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

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Energy framework must address multiple issues

- Climate
- Oil insecurity and wars
- Nuclear proliferation

Great Arctic Ice Melt of 2007

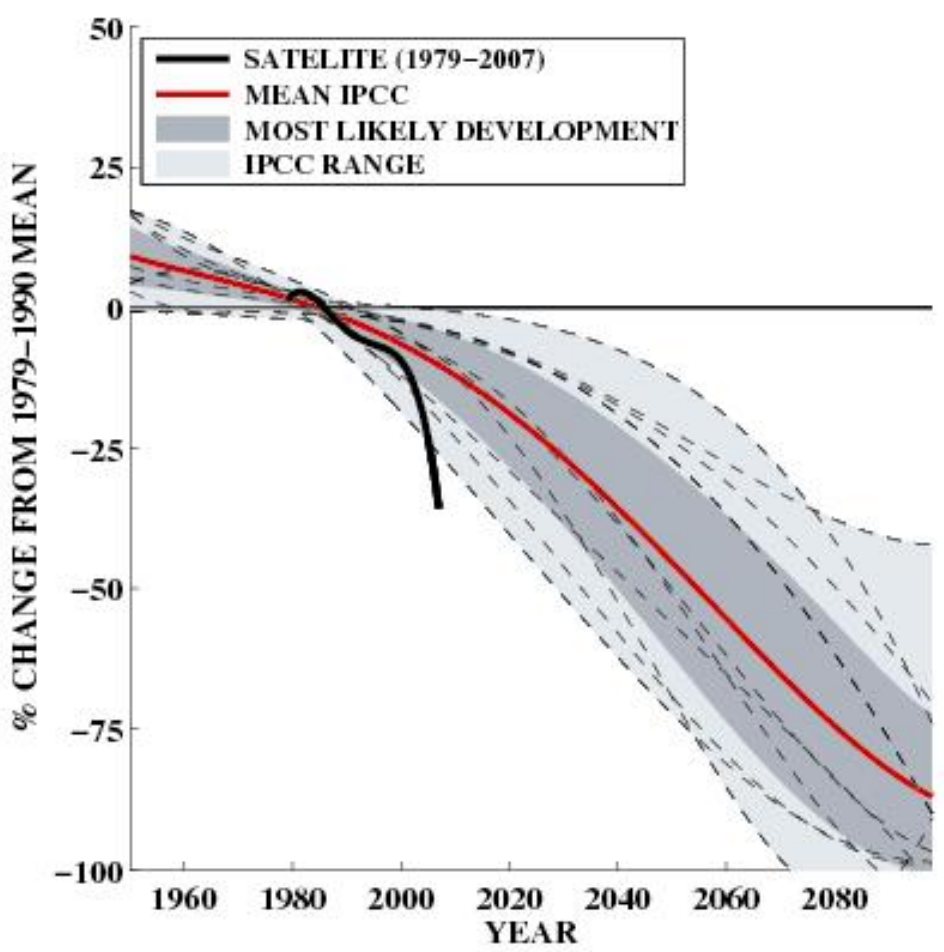


Chart courtesy of Dr. A. Sorteberg, Bjerknes Centre for Climate Research, University of Bergen, Norway.

United Nations Framework Convention on Climate Change

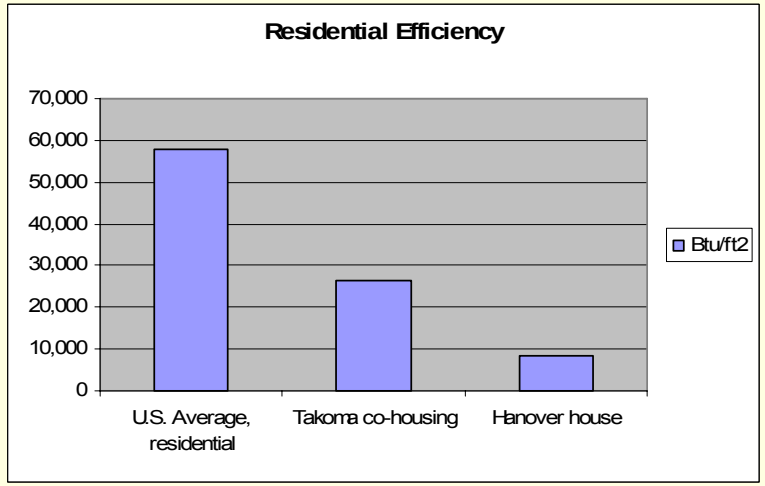
- Requires CO_2 reduction with due attention to historical inequities
- IPCC estimates that 50 to 85% global CO_2 reductions needed by 2050 to keep temperature rise less than 2 to 2.4 degrees Celsius
- Equal sharing of allowances worldwide means 88 to 96 percent reduction for U.S.

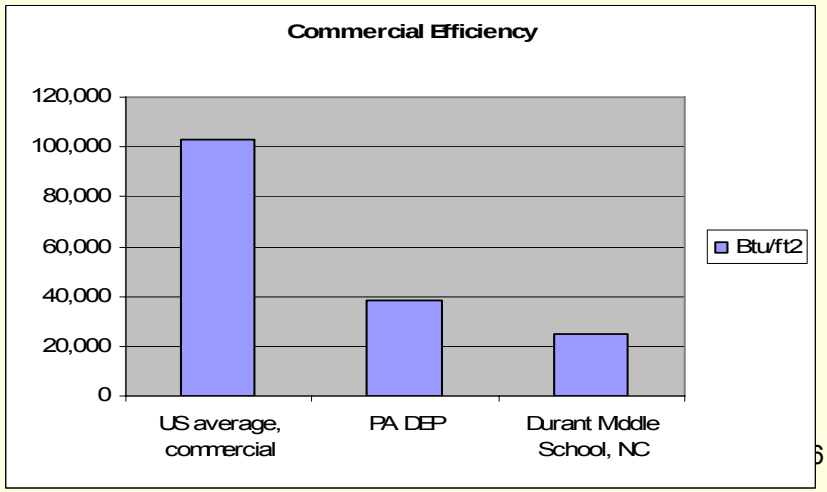
CO_2 abatement and cost

CO_2 Source	Method	Cost $/mt CO_2
Pulverized coal	Wind (short term)	A few to $15
Pulverized coal	Wind with natural gas standby (Short and medium term)	Negative to $46
Pulverized coal	Microalgae capture – daytime CO_2 emissions only (medium term)	Zero to negative (proponent estimate; demonstration needed. Full-scale plant not built)
Nat gas standby	V2G (long-term)	Less than $26??, <$200/kWh Li-ion battery needed for that.

Residential and Commercial Efficiency Examples

- Efficiency improvement of 3 to 7 times is possible per square foot
- Existing homes more costly to backfit but much is still economical
- Standards at the local and state level are needed





Phoenix Motorcars Pickup

- All electric: Range 130 miles, about one-third kWh per mile

Altairnano batteries can be:

- charged in 10 minutes with special equipment
- Retain 85% capacity after over 10,000 charging and discharging cycles
- Suitable for vehicle to grid applications
- Not yet economical – large cost reduction needed

Tesla: Off the shelf Li-ion in battery pack; 375V, 56 kWh, 200 kW; goal: 0 to 60 in 4 secs.; 200 mile range, 110 Wh/km,

Courtesy of Tesla Motors

Tesla Motors

- Off the shelf Li-ion in battery pack
- 375V, 56 kWh, 200 kW
- 0 to 60 in 4 secs. (not yet but anticipated)
- 220 mile range
- About 0.2 kWh per mile
- Equivalences: 60 mpg coal or nuclear, 100 mpg combined cycle, and over 160 mpg solar PV

Key energy supply and electricity technologies -- reference scenario

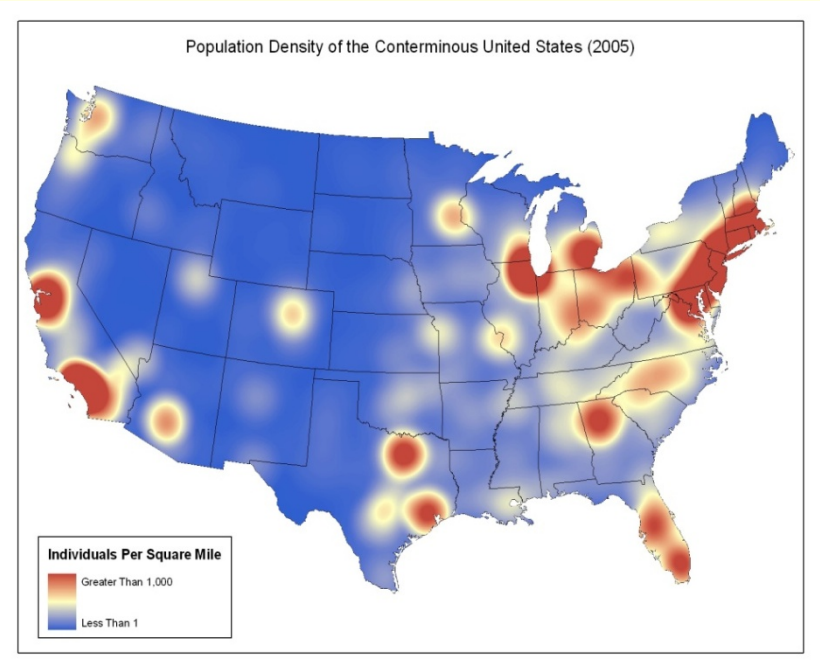
- Large-scale wind (10 to 15%)
- Small, medium, central station PV, against peak costs
- Solar thermal (with storage in the medium and long-term)
- Biofuels – aquatic plants, prairie grasses (no food crops for fuel)
- Capture of CO_2 in algae
- Solid biomass fuels for electricity (probably IGCC technology)

Resource availability - wind

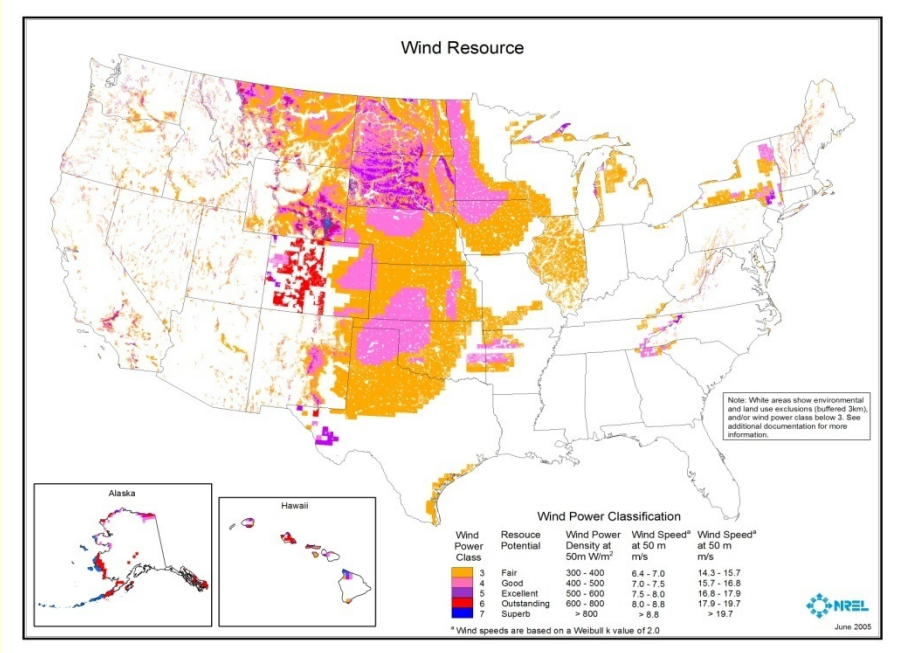
- Wind ~ 3 times US electricity generation – commercial now; no barrier to 15% of generation (0.7 percent today)
- **Each** of the top six states more than all nuclear generation. (North Dakota, Texas, Kansas, South Dakota, Montana, Nebraska). Nuclear generation about 750 billion kWh
- Intermittency is a big issue – various levels:

  Microfluctuations (on the level of minutes), hours, day-to-day, and seasonal

Population and Wind Geography



Provided by AWS Truewind, LLC

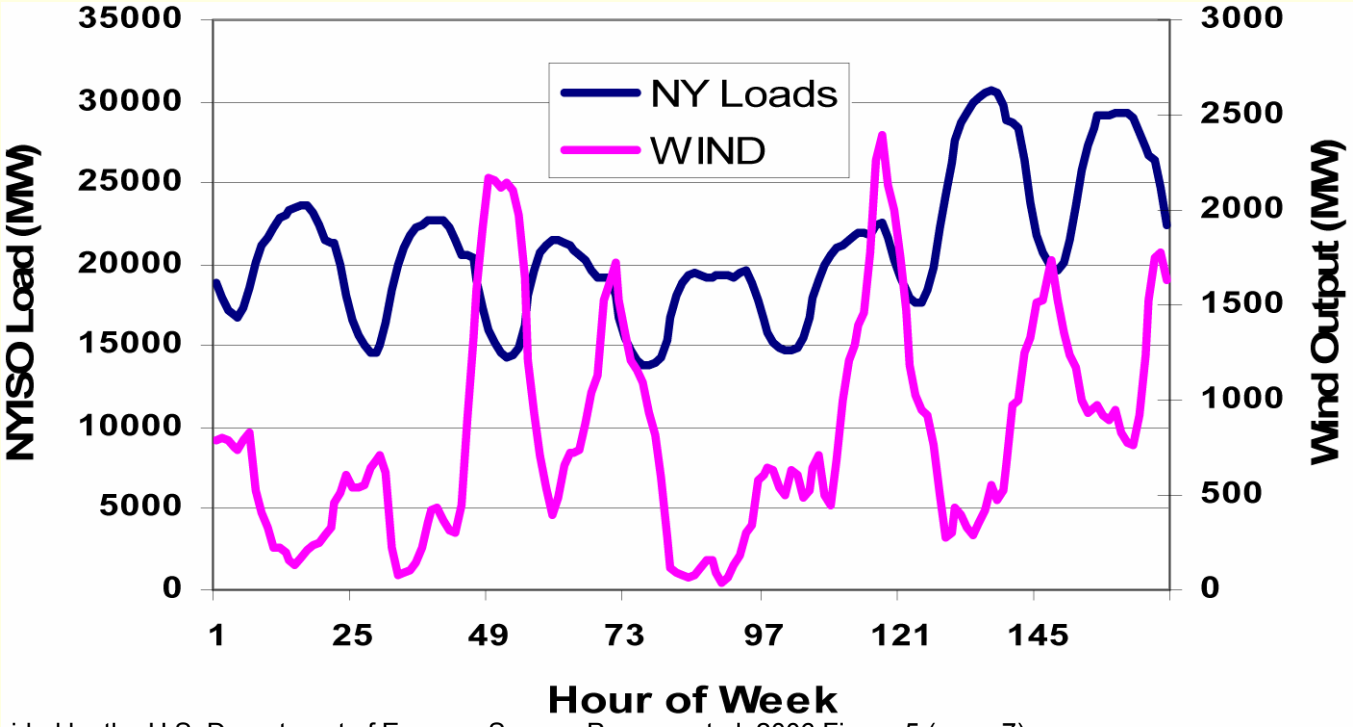


Provided by National Renewable Energy Laboratory

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

Weekly wind energy variability

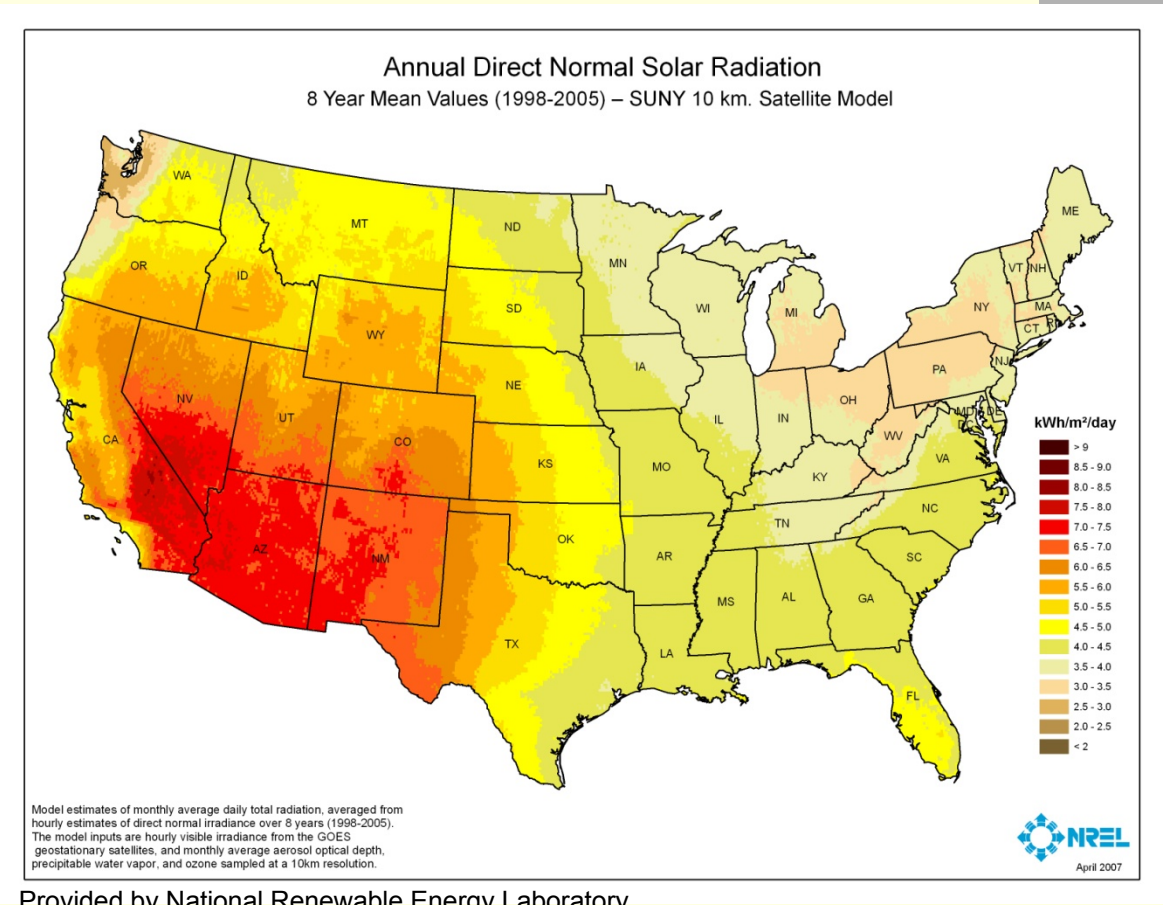
Illustration of Wind Energy Variability



Provided by the U.S. Department of Energy. Source: Parsons et al. 2006 Figure 5 (page 7)

Note: Wind output scale is on the right

Solar geography



Provided by National Renewable Energy Laboratory

750 kW US Navy San Diego Parking Lot

Courtesy of PowerLight Corporation

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

Copyright 2007 Kyocera Solar, Inc. All rights reserved.

Commercial rooftop parking lot solar PV advantages

- Total area is very large – can supply much or most of U.S. electricity requirements
- Can yield economies of scale without requiring new transmission corridors
- No new land required
- Compatible with vehicle-to-grid system

Parking lot installations

- require no roof penetrations
- Provide shade for parked vehicles
- Could allow water collection and reduce run off and associated pollution

Microalgae CO_2 capture – could yield 250 dry metric tons/hectare/year

↑ Demonstration bioreactor – coal-fired power plant in Louisiana

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

Photos courtesy of GreenFuel Technologies

Aquatic plants

- Water hyacinths – highest productivity plant ~5% efficiency (~10x corn plant)
- Considered a pest and for water purification
- Yields methane
- Demonstration needed
- Also a potential for 250 dry mt/ha/yr.

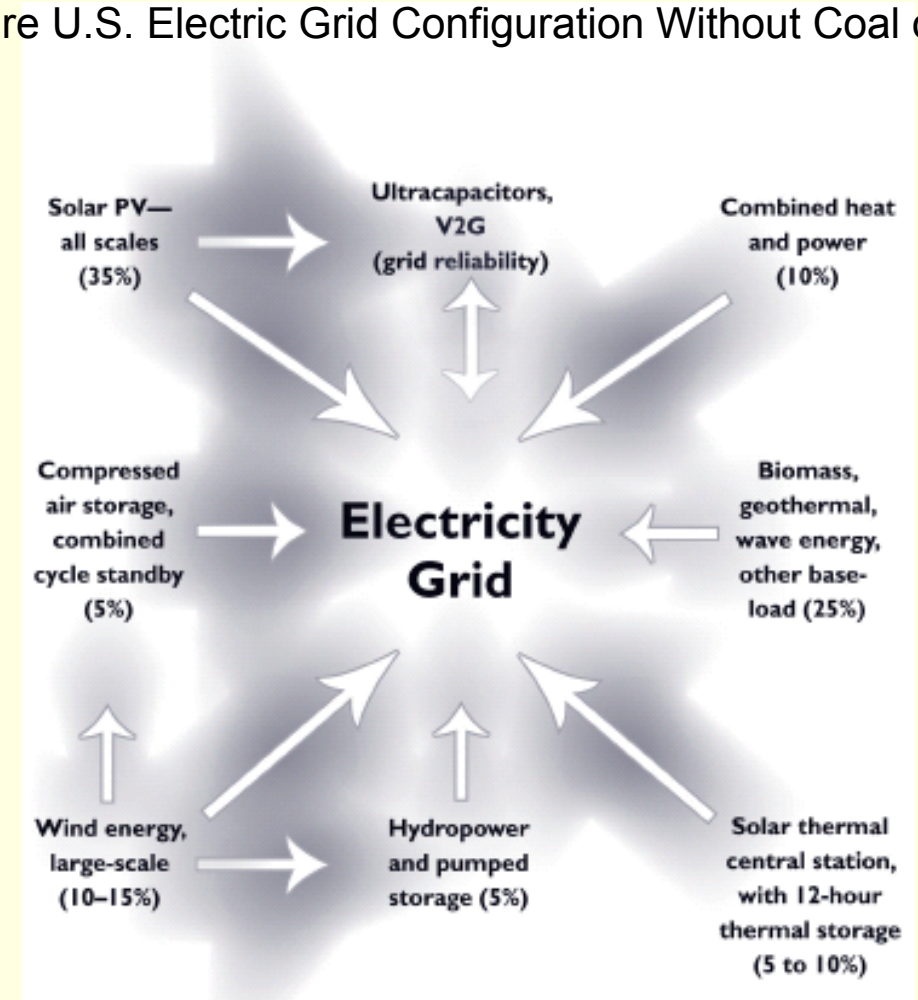
Courtesy of Center for Aquatic and Invasive Plants, Institute of Food and Agricultural Sciences, University of Florida

Duckweed

Courtesy of Gayla Chandler. See http://www.fractalnature.com/duckweed.html.

A renewable, distributed electricity grid configuration

One Possible Future U.S. Electric Grid Configuration Without Coal or Nuclear Power in the Year 2050



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	1,800	42	See note 2
Solar thermal (central station)	1,150	34	See note 3
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	**187,440**	**443**	**About 5.3 percent of U.S. land area**

Notes: 1. Wind capacity factor = 30% and land per megawatt = 0.6 hectares.
2. Solar PV efficiency = 15%; generation rate = 120 kWh/m^2/yr.
3. Solar thermal: generation rate = 75 kWh/m^2/yr.

Desirable technologies

To reduce land area needed for biofuels:

- Electrolytic hydrogen production from wind-generated electricity
- Direct production of hydrogen using solar energy (e.g., thermal cracking of water)
- Distributed hydrogen production and use infrastructure
- Larger increases in efficiency
- Can reduce area needed for biofuels to ~2 to 3% of U.S. land area

Water considerations – electricity sector

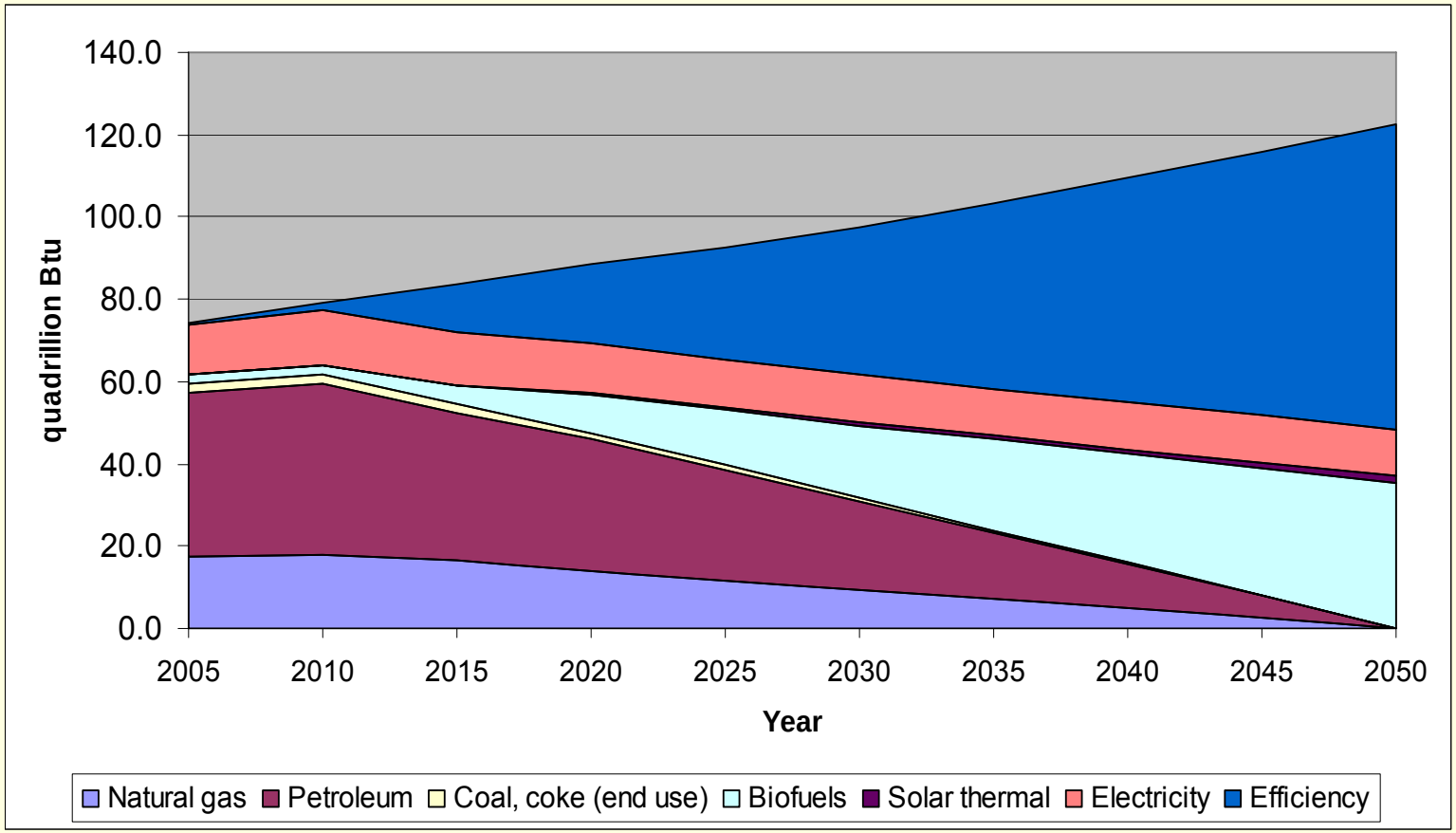
- Today's thermal power plants: 20 million gallons per day consumption for cooling tower, 1000 MW plant full capacity
- Once through water consumption is lower but water intake requirements are higher
- Over one trillion gallons per year (about 4.5 million acre-feet) of fresh water (rivers, lakes) consumed by fossil fuel and nuclear plants
- Other water pollution is also created, e.g. from mining and refining of fossil and nuclear fuels
- Solar PV and wind electricity require essentially no water – a major benefit

Air and water pollution considerations

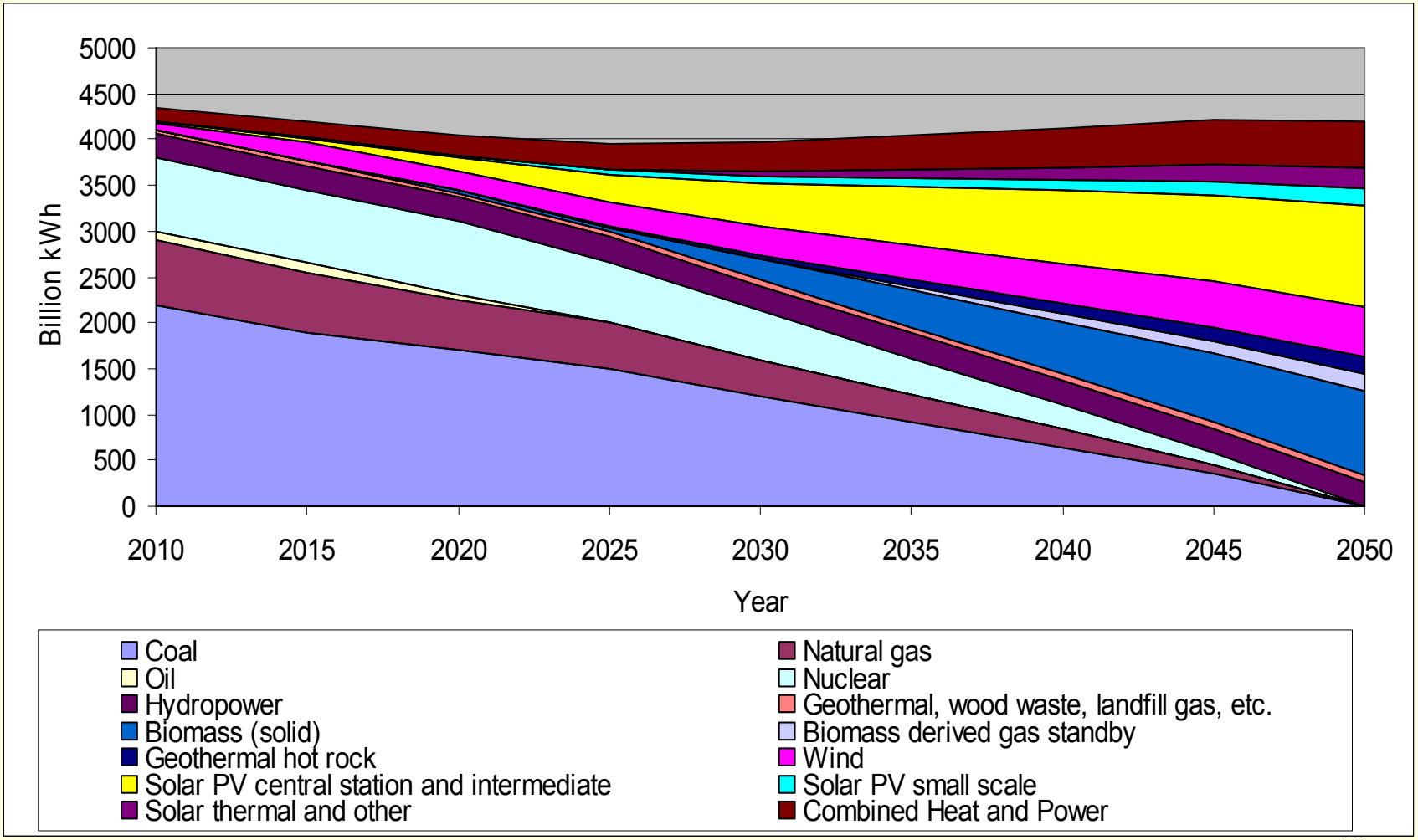
A renewable energy system would

- Greatly reduce urban air pollution
- Greatly reduce acid rain
- Greatly reduce mercury and heavy metal pollution
- Greatly reduce further radioactively contaminated sites due to oil production
- Eliminate further nuclear related water pollution
- Greatly reduce respiratory diseases

Reference Scenario



Electricity production



Policies – most critical

- Hard cap for large users going to zero by mid-century
- Sell all allowances
- Efficiency standards for buildings and transport sector (including cars, trucks)
- No subsidies for nuclear, fossil fuels, and biofuels from food
- Ban new coal fired power plants without carbon capture and storage.
- Large scale government performance-based purchases – like plug-in hybrids, zero-energy buildings – and demonstration plants.
- Federal contracting preferences for low CO_2 corporations
- Vigorous R&D

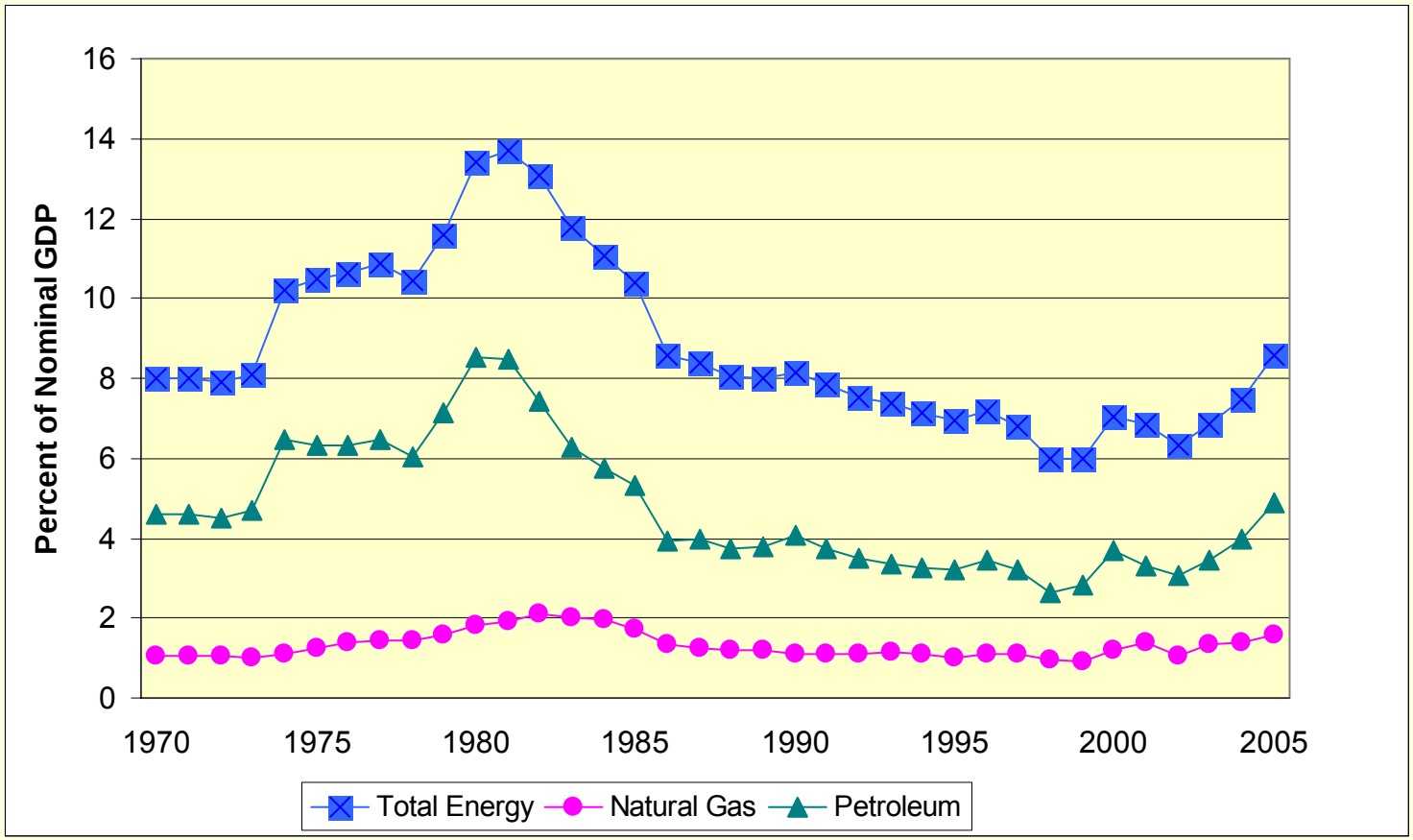
Key elements - recap

- Emphasis on building efficiency
- Plug-in hybrids and all-electric vehicles
- Parking lot and commercial rooftop solar PV
- Solar thermal with storage
- Distributed grid, in which wind, solar, hydro-standby natural gas/methane, and storage are coordinated.
- Aquatic plants for biofuels – solid, liquid, gas
- Distributed hydrogen production – electrolytic from wind
- Develop direct solar hydrogen – important R&D goal

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 ~40 percent renewables or more, build smart grid
- Phase 2: Add solar thermal with 12 hour storage, hot-rock geothermal, 100% solid biomass IGCC, natural gas standby
- Phase 3: V2G, stationary battery storage, compressed air storage, biomethane standby

Energy as Proportion of GDP – expected to remain ~8 percent of GDP in renewable economy



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

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 .

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