Carbon-Free and Nuclear-Free: A Roadmap for U.S. Energy Policy

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Hugh Haskell, Ph.D.
www.ieer.org
hhaskell@mindspring.com

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Why a Presentation about the US?

- US is the leading GHG emitter
- We have the greatest responsibility to work to fix the problem
- If we can't find the will to do what is right, it is doubtful anyone else will
- If we do find that will, we can show others how to learn from our mistakes
- Proposed plan for US to meet its obligations

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The Problem We face

- Four tightly interconnected problems
  - Global warming/environmental degradation
  - Renewable resource depletion
  - Pollution caused by fossil fuels and current technologies
  - Population growth & economic development
- We must find solutions that
  - Work on one without making the others worse
  - Do so without damaging the world economy

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Great Arctic Ice Melt of 2007

Graphic Credit: NASA

Great Arctic Ice Melt of 2007

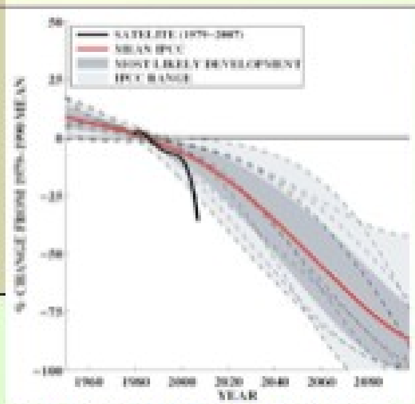


Chart courtesy of Dr. A. Sorteberg, Bjerknes Centre for Climate Research, University of Bergen, Norway.

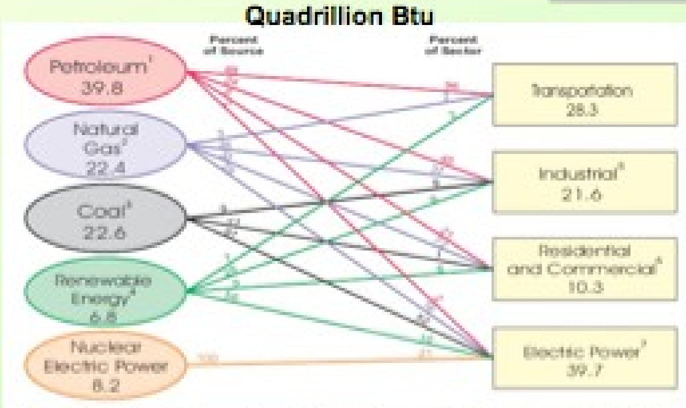
- **Dramatic change in worst case scenario**
- **Previously 2070**
- **Now 2010 or 2015**
  (Louis Fortier, Scientific Director, ArcticNet, Canada)

Three Faces of the Energy Crisis

1. ***Climate disruption*: CO_2 emissions due to fossil fuel are creating grievous harm to the global economy, society, and current ecosystems.**
2. ***Insecurity of fuel supplies*: Rapid increases in global oil consumption and conflict in and about oil exporting regions make prices volatile and supplies insecure.**
3. ***Nuclear proliferation*: Non-proliferation of nuclear weapons is being undermined in part by the spread of commercial nuclear power technology, which is being put forth as a major solution for reducing CO_2 emissions**

US Energy Consumption by Source and Sector, 2006

Quadrillion Btu



Sources: Energy Information Administration, *Annual Energy Review 2006*, Tables 1.3, 2.1b-2.1f, and 10.3.

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Main findings—carbon-free, nuclear free

- Zero CO_2 emissions without nuclear feasible
- It will be at least as reliable, more secure, healthier than what we have today
- Per unit cost of fuels is higher, but overall energy bill is lower
- More spent on efficiency and less on fuels to get the same services—miles flown, heat, light, etc.

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Main findings—carbon-free, nuclear free

- Total energy services costs are the same as business as usual—no significant GDP penalty—same share of GDP for energy services as typical: about 8%
- Rooftop and parking lot solar energy may make nuclear obsolete by about 2015—*i.e.,* by the time the first nuclear plants begin to come on line

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Premises

- EU goal—Global 50–85% cut in CO_2 by 2050
- Needed to keep estimated temperature rise to less than 2–2.4°C
- Based on global per capita allocation this means 88–96% for the US
- As rapidly as possible consistent with economic feasibility & business-as-usual economics—3%/yr growth

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Premises

- "Broad market failure" (Stern Review)
- Consistent with economic and technical choice
- Measurable CO_2 reductions in near term
- Focus on fossil fuel use, responsible for 84% of all US GHG emissions

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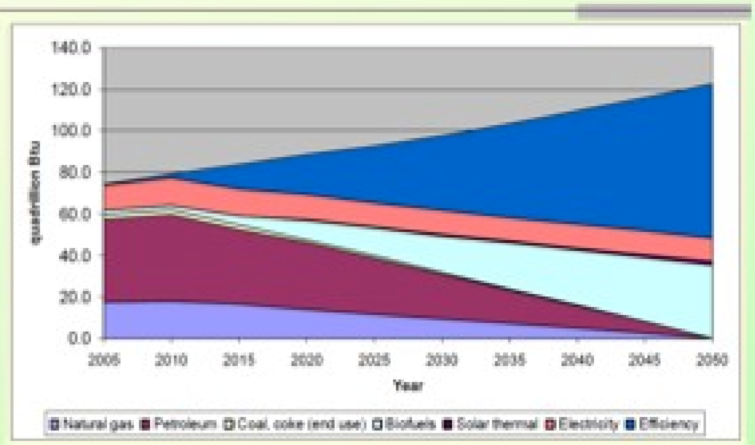
IEER Reference Scenario



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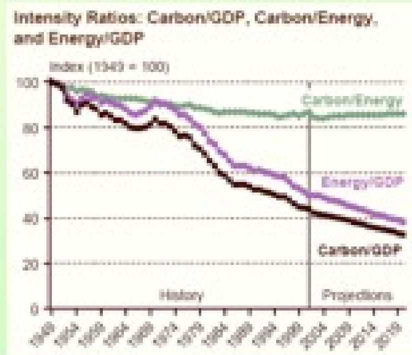
Business as Usual in Energy

- Business as Usual (BAU) used to be energy growth ~ GDP growth (1950s to 1973)
- Now energy growth ~ 1/3[rd] of GDP growth
- With BAU energy demand grows from 100 Quads in 2004 to 160 Quads in 2050



Demand side

- Overall efficiencies are low for major uses (heating, lighting, transport)
- Current trend 3% GDP and 1% energy growth
- 2% annual improvement in efficiency easily possible: delivered energy at -1% per year for 3% GDP growth

Demand side

- Residential and Commercial—existing opportunities not being used; disconnect between developers and those who pay the bills.
- Passive and active solar
- Transportation—biggest opportunities
- Industry makes a 1% per year improvement over BAU (feedstocks = constant) Combined heat and power

Policies—most critical

- CO_2 emissions cap for large users reducing steadily to zero by mid-century ("Large" > 100 billion Btu fossil fuels/year or > 5,000 mt/year)
- Sell all cap & trade allowances. Expected to raise $30 billion to $50 billion per year
- Efficiency standards for buildings, cars, trucks
- No subsidies for nuclear, fossil fuels, biofuels from food crops

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Policies—most critical

- Ban new coal-fired power plants without carbon capture and storage.
- Large-scale government performance-based purchases of renewable fuels and electricity
- Make plug-in hybrid the standard government car by 2015; mandate zero-energy government buildings by 2020, backfit existing govt. buildings

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Policies—most critical

- Demonstration projects in different climates for combining aquatic plants for wastewater treatment with biofuels production
- Federal contracting preferences for low-CO_2 corporations
- Vigorous R&D, including direct solar–hydrogen production
- Create new infrastructure in existing energy-dependent areas to ease community and worker transition

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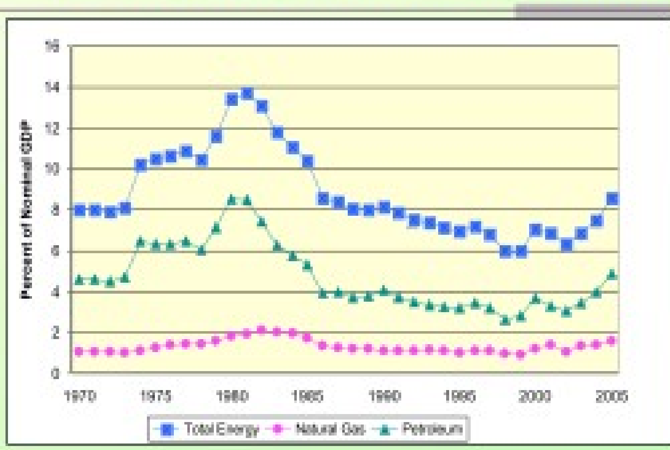
Energy as Proportion of GDP—expected to remain ~8% of GDP in renewable economy



Courtesy of the Energy Information Administration of the United States Department of Energy

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Nearly Zero CO_2 for the US

- A treaty requirement under the UNFCCC
- Needed to bring China, India, *etc.*, to the table
- Need to protect climate

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CO_2 Abatement and Cost

CO_2 Source	Method	Cost, \$/mt CO_2
Pulversized Coal	Wind (short term)	Less than \$15
Pulversized Coal	Wind w/nat gas standby (short & med term	Negative to \$46
Pulversized Coal	Microalgae capture Daytime CO_2 emissions only	Zero to negative (Proponent estimate; demo needed. Full-scale plant not built)
Nat. Gas Standby	V2G (long term)	Less than \$26?? < \$200/kWh—Li-ion batt. Needed for that

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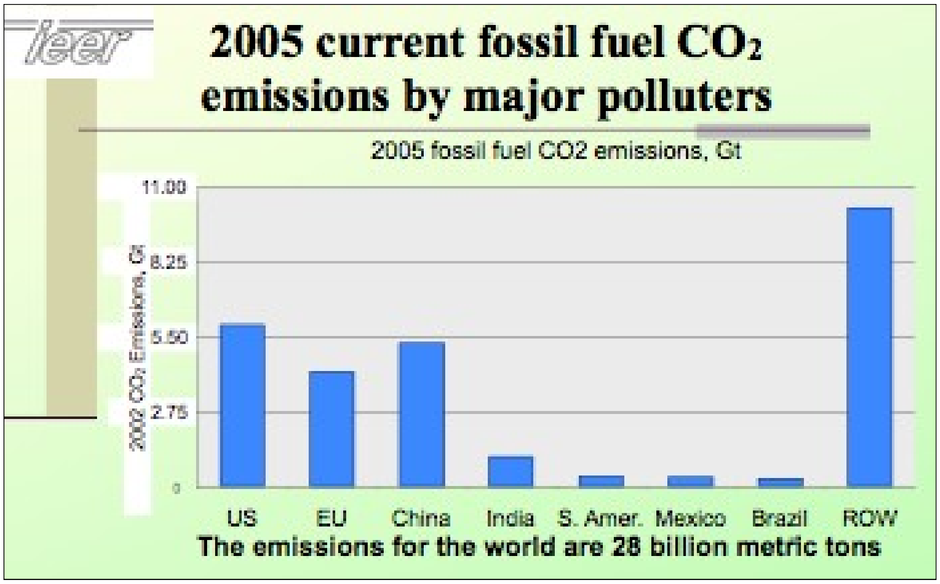
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2005 current fossil fuel CO2 emissions by major polluters
2005 fossil fuel CO2 emissions, Gt
2002 CO2 Emissions, Gt
11.00
8.25
5.50
2.75
0
US
EU
China
India
S. Amer.
Mexico
Brazil
ROW
The emissions for the world are 28 billion metric tons

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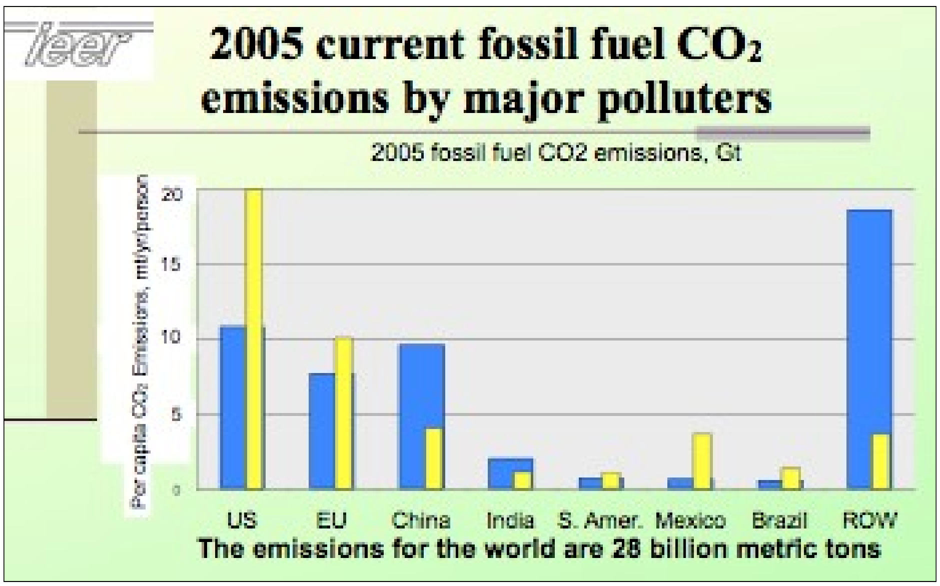
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2005 current fossil fuel CO2 emissions by major polluters
2005 fossil fuel CO2 emissions, Gt
Per capita CO2 Emissions, mt/yr/person
20
15
10
5
0
US
EU
China
India
S. Amer.
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The emissions for the world are 28 billion metric tons

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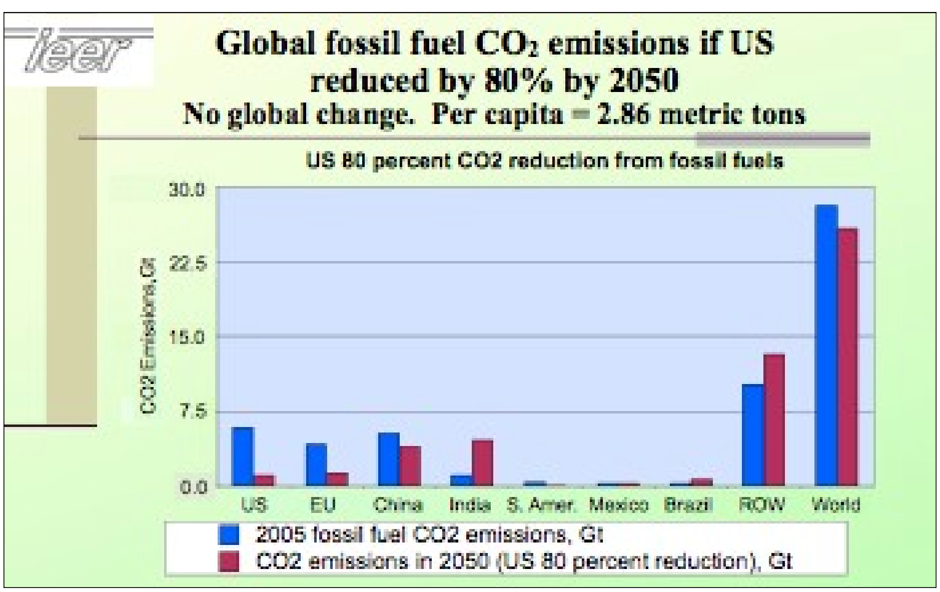
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Global fossil fuel CO2 emissions if US reduced by 80% by 2050
No global change. Per capita = 2.86 metric tons
US 80 percent CO2 reduction from fossil fuels
CO2 Emissions, Gt
30.0
22.5
15.0
7.5
0.0
US
EU
China
India
S. Amer.
Mexico
Brazil
ROW
World
2005 fossil fuel CO2 emissions, Gt
CO2 emissions in 2050 (US 80 percent reduction), Gt

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United Nations Framework Convention on Climate Change

- UNFCCC requires CO_2 reduction with due attention to historical inequities
- IPCC estimates imply 70–85% reduction in global CO_2 emissions to have a better than even chance to keep temperature rise less than 2–2.4° C
- 80% global reductions require 95% US reduction, given equal sharing of allowances

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Water Considerations

- Thermal Power plants (coal or nuclear): 75,000 m^3 per day water consumption for cooling tower—1000 MW plant
- Once-through consumption lower, but water intake higher
- > 3.8 billion m^3 per year of fresh water (rivers, lakes) consumed by fossil fuel & nuclear plants
- Other water pollution also created, e.g., mining and refining fossil & nuclear fuels

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Air and Water Pollution Considerations

A renewable energy system would greatly reduce:

- Urban air pollution
- Acid rain
- Mercury and heavy metal pollution
- Further radioactively contaminated sites due to oil production
- Respiratory diseases; and
- Eliminate further nuclear related water pollution

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Basic Nuclear Power Issues

- Cost
- Waste
- Proliferation
- Accident and Terrorism Risks
- Other Environmental Issues

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Nuclear Costs

- "Too cheap to meter" known to be false when first claimed in 1950s
  - Gave rise to Article IV of the NPT
  - High expectations and glamour from that time persist
- Capital costs are the main costs—reactor as a very expensive boiler
  - $US 3-9 per installed watt, depending on site & cost of capital
  - Converts to $US 0.04-0.12/kWh

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Nuclear Costs

- Several recent proposed plants abandoned on economic grounds
- Mainly going ahead where governments are giving the push
  - Michael J. Wallace, co-chief of UniStar Nuclear: "without loan guarantees, we will not build nuclear power plants"

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Keystone Joint Fact Finding Cost Estimates

Table 6. Summary of Levelized Cost
(Cents/kWh)

Cost Category	Low Case	High Case
Capital Costs	4.6	6.2
Fuel	1.3	1.7
Fixed O&M	1.9	2.7
Variable O&M	0.5	0.5
Total (Levelized Cents/kWh)	8.3	11.1

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France's Nuclear Fix?

- Has France solved the problem?
- Reprocessing: add $0.02 per kWh
- Send 95% of spent fuel (uranium) to Russia)
- Discharge over 400,000 m^3 of radioactive waste into the seas causing pollution all the way to the Arctic and protest by 12 West European governments

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France's Nuclear Fix?

- Still need a repository—public opinion now 54% against nuclear
- "Poulets de Bresse"

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US and Waste

- No good solution, but least bad needed
- Criteria: geology, confidence in characterization, water impacts
- Yucca Mountain—worst repository location of all considered in US
- No adequate waste solution in US
- Nuclear utilities have paid into waste site fund, but gov't has wasted most of it, with so site in sight

US and Waste

- Reprocessing increases overall waste
- Uranium mining waste & mill tailings
- Processing waste
- Depleted uranium
- Routine tritium discharges from power plants
- Leaks from plants & processing facilities

Nuclear Power as the Solution to Global Warming

- Nuclear power a low CO_2 emitter—but:
  - Cost is high—$3,000-9,000/installed kW.
  - Produces its own dangerous waste which we haven't figured out how to deal with yet
  - Makes weapons proliferation easier
- U.S. and Russia proposed a "Global Nuclear Energy Partnership" (GNEP)—sell reactors for use globally, enrichment, and reprocessing in states already having these facilities
- GNEP is unlikely to be acceptable by countries that want large role

Nuclear Power as the Solution to Global Warming

- 1000 new nuclear plants to keep up with electricity demand and keep nuclear power at same level it is now.
- 2500 nuclear plants to also replace coal
- Results:
  - Will need 1-3 new processing plants each year
  - One new geologic repository, Yucca Mountain scale every few years.
  - Energy costs will skyrocket
  - More reprocessing likely

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Proliferation

- Nuclear proliferation as a major issue has been at least part of the stated reason for war
- Large number of countries are suddenly deciding to exercise their Article IV NPT rights vigorously
- Uranium enrichment and reprocessing in the headlines with Iran and North Korea, and difference in their treatment has raised eyebrows and fanned nuclear desires

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Current Materials Reality & Accounting

- Amount of reactor-grade Pu for one bomb ~ 8 kilograms
- Plutonium in commercial sector: ~2,000 mt, most in spent fuel
- Amount of separated surplus Pu: 250 mt, ~ total weapons Pu
- Commercial surplus Pu ~30,000 nuclear bombs

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Current Materials Reality & Accounting

- Pu hard to track & keep track of
  - Processing uncertainties
  - Controlling agencies not forthcoming
  - Some states completely closed
- Japan & US both have had major accounting problems
- Unlikely that it has not happened in other weapons states
- Annual Pu generation from new plants ~ 250-600 mt

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Accident and Terrorism Risks

- Low (but not zero) probability of catastrophic release
- Cookie-cutter plants
- Spent fuel pools outside the reactor
- NRC laxness—evidence in boric acid corrosion, tritium leaks, fire risks, alarm problems
- Similar or worse in rest of world

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Accident and Terrorism Risks

- Increased number of nuclerar power plants likely to lead to increase in reproscessing
- Japan earthquake and demonstration of industry vulnerability
- German & Sweden nuclear plant accidents 2007

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Residential and commercial sector Billion $/yr in 2050

Item	IEER Reference	Business as Usual
R + C Electricity	$326	$442
R + C Fuel *cost*	$150	$247
Sub-total energy	*$476*	*$689*
Added annual investment for efficiency	$205	$0
Total GDP-basis amount (rounded)	**$681**	**$689**
GDP	**40,000**	**40,000**
Percent of GDP	**1.70%**	**1.72%**

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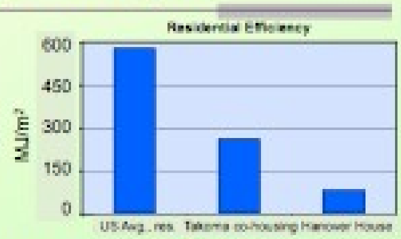
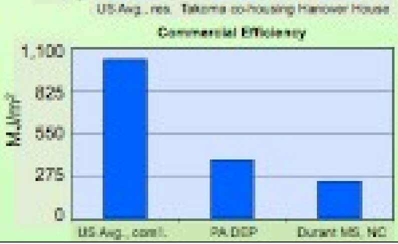
Residential and Commercial Efficiency Examples

- Efficiency improvement of 3 to 7 times possible
- Existing homes more costly to backfit but much still economical
- Standards at local and state level are needed
- Zero net CO_2 new buildings and communities by 2020 can be mandated





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Hanover House, NH

- Good insulation (Wall R-value > 25), energy star appliances, air infiltration barriers, high performance windows.
- Passive solar features
- Active solar (water + space) heating with electric resistance back up)
- All electric house, no A/C
- Annual electricity use ~5,000 kWh/yr
- 83 MJ/m² compared to 580 MJ/m² avg. for US (delivered energy)

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Durant Middle School, Raleigh, NC

- Building orientation, south facing windows for daylighting, light colors
- Lighting for the task, high efficiency lamps, automatic dimming
- high-efficiency luminaires
- photoelectric sensors
- Delivered energy 250 MJ/m^2 vs. 1,000 MJ/m^2 commercial sector average.
- Primary is 420 MJ/m^2 vs. 2,200 MJ/m^2 commercial sector avg.

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Wind Energy

- Wind ~ 3 times US electricity generation—commercial now; no barrier to 15% of total electric generation (0.7% today)
- Each top six states has more wind potential than all 104 US nuclear plants
- Intermittency a big issue—at all levels: micfrofluctuations (order of minutes), hours, day-to-day, seasonal
- Large-scale deployment & energy storage required

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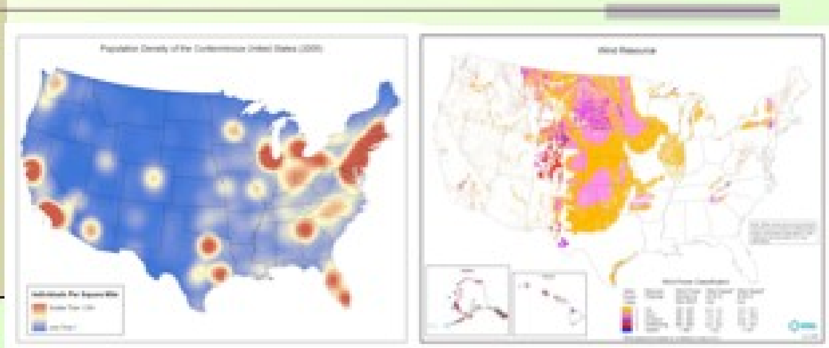
Population and Wind Geography



Provided by AWS Truewind, LLC

Provided by National Renewable Energy Laboratory

The idea of how to illustrate this problem comes from Walt Musial.

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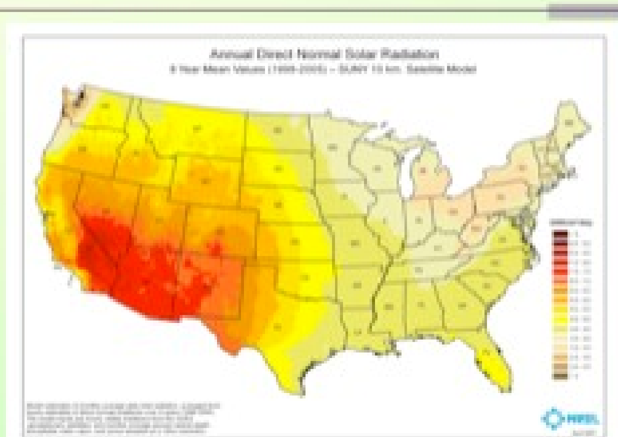
Solar Energy

- Solar at 1% of land area and 20% efficiency = 2x to 3x wind energy
- Parking lots and roof tops can supply much or most US electricity
- Storage for night-time power will be needed
- Intermittency
- Enhanced grid needed for large area structures (mostly in southwest)

Solar geography



Provided by National Renewable Energy Laboratory

Commercial Rooftop & Parking Lot Solar PV Advantages

- Total area is very large—could supply most of US electricity requirements
- No new transmission corridors & large grid not required
- No new land required
- Cheaper than residential solar PV due to economies of scale
- Compatible with vehicle-to-grid system

Commercial Rooftop & Parking Lot Solar PV Advantages

- Parking lot installations require no roof penetrations & provide shade for parked vehicles
- Could allow water collection and reduce run off and associated pollution

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750 kW US Navy San Diego Parking Lot

Courtesy of PowerLight Corporation

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Solar energy—PV to shade parking lots—Kyocera, 235 kW

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Key supply and electricity Technologies—reference scenario

- Large-scale Wind (up to 25%), with natural gas standby to 2040
- Small medium, central station PV, against peak costs
- Solar thermal (with storage in medium & long term)—150 GW
- Biofuels—aquatic plants, prairie grasses (no food crops for fuel)
- Algae capture of CO_2

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Key supply and electricity Technologies—reference scenario

- Other—hot rock geothermal, wave power, other ocean energy
- Optimize solar and wind; geographic diversity; natural gas standby, V2G
- Solid biomass fueld for electrcity (probably IGCC technology)

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Key storage technologies

- Compressed air storage
- Ultracapacitors—stationary storage
- V2G—Li-ion batteries
- Electrolytic Hydrogen
- Compressed CO_2 overnight storage for microalgae
- CO_2 sequestration
- Fossil fuel plus biomass plus sequestration—liquid fuels

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Phases for carbon-free and nuclear-free electricity grid

- Create zero-CO_2 emissions, non-nuclear electricity plans at the state level
- Phase 1: wind and solar (PV and solar thermal) coordinated with each other and with hydro and natural gas standby—can take the system to about 40% renewables (maybe more), build smart grid, possibly add V2G
- Phase 2: Add solar thermal with 12-hour storage, hot-rock geothermal, 100% solid biomass with IGCC, natural gas standby, possibly expand V2G
- Phase 3: V2G, stationary battery storage, compressed air storage, biomethane standby

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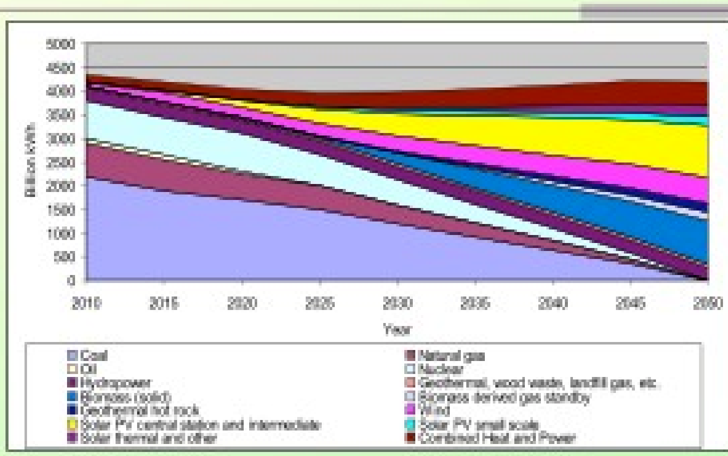
Electricity production



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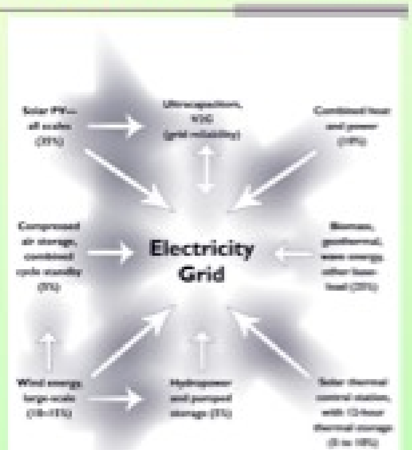
A renewable, distributed electricity grid configuration

One Possible U.S. Electric Grid Configuration by 2050 Without Coal or Nuclear Power



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Transportation

- Liquid fuel aircraft (much R&D needed)
- Plug-in hybrids in the 2010 period onward;
- Transition to electric vehicles over 30 years—Li-ion batteries are good enough
- Five fold cost reduction needed—$1000/kWh to $200/kWh (A123 and Altairnano or off the shelf as in Tesla Motors)
- Efficient ICE with biofuels

Transportation

- Possible electrolytic hydrogen from wind—now about $6 per kg. Need $3 per kg, compressed for ICE use.
- Fuel cells look distant for transportation

Li-ion battery specs: Altairnano

- 85% capacity after 10,000 to 15,000 charge/discharge cycles (Altairnnano)
- Fire tested: Li deposited on titanium oxide (no carbon):
- $1,000/kWh – cost reduction of a factor 5 needed
- Energy density ~120 Wh/kg

Electric car: Phoenix Motorcars Pickup

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Electric car: Phoenix Motorcars Pickup

- All electric: Range 210 km, ~ 1/6 kWh/km
- Payback time ~ 5 years
- Altairnano batteries:
  - Can be charged in 10 minutes with special equipment
- Suitable for V2G applications
- Other similar lithium-ion batteries from other manufacturers now coming to market

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Tesla
(British Equivalent—Lightning)

Courtesy of Tesla Motors

- 0 to 96 km/h in 4 secs. (goal) ~ ⅔ g
- 320-400 km range
- ~ 1/8 kWh/km
- Off-the-shelf lithium-ion batteries combined in special battery pack

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V2G and plug-in hybrids, from Google website (measured)

	Prius	Prius Plug-in
Wh/Mile	N/A	118.1
MPG	41	73.6
Btu/mile total (coal-fired/solar for plug-in)	3056	2879/1698

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Liquid fuels from microalgae.

Demonstration bioreactor – coal-fired power plant in Louisiana

Pilot engineering-scale bioreactor —Red Hawk gas-fired power plant in Arizona

- Much more efficient than corn
- Captures CO_2 emissions from power plants

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Other efficient aquatic plants

- Water hyacinths (tropical and subtropical)
- Duckweed(temperate)
- Demonstration plants needed; lab work has been done
- Can be used with wastewater treatment to sop up excess nitrogen and help protect water resources

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Land area considerations

Land Area Requirements for the IEER Reference Scenario (rounded)

Energy source	Land area, square miles	Side of a square	Comments
Wind	490	22	Mainly infrastructure, including roads
Centralized Solar PV	860	29	PV area + 30% infrastructure
Solar thermal (central station)	210	15	Collector area + 30% infrastructure
Biofuels (solid and liquid)	184,000	429	About five-sixths of the area is harvested area for biomass; rest is microalgae and aquatic plants
Total	**185,360**	**431**	**About 5.2 percent of U.S. land area**

Notes: 1. Wind capacity factor = 30% and land per megawatt = 0.6 hectares.
2. Solar PV efficiency 15%; average annual insolation 260 W/m².
3. Solar thermal efficiency 20%; average (tracking) insolation 300 W/m².

Reducing biofuels land area

- Electrolytic hydrogen production using wind energy
- Distributed hydrogen infrastructure – create hydrogen where used, eliminates need for hydrogen pipeline infrastructure
- R&D for direct solar hydrogen production
- Greater efficiency (there is much scope beyond reference scenario)
- Could reduce area to ~ 2–3% of US land area.

Worker Transition

Create new infrastructure where present jobs are (very possible):

- Microalgae for CO_2 capture, pulverized coal
- Wind, solar, biofuels in coal, oil, and gas areas
- Public transportation construction
- Aquatic plants in the south

Worker Transition

Create new infrastructure where present jobs are (very possible):

- Vehicle manufacturing – dislocations not energy related
- Use part of CO_2 revenues – estimated average ~$40 billion per year ($20/mt, 2 billion mt, average)

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Phase out schedule

- What is zero-CO_2?
- 2050 reference with technologies that are here or nearly here – cost reductions assumed; electric cars are critical
- 2060 if sequestration and other difficult technologies are needed
- 2040 if photoelectrochemical, thermochemical, or photolytic hydrogen, aquatic biomass, and higher efficiency can be realized

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Key elements—Recap

- Emphasis on Building Efficiency
- Plug-in Hybrids and all-electric vehicles
- Parking lot & commercial rooftop solar PV
- Solar thermal with storage
- Distributed grid—wind, solar, hydro-standby, natural gas/methane, storage coordiantion
- Aquatic plants for biofuels—solid, liquid, gas

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Key elements—Recap

- Distributed hydrogen production—electrolytic from wind
- Develop direct solar hydrogen—important R&D goal

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Action in the Direction of Carbon-free/Nuclear-free—Status

- New Zealand: adopted goal of increasing efficiency and 100% renewable energy economy by 2050—no fossil fuels (incl. no coal with carbon sequestration) & no nuclear power
- Abu Dhabi: has broken ground on new 7 km^2 100% renewable energy city
- State of Maryland (US): considering 90% CO_2 emissions reduction by 2050

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Conclusion

We have a difficult task ahead of us

If we don't find a solution, Nature will do it for us

We probably won't like Nature's solution

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End note

- Slides are primarily a summary of *Carbon-Free and Nuclear-Free: A Road Map for U.S. Energy Policy* by Arjun Makhijani
- Find the source citations in the downloadable version of the book, available at no cost, on the Web at http://www.ieer.org/carbonfree/CarbonFreeNuclearFree.pdf or contact IEER .
- The book can be purchased in hard copy at www.rdrbooks.com or www.ieer.org