



Transitioning the World to 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 heaters
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 (1250 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

Electric Appliances



Electric lift



Electric lawn mower



Electric leaf blower

Types of Storage for a 100% WWS System

ELECTRICITY

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

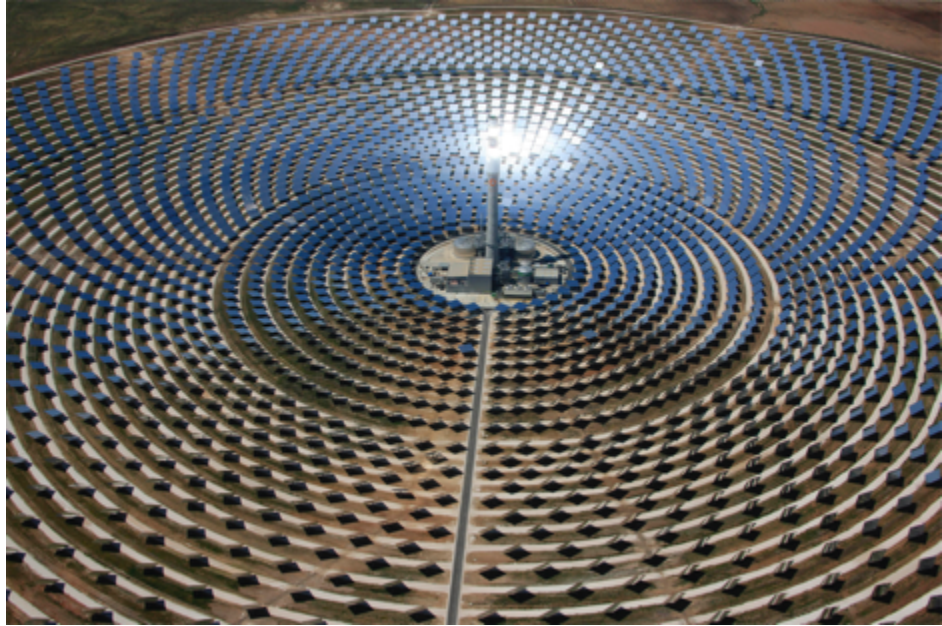
HEATING/COOLING

Water tank
Ice
Underground
Borehole
Water Pit
Aquifer
Building materials

OTHER

Hydrogen

Concentrating Solar Power



Top: Gemasolar CSP plant. 19.9 MW with 15 hours of storage.

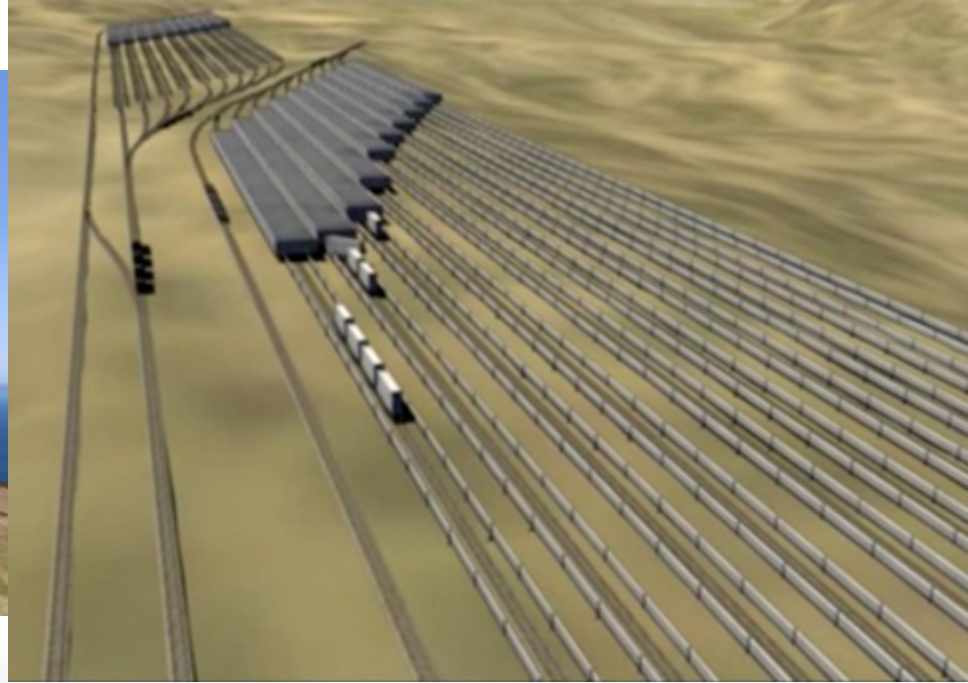


Bottom: 392 MW Ivanpah CSP

Stationary Battery Storage



Gravitational Storage With Solid Masses



Stanford University 4th Generation District Heating System



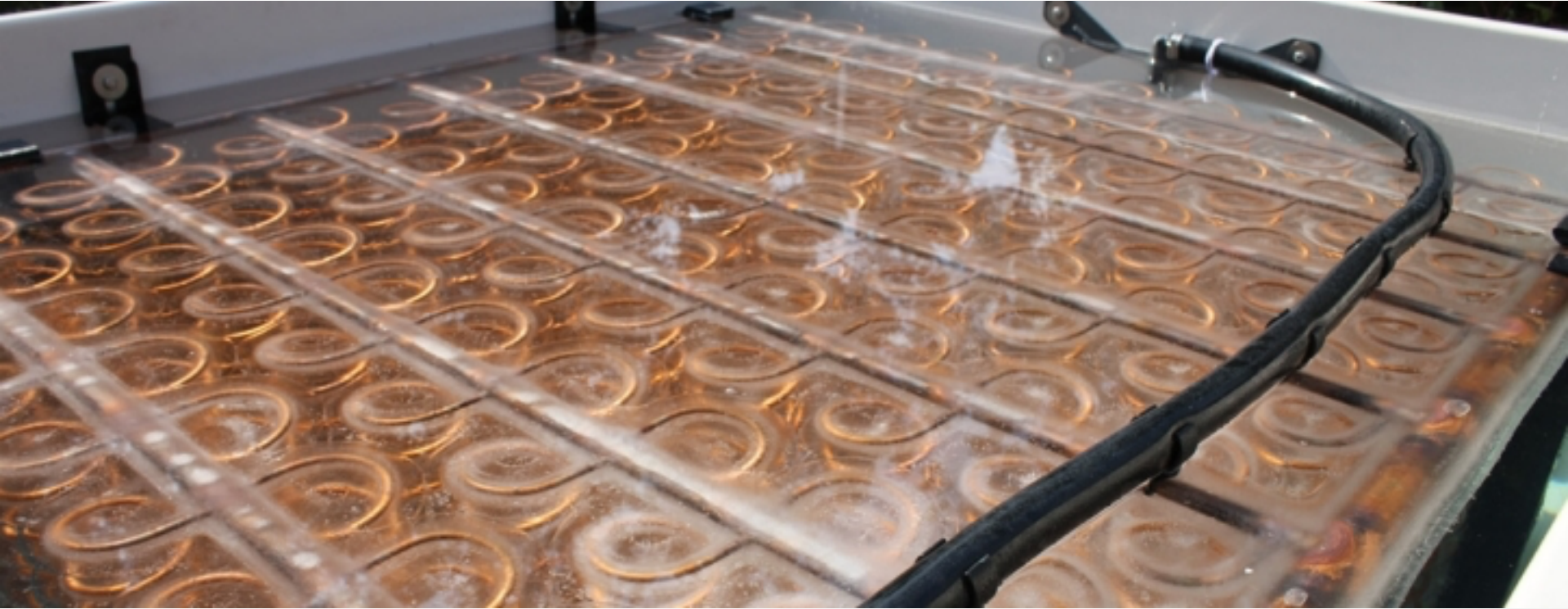
Seasonal Heat Storage in Underground Boreholes Okotoks, Canada



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

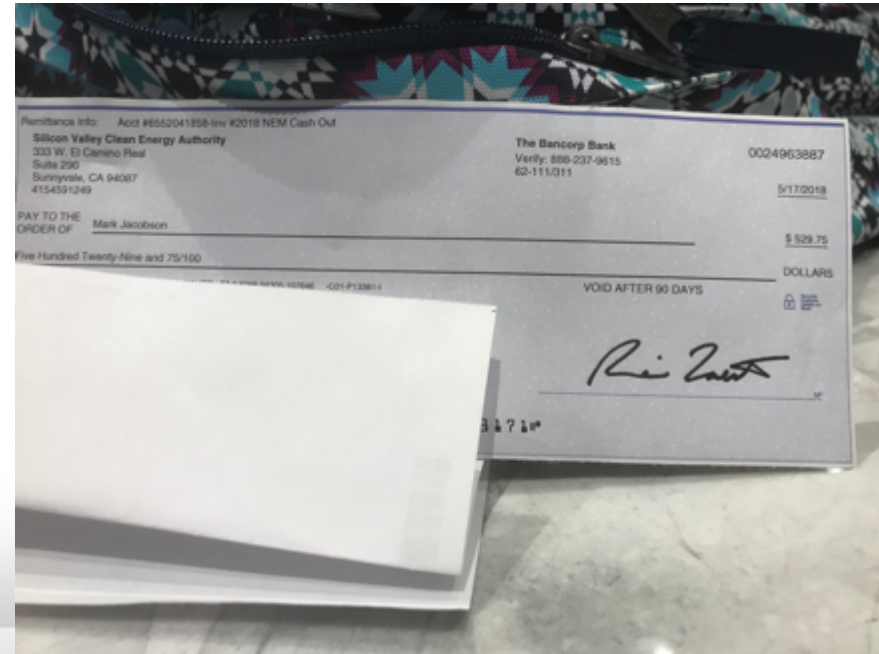
Gas pipes: 1-7 K

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



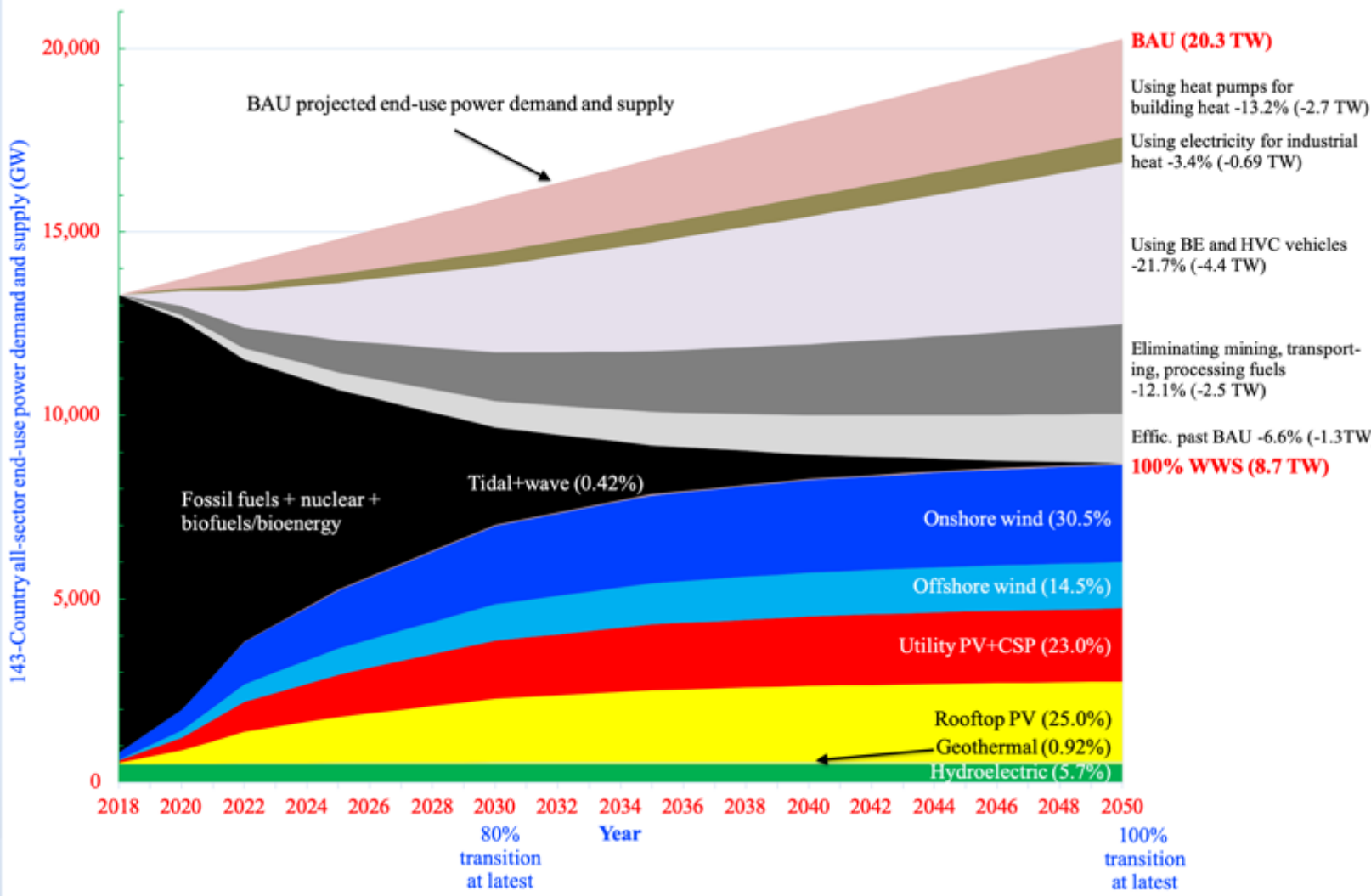
Can the World Transition to 100%, Clean, Renewable Energy for all Purposes?

Roadmaps for 143 Countries

All-Purpose End-Use Power Demand

Year and Fuel Type	143-Countries
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	57.1%
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	

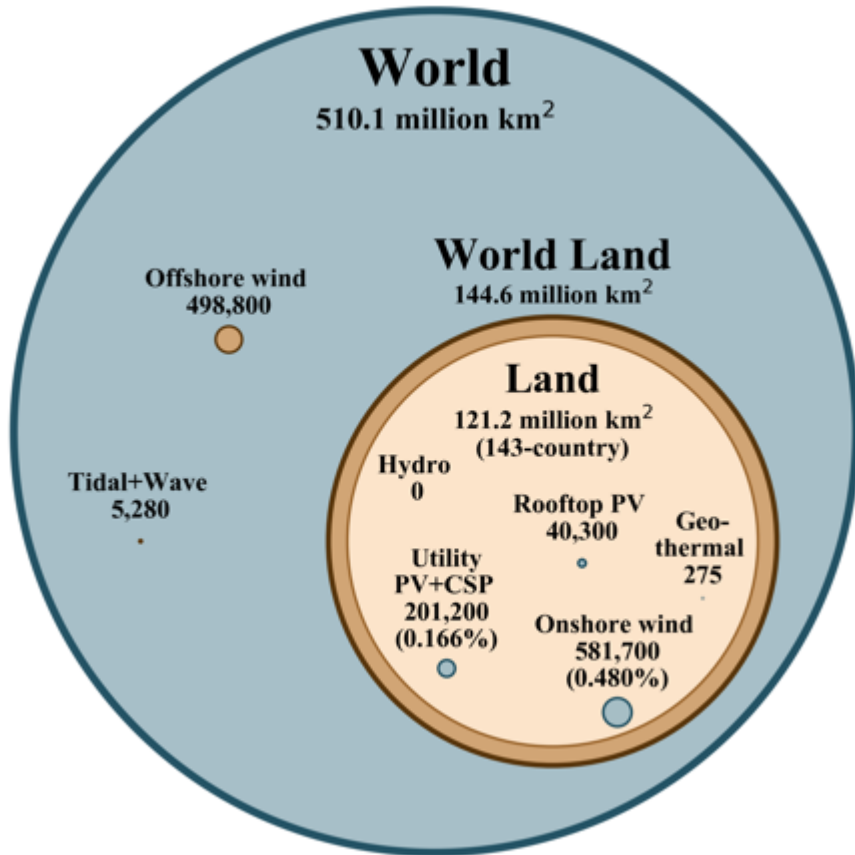
Time-line for a Transition



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



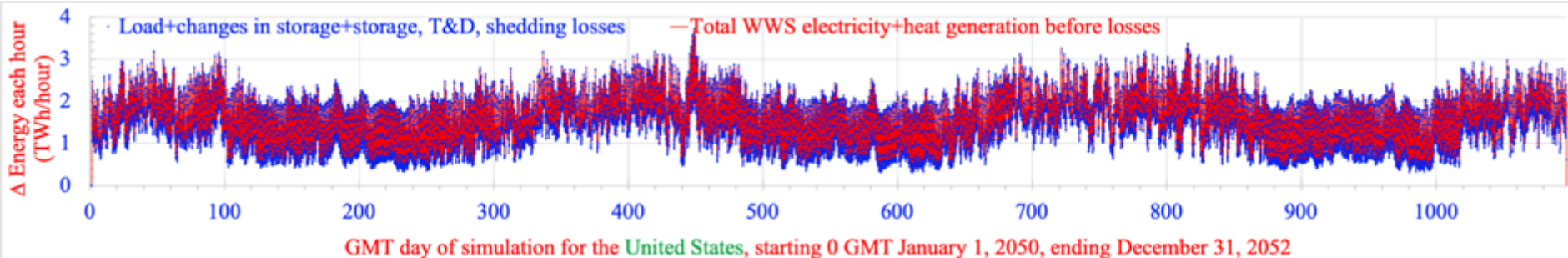
Percent of 143-Country Land

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

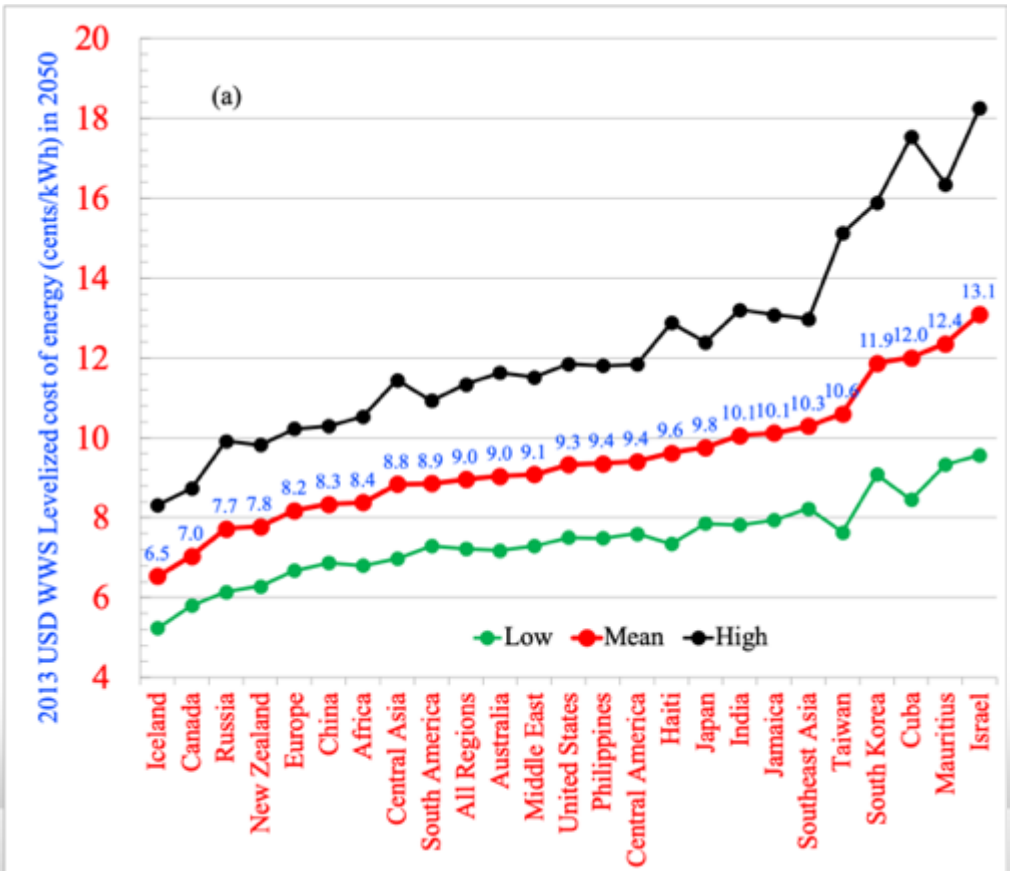
Energy Cost for 143 Countries in 24 Regions Resulting in a Stable Grid Upon Electrification of all Energy With 100% WWS+Storage

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
<u>BAU fuel climate cost</u>	<u>\$28.4 trillion/yr</u>
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%

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	

10 Countries near or above 100% Renewable Electricity

Iceland

Norway

Costa Rica

Paraguay

Uruguay

Tajikistan

Bhutan

Albania

Kenya

Scotland

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

Laws Arising From 100% WWS Roadmaps

100% renewable electricity by 2032

Washington D.C.

100% renewable electricity by 2045

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

100% renewable electricity by 2050

Puerto Rico, Nevada, Maine, Wisconsin, Virginia

Some of 140 Cities/Counties Committed to 100% Renewables

Atlanta (GA)

Chicago (IL)

Cincinnati (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 210 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	Dell	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

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Infographic maps

<https://thesolutionsproject.org/why-clean-energy/>

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

Texbook on 100% WWS

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