

**From ambition to reality:
weaving the threads
of net-zero delivery.**

October, 27th 2021, 2.30 pm
«Ecomondo», Fiera di Rimini

Transitioning the World to 100% Clean, Renewable Energy and Storage for Everything

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International Conference, Italy



What are the Problems? Why act Quickly?

Fossil-fuel and biofuel air pollution cause ~7 million air pollution deaths/yr worldwide, costing ~\$30 trillion/year

Global warming will cost ~\$30 trillion/year by 2050.

Fossil fuels will become scarce, increasing energy prices and economic, political, and social instability

Drastic problems require immediate solutions

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	H₂ fuel cell	District heat/cold	Induction furnaces
Geothermal		Geothermal heat	Resistance furnaces
Hydro		Solar heat	Dielectric heaters
Tidal/Wave			Electron beam heaters



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

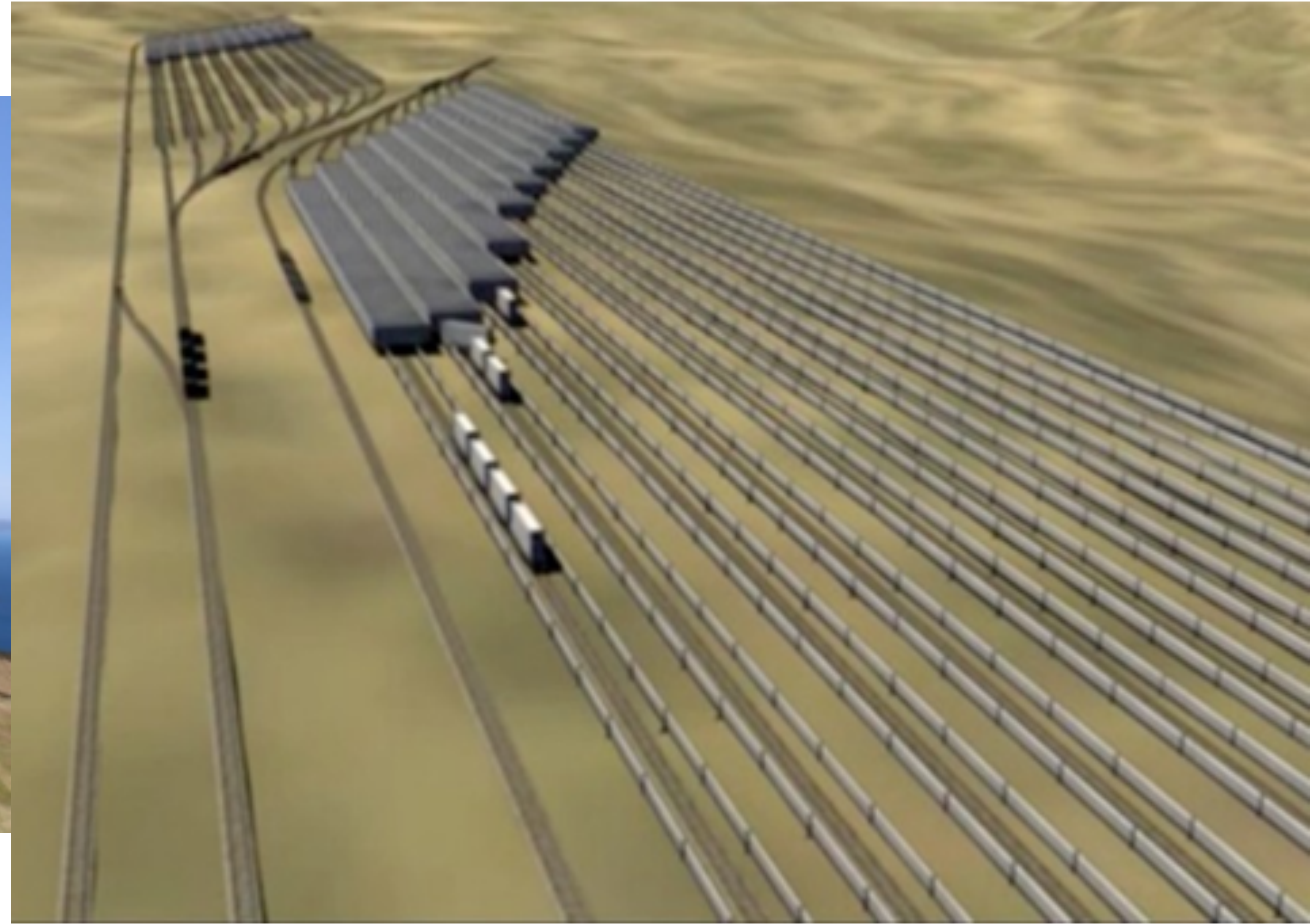
Aquifer

Building materials

OTHER

Hydrogen

Gravitational Storage With Solid Masses



Stanford University 4th Generation District Heating System



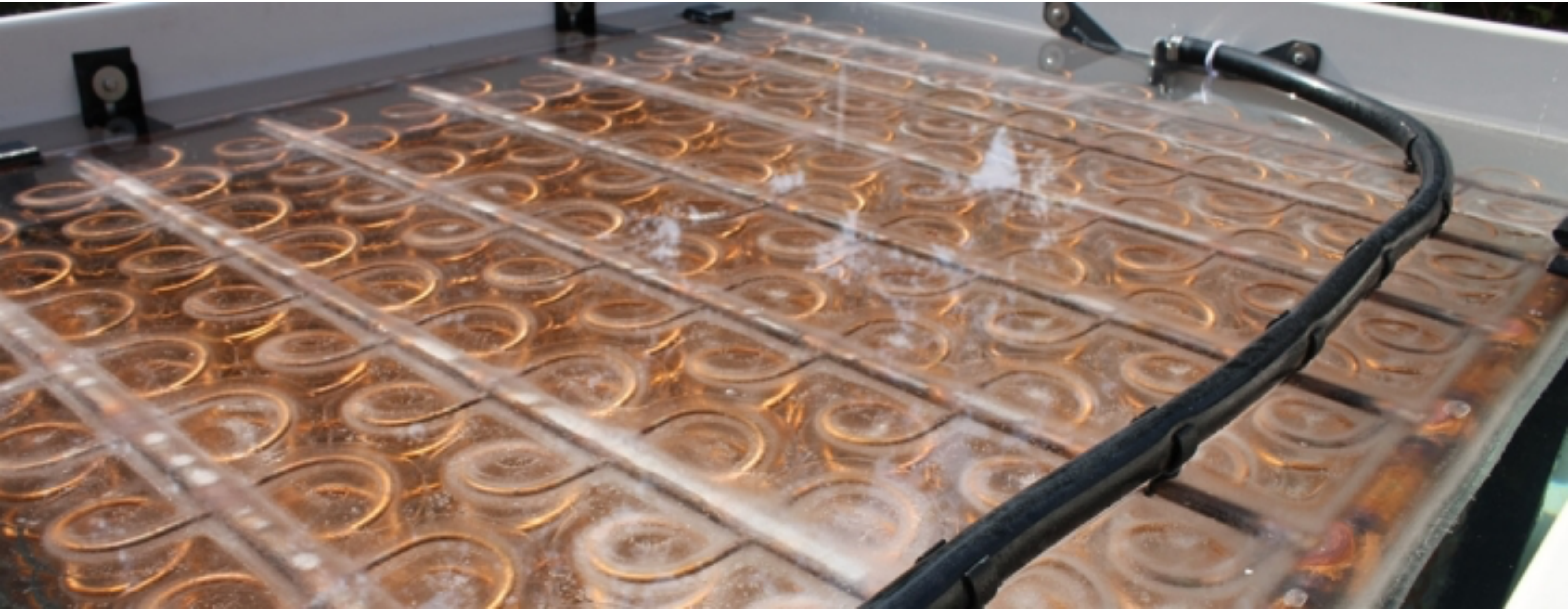
Seasonal Heat Storage in Underground Boreholes Okotoks, Canada



Seasonal District Heat Storage in Covered Water Pit Vojens, Denmark



Nighttime Storage in Ice for Daytime Air Cooling

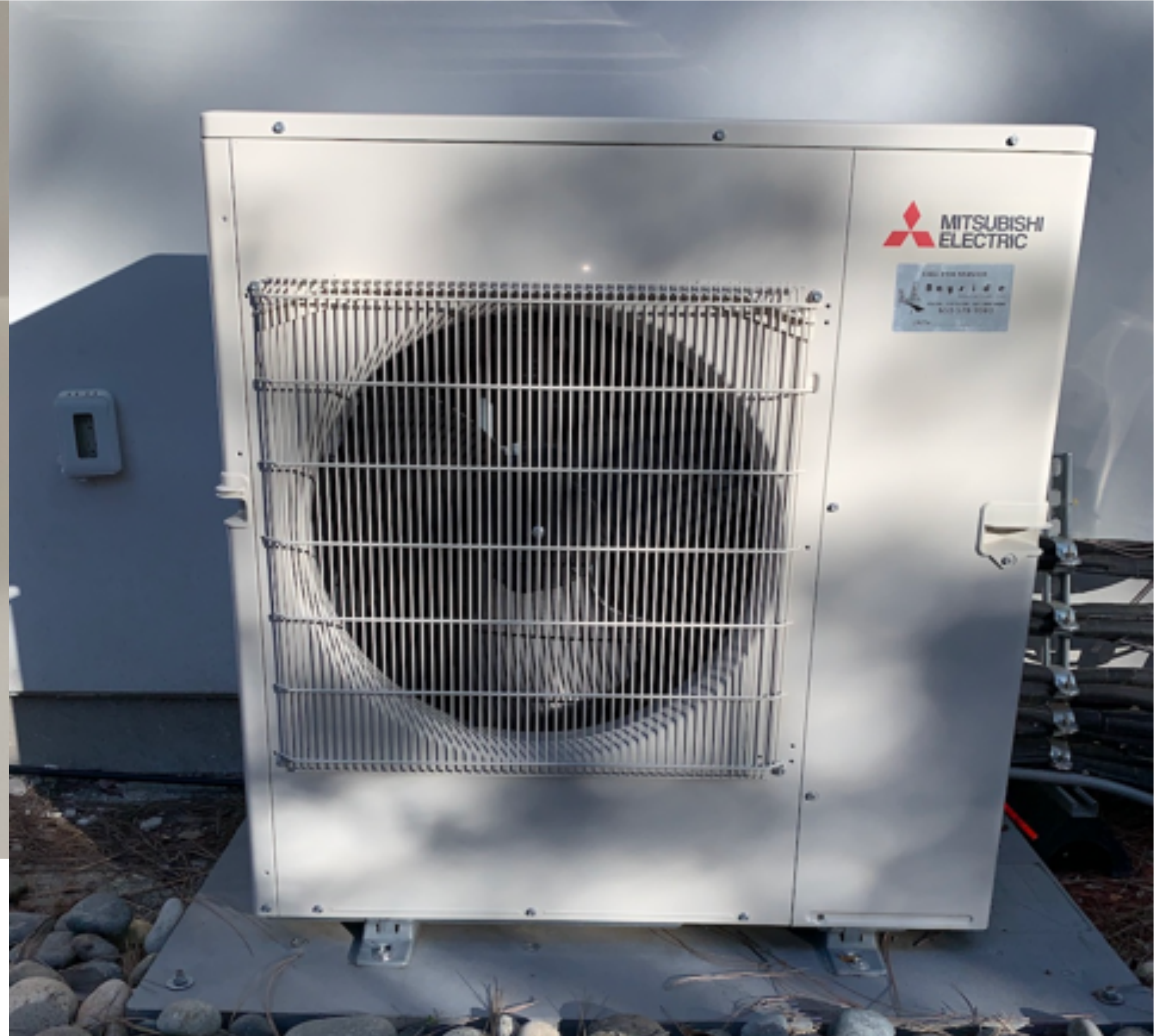


Transitioning an Individual Home to Run on WWS Electricity/Storage and No Gas

Rooftop Solar Plus Battery Storage



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



Electric Heat Pump Water Heater



Electric Induction Cooktop



Four Years of Energy Use

Generated 120% of all home and vehicle energy

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

Received average \$800/yr from CCA for excess electricity to grid

Avoided costs of all-electric home

Gas hookup fee: 3-8 K

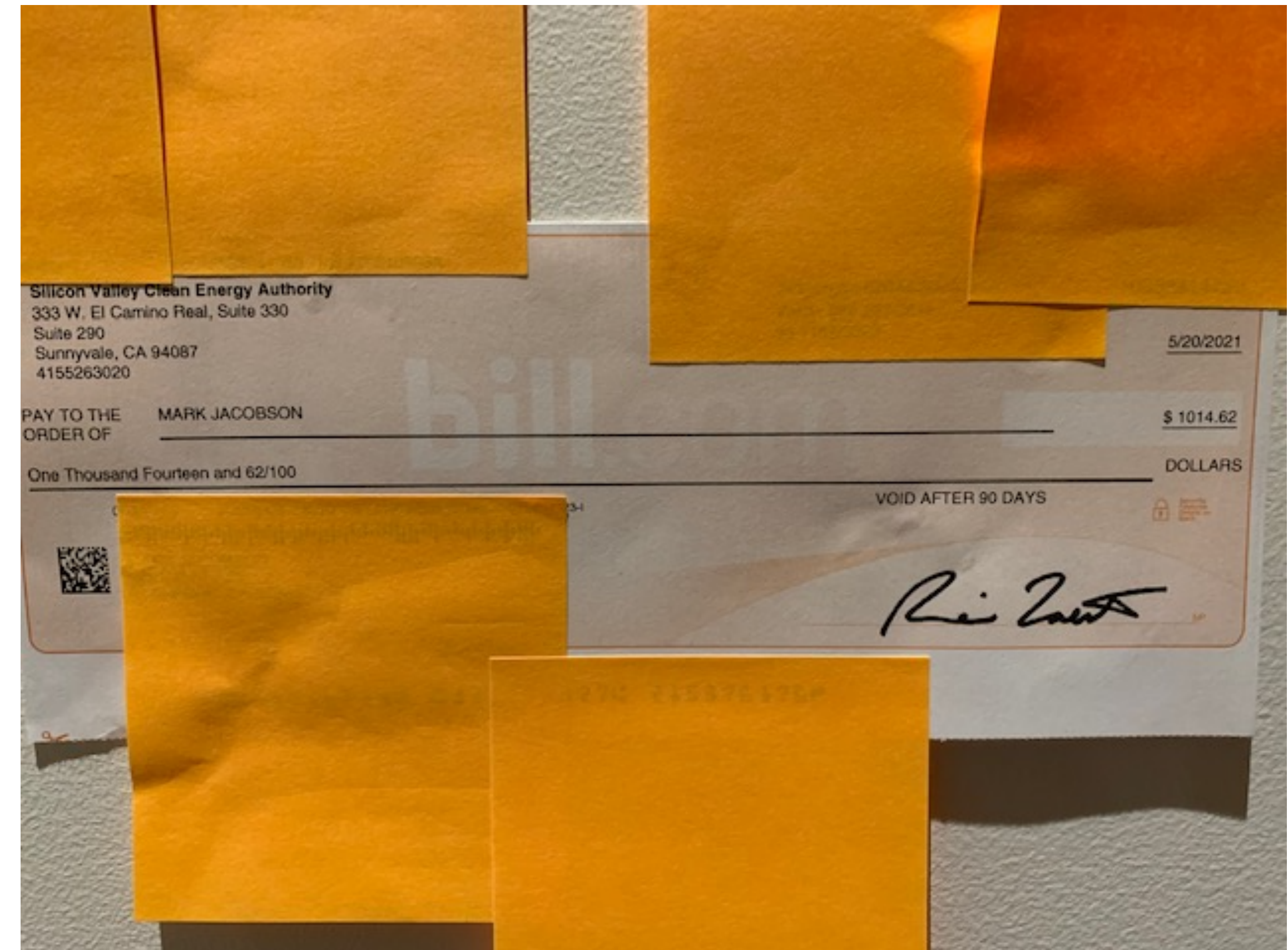
Gas pipes: 2-15 K

Electric bill 1-3 K per year

Natural gas bill 1-3 K per year

Vehicle fuel bill 1-4 K per year

Total: 5-23 K plus 3-10 K per year



5y payback with subsidy: 10y w/o

No Blackout on Hottest Day of Year

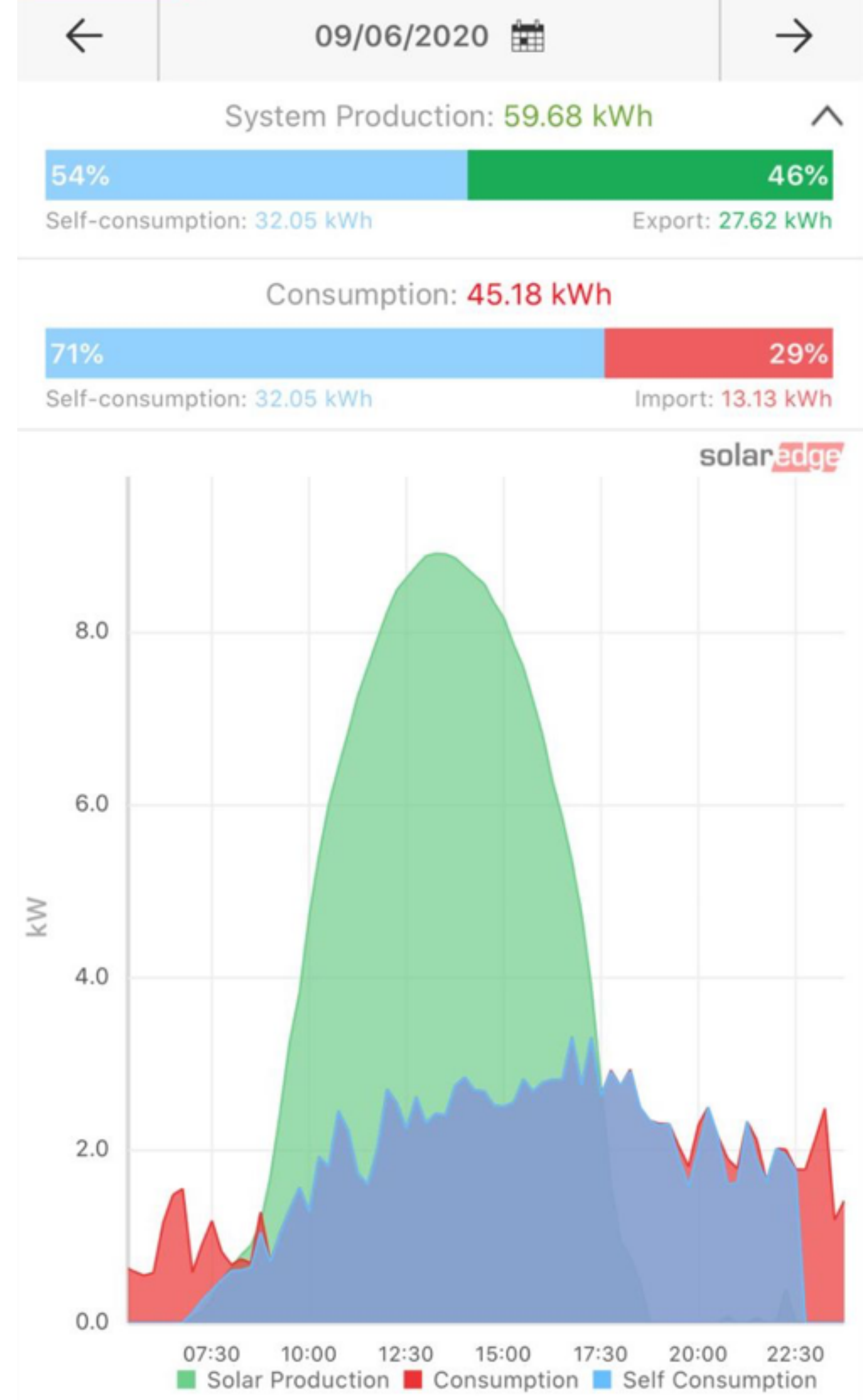
Sept. 6, 2020

Outside temperature: 106 F

Inside temperature: 77 F

Blue=consumption by solar during day or batteries after sunset (2-3.3 kW/6.4 kWh)

Red=grid electricity



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

Roadmaps for 143 Countries

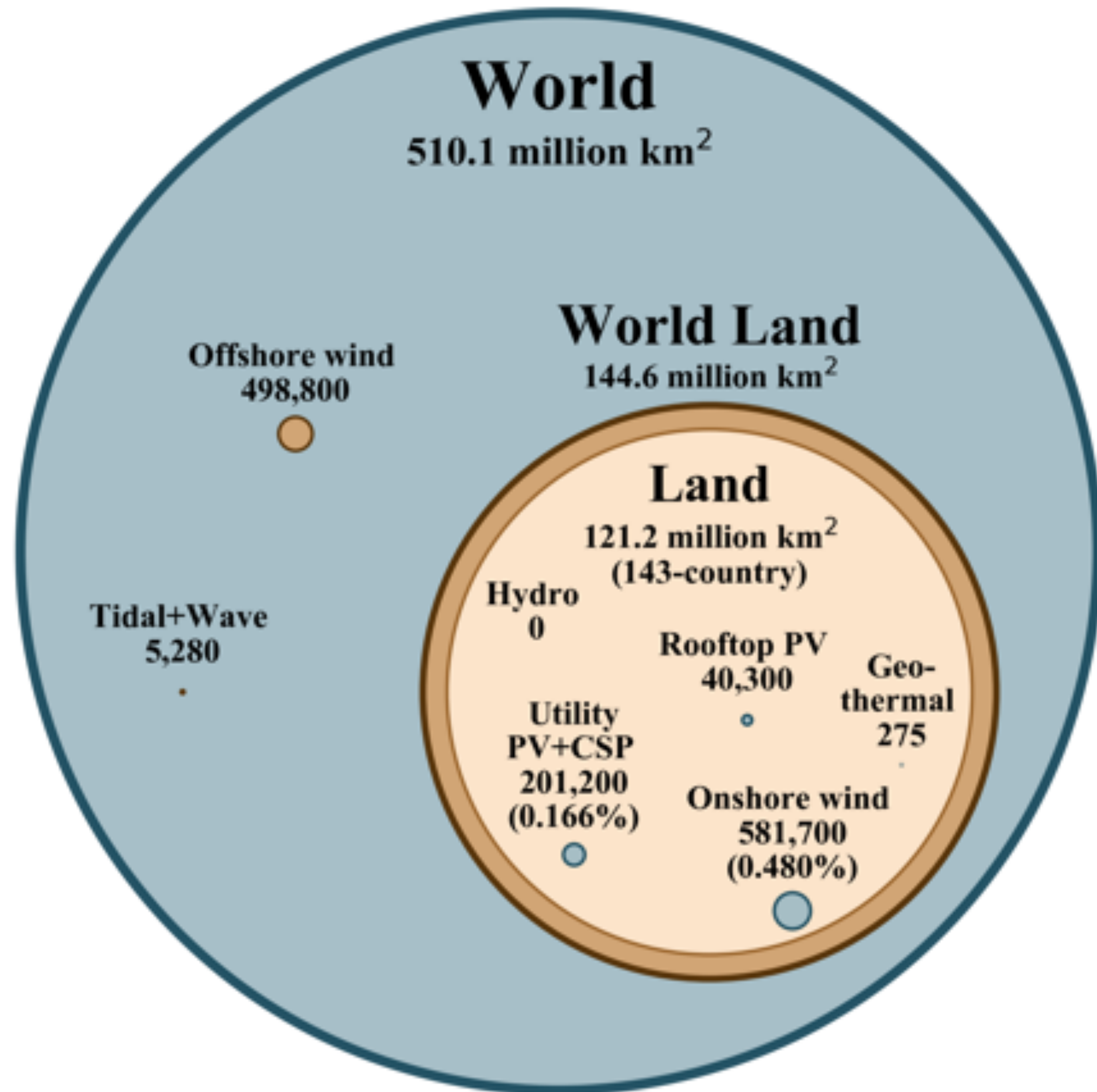
All-Purpose End-Use Power Demand

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	

Percent of 2050 143-Country and Southeast U.S. End-Use Demand Supplied by WWS

TECHNOLOGY	World	Italy
Onshore wind	30.5%	36.8%
Offshore wind	14.5	14.8
Rooftop Solar PV	24.9	21.6
Utility PV	19.0	14.8
CSP	3.93	2.72
Geothermal	0.92	0.97
Hydroelectric	5.72	8.03
Tidal	0.08	0.02
Wave	0.34	0.18
	100%	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%

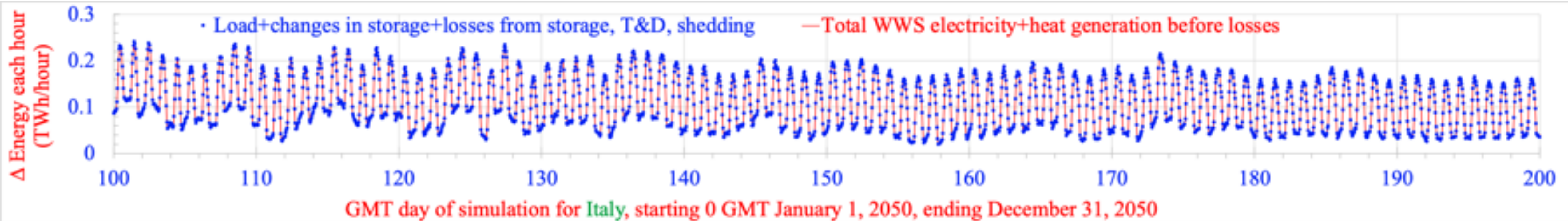
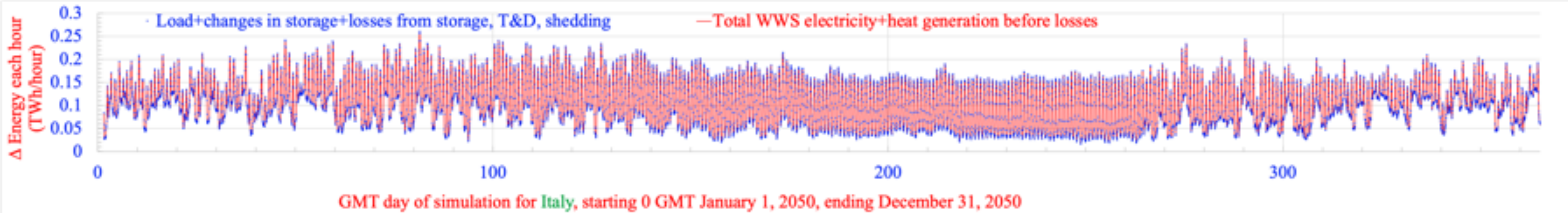
Percent of Italy Land

Onshore wind: 1.55%

Utility PV+CSP: 0.34%

Total 1.89%

Matching the **Italy** All-Sector Demand Every 30 Sec. With 100% WWS+Storage for 1 Year (2050) and 100 Days



Red = Energy supply

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

Interconnecting Countries Reduces Cost

Norway alone: \$10.8 billion/yr

Denmark alone: \$11.0 billion/yr

Total: \$21.8 billion/yr

Norway+Denmark: \$17.3 billion/yr

→ Interconnecting 21% less expensive

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**

**Italy: 8.4 cents/kWh
Capital cost: \$570 billion**

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>
BAU total social cost	\$76.1 trillion/yr

WWS total social cost \$6.8 trillion/yr

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

2050 Italy BAU vs WWS Cost

BAU fuel energy cost	\$211 bil/yr
BAU fuel health cost	\$169 bil/yr
<u>BAU fuel climate cost</u>	<u>\$239 bil/yr</u>
BAU total social cost	\$618 bil/yr

WWS total social cost \$61.4 bil/yr

WWS reduces energy cost 71% and economic (social) cost 90%

RETHINKING "HOBBITS"
What They Mean for Human Evolution

THE EVERYTHING TV
Get Ready for the Wide-Screen Web

SCIENTIFIC AMERICAN

November 2009

www.ScientificAmerican.com

The Long-Lost
Siblings of
OUR SUN
page 40



A Plan for a

Sustainable Future

How to get all energy from
wind, water and solar power
by 2030

Chronic Pain
What Goes Wrong

Plus:

- The Future of Cars
- Farms in Skyscrapers



\$5.99

2009

100% worldwide wind, water,
solar (WWS) all-sector energy
plan introduced

Basis for *Green New Deal*

Conclusion

While technically and economically
possible to transition by 2030, social
and political barriers make
complete transition more practical
by 2050 with most (~80%) by 2030

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	

13 Countries Near or Above 100% Renewable Electricity in Annual Average and Their Top Two Electricity Sources

Iceland (H,G)

Norway (H, W)

Costa Rica (H, W)

Paraguay (H)

Uruguay (H, W)

Tajikistan (H)

Albania (H)

Scotland (W, H)

Kenya (G, H)

Bhutan (H)

Nepal (H)

Ethiopia (H, W)

Congo, DR (H)

H = hydro

G = geothermal

W = wind

15 100% Renewable Electricity State/Territory Laws/Exec Orders Resulting From WWS Roadmaps

100% by 2030

Rhode Island

By 2032

Washington D.C.

By 2040

Connecticut, Oregon

By 2045

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

By 2050

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

Some of 180+ US 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 340+ 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

Summary – Transitioning World 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

Book on 100% WWS

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

Roadmaps

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

Online Course on 100% WWS

<https://online.stanford.edu/courses/cee176b-100-clean-renewable-energy-and-storage-everything>

Infographic maps

<https://sites.google.com/stanford.edu/wws-roadmaps/home>

Twitter: @mzjacobson

Thanks

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