A Plan For a Sustainable Future

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Steps in Analysis

1. Rank climate, pollution, energy solutions in terms of

Resource abundance

Carbon-dioxide equivalent emissions

Air pollution mortality

Water consumption

Footprint on the ground and total spacing required

Ability to match peak demand

Effects on wildlife, thermal pollution, water pollution

2. Evaluate replacing 100% of energy with best options in terms of resources, materials, matching supply, costs, politics

Electricity/Vehicle Options Studied

Electricity options

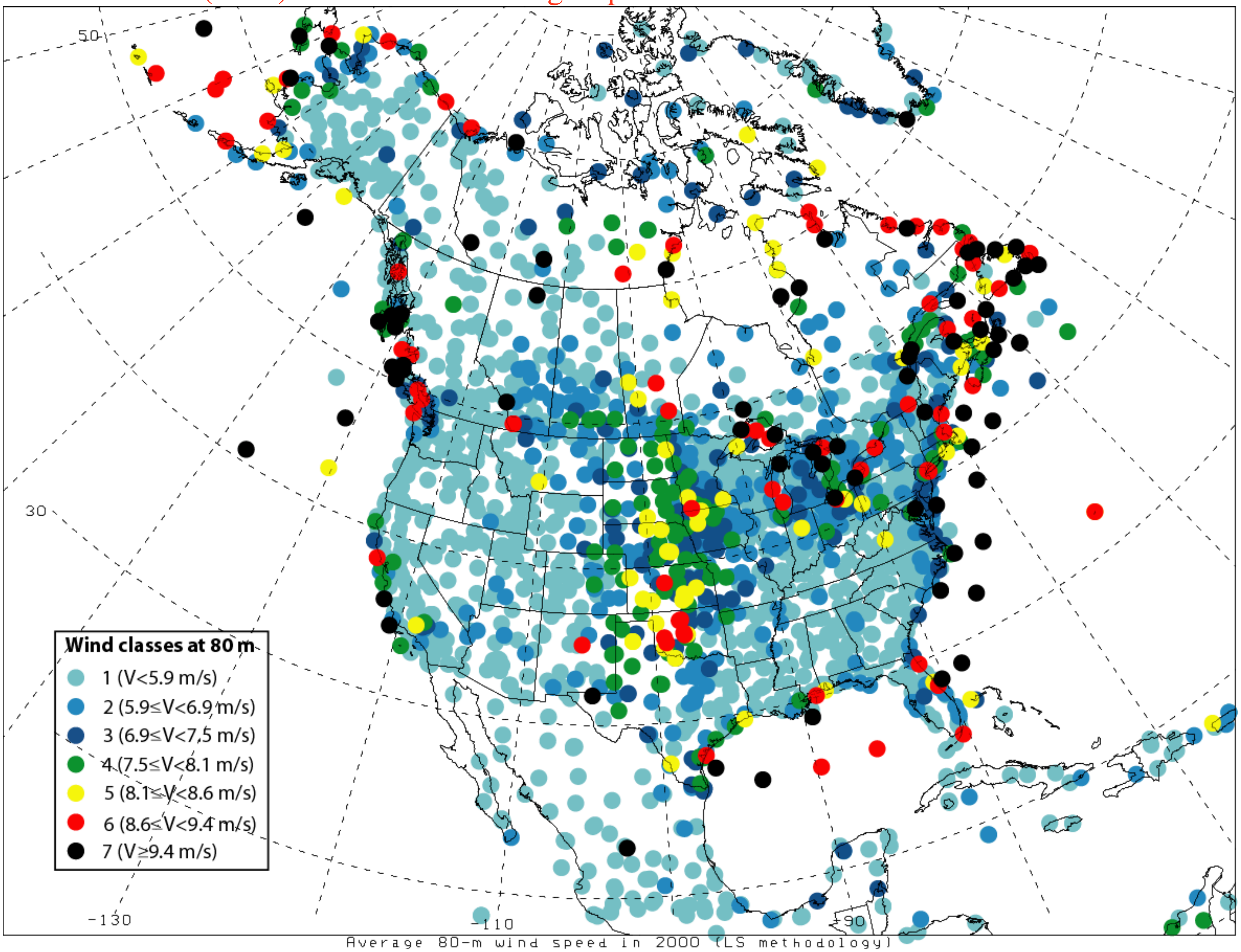
- Wind turbines
- Solar photovoltaics (PV)
- Geothermal power plants
- Tidal turbines
- Wave devices
- Concentrated solar power (CSP)
- Hydroelectric power plants
- Nuclear power plants
- Coal with carbon capture and sequestration (CCS)

Vehicle Options

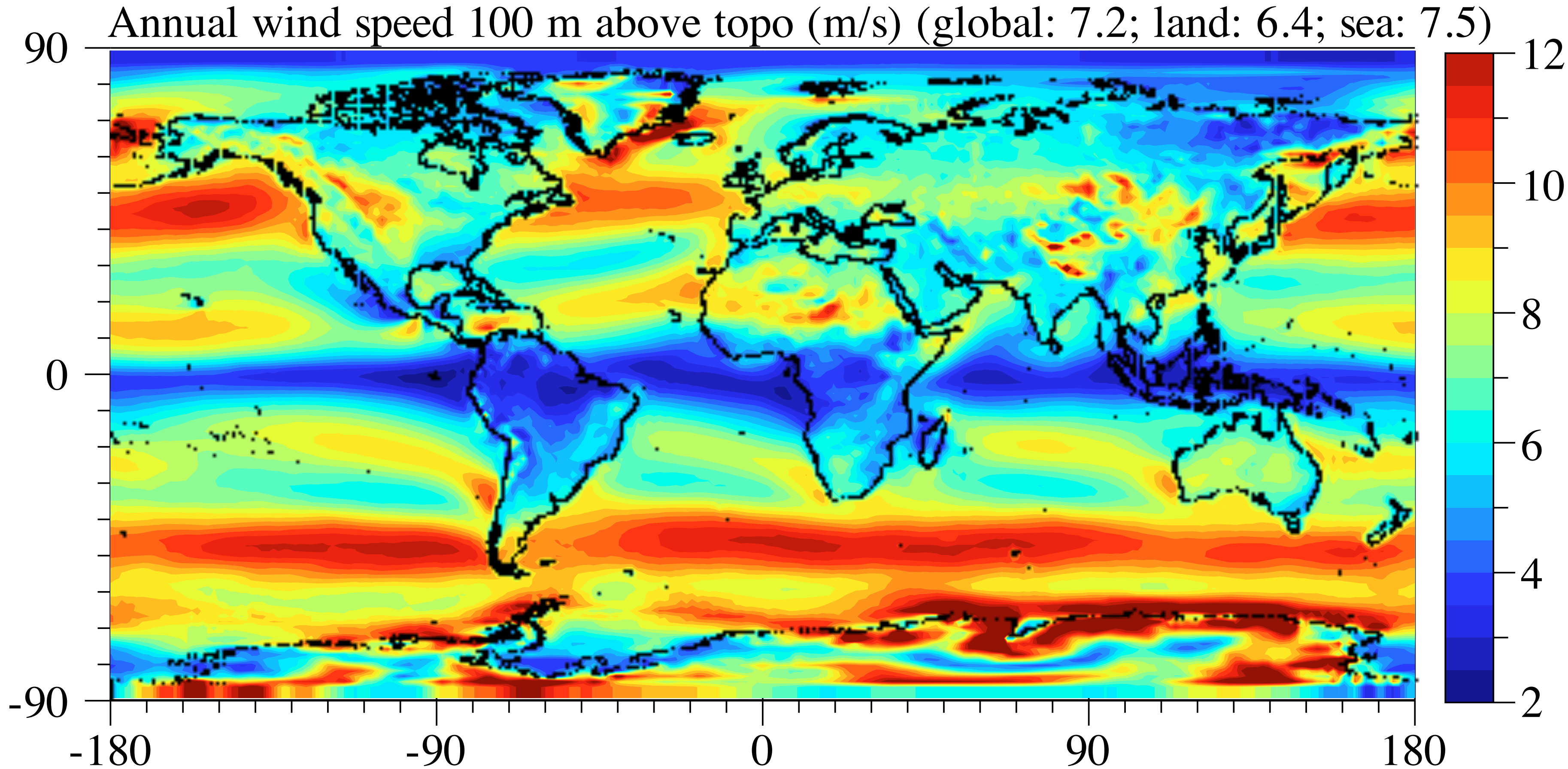
- Battery-Electric Vehicles (BEVs)
- Hydrogen Fuel Cell Vehicles (HFCVs)
- Corn ethanol (E85)
- Cellulosic ethanol (E85)

80-m Wind Speeds From Data

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



Modeled World Wind Speeds at 100 m

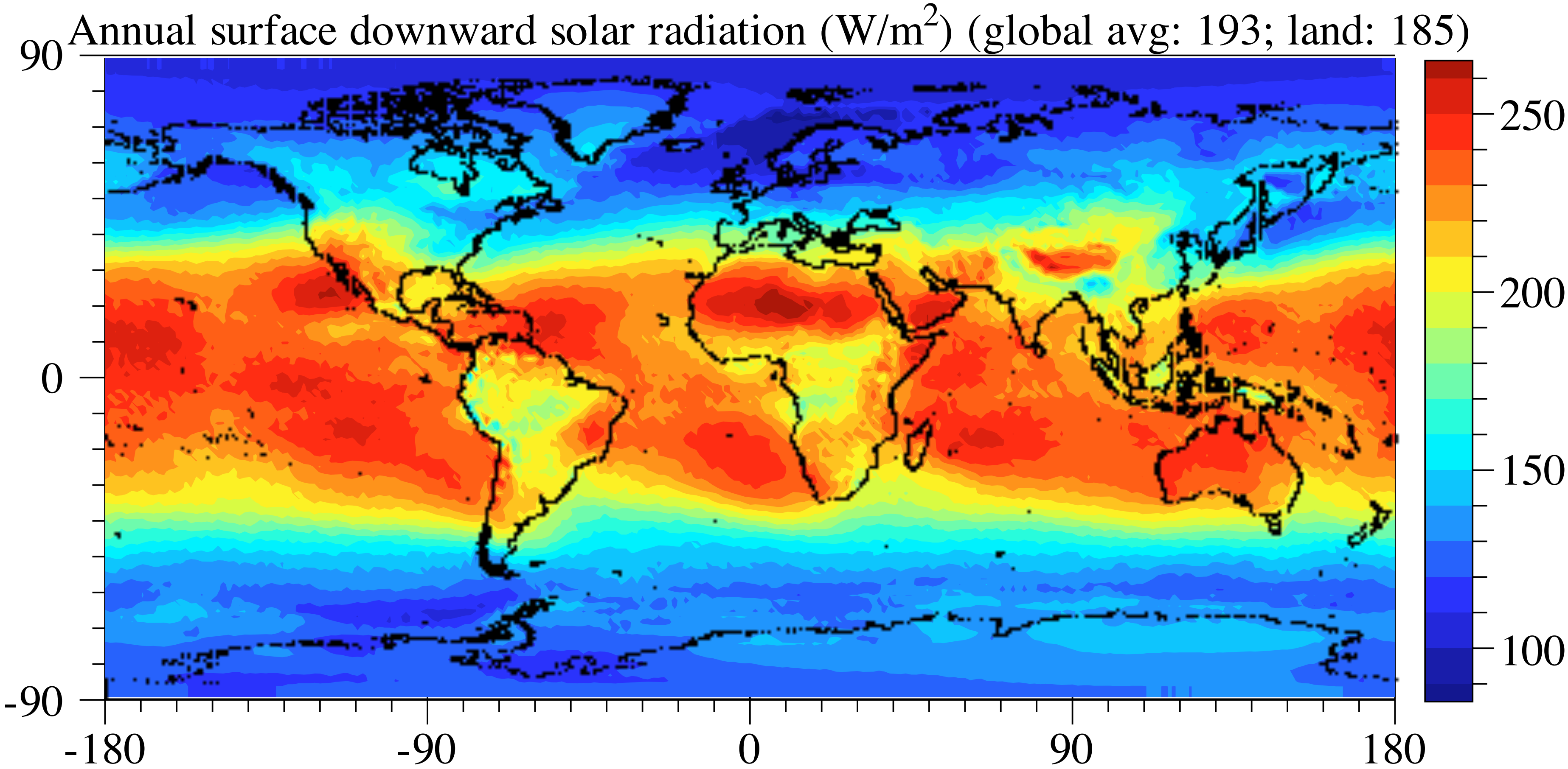


All wind worldwide: 1700 TW;

All wind over land in high-wind areas outside Antarctica ~ 70-170 TW

World power demand 2030: 16.9 TW

Modeled World Surface Solar

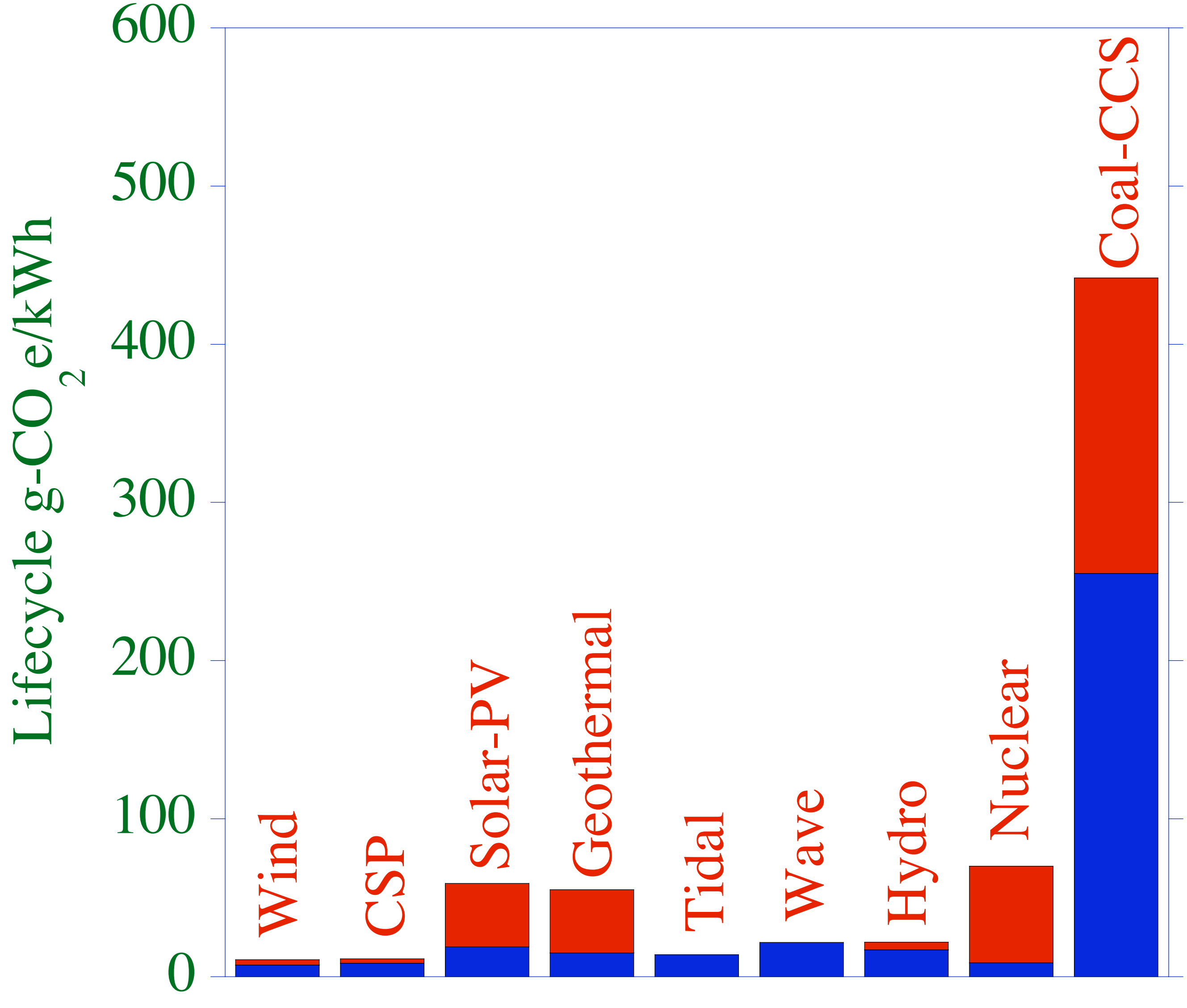


All solar worldwide: 6500 TW;

All solar over land in high-solar locations~ 340 TW

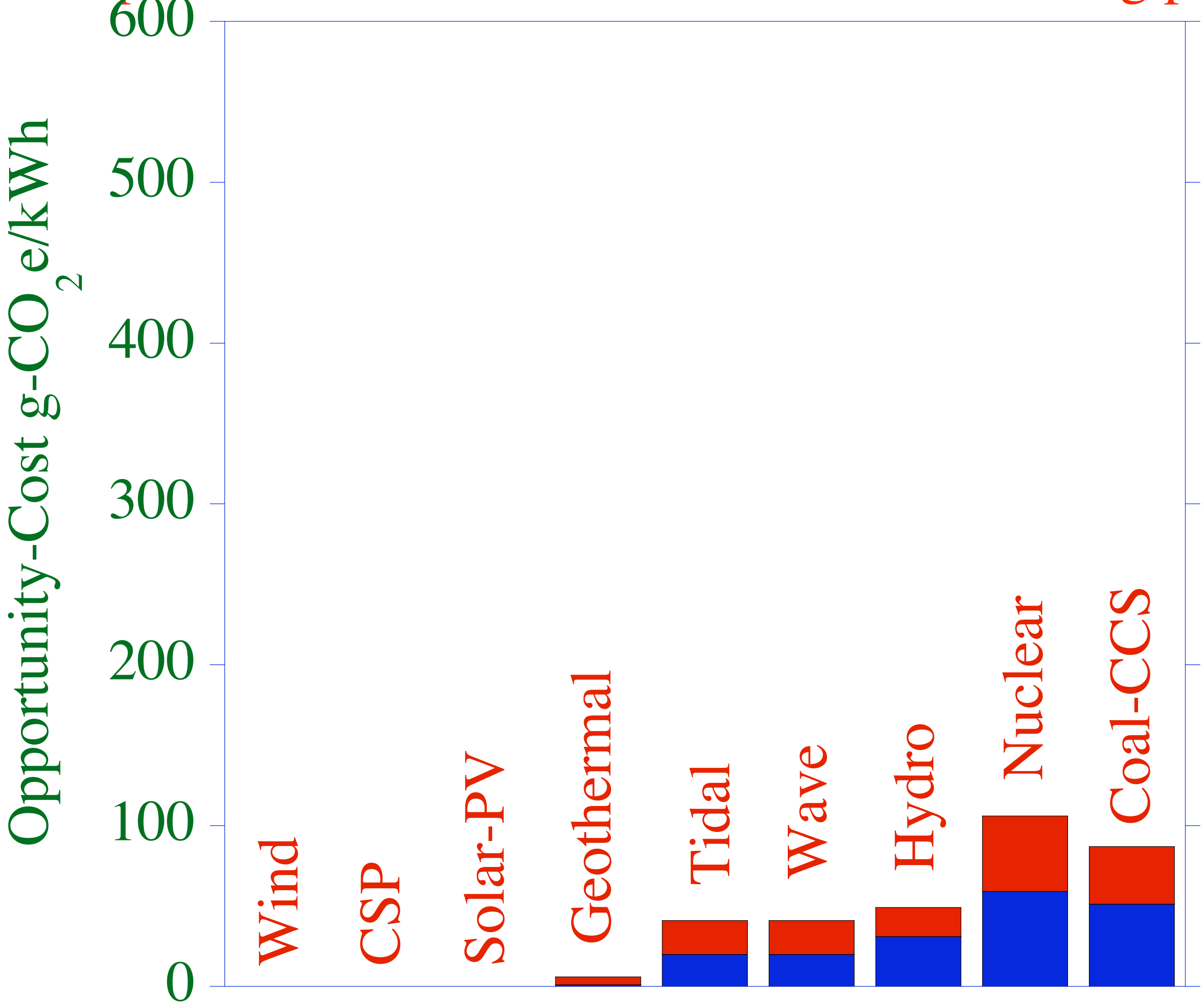
World power demand 2030: 16.9 TW

Lifecycle CO_2e of Electricity Sources

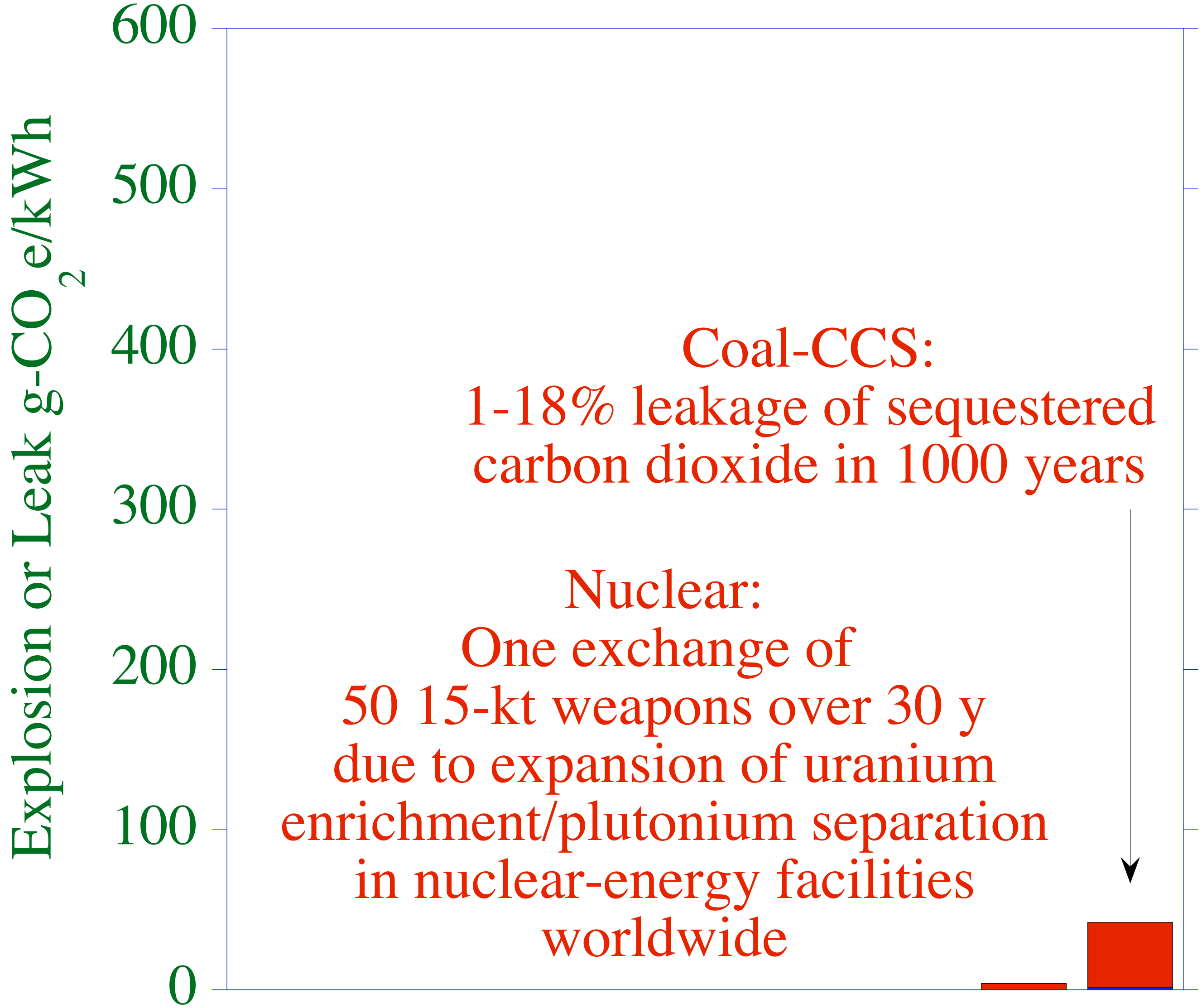


Opportunity-Cost CO_2e

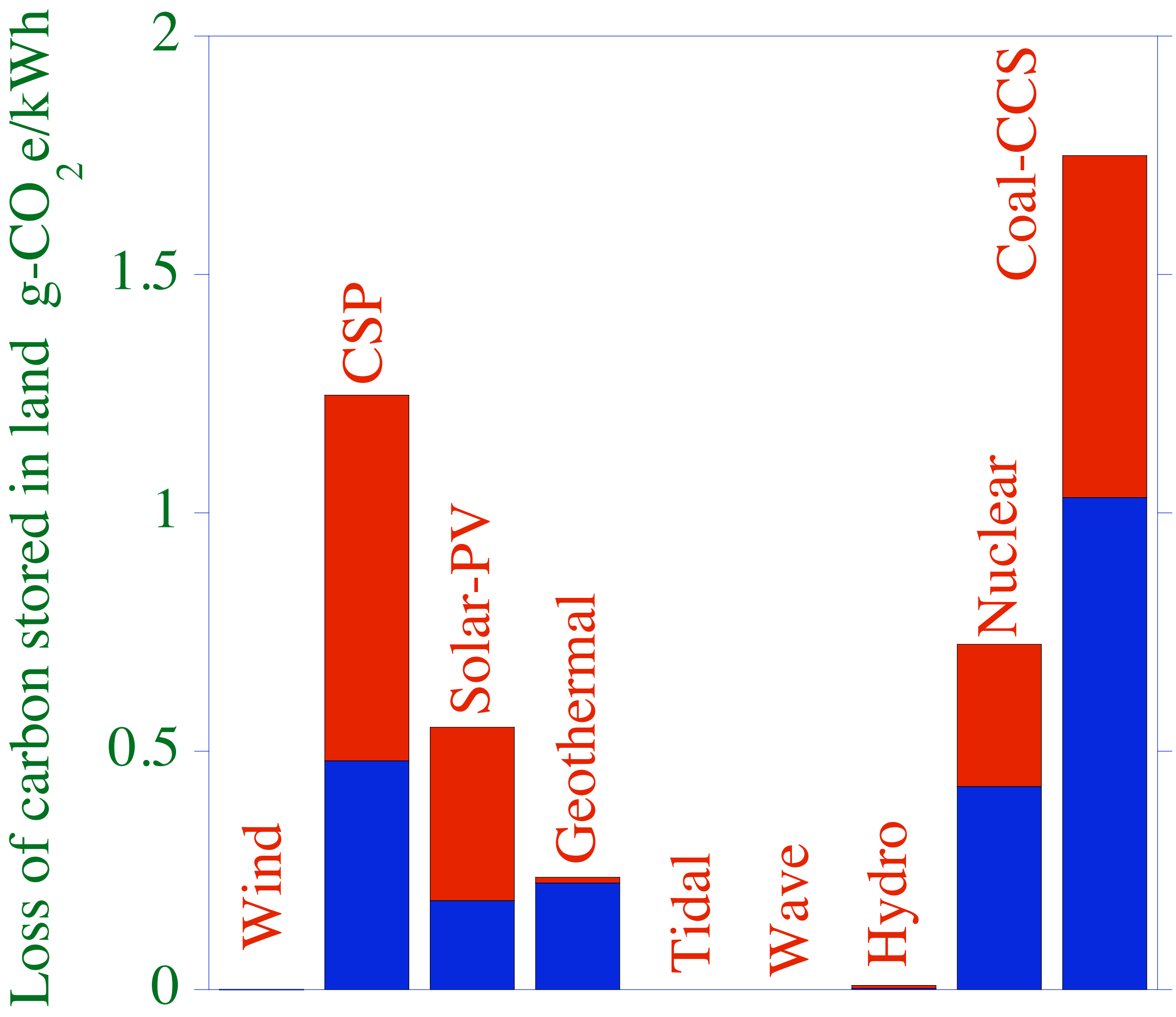
Emissions from current electricity mix due to time between planning & operation of power source minus that from least-emitting power source



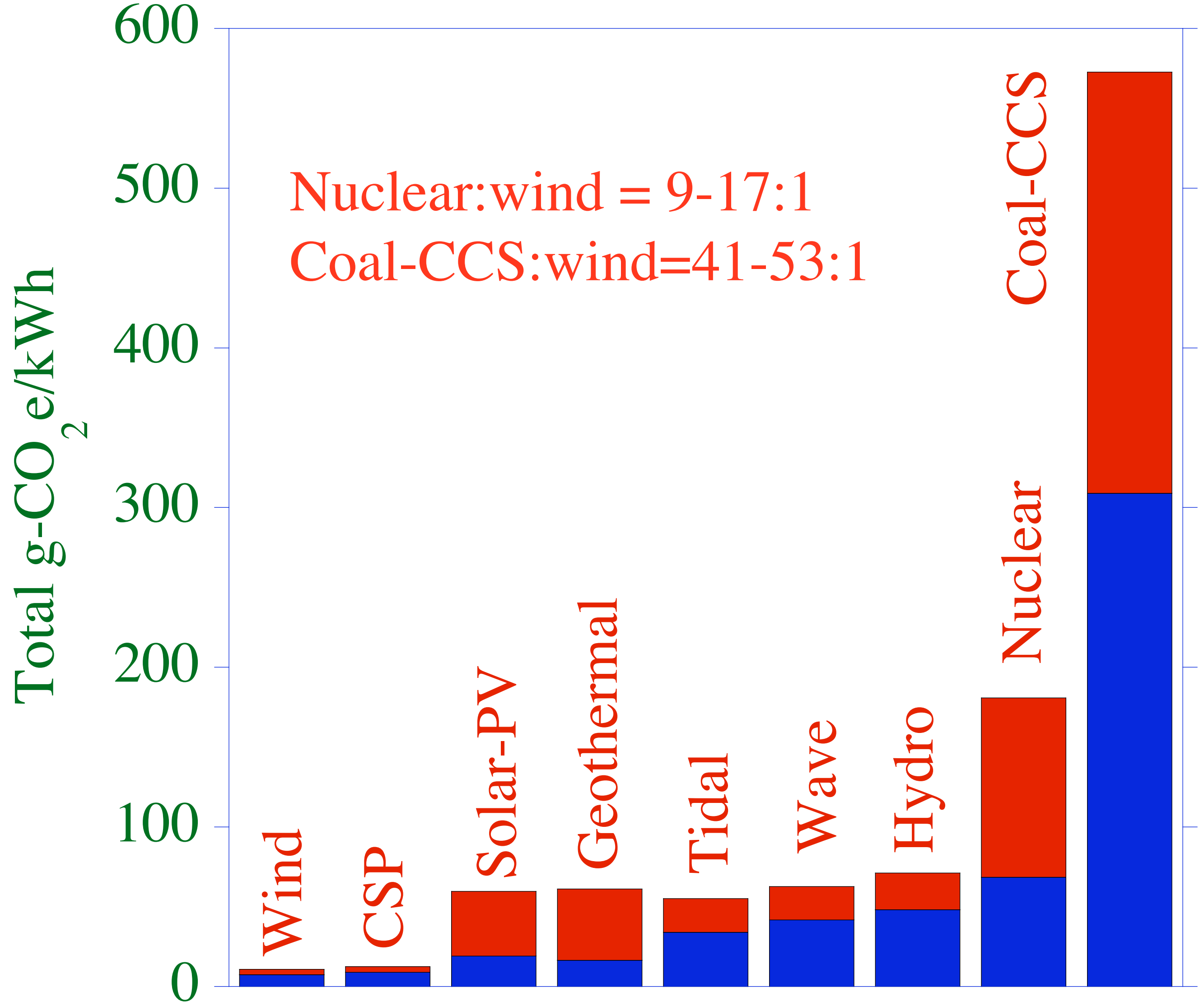
War/Leakage CO_2e of Nuclear, Coal



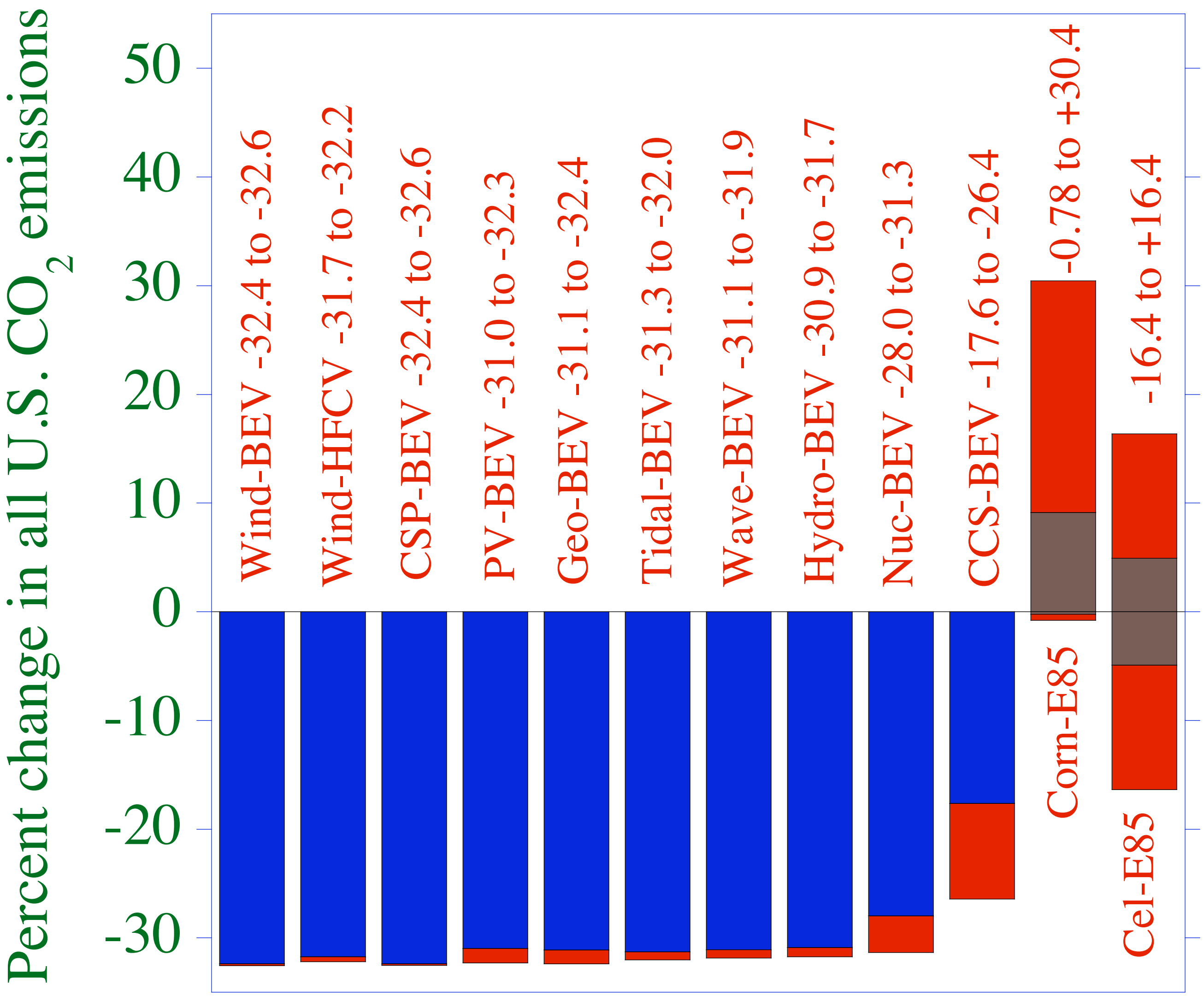
Loss of Carbon Stored in Land



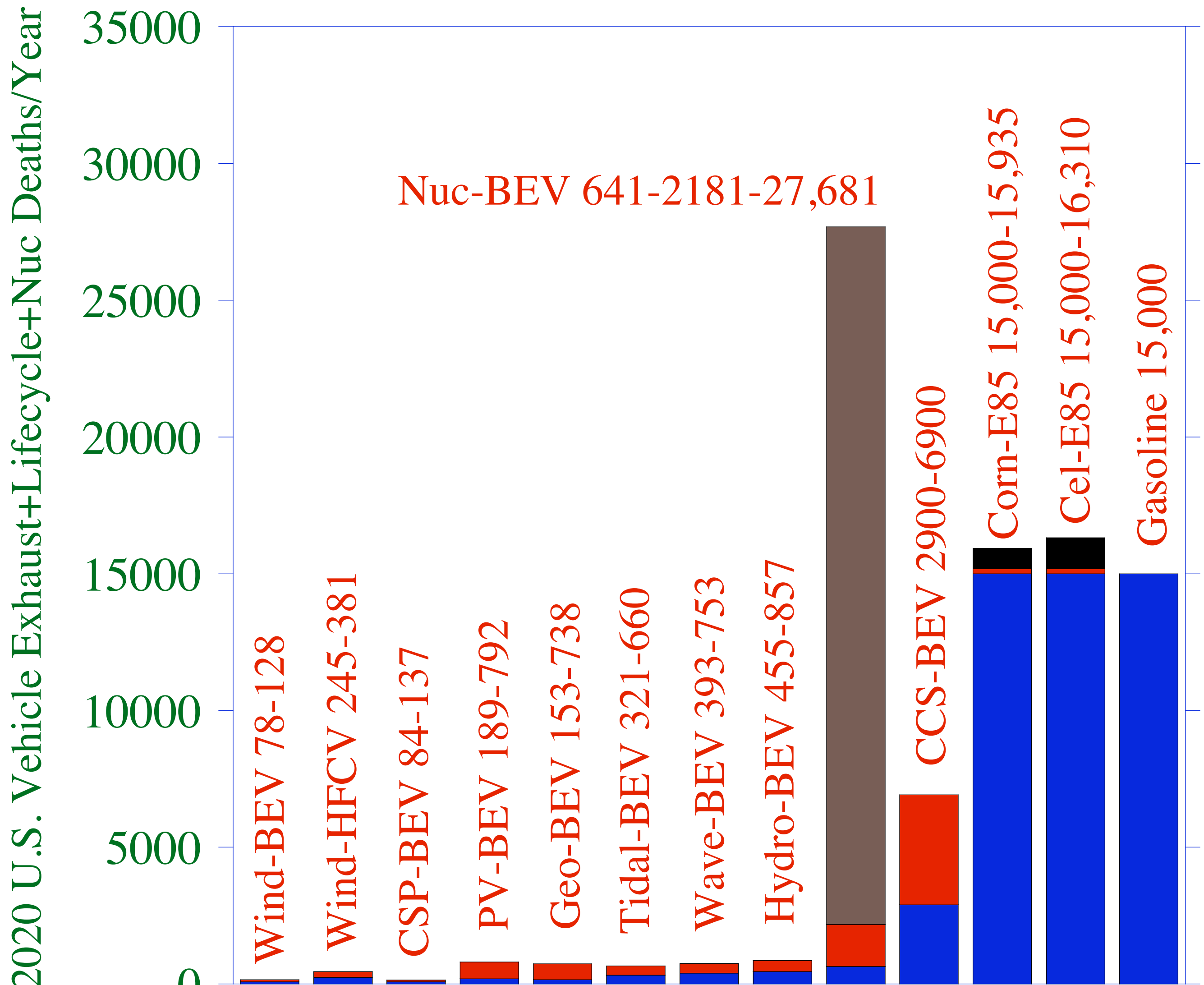
Total CO_2e of Electricity Sources



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



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

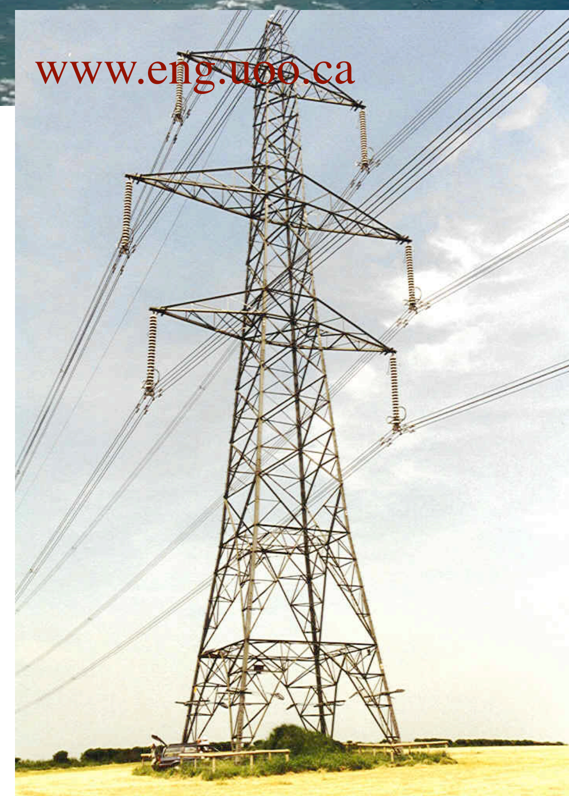
Wind-BEV	1:1 (1-3 square kilometers)
Wind-HFCV	3-3.1:1
Tidal-BEV	100-130:1
Wave-BEV	240-440:1
Geothermal-BEV	250-570:1
Nuclear-BEV	770-1100:1
Rhode Island	960-3000:1
Coal-CCS-BEV	1900-2600:1
PV-BEV	5800-6600:1
CSP-BEV	12,200-13,200:1
Hydro-BEV	84,000-190,000:1
California	143,000-441,000:1
Corn-E85	570,000-940,000:1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

Wind Footprints

Pro.corbins.com

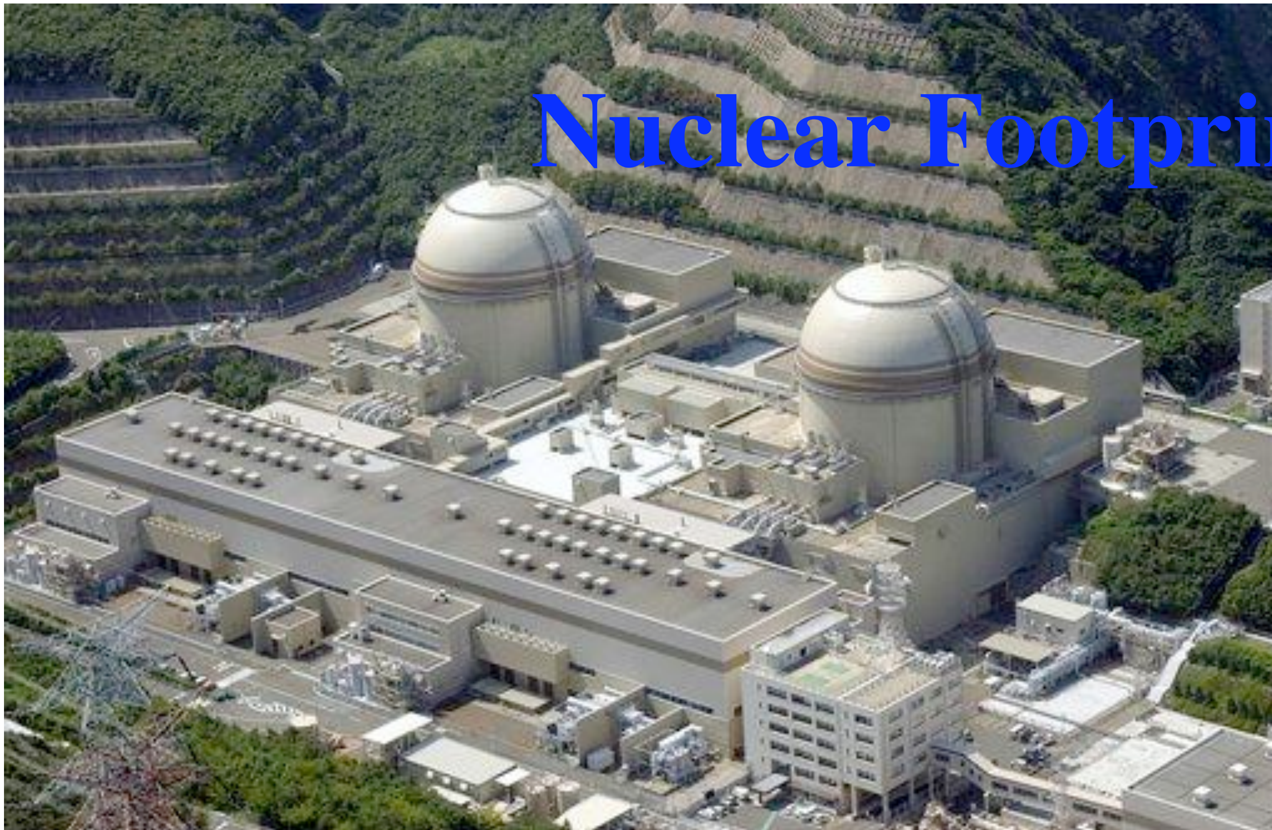
www.offshore-power.net

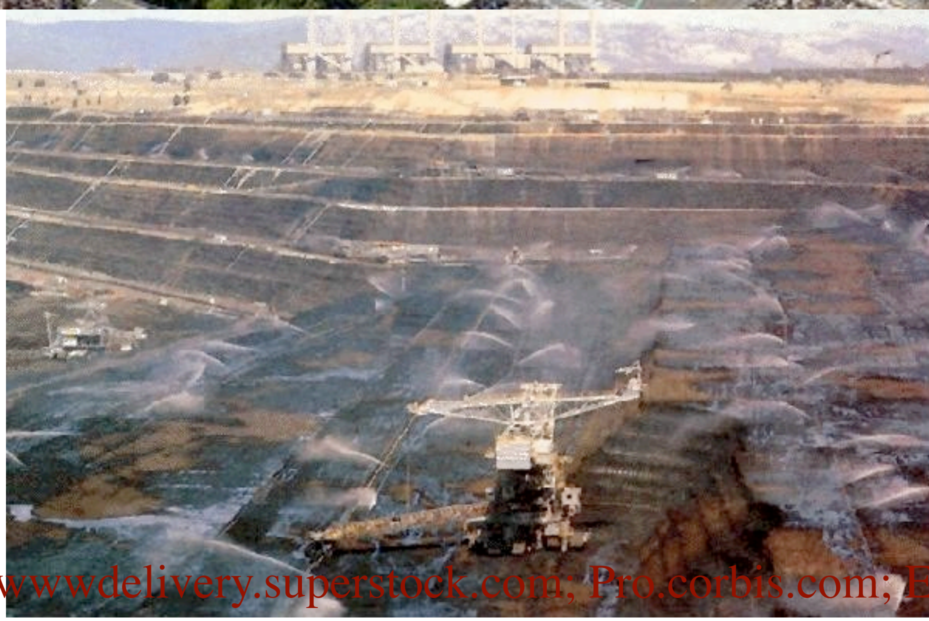
Pro.corbins.com



www.eng.uoo.ca

Nuclear Footprints



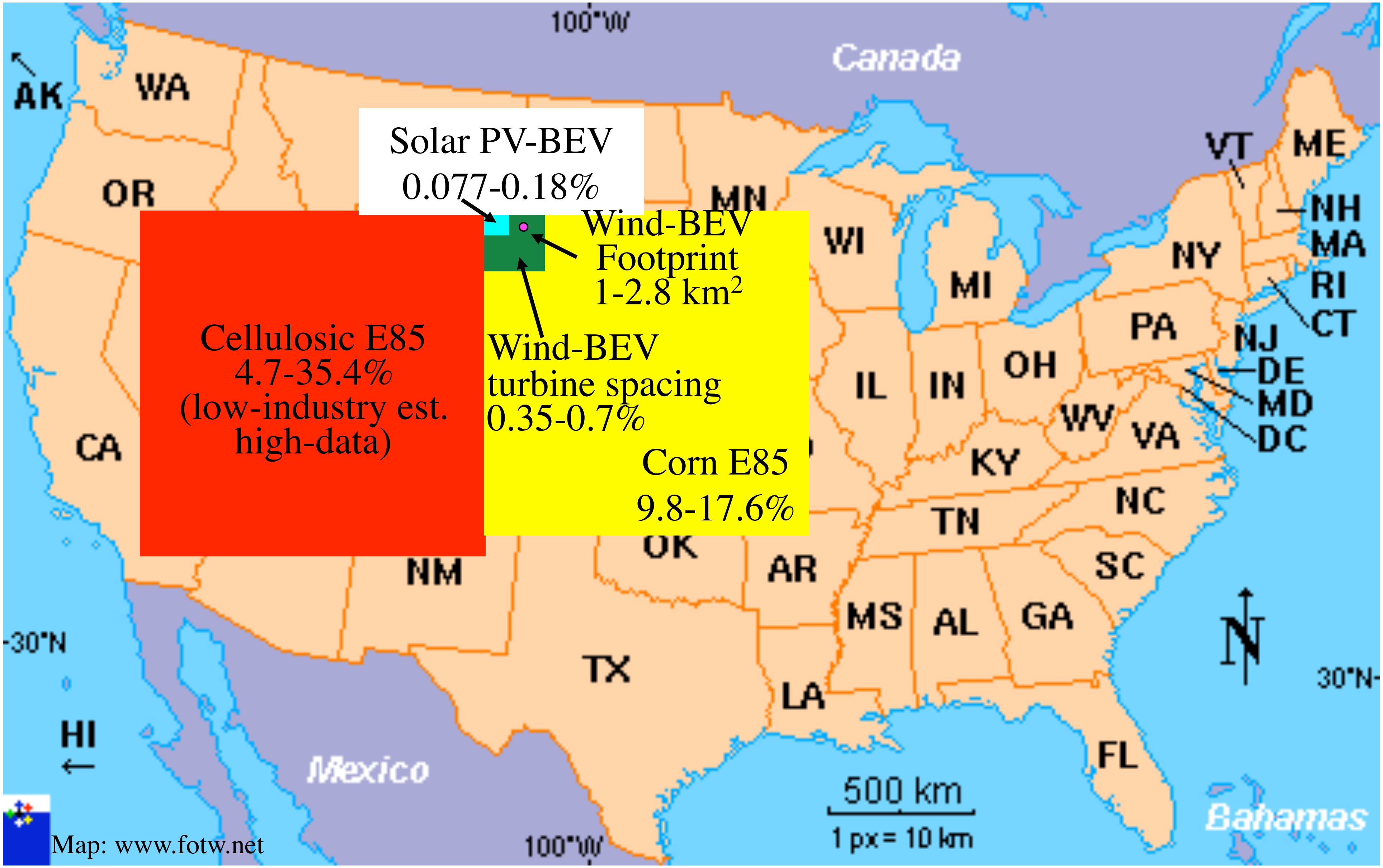


www.delivery.superstock.com; Pro.corbis.com; Eyeball-series.org; xs124.xs.to

Ethanol Footprints

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

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

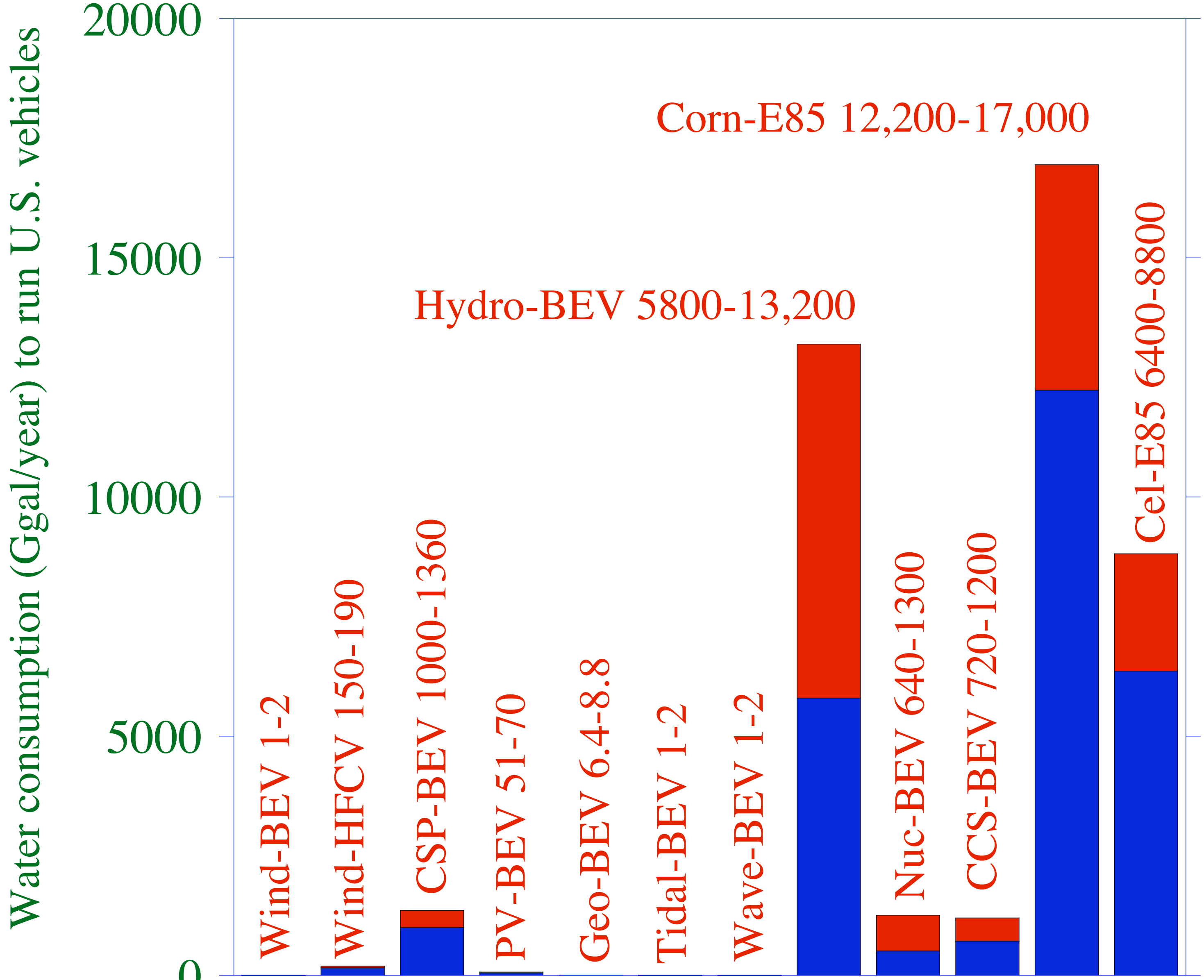


Land For 50% of All US Energy From Wind

Alternatively, Water For 50% of All US Energy From Wind

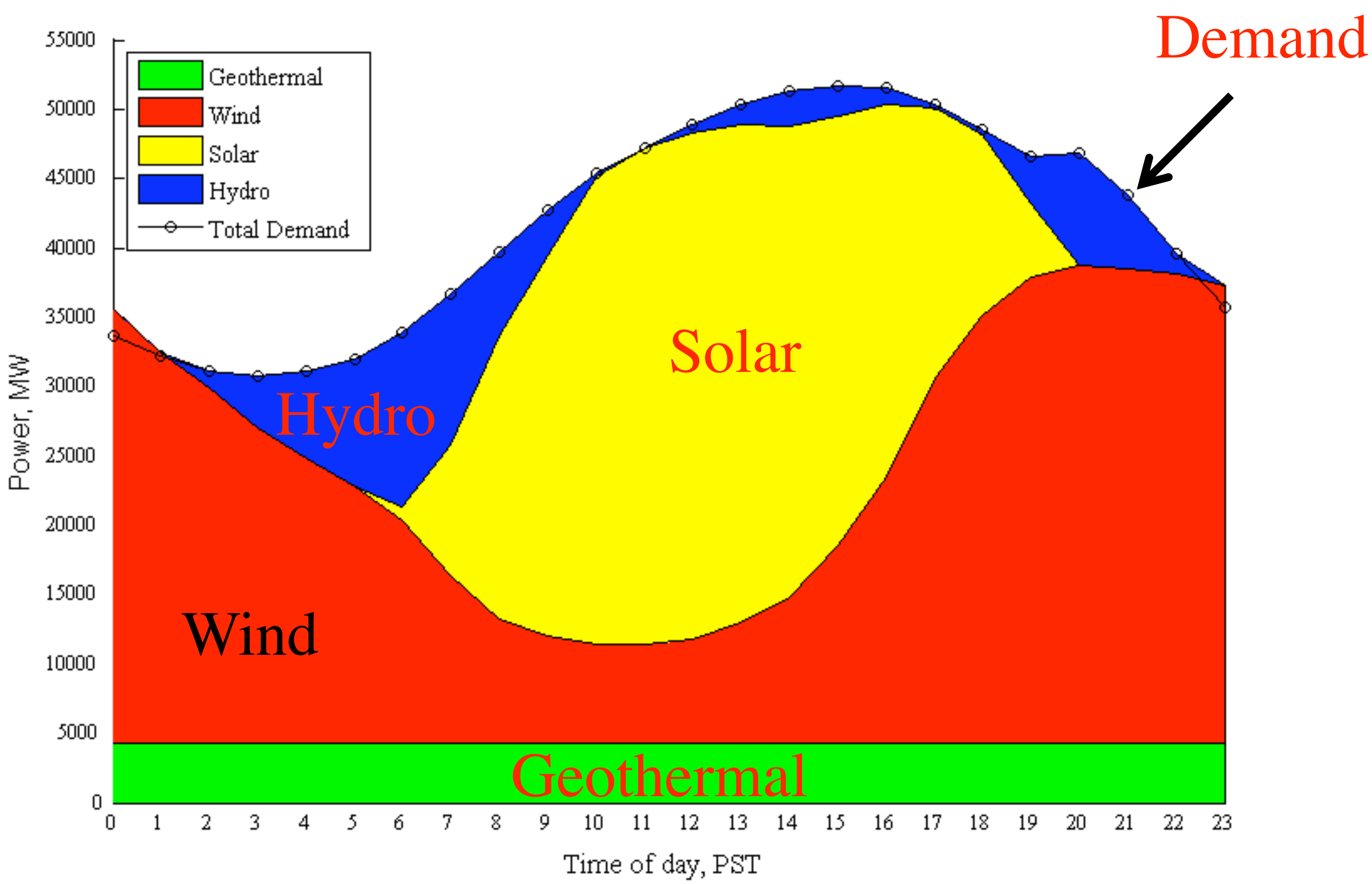
Map: www.fotw.net

Water Consumed to Run U.S. Vehicles



U.S. water demand = 150,000 Ggal/yr

Matching Hourly Electricity Demand in Summer 2020 With 100% Renewables With no Change in Current Hydro



Hoste et al. (2009)

Overall Ranking

Cleanest solutions to global warming, air pollution, energy security

Electric power
1. Wind
2. CSP
3. Geothermal
4. Tidal
5. PV
6. Wave
7. Hydroelectricity

Vehicles
1. Wind-BEVs
2. Wind-HFCVs
3. CSP-BEVs
4. Geothermal-BEVs
5. Tidal-BEVs
6. PV-BEVs
7. Wave-BEVs
8. Hydro-BEVs

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Not Recommended

8. Nuclear (tie)
8. Coal-CCS (tie)

9. Nuclear BEVs
10. Coal-CCS BEVs (tie)
11. Corn ethanol
12. Cellulosic ethanol

Powering the World on Renewables

Global power demand 2010 (TW)

Electricity: 2.2 Total: 12.5

Global overall power demand 2030 with current fuels (TW)

Electricity: 3.5 Total: 16.9

Global overall power demand 2030 converting to wind-water-sun (WWS) and electricty/H_2(TW)

Electricity: 3.3 Total: 11.5

→ Conversion to electricity, H_2 reduces power demand 30%

Number of Plants or Devices to Power the World

Technology	Percent Supply 2030	Number
5-MW wind turbines	50%	3.8 mill. (0.8% in place)
0.75-MW wave devices	1	720,000
100-MW geothermal plants	4	5350 (1.7% in place)
1300-MW hydro plants	4	900 (70% in place)
1-MW tidal turbines	1	490,000
3-kW Roof PV systems	6	1.7 billion
300-MW Solar PV plants	14	40,000
300-MW CSP plants	20	49,000
	100%	

Materials, Costs

Wind, solar

Materials (e.g., neodymium, silver, gallium) present challenges, but are not limitations.

Lithium for batteries

Known resources > 13,000,000 tonnes, half in Bolivia

Enough known supply for 26 million vehicles/yr for 50 yrs. If recycling → supply for much longer

Costs

$100 trillion to replace world's power

→recouped by electricity sale, with direct cost 4-10¢/kWh

→Eliminates 2.5 million air pollution deaths/year

→Eliminates global warming, provides energy stability

Summary

The use of wind CSP, geothermal, tidal, PV, wave, and hydro to provide electricity fo all uses, including BEVs and HFCVs and will result in the greatest reductions in global warming and air pollution and provide the least damage among the energy options considered.

Coal-CCS and nuclear cause climate and health opportunity cost loss compared with the recommended options and should not be advanced over them. Coal-CCS emits 41-53 times more carbon, and nuclear emits 9-17 times more carbon than wind.

Corn and cellulosic ethanol 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.

Summary

Converting to Wind, Water, and Sun (WWS) and electricity/ hydrogen will reduce global power demand by 30%, eliminating 13,000 current or future coal plants.

Materials are not limits although recycling will needed.

Electricity cost should be similar to that of conventional new generation and lower when costs to society accounted for.

Barriers to overcome: lobbying, politics, transmission needs, up-front costs

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

Scientific American, November (2009)
www.stanford.edu/group/efmh/jacobson/susenergy2030.html