Evaluation of Energy Solutions to Global Warming, Air Pollution, and Energy Security

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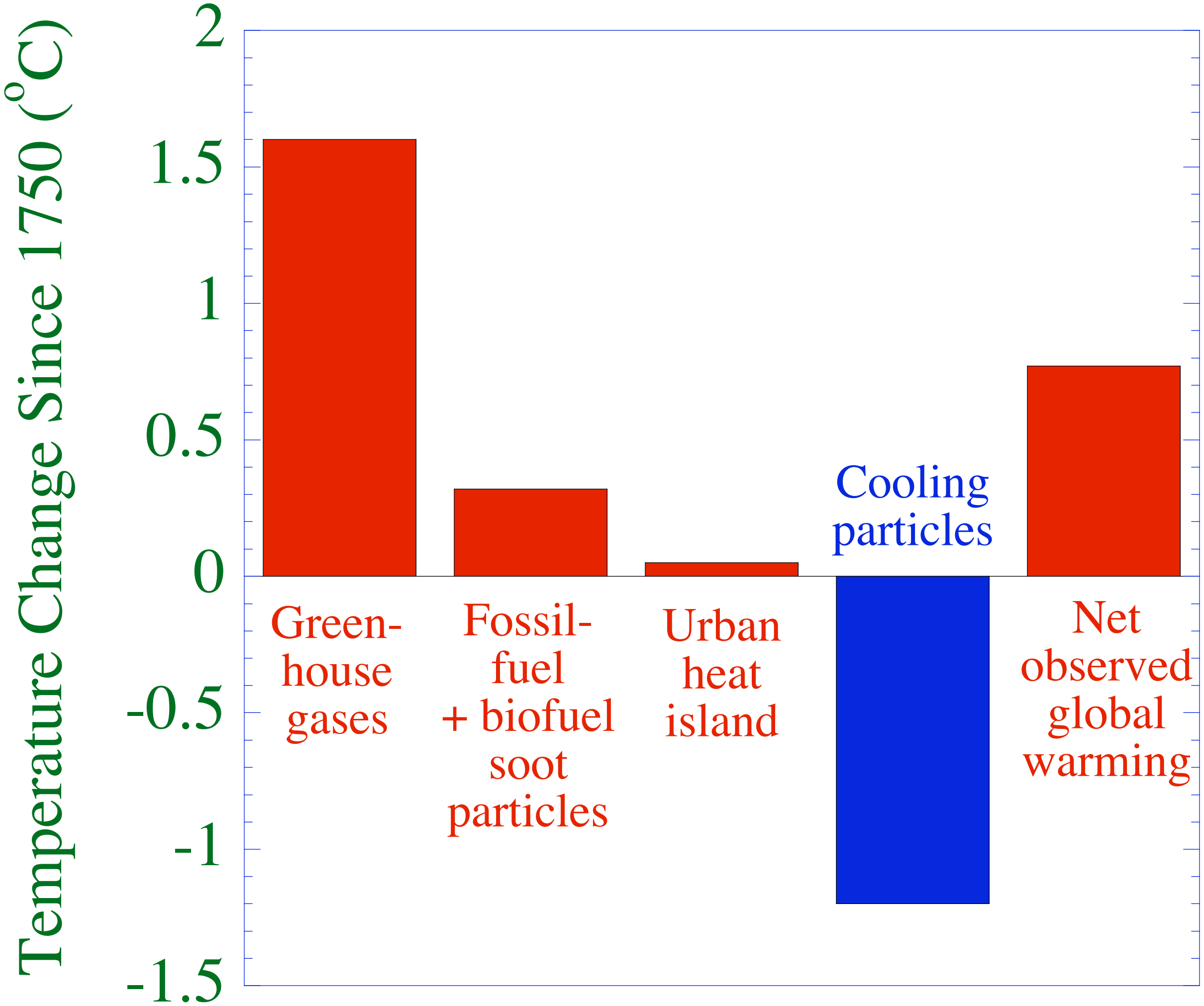
Causes of Global Warming



M.Z. Jacobson

Electricity/Vehicle Options Compared

Electricity for Power Generation, Battery Electric Vehicles (BEVs) or Hydrogen Fuel Cell Vehicles (HFCVs)

- Wind turbines
- Solar photovoltaics (PV)
- Geothermal power plants
- Tidal turbines
- Wave devices
- Concentrated solar power (CSP)
- Hydroelectric power plants
- Nuclear power plants
- Coal with carbon capture and sequestration (CCS)

Liquid Fuels for Flex-Fuel Vehicles

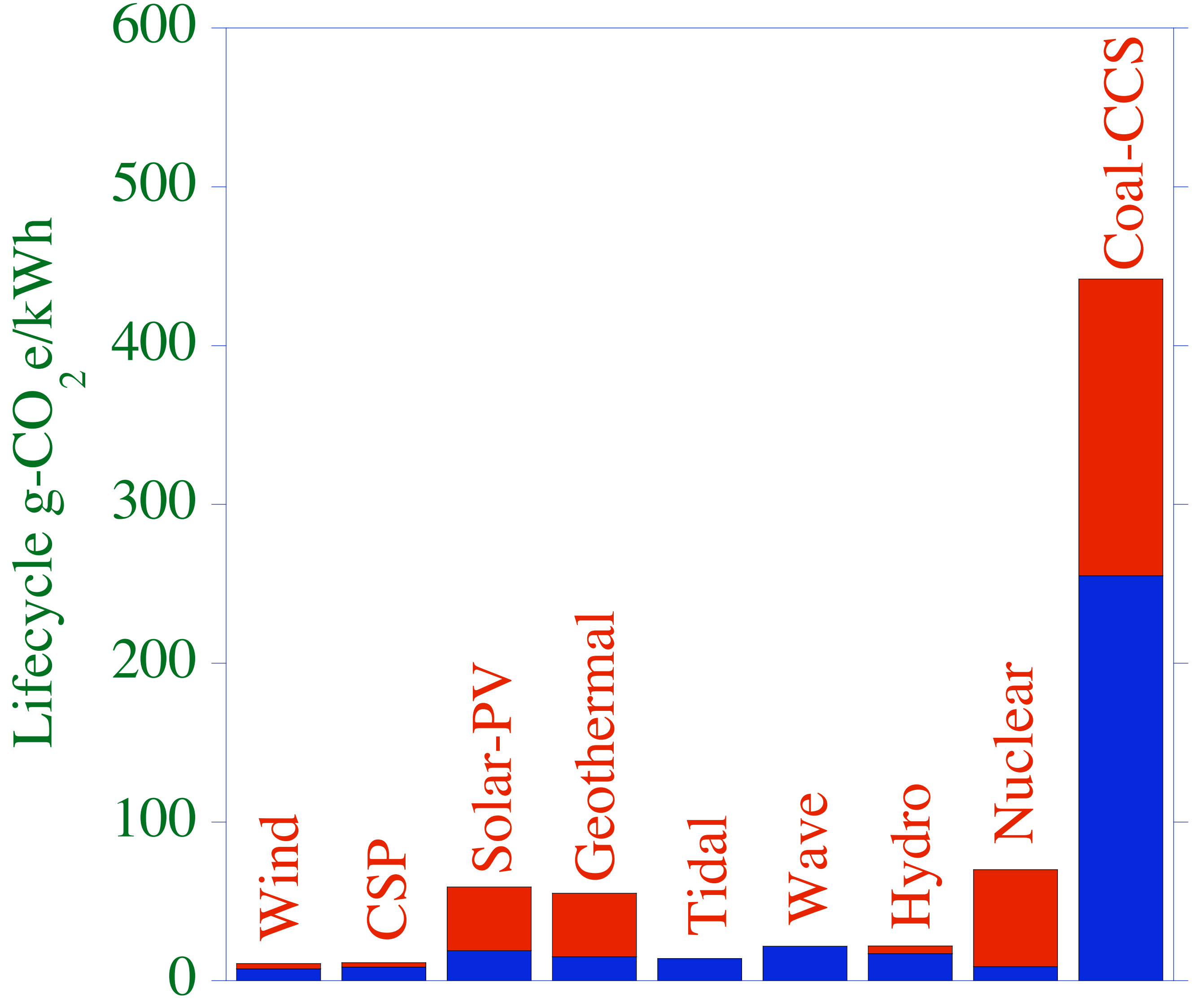
- Corn ethanol (E85)
- Cellulosic ethanol (E85)

Effects Examined

Resource abundance
Carbon-dioxide equivalent emissions
- Lifecycle
- Opportunity cost emissions from planning-to-operation delays
- Leakage from carbon sequestration
- Nuclear war / terrorism emission risk from nuclear-energy
- Carbon loss due to covering soil with energy structures

Air pollution mortality
Water consumption
Footprint on the ground
Spacing required
Effects on wildlife
Thermal pollution
Water chemical pollution / radioactive waste
Energy supply disruption
Normal operating reliability

Lifecycle CO_2e of Electricity Sources

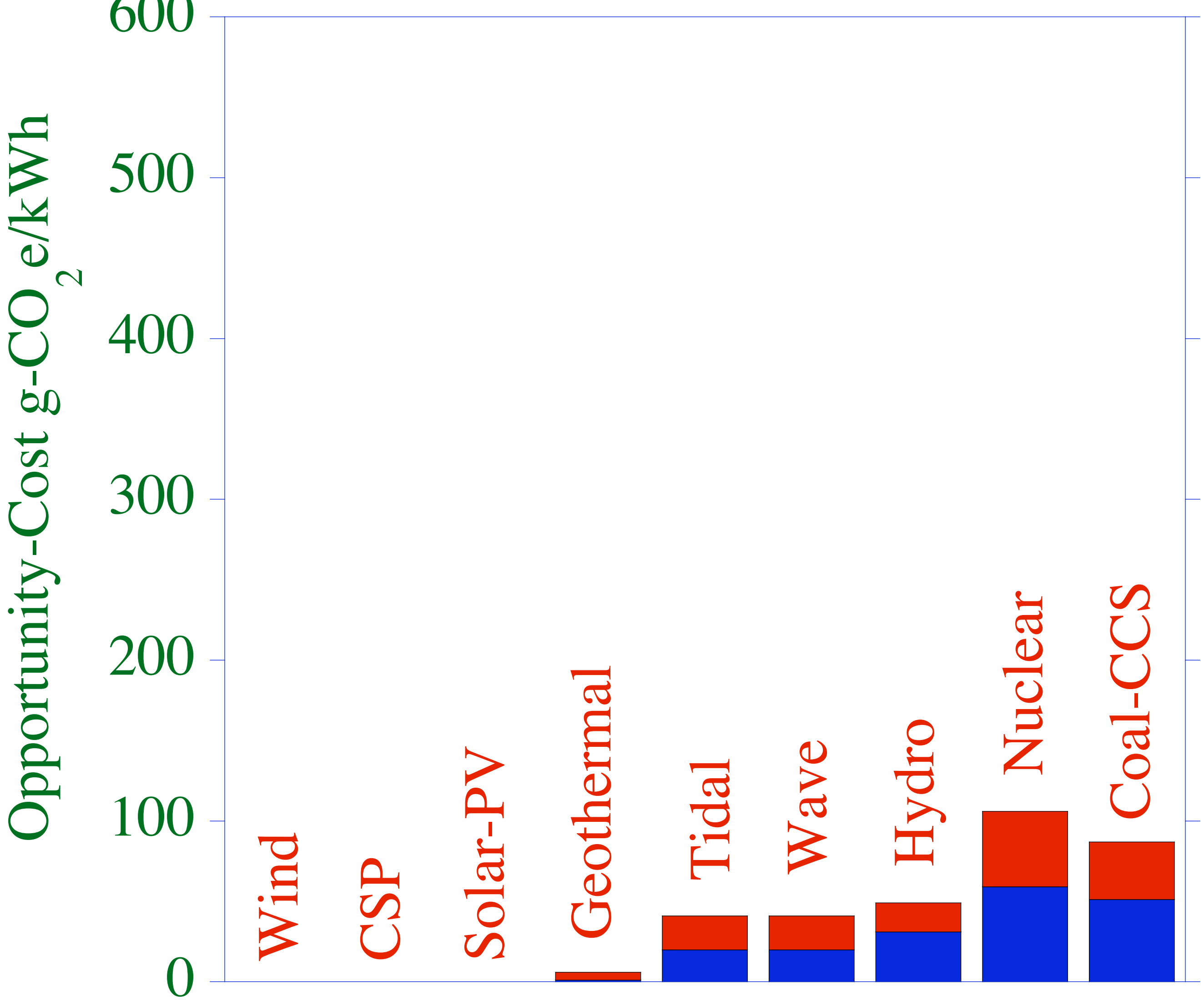


Time Between Planning & Operation

Nuclear:	10-19 y (lifetime 40 y)
Site permit (NRC): 3.5 y minimum with new regs. – 6 y	
Construction permit approval and issue 2.5-4 y	
Construction time 4-9 years (Low value Europe/Japan)	
Hydroelectric:	8-16 y (lifetime 80 y)
Coal-CCS:	6-11 y (lifetime 35 y)
Geothermal:	3-6 y (lifetime 35 y)
Ethanol:	2-5 y (lifetime 40 y)
CSP:	2-5 y (lifetime 30 y)
Solar-PV:	2-5 y (lifetime 30 y)
Wave:	2-5 y (lifetime 15 y)
Tidal:	2-5 y (lifetime 15 y)
Wind:	2-5 y (lifetime 30 y)

Opportunity-Cost CO_2e

Emissions from current electricity mix due to time between planning & operation of power source minus that from least-emitting power source



Nuclear Energy/Weapons Risks

“There is no technical demarcation between the military and civilian reactor and there never was one” (Los Alam. Rept. LA8969MS,UC-16)

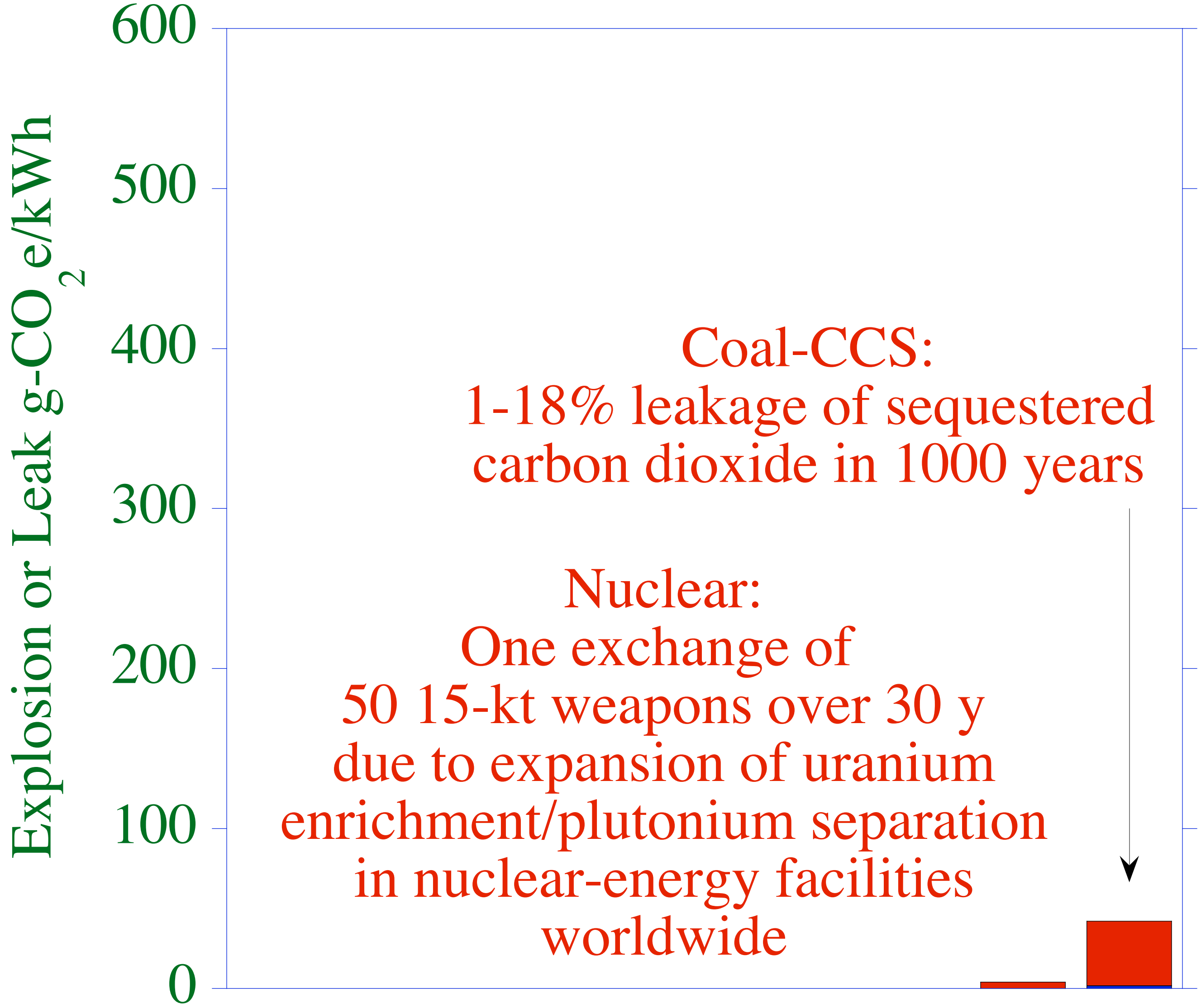
42 countries have fissionable material to produce weapons; 22 of these have facilities in nuclear energy plants to produce enriched uranium or to separate plutonium; 13 countries are actively doing so

9 countries have nuclear weapons stockpiles
(US, Russia, UK, France, China, India, Pakistan, Israel, N. Korea)

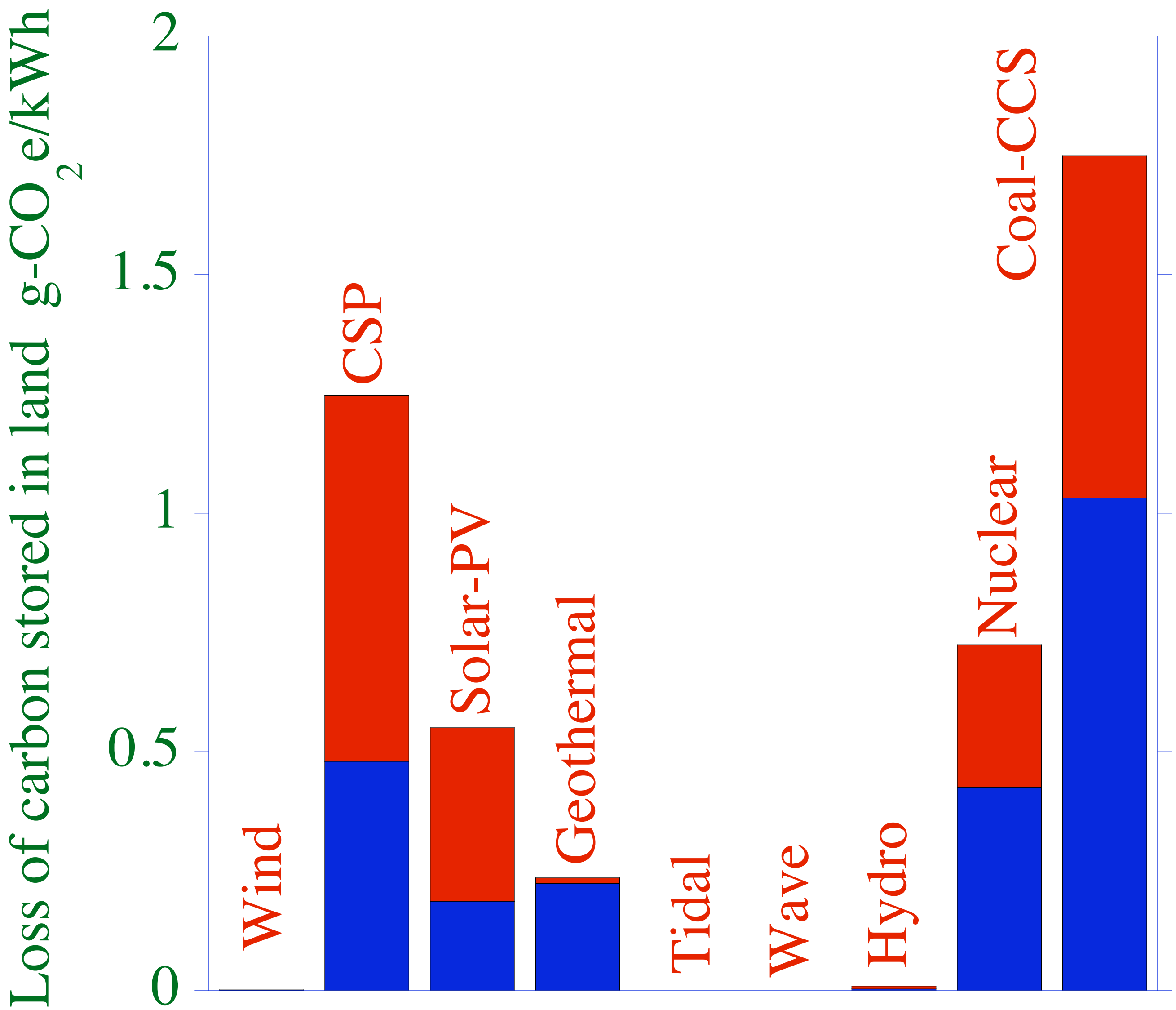
India, Pakistan, for example, developed nuclear weapons secretly in nuclear energy facilities whose components were sold by the nuclear energy industry to these countries.

→The large-scale expansion of nuclear energy worldwide will allow more countries to produce weapons-grade material and weapons as it has in the past, further increasing the risk of nuclear war and terrorism.

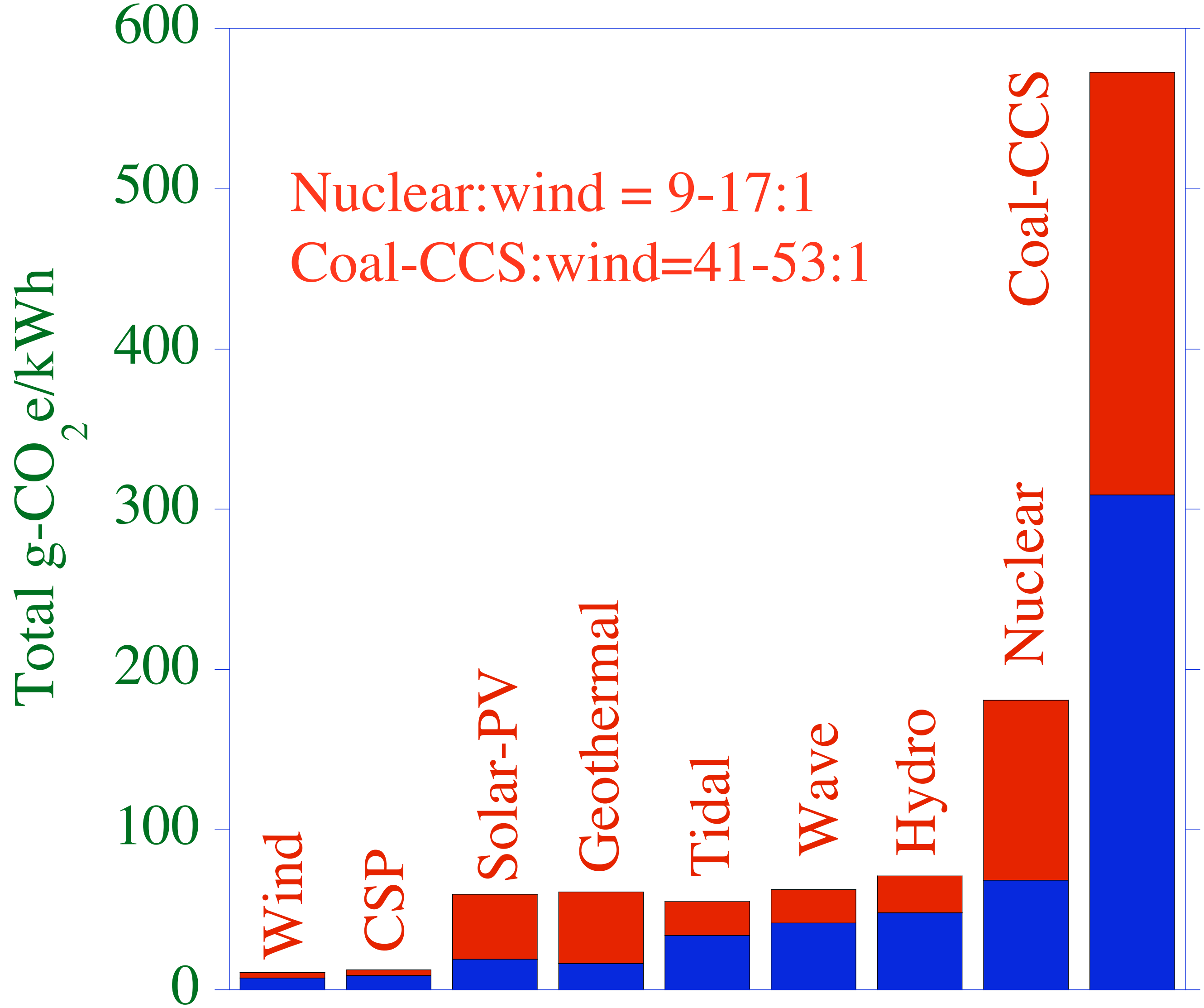
War/Leakage CO_2e of Nuclear, Coal



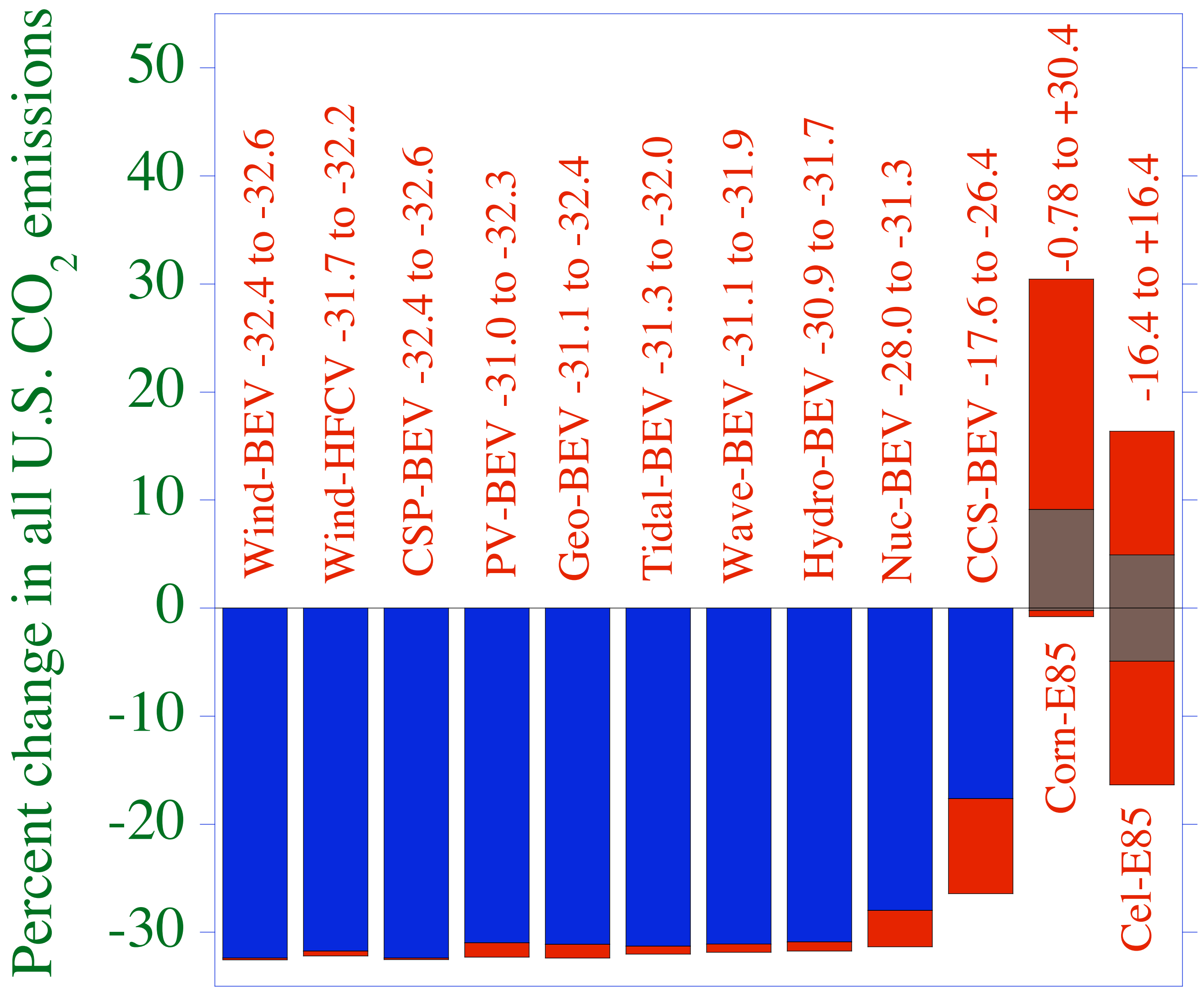
Loss of Carbon Stored in Land



Total CO_2e of Electricity Sources



Percent Change in U.S. CO_2 From Converting to BEVs, HFCVs, or E85

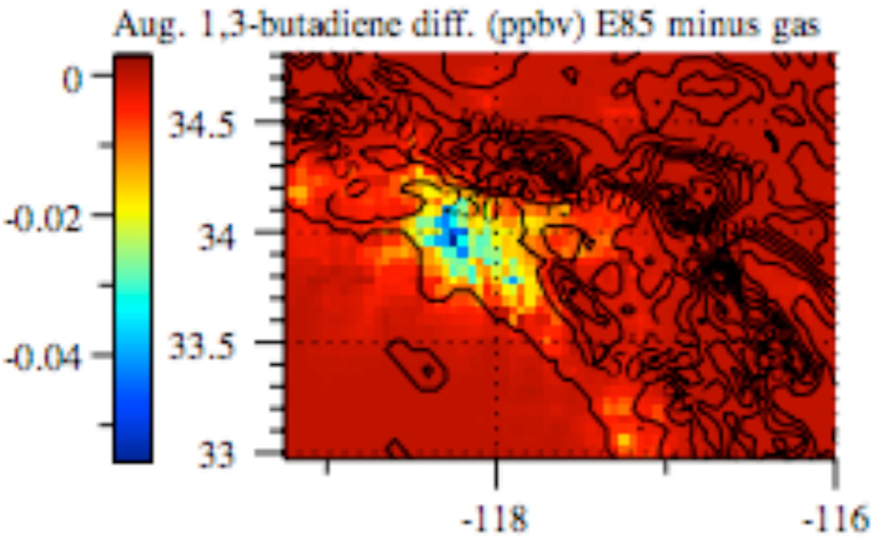


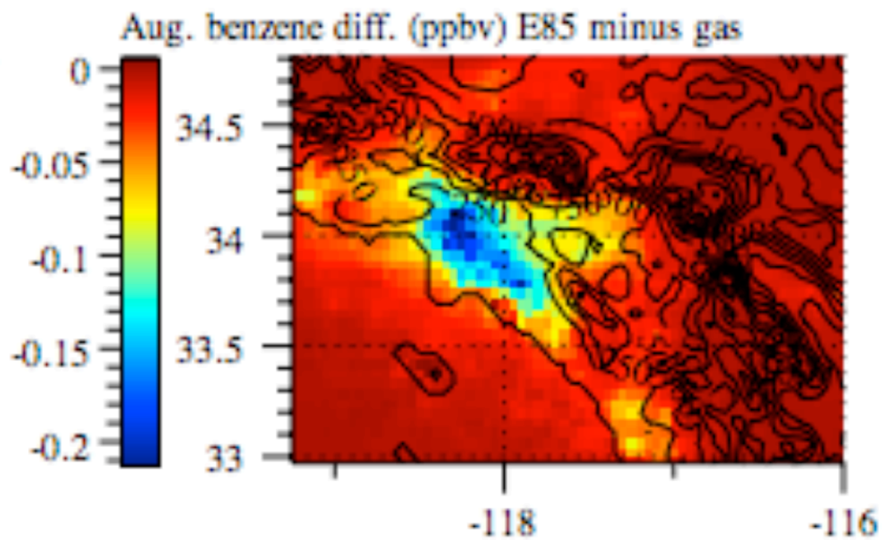
Percent Changes E85 Minus Gas From Data

NMOG	+ 45%
NO_x	- 30%
Benzene	- 64%
1,3-butadiene	- 66%
Acetaldehyde	+ 4500%
Formaldehyde	+ 200%

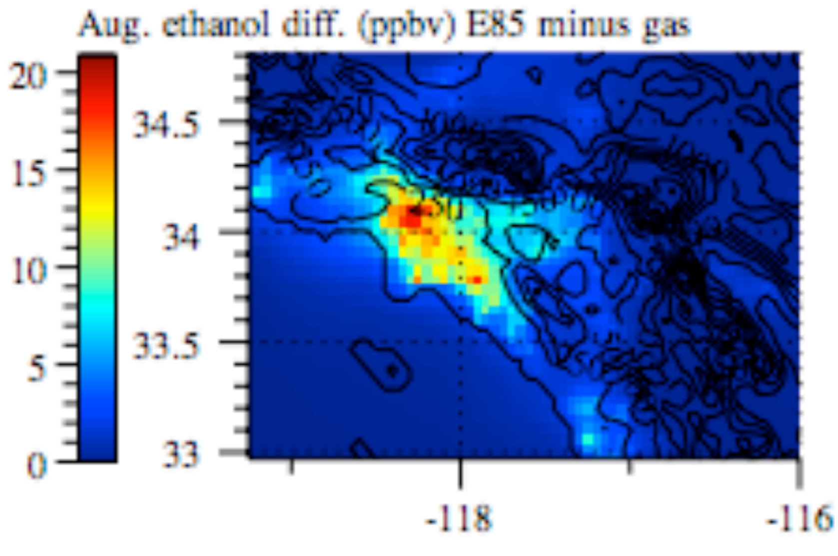
Whitney (2007)

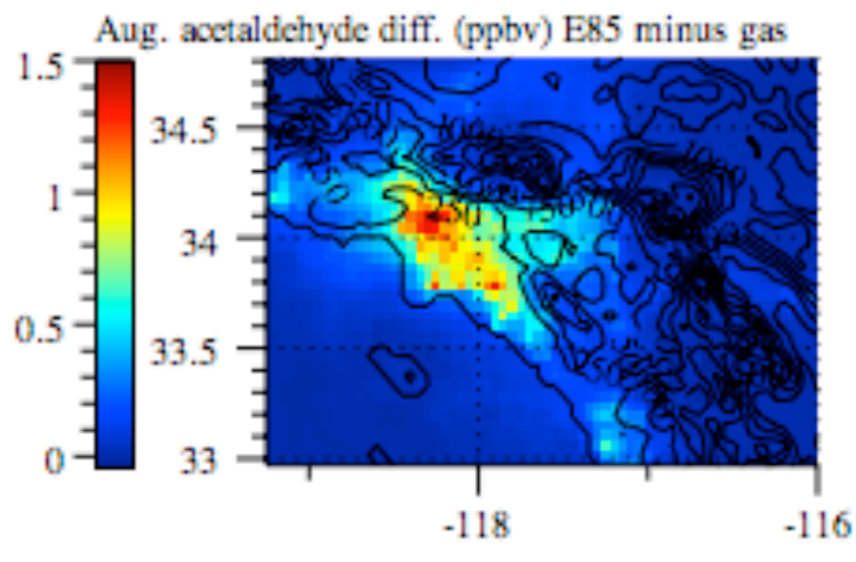
Effect in 2020 of E85 vs. Gasoline on 1,3-Butadiene and Benzene



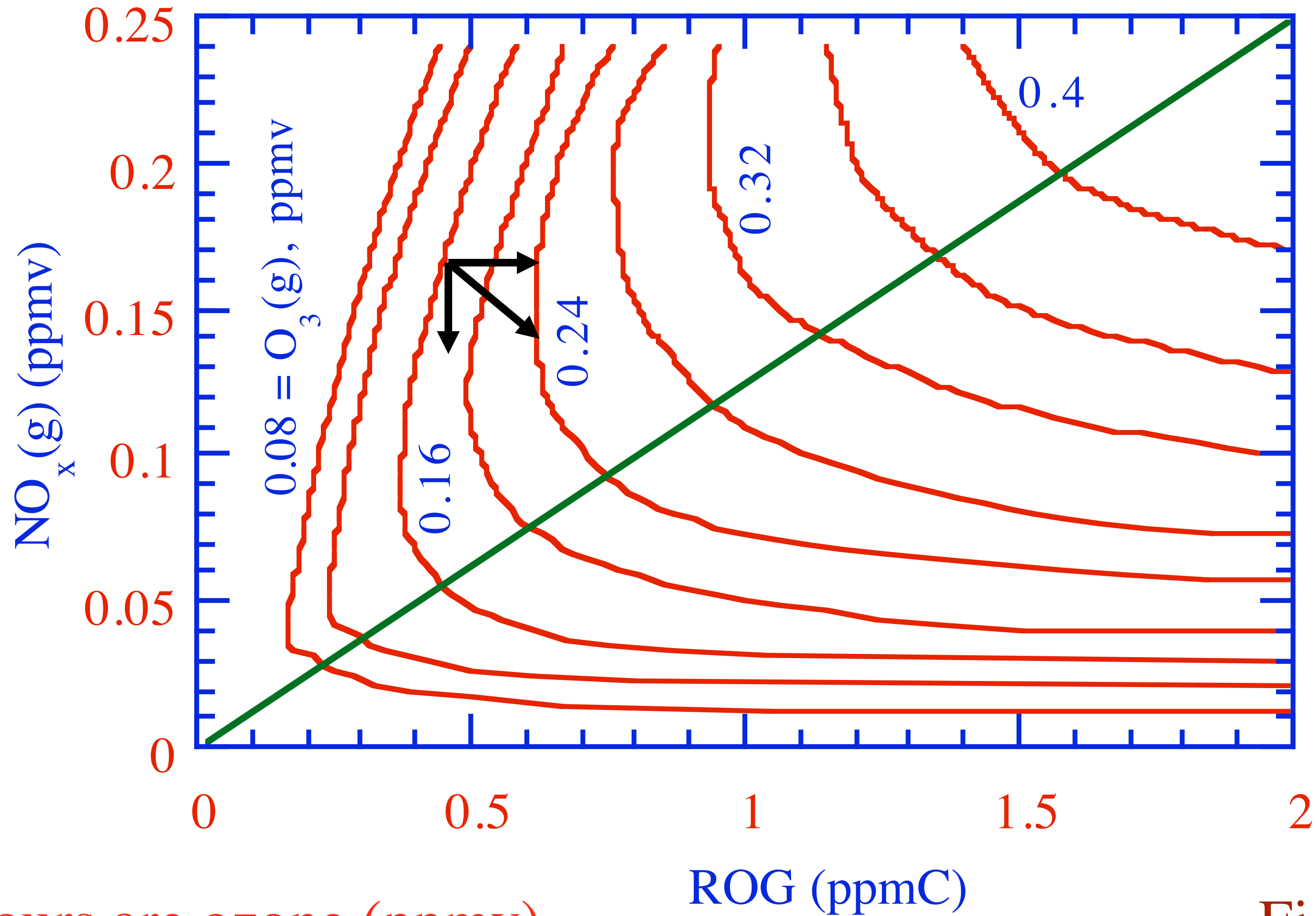


Effect in 2020 of E85 vs. Gasoline on Ethanol and Acetaldehyde





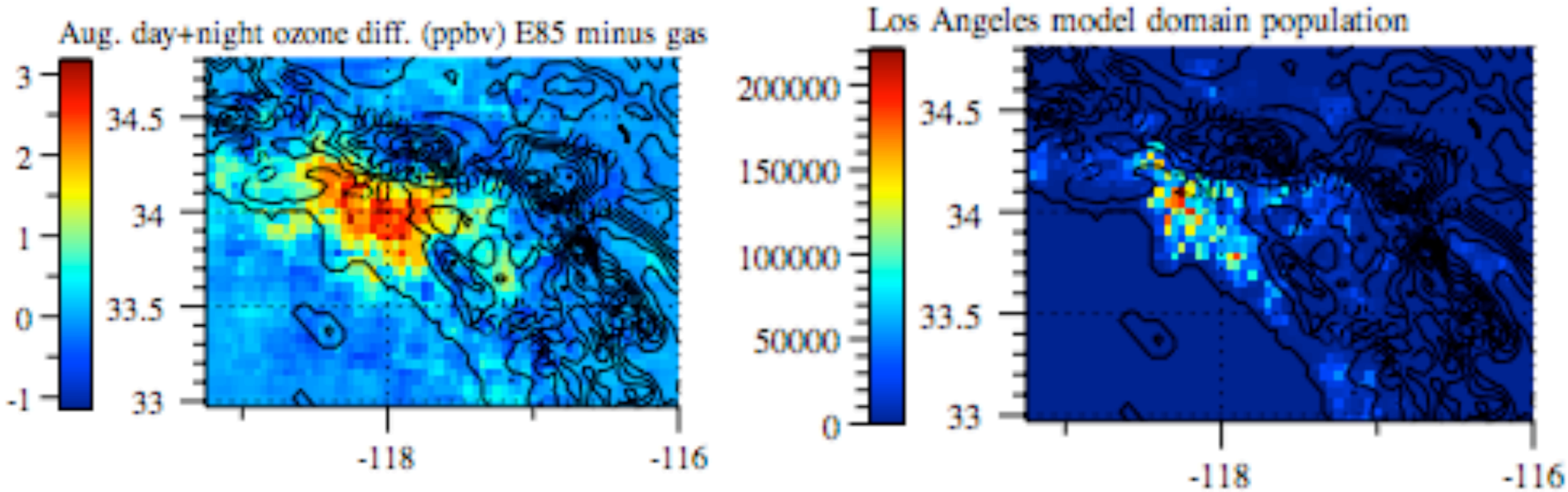
Ozone isopleth



Contours are ozone (ppmv)

Figure 4.9

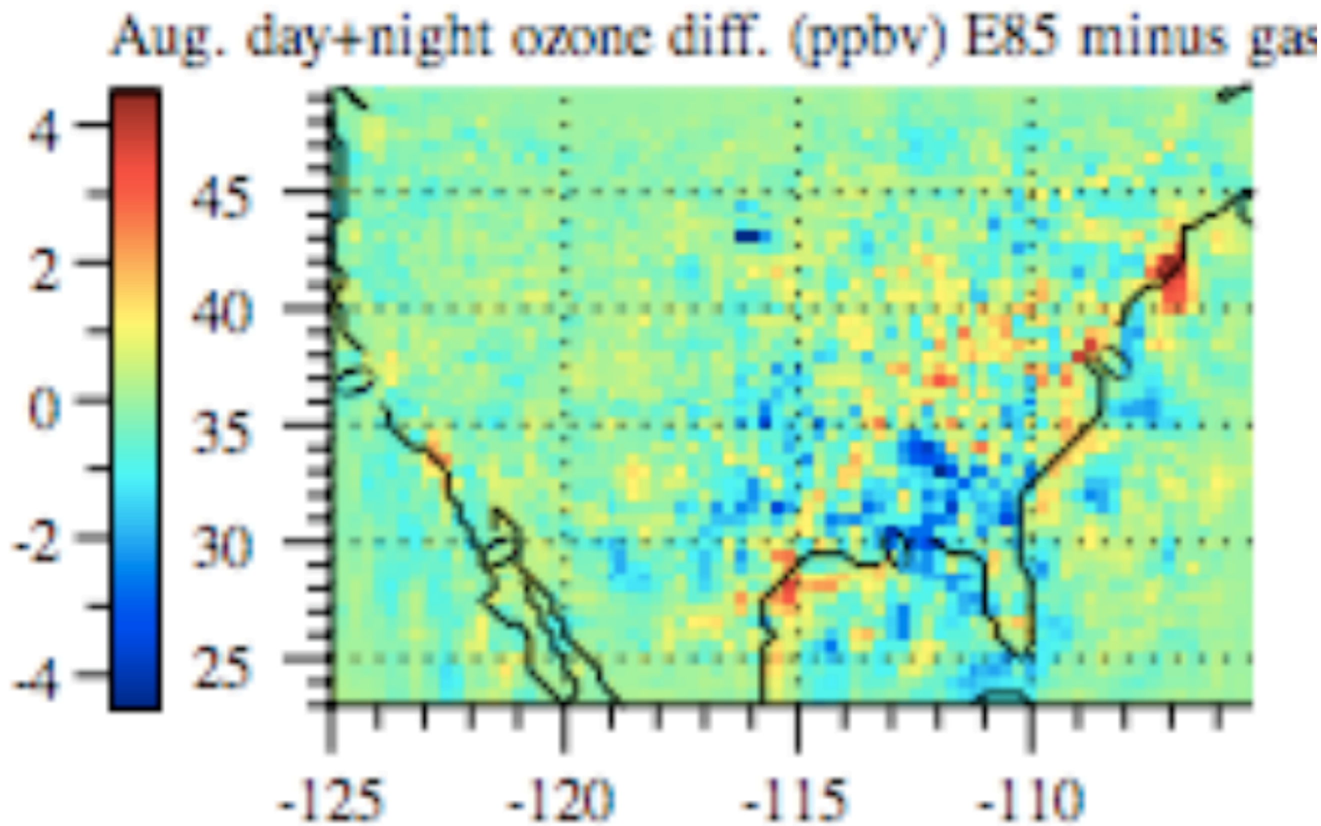
Effect in 2020 of E85 vs. Gasoline on Ozone and Health in Los Angeles



Change in ozone deaths/yr due to E85: +120 (+9%) (47-140)

Changes in cancer/yr due to E85: -3.5 to +0.3

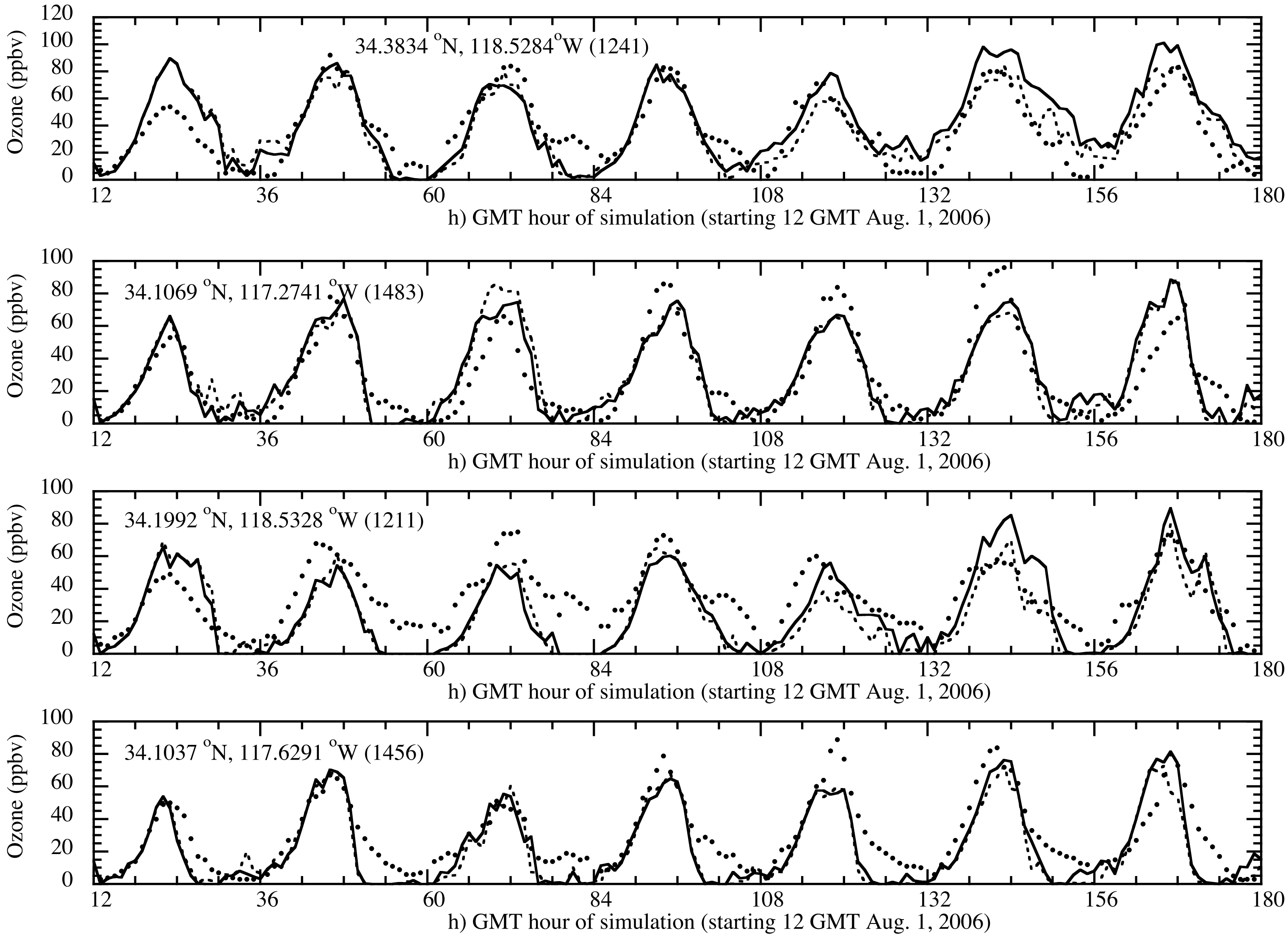
2020 U.S. Effects of E85 vs. Gasoline



Additional ozone deaths/yr: +185 (72-213)

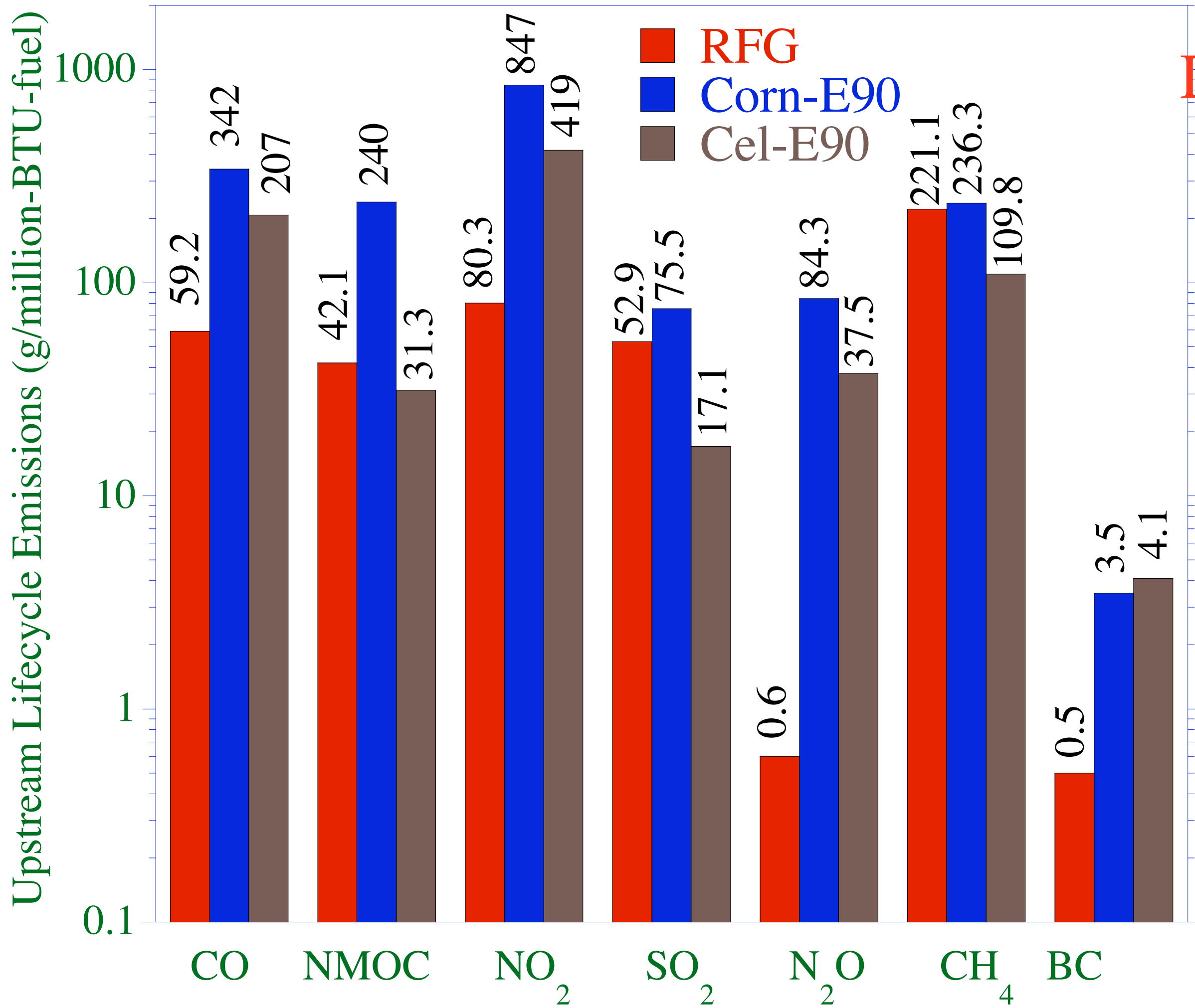
E85, regardless of source, causes as much or more U.S. air pollution mortality from the tailpipe as gasoline

Modeled vs. Observed L.A. O_3



Solid; dashed = modeled with or no emittedCO_2; dots=data (EPA)

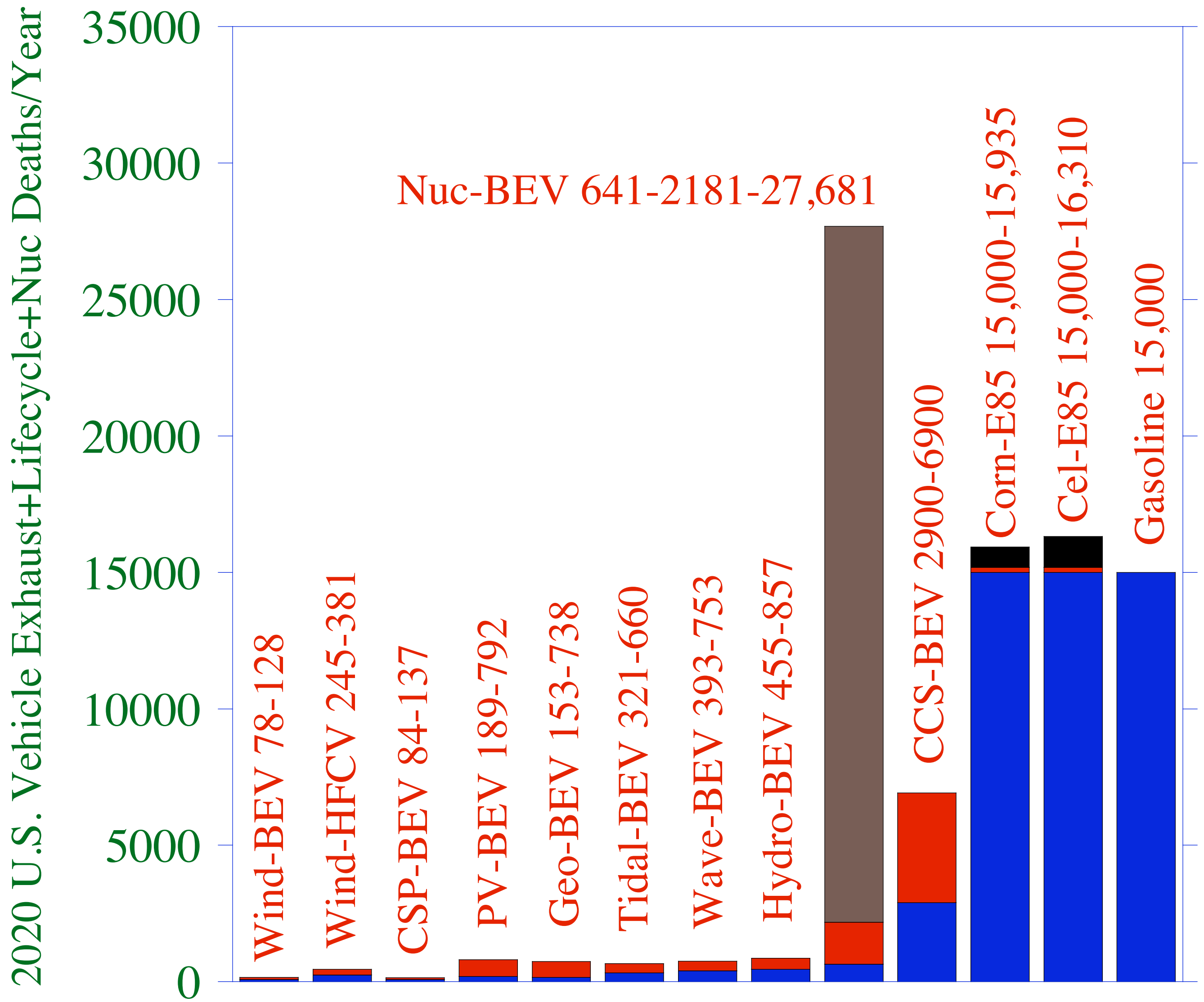
Upstream Lifecycle Emissions Gasoline, Corn-E90, Cellulosic-E90



DeLucchi, 2006

Cell and corn E85 may increase upstream PM over gasoline by 7-8 x.

Low/High U.S. Air Pollution Deaths For 2020 BEVs, HFCVs, E85, Gasoline



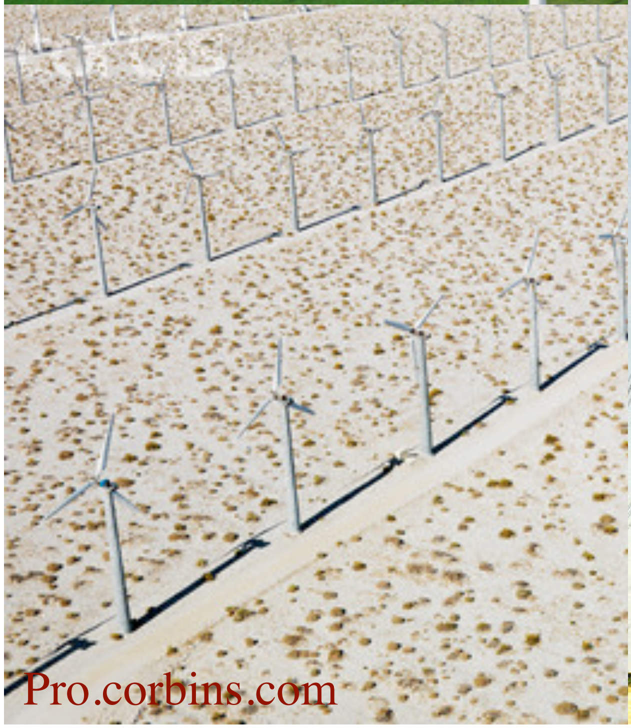
Ratio of Footprint Area of Technology to Wind-BEVs to Run All U.S. Vehicles

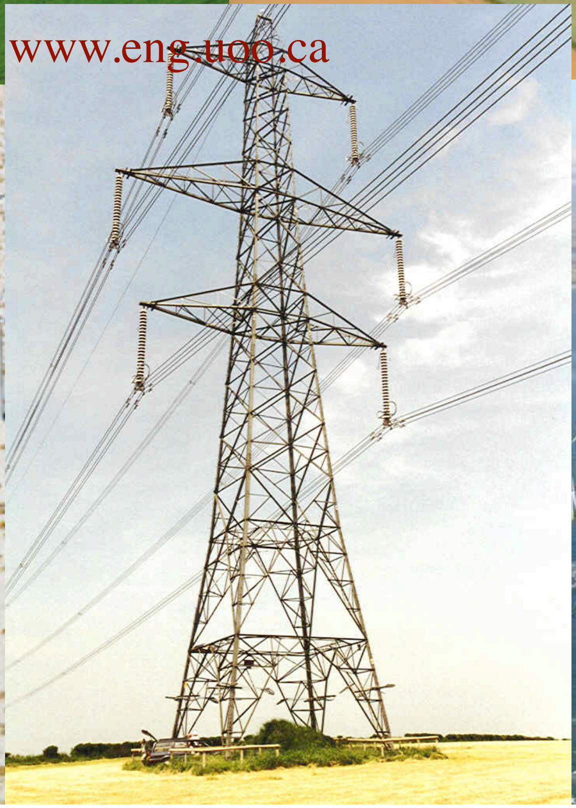
Wind-BEV	1:1 (1-3 square kilometers)
Wind-HFCV	3-3.1:1
Tidal-BEV	100-130:1
Wave-BEV	240-440:1
Geothermal-BEV	250-570:1
Nuclear-BEV	770-1100:1
Rhode Island	960-3000:1
Coal-CCS-BEV	1900-2600:1
PV-BEV	5800-6600:1
CSP-BEV	12,200-13,200:1
Hydro-BEV	84,000-190,000:1
California	143,000-441,000:1
Corn-E85	570,000-940,000:1
Cellulosic-E85	470,000-1,150,000:1

Wind Footprints


Pro.corbins.com

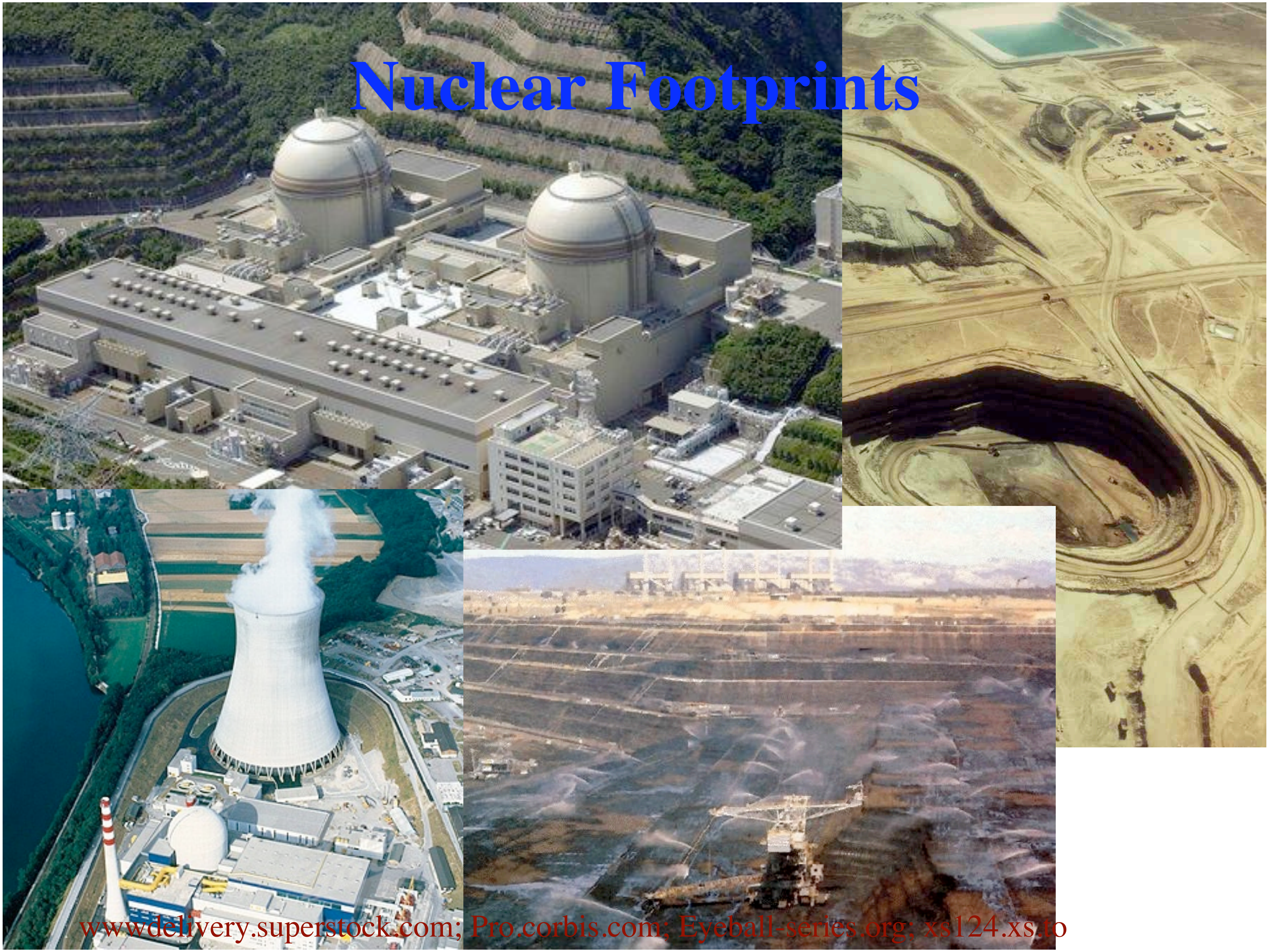

www.npower-renewables.com


Pro.corbins.com


www.eng.uoo.ca


www.offshore-power.net

Nuclear Footprints



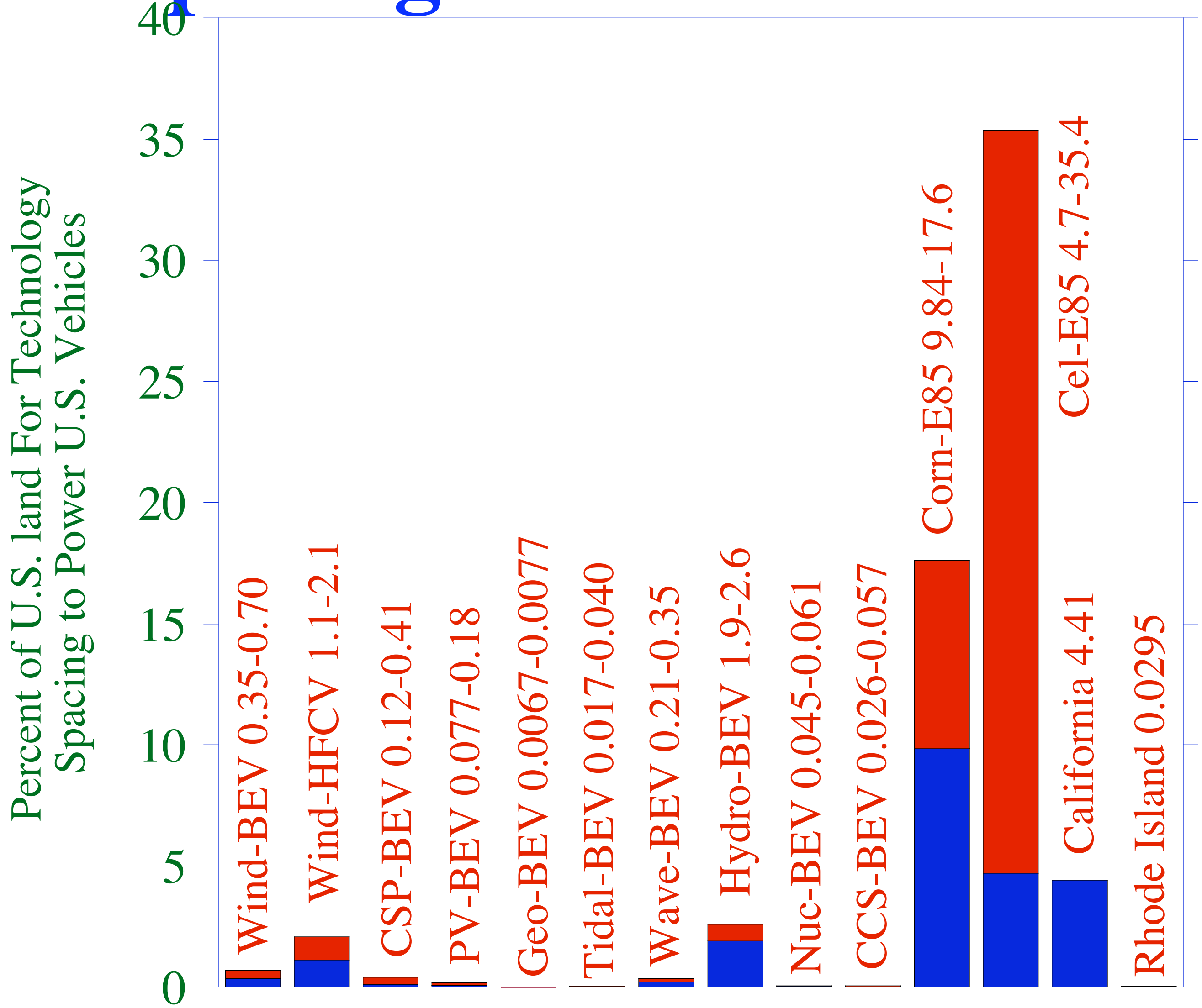
www.delivery.superstock.com; Pro.corbis.com; Eyeball-series.org; xs124.xs.to

Ethanol Footprints

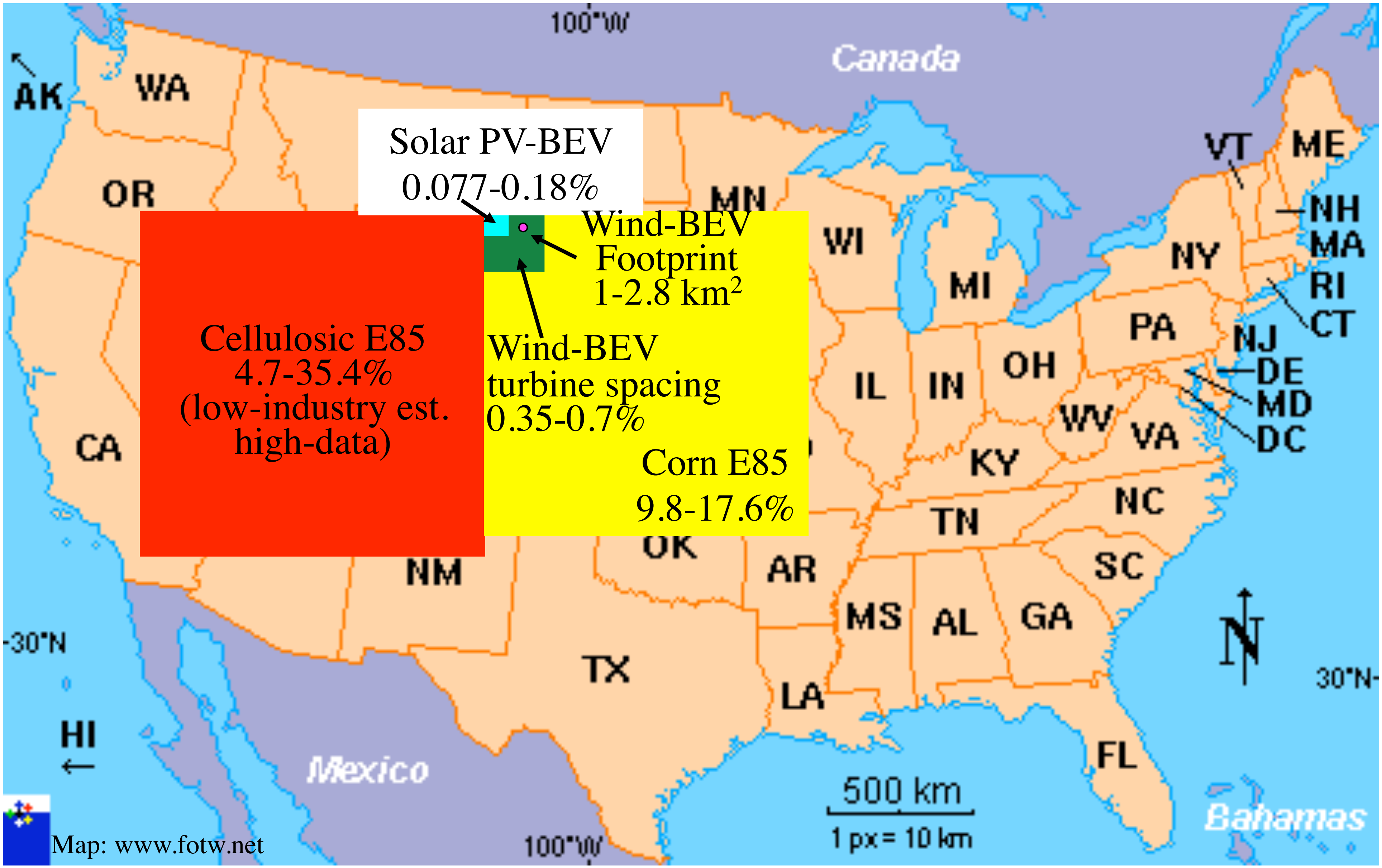
Cellulosic refinery development

www.k0lee.com; amadeo.blog.com; www.istockphoto.com; www.thereisaway.us; media-2.web.britannica.com

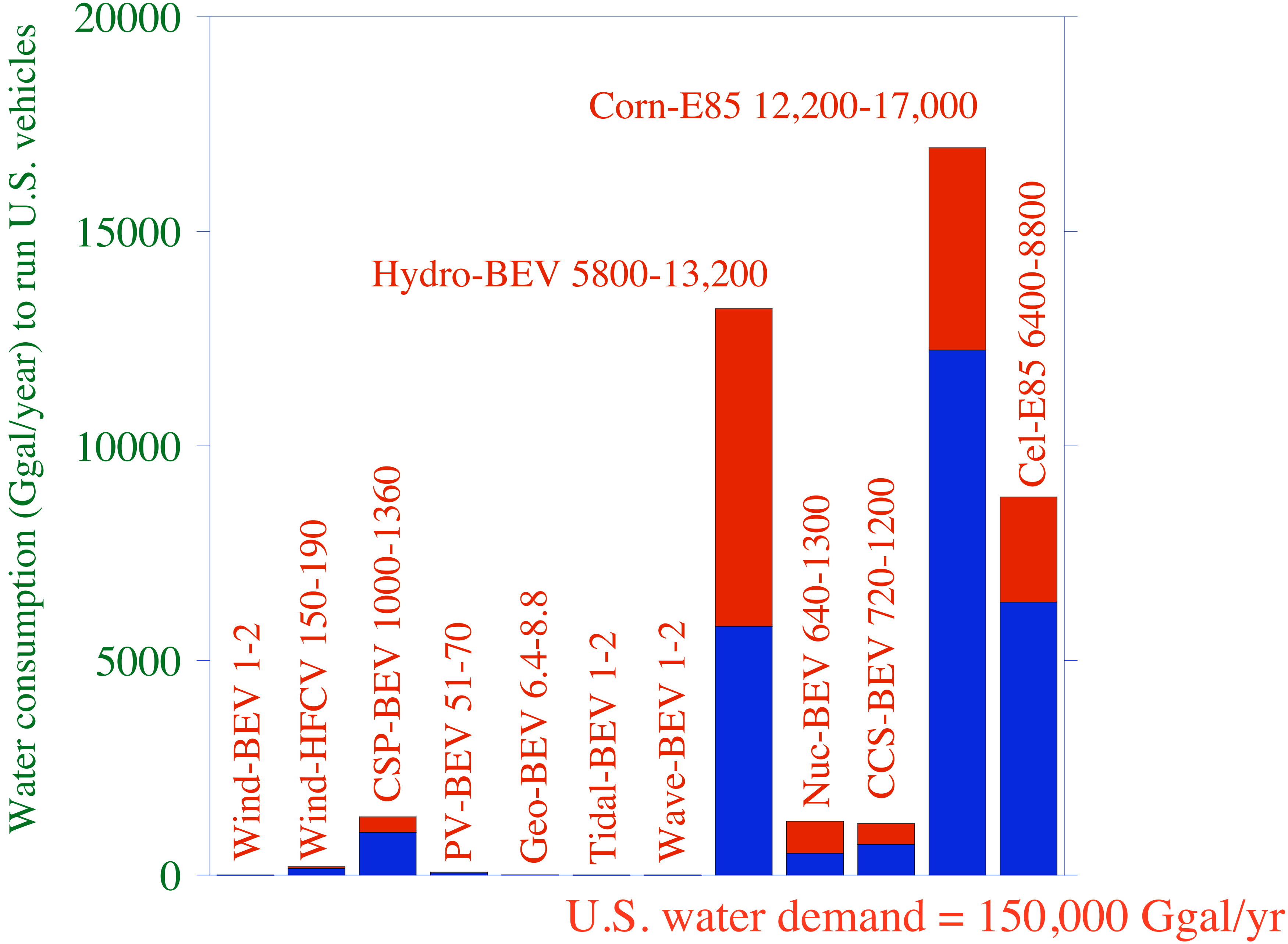
Percent of U.S. (50 states) for Footprint + Spacing to Run U.S. Vehicles



Area to Power 100% of U.S. Onroad Vehicles



Water Consumed to Run U.S. Vehicles



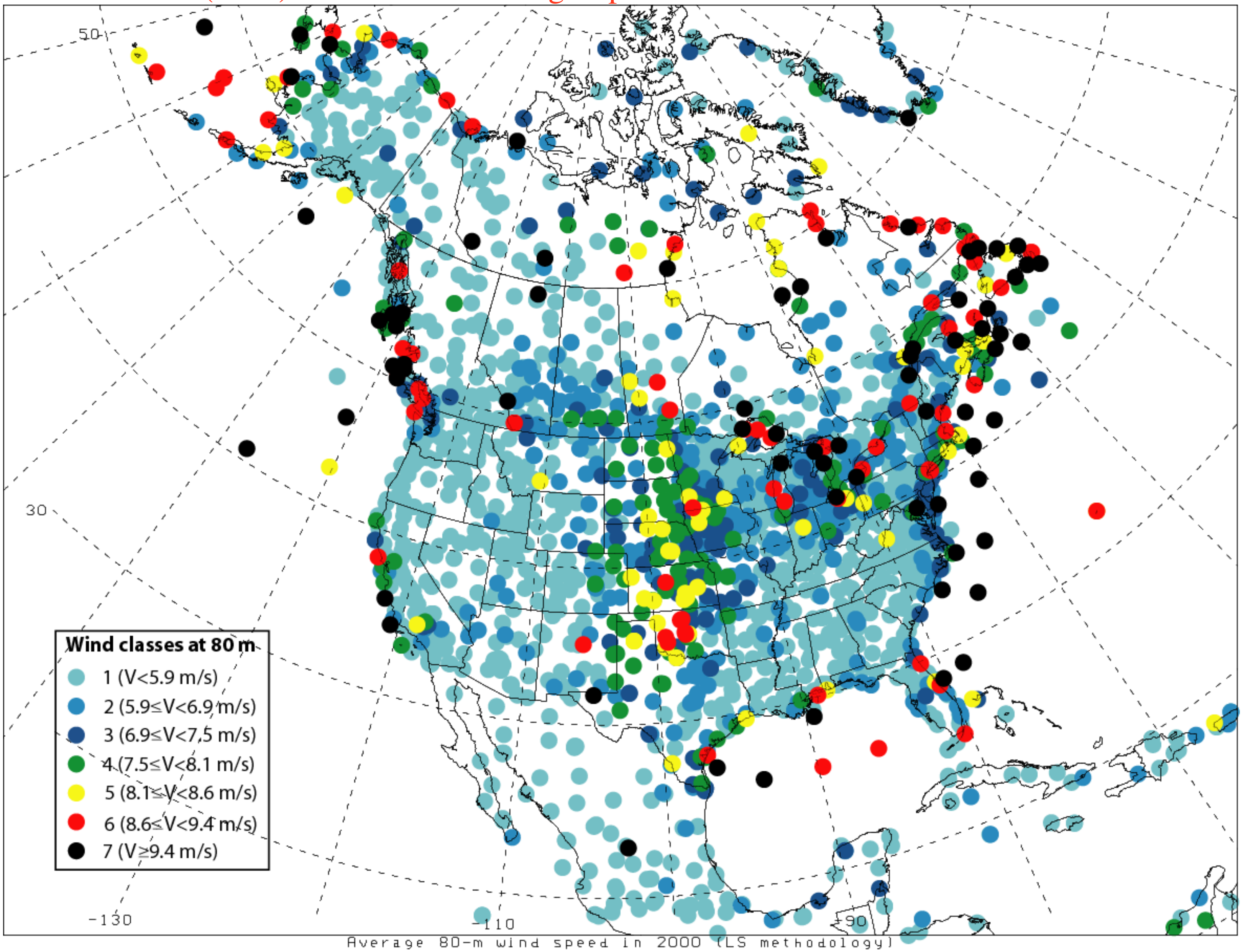
Global Wind, Solar Availability

	Max	Potential	Current
Wind over land > 6.9 m/s (TW)	70-110	40-60	0.02
Solar over land (TW)	1700	340	0.001

Global electric power demand (TW)	1.6-1.8
Global overall power demand (TW)	9.4-13.6

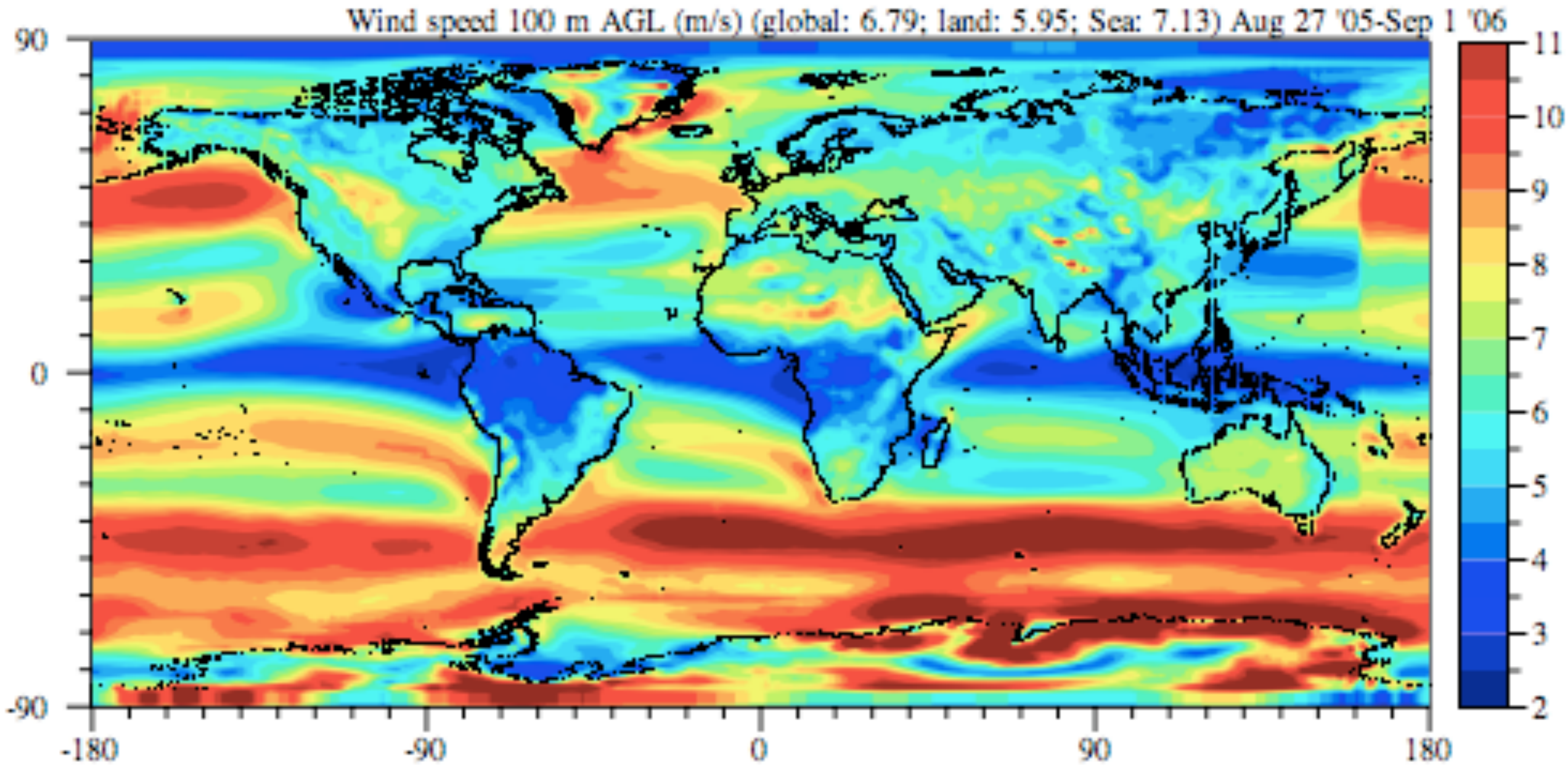
80-m Wind Speeds From Data

Archer and Jacobson (2005) www.stanford.edu/group/efmh/winds/

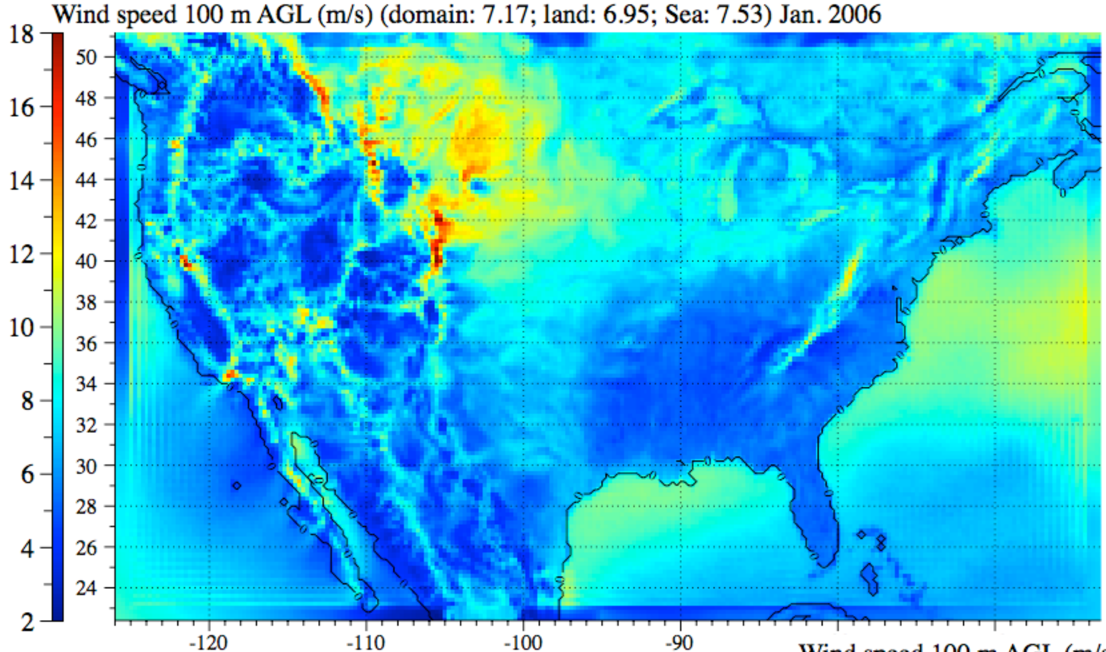


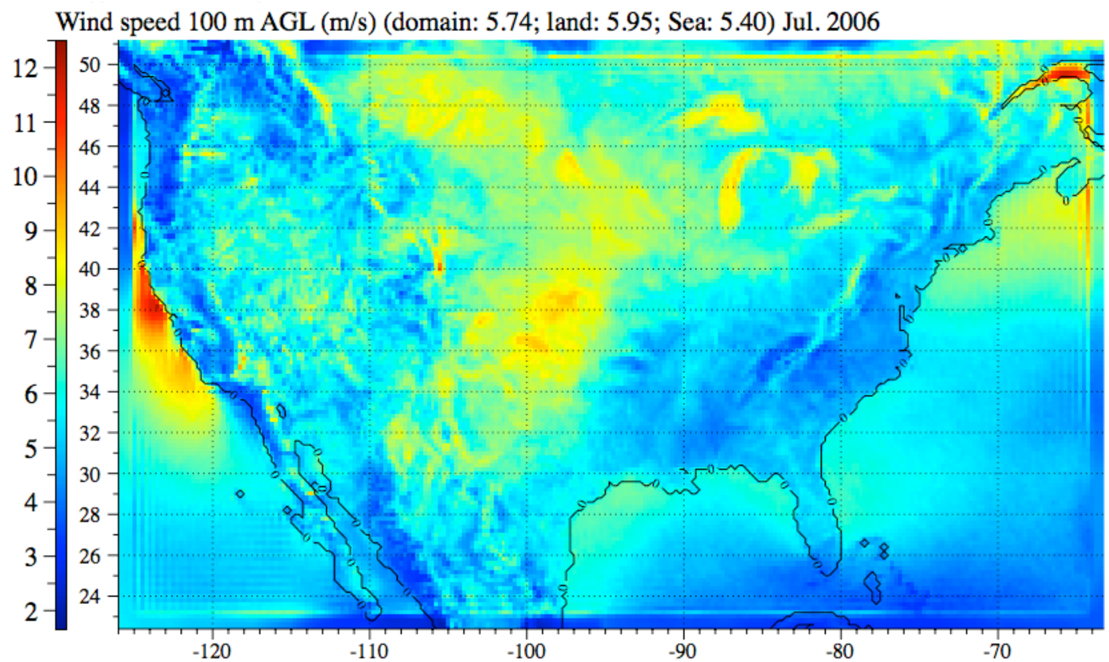
Modeled Wind Speeds at 100 m

The modeled wind power over land outside Antarctica where wind speed > 6.9 m/s is ~ 80 TW

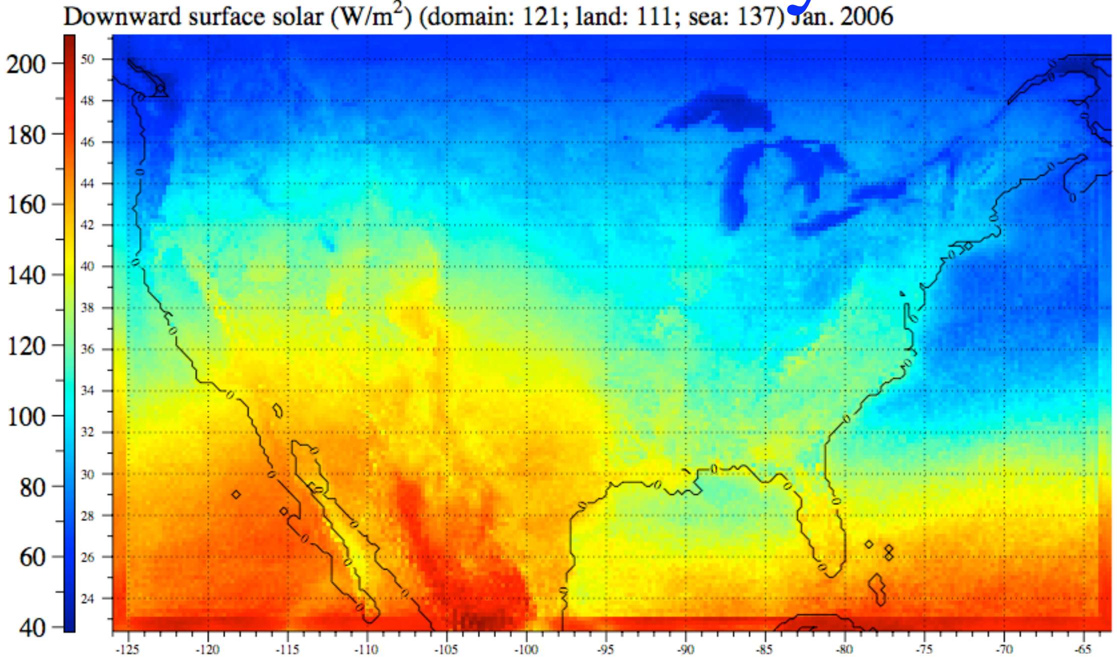


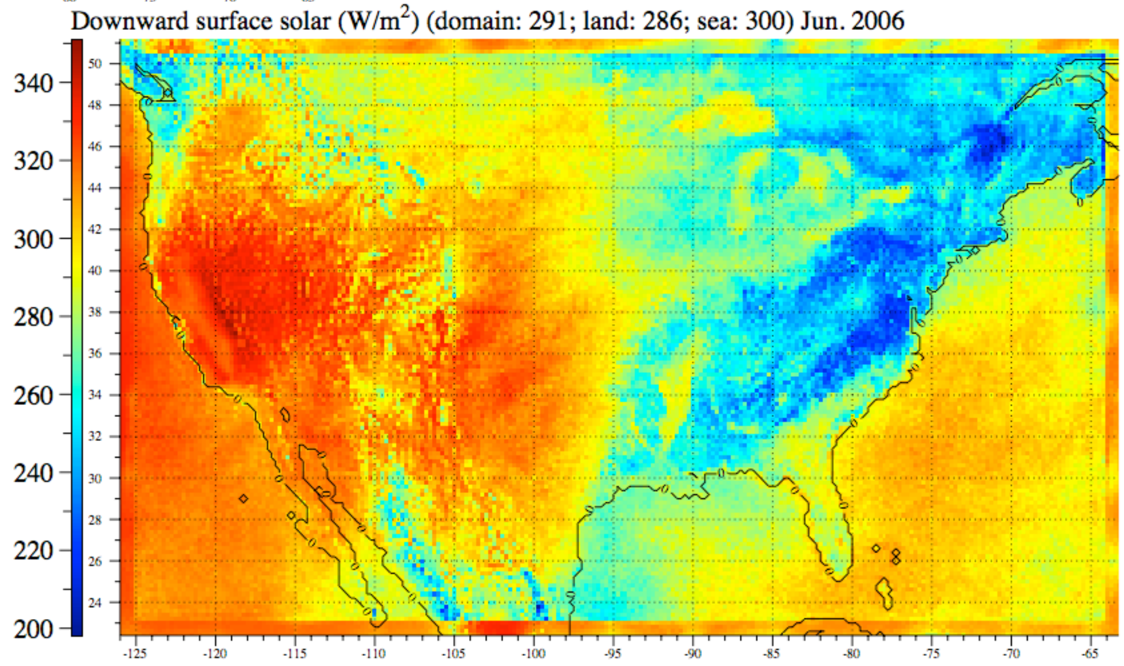
Modeled Jan/July U.S. 100-m Wind Speeds



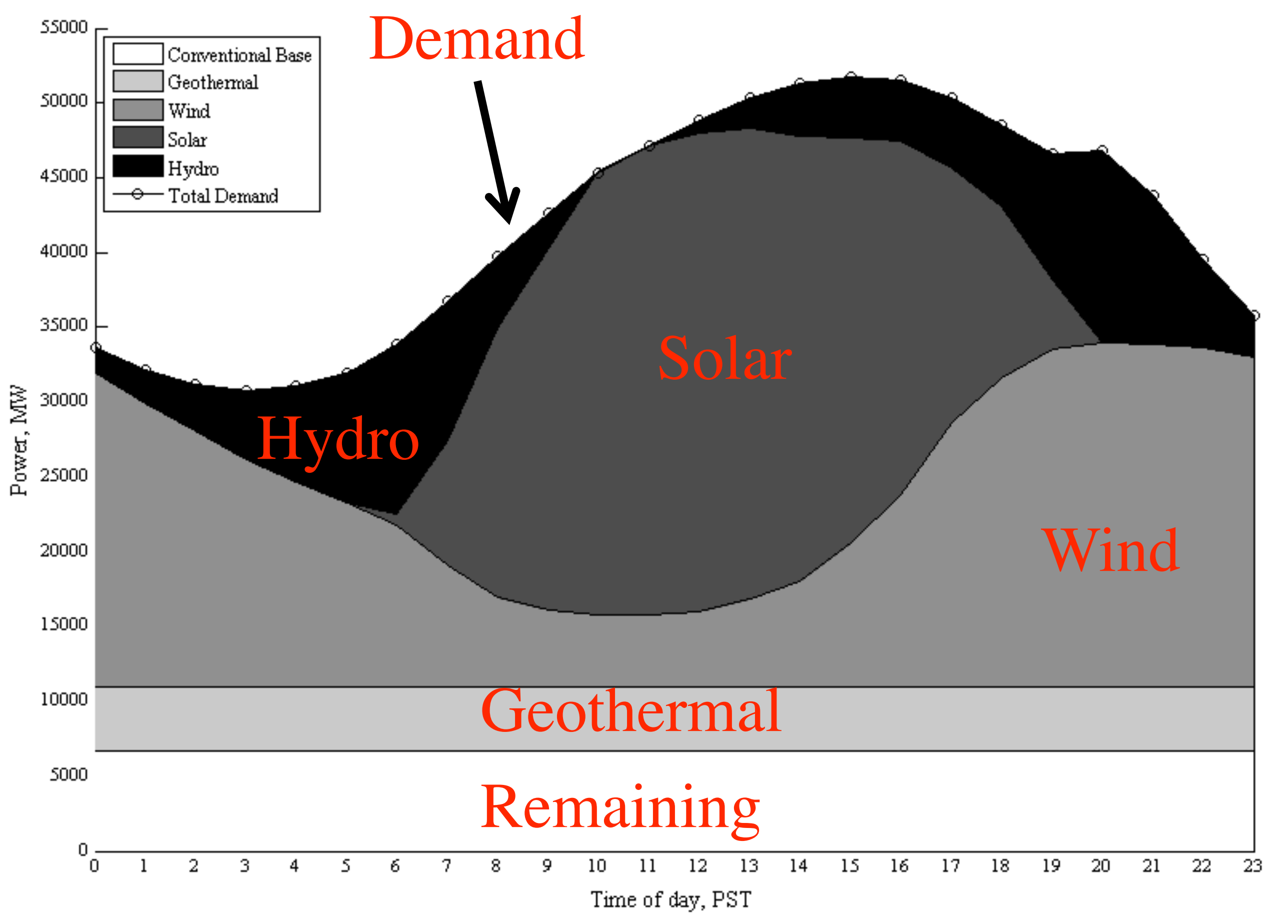


Modeled Jan/July U.S. Down Surf. Solar



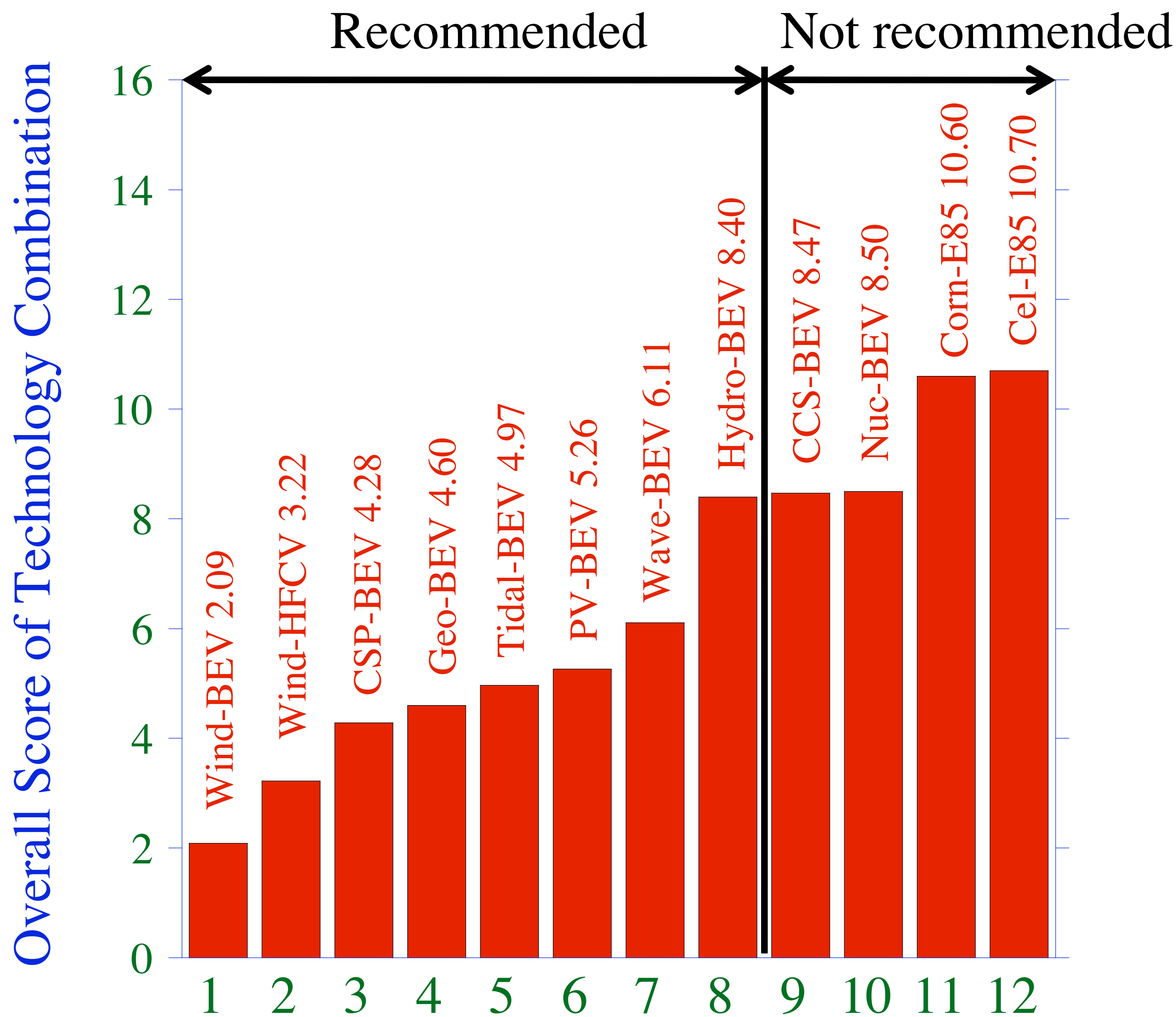


Matching Hourly Electricity Demand in Summer 2020 With 80% Renewables with no change in current hydro



Hoste et al. (2008)

Overall Scores/Rankings (Lowest is Best)



Summary

The use of wind CSP, geothermal, tidal, PV, wave, and hydro to provide electricity for battery-electric and hydrogen fuel cell vehicles and, by extension, electricity for the residential, industrial, and commercial sectors, will result in the greatest reductions in global warming, air pollution, and other externality effects among the energy options considered here. The combination of these technologies should be advanced as a solution to global warming, air pollution, and energy security.

Coal-CCS and nuclear offer less benefit thus represent a climate and health opportunity cost loss compared with the recommended options and should not be advanced over these other options. Coal-CCS emits 41-53 times more carbon, and nuclear emits 9-17 times more carbon than wind.

Corn and cellulosic ethanol appear to provide the greatest negative impacts among the options considered, thus their advancement at the expense of other options will severely damage efforts to solve global warming and air pollution problems.

www.stanford.edu/group/efmh/jacobson/revsolglobwarmairpol.htm
Energy Environ. Sci. (2008) doi:10.1039/b809990C

Summary

	CO_2e (% US Reduction)	Human Mortality (Deaths/yr)	Footprint (km^2)	Water (% of US Demand)
Wind-BEV	-32.4 to -32.6	78-128	<3	0.0001
Nuclear-BEV	-28 to -31.3	640-2200 -28,000	990-2170	0.34-0.84
Coal-CCS-BEV	-17.6 to -26.4	2900-6900	2400-5200	0.50-0.80
Corn-E85	-0.8 to +30.4	15,000-16,000	0.9-1.6 mil.	8.2-11.3
Cel-E85	-16.4 to +16.4	15,000-16,300	0.43-3.2 mil.	4.3-5.9