



Transitioning Countries, Cities, and Homes to 100% Clean, Renewable Wind, Water, Solar, and Storage For Everything"

Mark Z. Jacobson
Stanford University

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Wind, Water, Solar (WWS) Solution

Electrify or Provide Direct Heat For All Sectors and Provide the Electricity and Heat with 100% WWS

ELECTRICITY

TRANSPORTATION

HEATING/COOLING

INDUSTRY

Wind	Battery-electric	Electric heat pumps	Electric arc furnaces
Solar PV/CSP	HFC-BE hybrids	Solar heat	Induction furnaces
Geothermal		Geothermal heat	Resistance heaters
Hydro		District heat/cold	Dielectric heaters
Tidal/Wave			Electron beam heaters

Onshore and Floating Offshore Wind



PV Over Canal and Floating PV



Left: 1 MW PV over canal in Gujarat State, India

Right: 70 MW floating solar PV farm, Anhui Province, China

Utility PV



Left: 850 MW farm, Qinghai Province, Tibetan Plateau

Right: 18.2 MW farm, Les Mees Plateau, France

Electric & Hydrogen Fuel Cell Trucks and Buses



Tesla Semi-electric (850km)



Nikola One Semi-hydrogen fuel cell (1900 km)



Protera electric bus



Hydrogen fuel cell-electric hybrid bus

Planes: Replace Jet Fuel With Batteries & Hydrogen Fuel Cells



Battery electric aircraft-Ampaire

Cells



Cryogenic hydrogen aircraft



Hydrogen fuel cell aircraft

Electric Appliances



Electric lift



Electric lawn mower



Electric leaf blower

Types of Storage for a 100% WWS System

ELECTRICITY

CSP with storage
Pumped storage hydro
Existing hydroelectric
Batteries
Flywheels
Compressed air
Gravitational Storage

HEATING/COOLING

Water tank
Ice
Underground
Borehole
Water Pit
Aquifer
Building materials

OTHER

Hydrogen

Concentrating Solar Power

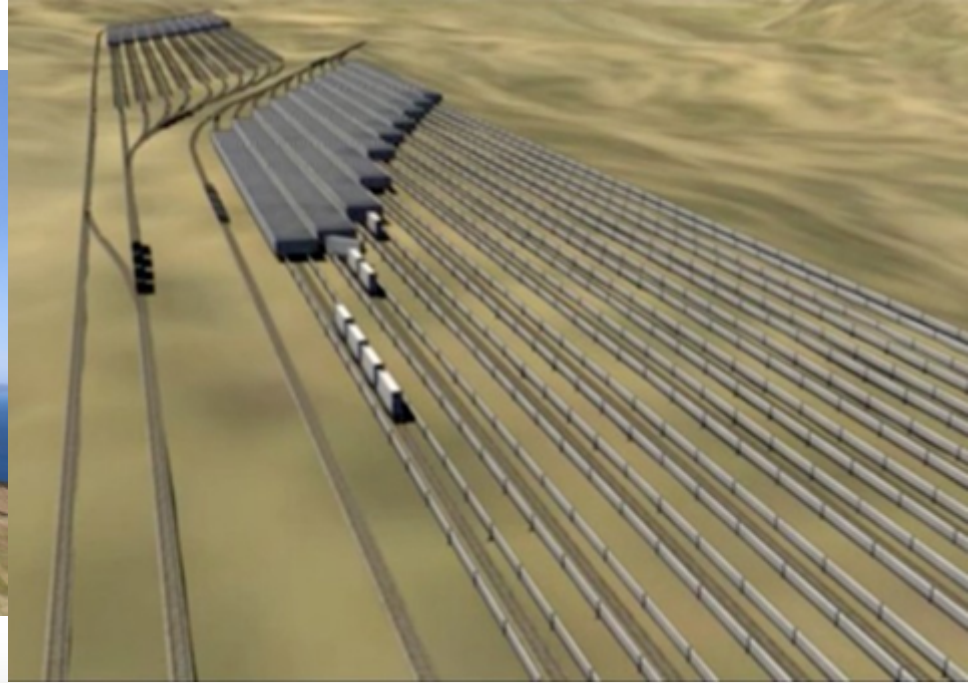


Solar Reserve 110 MW CSP With 1.1 GWh of storage in Tonopah, Nevada

Stationary Battery Storage



Gravitational Storage With Solid Masses



Stanford University 4th Generation District Heating System



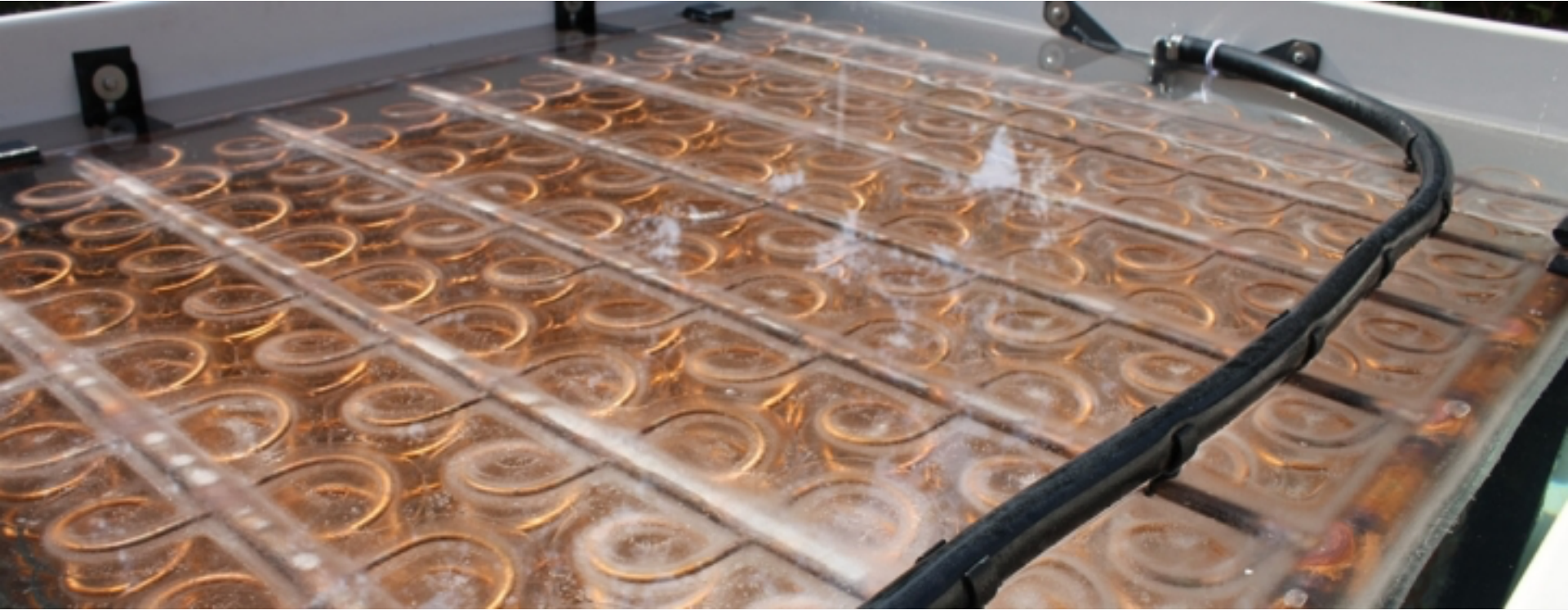
Seasonal Heat Storage in Underground Boreholes Okotoks, Canada



Seasonal District Heat Storage in Covered Water Pit Vojens, Denmark



Nighttime Storage in Ice for Daytime Air Cooling



Transitioning an Individual Home to Run on WWS Electricity/Storage and No Gas

Rooftop Solar Plus Battery Storage



Ductless Mini-Split Electric Heat Pump Air Heater / Air Conditioner



Electric Heat Pump Water Heater



Electric Induction Cooktop



One Year of Energy Use

Generated 120% of all home and vehicle energy

→ No electric bill, natural gas bill, or gasoline bill

Received \$530 from CCA for excess electricity to grid

Avoided costs of all-electric home

Gas hookup fee: 3-8 K

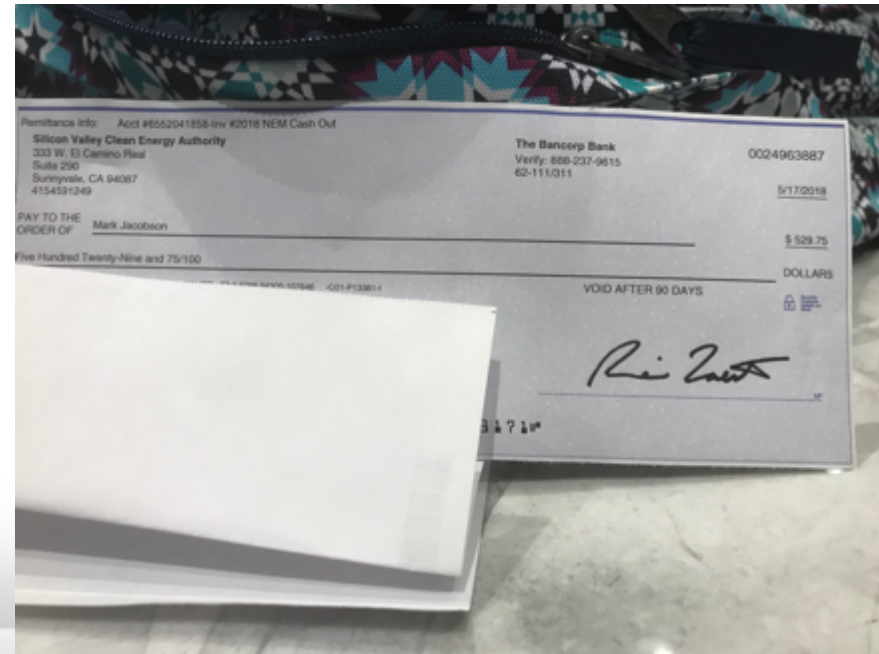
Gas pipes: 1-7 K

Electric bill 1-3 K per year

Natural gas bill 1-3 K per year

Vehicle fuel bill 1-4 K per year

Total: 4-15 K plus 3-10 K per year



Can the World Transition to 100%, Clean, Renewable Energy for all Purposes?

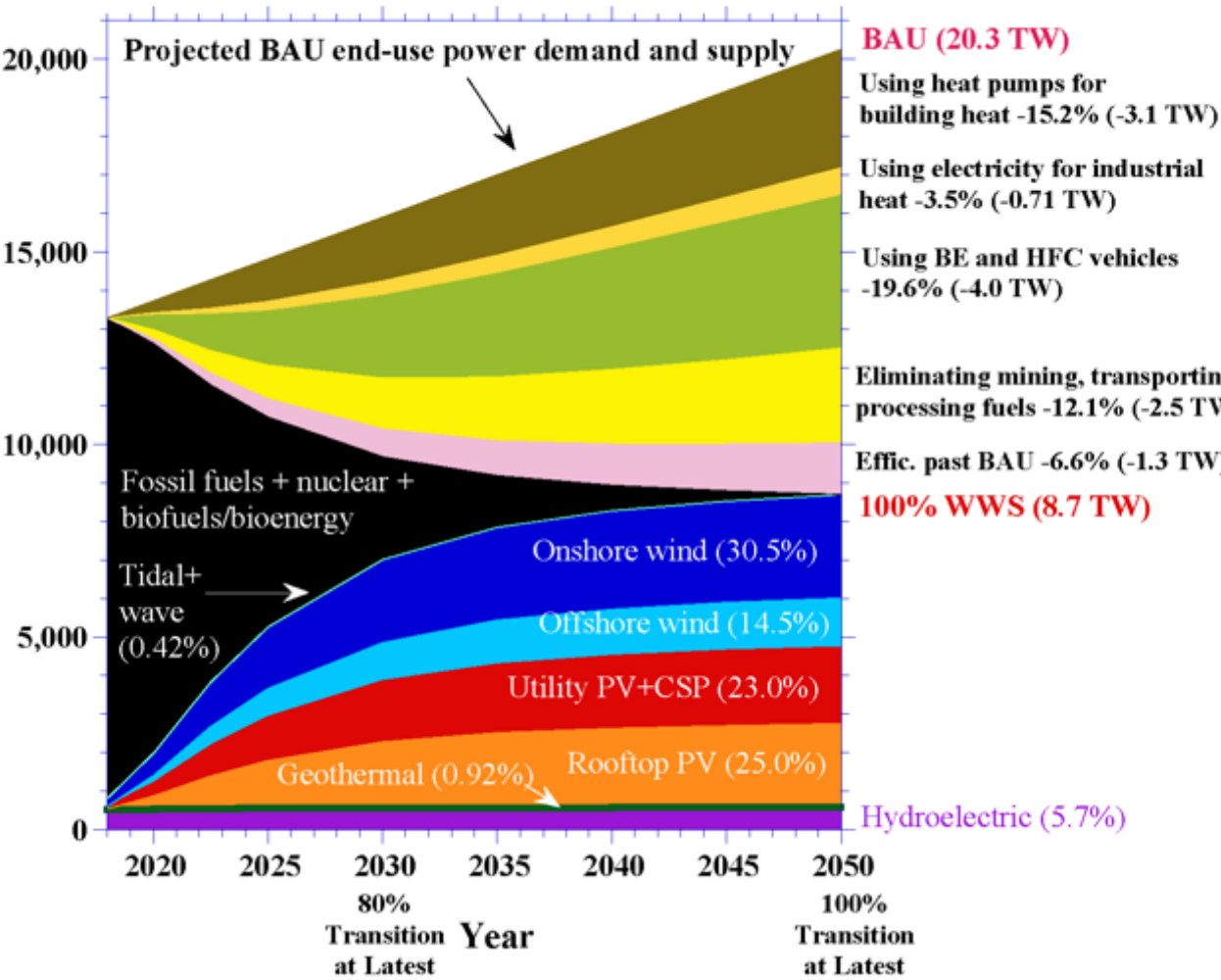
Roadmaps for 143 Countries

All-Purpose End-Use Power Demand

Year and Fuel Type	143-Countries
2015 End-use demand	12.6 TW
2050 Demand with current fuels (BAU)	20.2 TW
2050 Demand with WWS	8.7 TW
2050 Demand reduction w/ WWS	57.1%
19.6% efficiency of BE, HFC v. ICE	
3.5% efficiency of electric industry	
15.2% efficiency of heat pumps	
12.1% eliminating fuel mining	
6.6% efficiency beyond BAU	

Timeline for a Transition

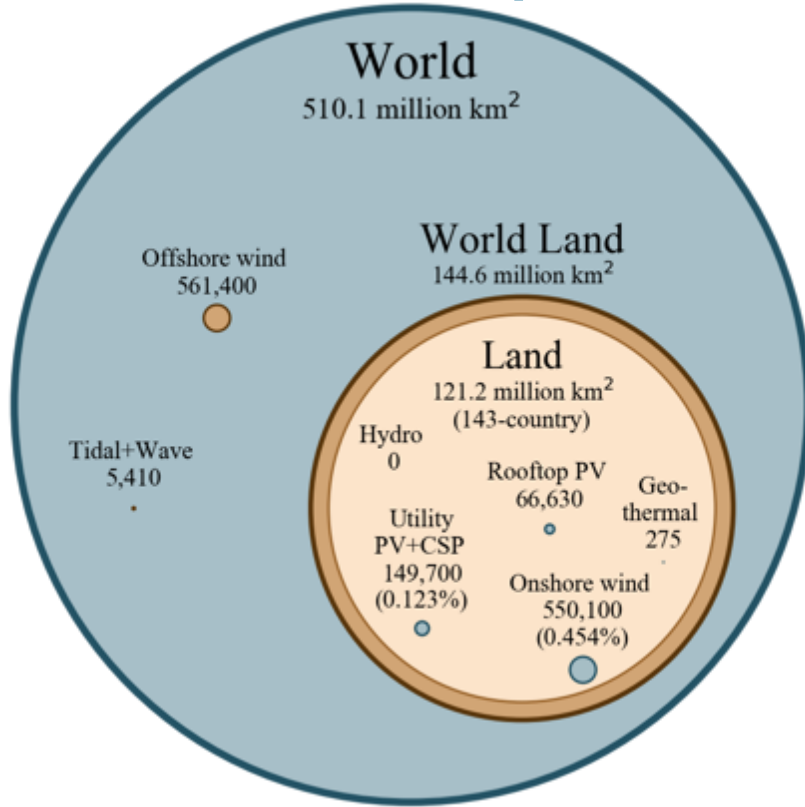
143-Country All-Sector End-Use Power Demand and Supply (GW)



Percent of 2050 143-Country End-Use Demand Supplied by WWS Devices and Number of New Devices

TECHNOLOGY	PCT SUPPLY 2050
5-MW onshore wind turbines	30.5%
5-MW offshore wind turbines	14.5
5-kW Res. roof PV systems	11.1
100-kW com/gov roof PV systems	13.8
50-MW Solar PV plants	19.0
100-MW CSP plants	3.93
100-MW geothermal plants	0.92
1300-MW hydro plants	5.72
1-MW tidal turbines	0.08
0.75-MW wave devices	0.34
	100%

Area Beyond 2018 Installations to Power 143 Countries for all Purposes With 100% WWS in 2050



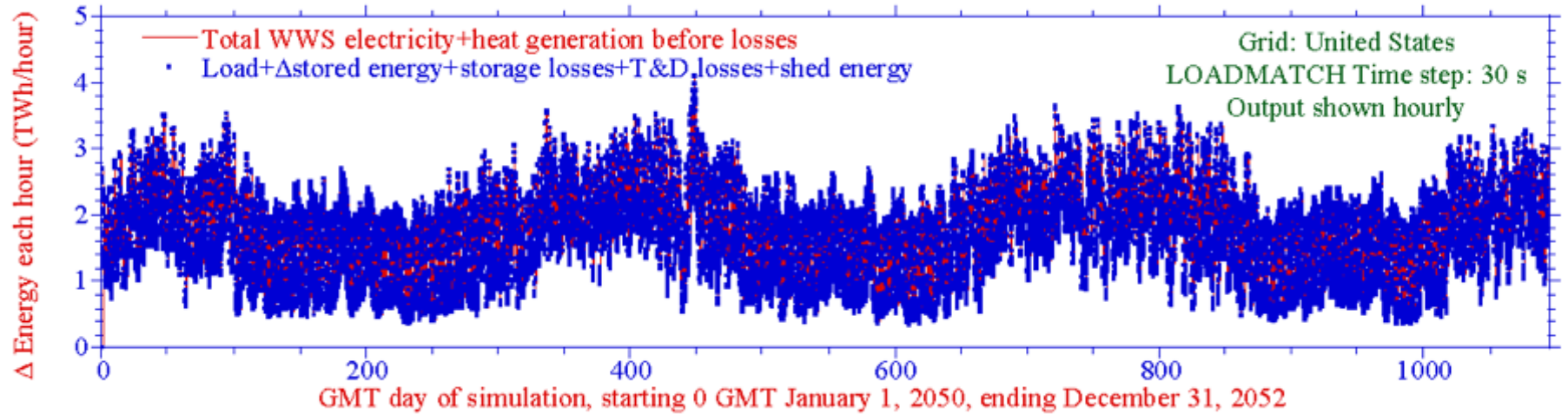
Percent of 143-Country Land

Onshore wind: 0.45%

Utility PV+CSP: 0.12%

Total 0.57%

3 Years of Results (2050-2052) From Study of Matching U.S. All-Sector Demand Exactly Every 30 Sec. With 100% WWS+Storage



Red = Energy supply

Blue = Energy demand + change in storage + losses + shedding

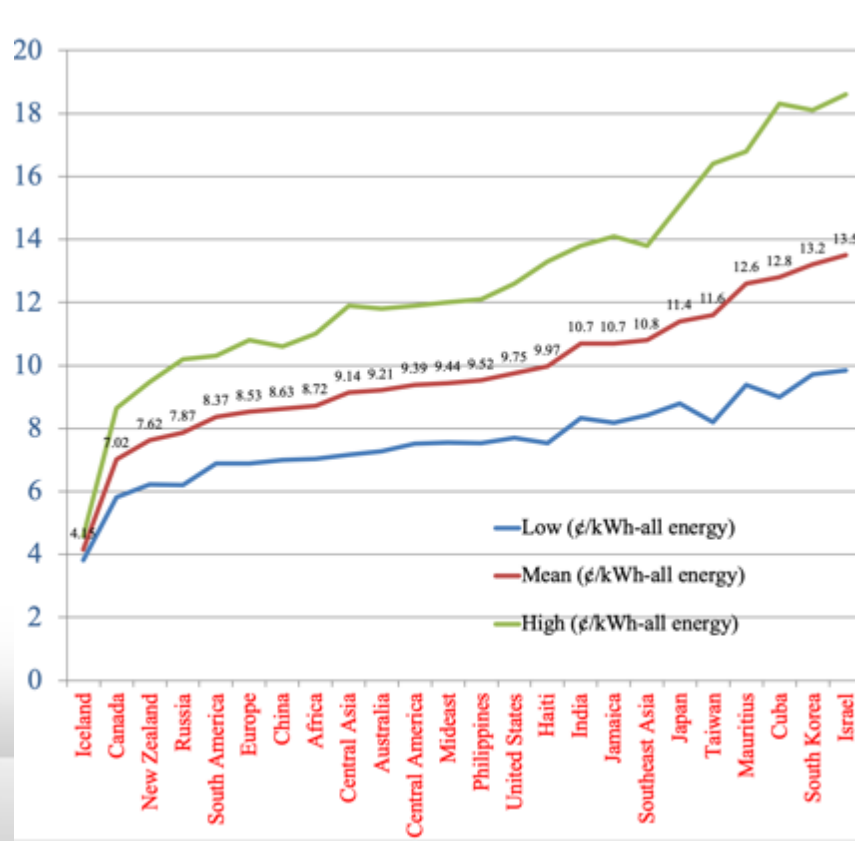
Levelized Cost of Energy for Each of 24 Regions Encompassing 143 Countries That Gives a Stable Grid Upon Electrification of all Energy Sectors With 100% WWS+Storage

World: 9.3 cents/kWh
Capital Cost: \$92.3 trillion

Europe: 8.5 cents/kWh
Capital cost: \$8 trillion

U.S.: 9.5 cents/kWh
Capital cost: \$9.75 trillion

China: 8.5 cents/kWh
Capital cost: \$24.4 trillion



2050 U.S. WWS vs. BAU Cost

BAU energy	\$2 trillion/yr
BAU fuel health cost	\$0.6 trillion/yr
<u>BAU fuel climate cost</u>	<u>\$3.3 trillion/yr</u>
Total conventional fuel electricity sector cost	\$5.9 trillion/yr

WWS replacing all BAU energy sectors \$0.85 tril/yr

WWS reduces energy cost 58% and economic (social) cost 86%

House Resolution H.Res.540, Senate Resolution S.Res.632

“...U.S. should support a transition to...100% clean renewable energy,...”

Senate Bill S.987, House Bills H.R.3314, 3671, 330

“100% clean and renewable energy by 2050”

“100% clean and renewable energy by 2050”

“100% clean, renewable energy by 2035”

“100% renewable electricity by 2035”

Green New Deal

100% Renewable Energy for the U.S.

Contributory Impacts of 100% WWS Roadmaps

Laws: Hawaii, California, Washington State

100% renewable electricity by 2045

Law: Washington D.C.

100% renewable electricity by 2035

Law: Puerto Rico

100% renewable electricity by 2050

Law: New Mexico

Up to 100% renewable electricity by 2045

Proposed 100% Laws

NY, IL, FL, MN, WI

Some of 120 Cities/Counties Committed to 100% Renewables

Burlington (VT)	Grand Rapids (MI)	Sylva (NC)
Greensburg (KS)	Los Angeles (CA)	Atlanta (GA)
Aspen (CO)	Park City (UT)	Orlando (FL),
Vancouver (BC)	San Jose (CA)	East Hampton (NY)
San Diego (CA)	Santa Fe (NM)	Rochester (MN)
Honolulu (HI)	Santa Monica (CA)	WestChester (PA)
Columbia (SC)	Pueblo (CO)	S. Lake Tahoe (CA)
Palo Alto (CA)	Boone (NC)	Nelson (BC)
San Francisco (CA)	Moab (UT)	St. Petersburg (FL)
Georgetown (TX)	Abita Springs (LA)	St. Louis (MO)
Madison (WI)	Portland (OR)	Sarasota (FL)
Santa Barbara (CA)	Salt Lake City (UT)	Nevada City (NV)
Oxford County (ON)	Fayetteville (AR)	Boulder (CO)

Some of the 176 Companies Committed to 100% Renewables

IKEA	Adobe	Autodesk	Coca Cola
Google	H&M	HP	Goldman-Sachs
Microsoft	Nestle	Nike	Johnson & Johnson
Apple	S&P	Starbucks	Walmart
Workday	T-Mobile	AB InBev	Bank of America
Bloomberg	BMW Group	Burberry	Citi
Clif Bar	Ebay	Facebook	Estee Lauder
GM	Goldman-Sachs	HSBC	Infosys
Kellogg's	Lego	Mars	Morgan Stanley
Salesforce	Organic Valley	VM Ware	Wells Fargo

Some of the 100+ NGOs Committed to 100%

The Solutions Project

100.Org

Sierra Club

350.Org

Greenpeace

theRE100.org

go100percent.org

renewables100.org

Climate Reality

iclei.org

The Center for Working Families

Miami Climate Alliance

Environment America

Toxics Action Center

Renewable Cities

National People's Action

Institute for Self-Reliance

Hip Hop Caucus

Environmental Action

Renewable Energy Long Island

Emerald Cities Collaborative

Community Power

Center for Community Change

Asian Pacific Environmental Network

Summary – Transitioning to 100% WWS

Creates millions more jobs than are lost worldwide

Requires only 0.12% of land for footprint; 0.45% for spacing

Avoids ~4-9 mil. air pollution deaths per year

Slows then reverses global warming

Grids can stay stable throughout the world with 100%

WWS energy cost per kWh slightly less than that of fossils

WWS energy+health+climate costs per kWh are 1/4th that of fossils

Absolute WWS energy+health+climate costs are 1/8th that of fossils

Roadmaps

web.stanford.edu/group/efmh/jacobson/Articles/I/WWS-50-USState-plans.html

Grid Studies

www.stanford.edu/group/efmh/jacobson/Articles/I/CombiningRenew/combining.html

Infographic maps

www.thesolutionsproject.org

Twitter: [@mzjacobson](https://twitter.com/mzjacobson)