100% Clean, Renewable Energy and Storage for Everything

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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	H_2 fuel cell	Solar heat	Induction furnaces
Geothermal		Geothermal heat	Resistance furnaces
Hydro		District heat/cold	Dielectric heaters
Tidal/Wave			Electron beam heaters

Onshore and Floating Offshore Wind

Solar Photovoltaics (PV)

Electric & Hydrogen Fuel Cell Transportation

Tesla Semi-electric (850km)

Nikola Tre Semi-hydrogen fuel cell (1200 km)

Fjellstrand electric ferry

Protera electric bus

Planes: Replace Jet Fuel With Batteries & Hydrogen Fuel Cells

Battery electric aircraft-Ampaire

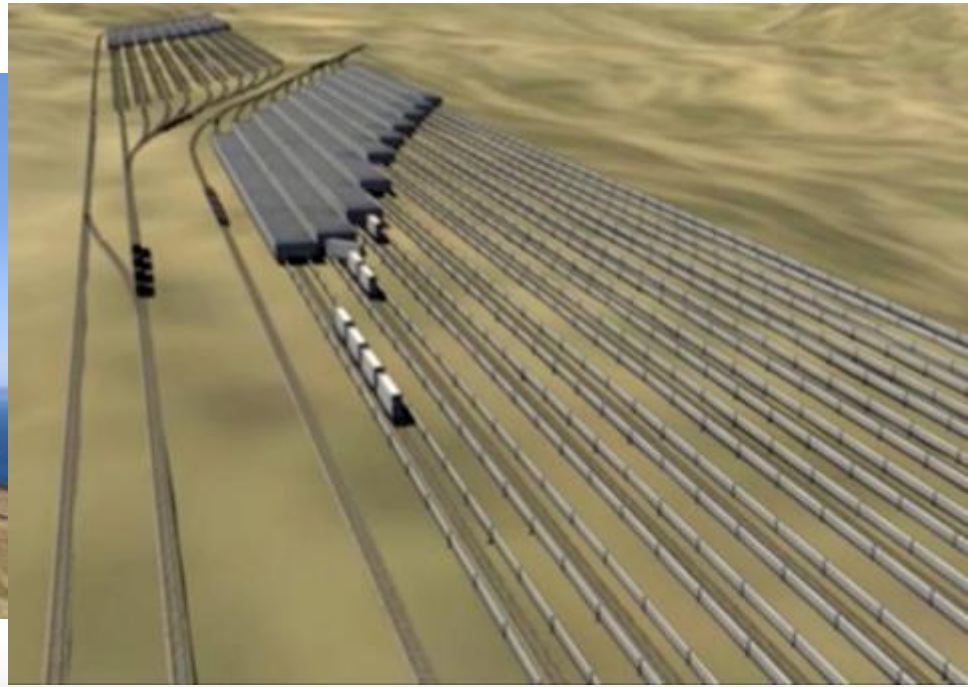
Cryogenic hydrogen aircraft

Hydrogen fuel cell aircraft

Types of Storage for a 100% WWS System

ELECTRICITY	HEATING/COOLING	OTHER
CSP with storage	Water tank	Hydrogen
Pumped hydro storage	Ice	
Existing hydroelectric	Underground	
Batteries	Borehole	
Flywheels	Water Pit	
Compressed air	Aquifer	
Gravitational Storage	Building materials	

Gravitational Storage With Solid Masses



Stanford University 4th Generation District Heating System

Seasonal Heat Storage in Underground Boreholes
Okotoks, Canada

http://www.sustainapedia.com/drake-landing-solar-community/ https://www.leidos.com/project/north-america's-first- Mark Z. Jacobson (2015) right

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

Photo by M.Z. Jacobson

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

Electric Heat Pump Water Heater

Photo by M.Z. Jacobson

Electric Induction Cooktop

Photo by M.Z. Jacobson

Three Years of Energy Use

Generated 120% of all home and vehicle energy

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

Received average $700/yr from CCA for excess electricity to grid

Avoided costs of all-electric home

Gas hookup fee: 3-8 K

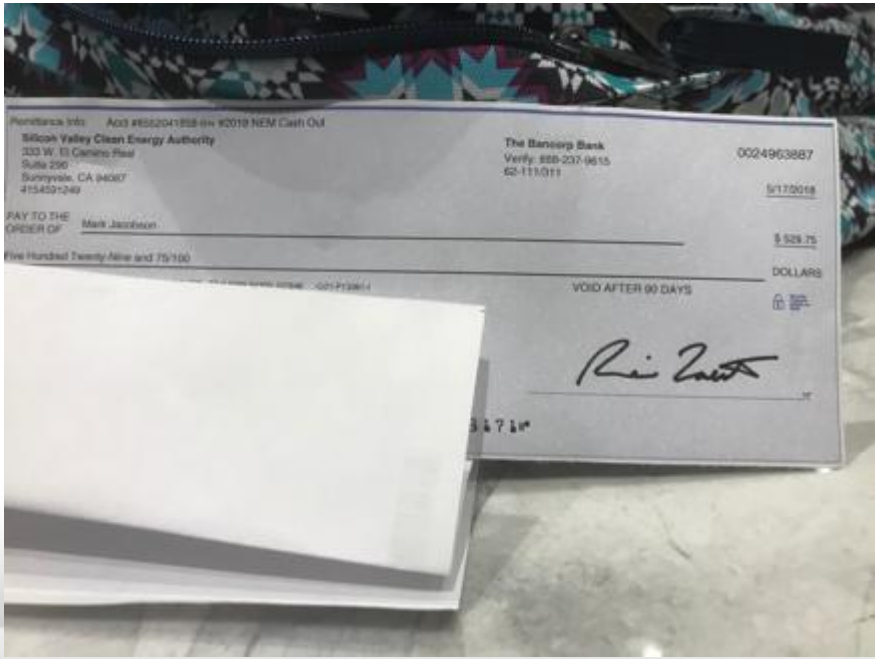
Gas pipes: 1-7 K

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



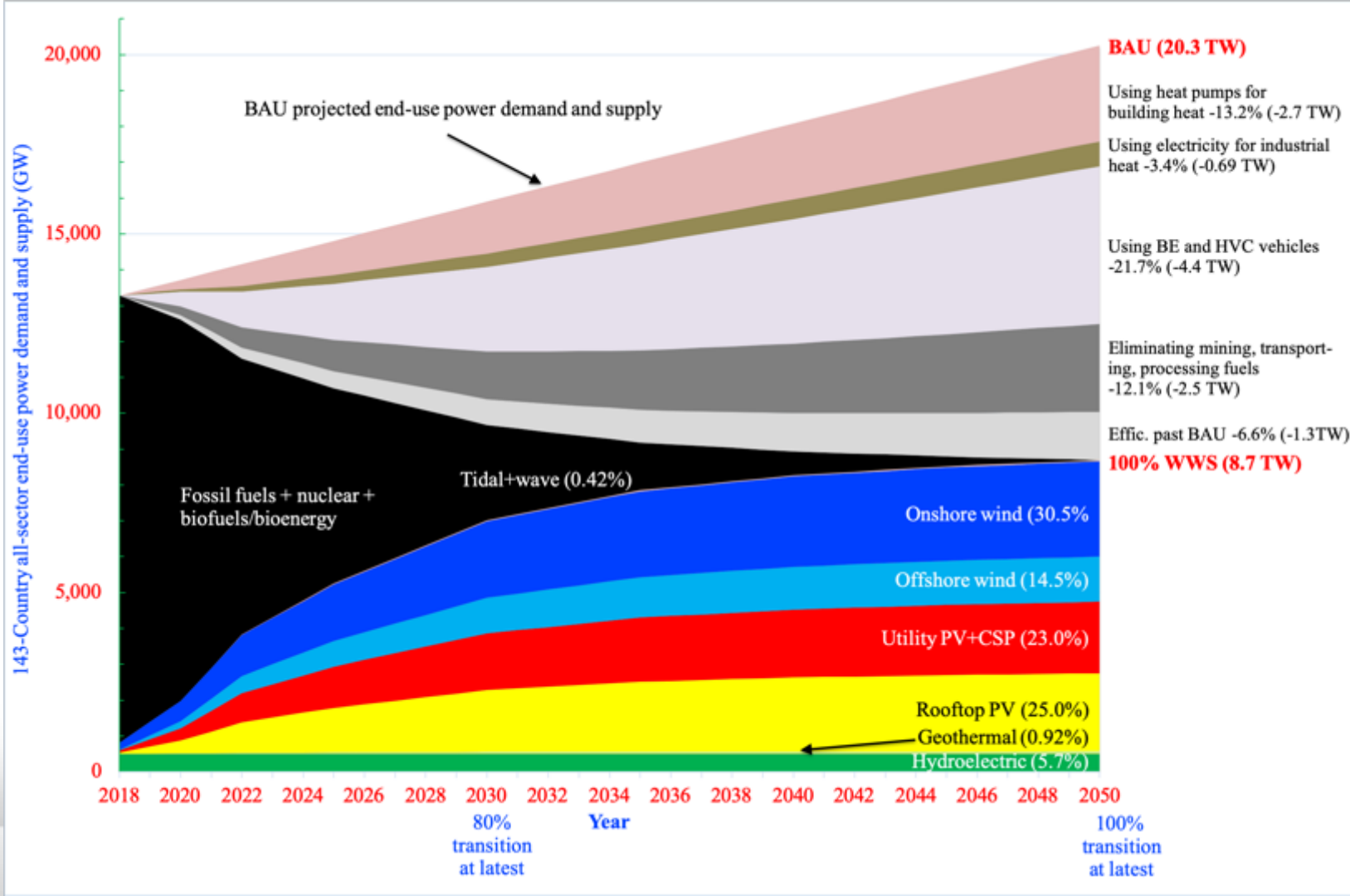
Can the World Transition to 100%, Clean, Renewable Energy for all Purposes?

Roadmaps for 143 Countries

All-Purpose End-Use Power Demand

Year and Fuel Type	143-Countries
2016 End-use demand	12.6 TW
2050 Demand with current fuels (BAU)	20.3 TW
2050 Demand with WWS	8.7 TW
2050 Demand reduction w/ WWS 21.7% efficiency of BE, HFC v. ICE 3.4% efficiency of electric industry 13.2% efficiency of heat pumps 12.1% eliminating fuel mining 6.6% efficiency beyond BAU	57.1%

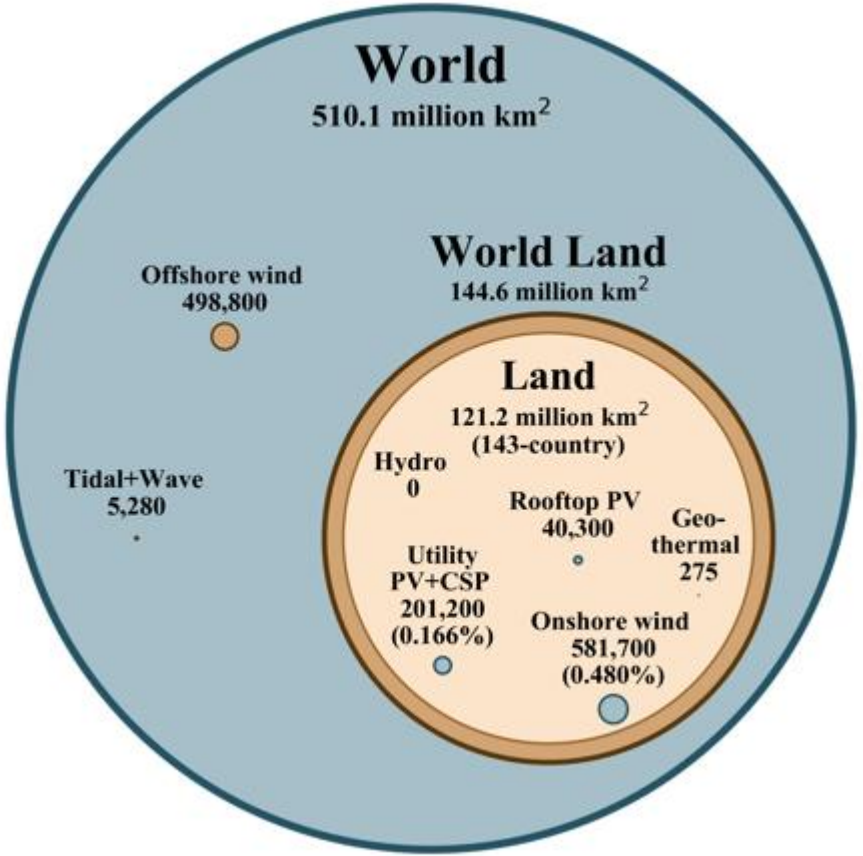
Time-line for a Trans-ition



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

TECHNOLOGY	PCT SUPPLY 2050 World
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%

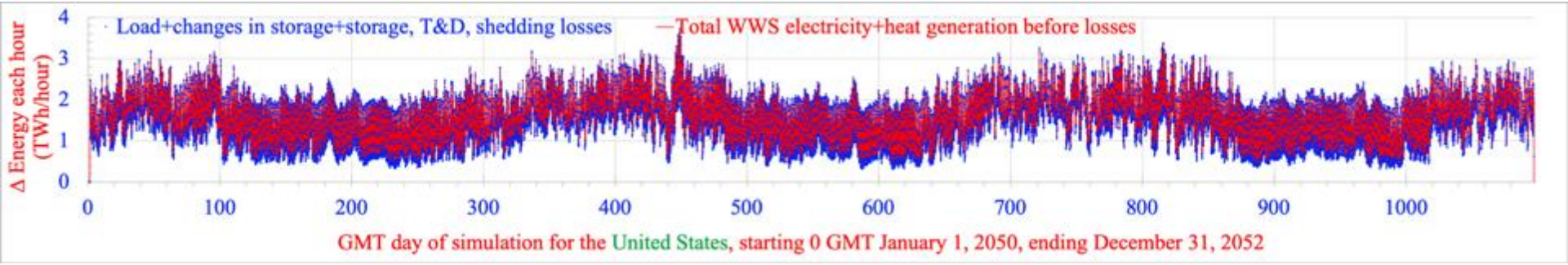
Area Beyond 2018 Installations to Power 143 Countries for all Purposes With 100% WWS in 2050



Percent of 143-Country Land

Onshore wind:	0.48%
Utility PV+CSP:	0.17%
Total	0.65%

Matching U.S. All-Sector Demand Every 30 Sec. With 100% WWS+Storage for 3 Years (2050-2052) and 100 Days



Red = Energy supply

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

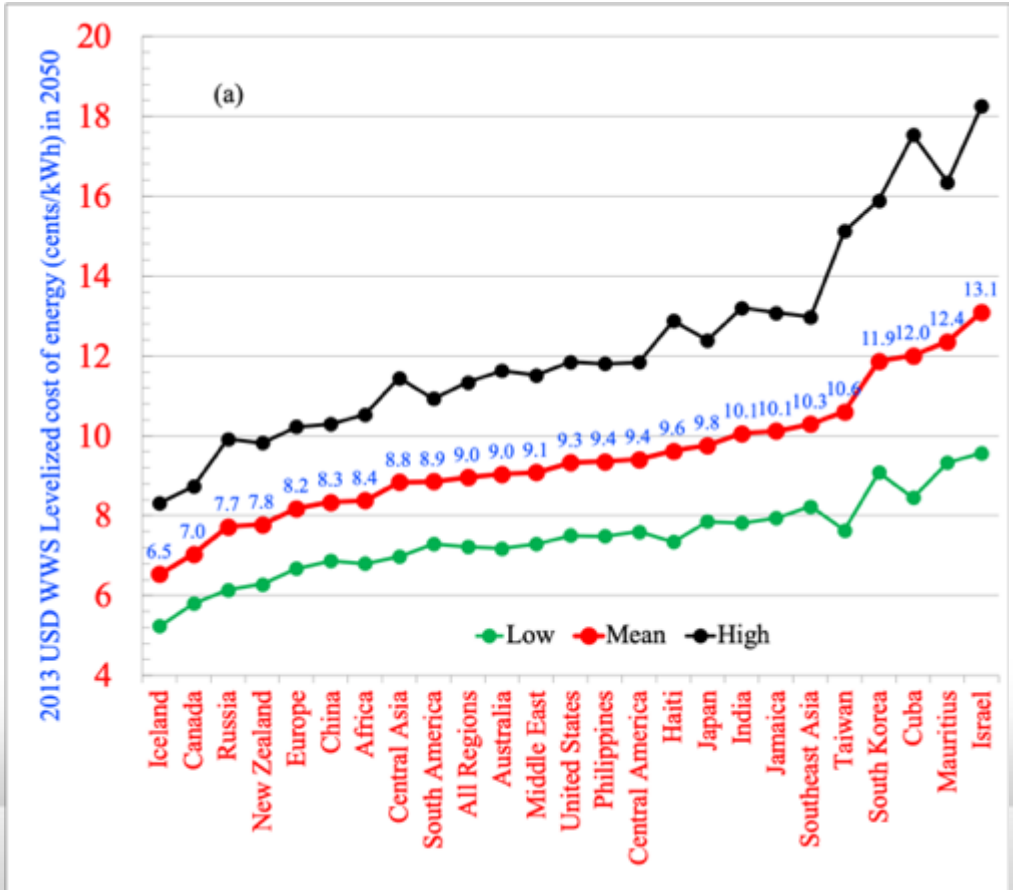
Energy Cost for 143 Countries in 24 Regions Resulting in a Stable Grid Upon Electrification of all Energy With 100% WWS+Storage

World: 9.0 cents/kWh
Capital Cost: $73 trillion

U.S.: 9.3 cents/kWh
Capital cost: $7.8 trillion

China: 8.3 cents/kWh
Capital cost: $16.6 trillion

Europe: 8.2 cents/kWh
Capital cost: $6.2 trillion



2050 World BAU vs WWS Cost

BAU fuel energy cost	$17.7 trillion/yr
BAU fuel health cost	$30.0 trillion/yr
BAU fuel climate cost	$28.4 trillion/yr
Total conventional fuel electricity sector cost	$76.1 trillion/yr

WWS replacing all BAU energy sectors $6.8 tril/yr

WWS reduces energy cost 61.4% and economic (social) cost 91%

Jacobson et al. (2018)

61 Countries Committed to 100% Renewable Electricity

Afghanistan	Denmark	Kirbati	Papua N.G.	Tanzania
Aruba	Djibouti	Lebanon	Philippines	Timor-Les
Bangladesh	Dominica	Madagas	Portugal	Tokelau
Barbados	Dom Rep.	Malawi	Rwanda	Tunisia
Bhutan	Ethiopia	Maldives	Samoa	Tuvalu
Burkina Faso	Fiji	Marsh Is.	Senegal	Scotland
Cabo Verde	Gambia	Mongolia	Solom Is.	Vanuatu
Cambodia	Ghana	Morocco	S. Sudan	Vietnam
Colombia	Grenada	Nepal	Spain	Yemen
Comoros	Guatemala	Niger	Sri Lanka	
Congo, DR	Haiti	Niue	St. Lucia	
Cook Islands	Honduras	Palau	Sudan	
Costa Rica	Kenya	Palestine	Sweden	

U.S. House H.Res.540 (2015), Senate S.Res.632 (2016)

U.S. transition to “100% clean renewable energy by 2050”

U.S. Senate Bill S.987 (2017) and House Bill H.R. 3314 (2017)

“100% clean and renewable energy by 2050”

U.S. House Bills H.R. 3671 (2017), H.R. 330 (2019)

“100% clean, renewable energy by 2035”

“100% renewable electricity by 2035”

U.S. Green New Deal (H.Res. 109; S.Res. 59)

100% Renewable Energy for the U.S. by 2030

100% Renewable Electricity State Laws Resulting From WWS Roadmaps

100% by 2030

Rhode Island

By 2032

Washington D.C.

By 2040

Connecticut

By 2045

Hawaii, California, New Mexico, Washington State, New York

By 2050

Puerto Rico, Nevada, Maine, Wisconsin, Virginia, New Jersey

Some of 176 US Cities/Counties Committed to 100% Renewables

Atlanta (GA)
Chicago (IL)
Cincinatti (OH)
Cleveland (OH)
Denver (CO)
Kansas City (MO)
Los Angeles (CA)
Madison (WI)
Minneapolis (MN)
Orlando (FL)
Philadelphia (PA)
Portland (OR)
Salt Lake City (UT)
San Diego (CA)
San Francisco (CA)
San Jose (CA)
Spokane (WA)
St. Louis (MO)
St. Paul (MN)
St. Petersburg (FL)
Tallahassee (FL)
Abita Springs (LA)
Sarasota (FL)
Hanover (NH)
Sylva (NC)
Moab (UT)
Boulder (CO)
Burlington (VT)
Rochester (MN)
Fayetteville (AR)
Palo Alto (CA)
Middleton (WI)
Missoula (MT)
Questa (NM)
Fayetteville (AR)
Clarkston (GA)

Some of the 235 Companies Committed to 100% Renewables

IKEA	Adobe	JPMor/Chas	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
P&G	Ebay	Facebook	Estee Lauder
GM	Goldman-Sachs	HSBC	Infosys
Kellogg’s	Lego	Mars	Morgan Stanley
Salesforce	Organic Valley	Amazon	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 28 million more jobs than are lost worldwide

Requires only 0.17% of land for footprint; 0.48% for spacing

Avoids ~7 mil. air pollution deaths per year

Slows then reverses global warming

Grids can stay stable throughout the world with 100%

WWS absolute energy costs are 60% less than of fossils

WWS absolute energy+health+climate costs 90% less than of fossils

Online Course on 100% WWS

http://stanford.io/windwatersolar

Roadmaps

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

Infographic maps

www.thesolutionsproject.org

Textbook on 100% WWS

https://web.stanford.edu/group/efmh/jacobson/WWSBook/WWSBook.html

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