not transient, *paper*) wealth. This process has begun. In 2007, investments in clean technologies reached $117 billion, up 35% from 2006 (NEF 2008). Such "socially-responsible investing" must be complemented by tailoring lending guidelines to influence industrial practices. Some banks have begun to do both.

The insurance sector, which shares with public health the "precautionary principle" for reducing risks (within manageable bounds), can play a pivotal role through such measures as: 1. Reducing premiums for builders of (safe) green buildings and drivers of hybrids; 2. Rewarding directors and officers whose firms adequately address climate change; 3. Promoting new building and zoning codes; and 4. Advocating for wetland and barrier island protection.



A twin rotor tidal stream assembly (each with a diameter of 50 meters), in Strangford Narrows, Northern Ireland, will supply 1.2 MW of power. More powerful turbines are proposed for ocean floor placement to harness current energy. Image: Courtesy of Marine Current Turbines Limited

All firms can promote sound public policies.

The public sector must provide the guidelines, financial incentives and infrastructure for the clean energy transformation. Setting a price for carbon to aid long-term planning can be accomplished with: 1. A cap-and-trade system; 2. A downstream carbon tax for all users; or 3. An upstream carbon tax for the energy sector.

But such market mechanisms are designed to achieve the least-cost solutions. Additional incentives, funds and regulations (e.g., renewable energy portfolios; progressive efficiency standards) are needed to promote more costly technologies, such as solar and geothermal.

GENERATING GLOBAL FUNDS

All three methods above (if cap-and-trade permits are auctioned), would generate substantial funds that could prime and sustain the development of clean technologies. The 2006 Stern Review on the economics of climate change calculated that 1% of world output per year ($350 billion; the total being $35 trillion) for an initial period would be needed for climate stabilization. This contrasts with the potential for non-linear cli-

Financial Mechanisms and Policy Instruments

This table depicts private sector measures, with national and international policies needed to facilitate them.

Private Sector Measures	National Policies	International Policies
Carbon budget disclosure	Reporting (in U.S.) to the Securities and Exchange Commission	Reporting and compliance under the U.N. Post-Kyoto Protocol
Shift assets under management	Establish a price for carbon	Establish a standardized international trading regime
Tailor bank lending guidelines and project financing	Targeted national investments Supply surplus state land for clean tech enterprises	Alter guidelines of the International Financial Institutions (IFIs: World Bank, regional development banks, and the IMF)
Creative risk transfer mechanisms for innovative technologies	Stream-line approval processes Dismantle regulations that hinder innovation	Provide incentives for tailoring capital markets into clean development
Private investments in R&D	Translational grants to commercialize promising technologies Reward products brought rapidly to markets Establish government/university collaboratives	Internationally-coordinated R&D and implementation, compliance and monitoring programs
Corporate efficiencies for energy, water and materials, with performance metrics	Progressively-increasing energy efficiency standards for mobile and stationary sources Renewable energy portfolio standards Decouple utility profits from energy use Net metering Feed-in tariffs	Progressively-increasing energy efficiency standards for all nations, to provide equity in development goals Include avoided deforestation, CH_4 capture and avoided air pollution (e.g., black soot) in post-Kyoto Protocol
Full cost accounting, including supply chains, marketing and disposal	Standards for appliances, materials and processes	International business standards
Procurement practices, e.g., all-hybrid vehicle fleets	Procurement practices in cities, towns, states and on national levels, to build markets	International organizations commit to purchase new products (e.g., WHO purchases solar refrigerators for vaccine distribution; hybrid automotives and ships)
Adapt insurance policies for directors and officers, errors and omissions, green buildings and hybrid owners	Federal insurance for defined risks	Expand micro- and macro-insurance schemes
	Provide financial incentives to producers and consumers	Establish a Global Fund for Adaptation and Mitigation: order of magnitude, $350 billion/yr for initial period
	Shift subsidies	Administration and allocation of funds via GEF/UNFCCC[a], for example
Creative financing, such as: Amortized up-front capital costs for new technologies	Provide incentives for creative financers	Creative financing by IFIs Reset international market and World Trade Organization signals
Internally employ energy efficiency and purchase of renewable energy	Provide the energy infrastructure	International "super-grids" and distributed generation

a. The Global Environmental Facility issues grants, not loans, under the auspices of the World Bank, the United Nations Development Programme and the United Nations Environmental Programme. The United Nations Framework Convention on Climate Change is the institutional structure for the international climate protocols.

mate *impacts* (e.g., large forest diebacks; widespread crop failures; coral reef collapse) that could cause damages of 5-20% of world output (up to $7 trillion) per year.

The relative figures are key; and the differential would be even greater if one replaced the discount rate with an "appreciation rate" for Earth's life support systems.

An historical note: A technology transfer fund was needed to realize the 1987 Montreal Protocol to phase out stratospheric ozone-depleting chemicals.

As a cost to one is revenue (and potential investment) for another, this level of allocation of global finances may be viewed as an investment in our common future; one that would bring many health, ecological and economic returns.

CONCLUSIONS

While the consequences of climate change fall disproportionately on poor communities and poor nations, no one is immune to changing weather patterns and the loss of Earth's ice cover. For many reasons, our dependence on oil and coal are not sustainable. "Business-as-usual" must be replaced by bold and transformative changes in the operating rules that drive the global economy.

LOOKING TOWARD COPENHAGEN: IS IT TIME FOR "BRETTON WOODS II?"

In July of 1944, capping almost four decades of world war and depression, Western world leaders met at the Mount Washington resort in Bretton Woods, New Hampshire to craft a new international economic order.

Under the stewardship of John Maynard Keynes, three rules were established: 1. Fixed exchange rates, tied to the gold standard; 2. Free trade in goods; and 3. Regulation of international capital markets. (Adam Smith and David Ricardo both concluded that comparative advantage among nations would not work if capital flowed freely across borders.) The Marshall Fund for Europe and the U.S. G.I. Bill provided the funds to propel post-war prosperity.

But, in 1971, the Bretton Woods rules were abandoned, unleashing four decades of inflation, debt and cycles of speculation. Today, as food, fuel, financial and climate crises converge, the guideposts of globalization – *deregulation, privatization and liberalization* (of goods and capital) – are yielding to a new paradigm with better regulated capital markets and a public/private partnership, *writ large*.

The United Nations Climate Change Conference, to be held in Copenhagen at the end of 2009, provides a pivotal juncture for halting "business-as-usual," redesigning the international financial architecture and institutionalizing the monetary resources commensurate with the challenges we face.

Today's deliberations will be different from those held in 1944: there will be representation from all nations, non-governmental organizations and the business and scientific communities. Realigning the rules, regulations and rewards will be needed to promote less and very different patterns of consumption and waste generation. The good news is that, properly funded, renewable energy, smart technologies, efficient transport and healthy cities programs can form the foundation for a sustainable low carbon economy.

Harmonizing Adaptation and Mitigation: Investment Opportunities

Measures to Decrease CO_2 Emissions	Co-Benefits	Investment Opportunities
1. A smart, self-healing grid	Improve coping ability (storms and heat waves) Meet critical needs Decrease energy demands	Smart technologies, new generation batteries, efficient appliances
2. Healthy cities	Reduced air pollution Diminished heat island effect Reduced traffic accidents Exercise promotion	Insulation, specialized windows, recyclable carpets, green chemistry products, distributed energy systems with solar, wind, ground source heat pumps and fuel cells, sustainable forestry
3. Transport: public and PHEVs	Exercise promotion Congestion control	Invest in bicycles, motorized bicycles and motor scooters
4. Forest preservation	Habitat preservation Flood control Oxygen generation Carbon sequestration	Sustainable forestry Tree-seed oil sustainably-harvested Financing: "Debt-for-nature swaps" Clean Development Mechanism International Funds
5. Wetland preservation (inland and coastal)	Flood control Wildlife preservation Marine nurseries	Green design and development Project financing guidelines
6. Agriculture (locally grown; organic, pasture-raised livestock; conservation tillage)	Healthy food Water conservation Soil preservation	Sustainable farming and allied food industries
7. Coral reef preservation	Island and low-lying nation survival Storm buffers Protect island freshwater lenses Preserve marine nurseries Protect coastal property, hotels, tourism and travel Long-term carbon sequestration	Sustainably managed fisheries Eco-tourism Marine protected areas

No-Regrets Solutions Vs. Those Requiring Study

No-Regrets Solutions to Rapidly Scale-Up

1. Energy Efficiency and Conservation
2. Smart Technologies for Intelligent Grids
3. Green Buildings and Rooftop Gardens
4. Efficient Appliances
5. Distributed Generation with Renewable Sources
6. Passive Solar Heating and Day Lighting
7. Ground Source Heat Pumps
8. Co-generation
9. Solar Thermal Arrays
10. Photovoltaic Arrays
11. Wind Farms
12. Geothermal Energy
13. Industrial Efficiency
14. Green Chemistry
15. Smart Urban Growth
16. Healthy Cities Programs
17. Public Transport and Light-Rails
18. Plug-in Hybrid Electric Vehicles
19. Sustainable Forestry
20. Conservation Tillage
21. Locally-grown Organic Agriculture
22. Less Intensive Livestock Practices
23. Municipal Solid Waste Management
24. Low Technology/Human-Powered Devices

Life Cycle Analysis Needed Before Wide Scale Adoption

1. Oil Sands and Shale Oil
2. Ethanol and Biodiesel
3. Coal with CO_2 Capture and Storage
4. Geoengineering
5. Nuclear Fission
6. Nonotechnology
7. Wave, Current and Tidal Energy

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