Third Annual Trottier Symposium on
Sustainable Engineering, Energy and Design

The Trottier Institute for Sustainability in Engineering and Design (TISED) and the Institut de l'énergie Trottier (IET) present:

Renewables: What holds us back? What moves us ahead?

March 8 & 9, 2016

Montréal, Québec, Canada

#energyhorizon

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www.trottiersymposium.org

McGill Faculty of Engineering

TISED Trottier Institute for Sustainability in Engineering and Design

IET INSTITUT DE L'ÉNERGIE TROTTIER

POLYTECHNIQUE MONTRÉAL

Roadmaps for Transitioning all 50 U.S. States and 139 Countries to Wind, Water, and Solar Power for all Purposes

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3rd Symposium Trottier Inst.
McGill Univ, Montreal, Canada
March 9, 2016

J. G. Swanepoel/Dreamstime.com

Wind farm near Middelgrunden, Denmark

What's the Problem? Why act Quickly?

Fossil-fuel + biofuel air pollution cause 4-7 mil. premature air pollution deaths/yr worldwide costing >3% of world GDP

Global warming due to world emissions will cost ~$16-20 trillion/year by 2050.

Increasing fossil energy use increases energy prices→ economic, social, political instability

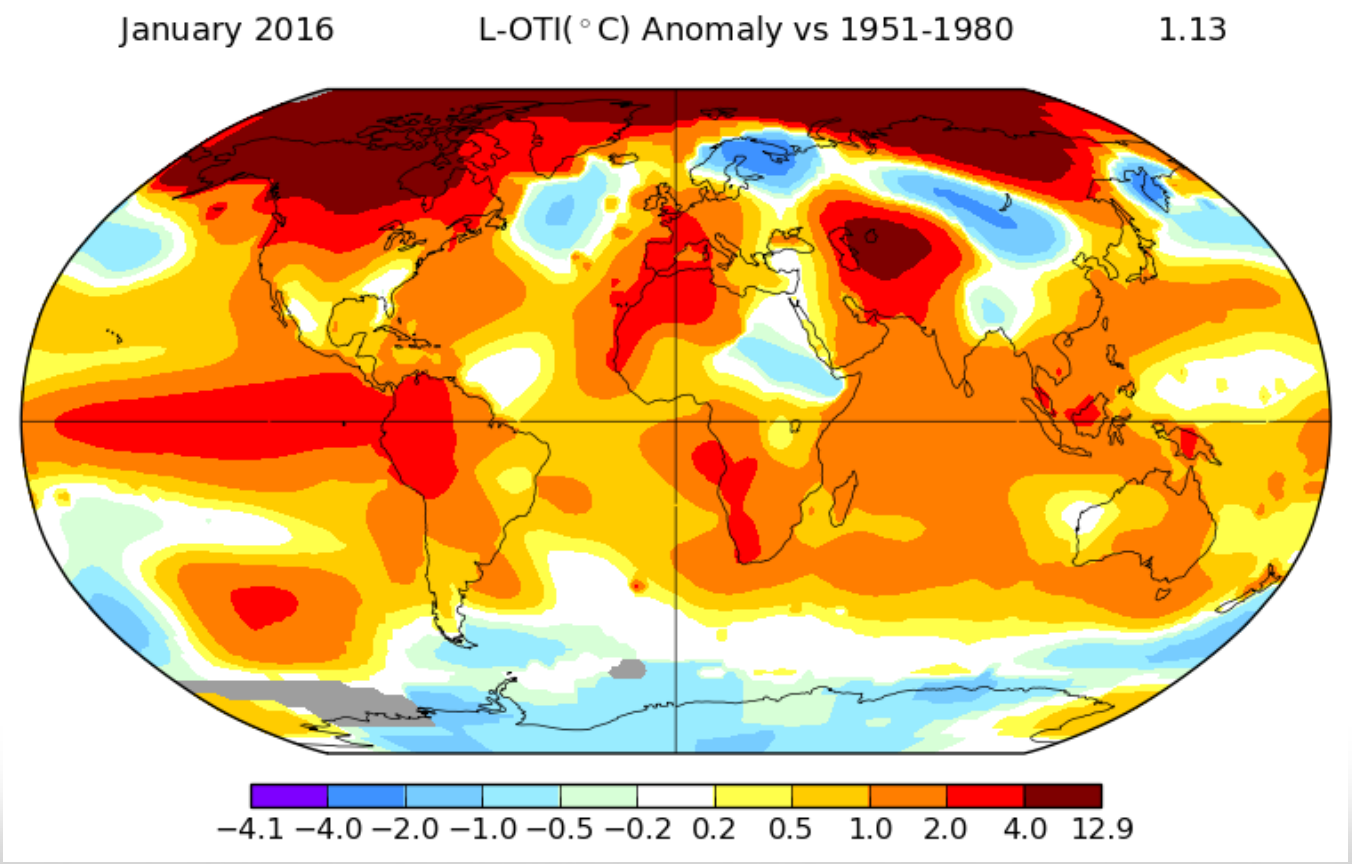
Drastic problems require immediate solutions.

Beijing, China, Jan 11-14, 2013

Lung of LA Teenage Nonsmoker in 1970s;

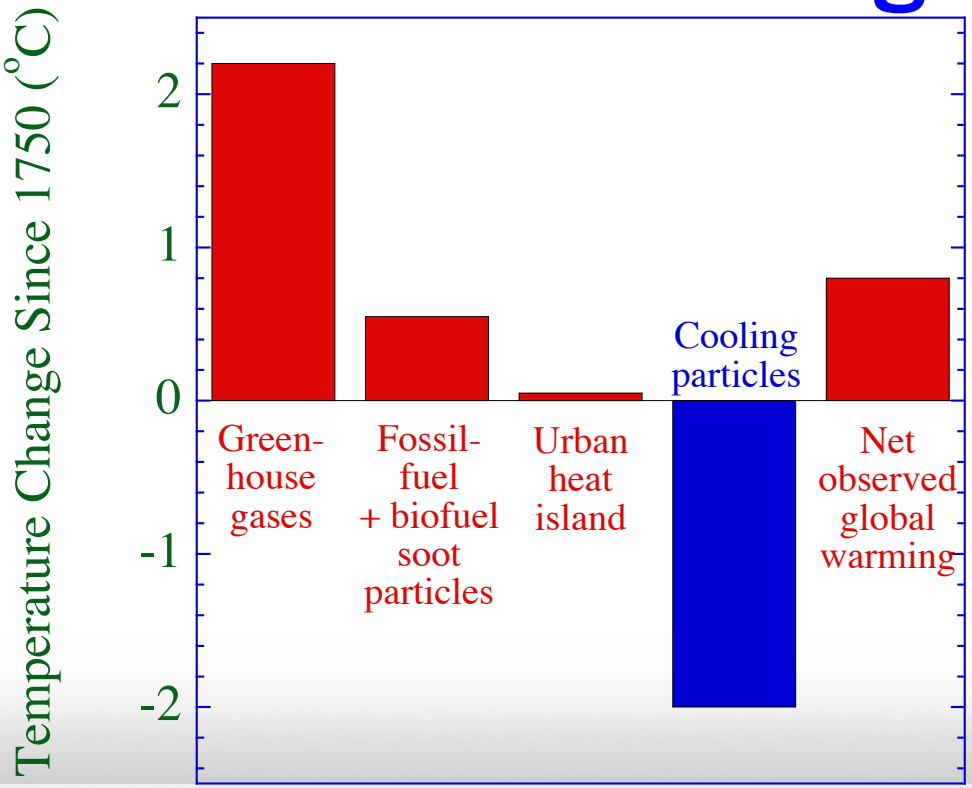
SCAQMD/CARB

Jan 2016 Global Warming 1.1 K=2 F



NASA GISS, 2014

Primary Contributors to Net Observed Global Warming



Wind, Water, Solar (WWS) All-Sector Solutions to Energy and Job Security, Air Pollution, Global Warming

ELECTRICITY	TRANSPORTATION	HEATING/COOLING	INDUSTRY
Wind	Battery-electric	Electric heat pumps	Electric resistance
Solar PV/CSP	Hydrogen fuel cell	Electric resistance	Electric arc furnaces
Geothermal	Cryogenic H_2	Solar water preheat	Induction furnaces
Hydro			Dielectric heating
Tidal/Wave			Hydrogen

Energy & Env. Sci, 2, 148 (2009)

Types of Storage for 100% WWS System

ELECTRICITY	HEATING/COOLING	OTHER
CSP with storage	Water	Hydrogen
Pumped hydro	Ice	Demand-response
Existing hydroelectric	Rocks in soil	

Why Not Natural Gas?

Gas wells in Upper Green River Valley, WY: Ecoflight.org

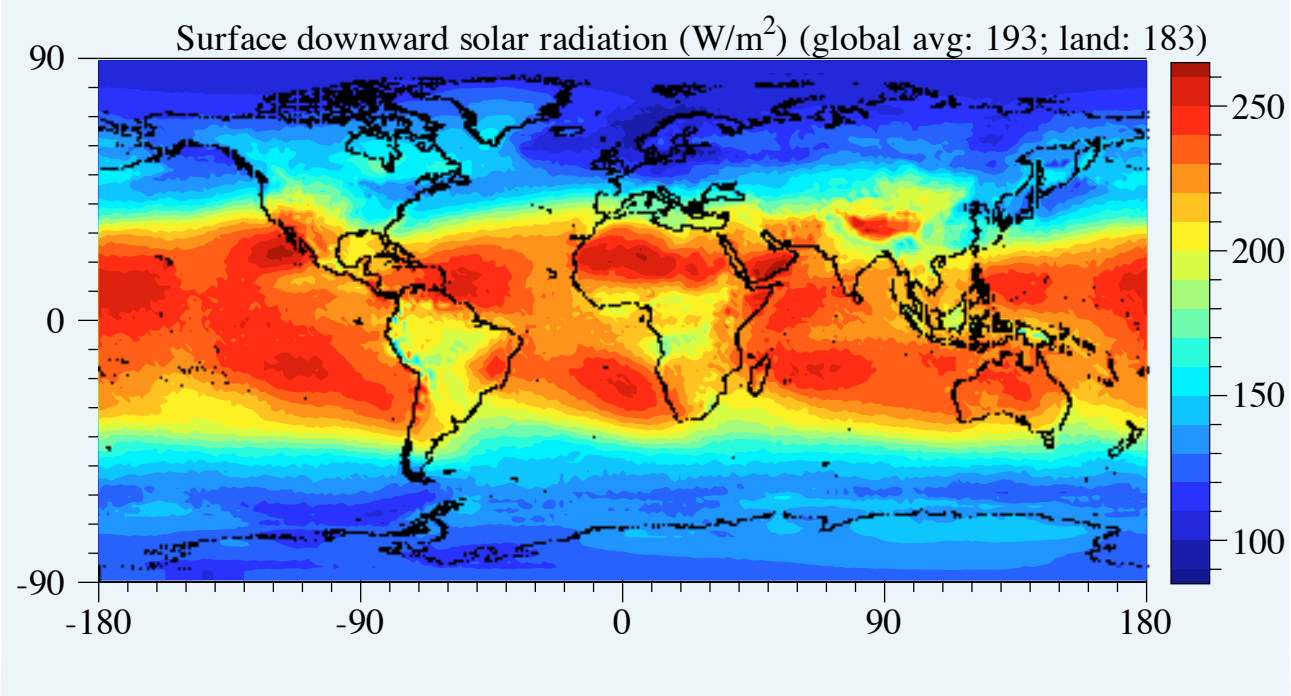
50-70 times more CO_2 and air pollution per kWh than wind

Methane from natural gas a main contributor to Arctic ice loss.

Natural gas mining, transport, and use causes 5000 premature mortalities/year in the U.S.

Hydrofracking causes land and water supply degradation and enhanced methane leaks.

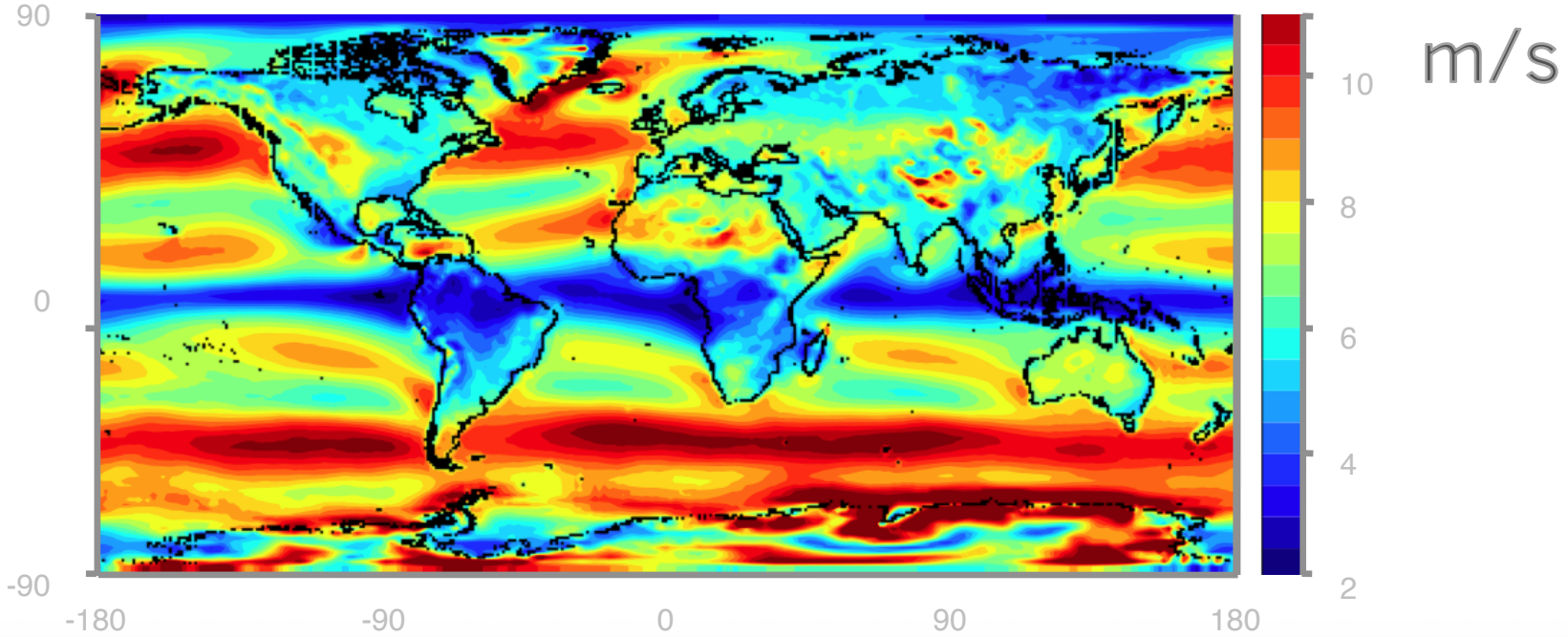
World Surface Solar



W/m²

All solar over land in high-solar locations~ 340 TW
= 25 times world end-use WWS power demand 2050 of 13.4 TW

World Wind Speeds at 100m

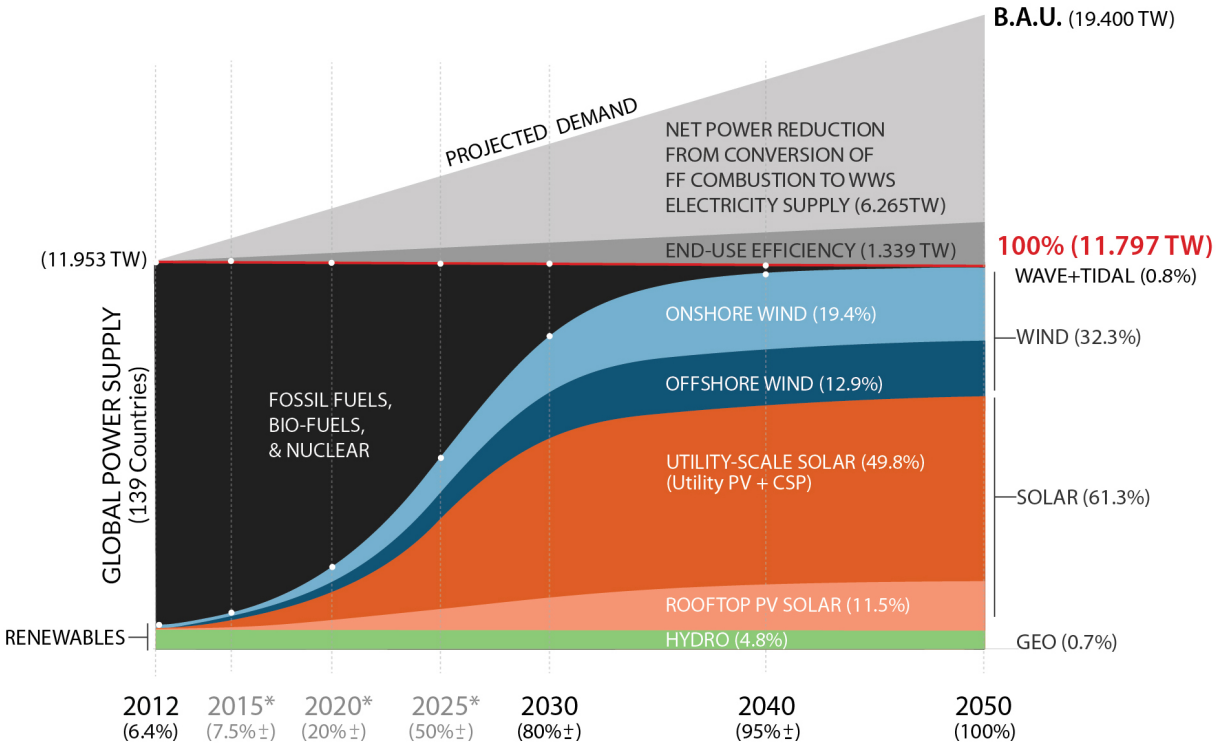


All wind over land in high-wind areas outside Antarctica ~70-80 TW
= ~5-6 times world end-use WWS power demand 2050 of 13.4 TW

End-Use Power Demand For All Energy Purposes

Year and Fuel Type	139-Countries	Canada
2012 (TW)	12.0	0.3
2050 with current fuels (TW)	19.4	0.41
2050 WWS (TW)	11.8	0.24
2050 Reduction w/ WWS (%)	39	43

Timeline for 139-Country Transition to WWS

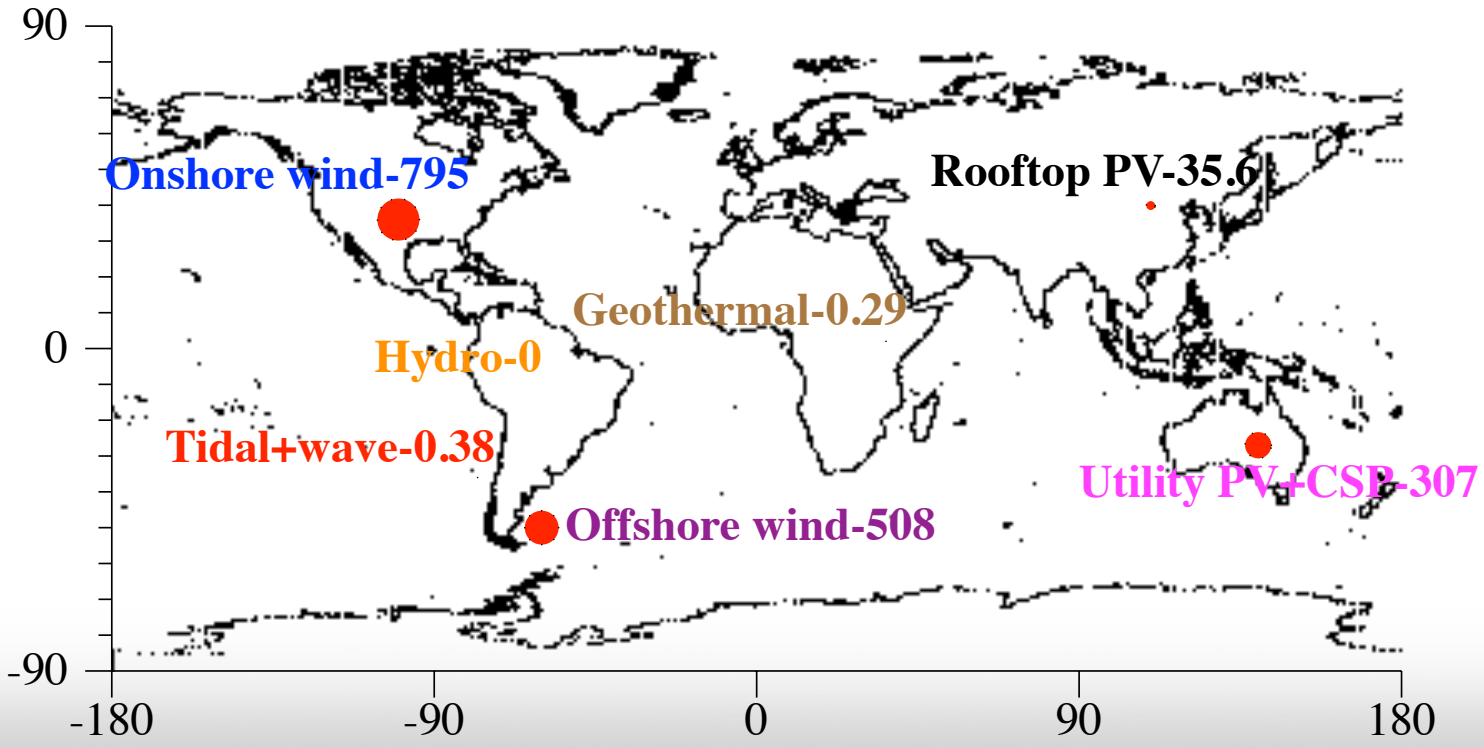


Projected Energy Supply & Demand, **139 Countries**

Number of New Plants to Power 139 Countries All Purposes

TECHNOLOGY	PCT SUPPLY 2050	NUMBER
5-MW onshore wind turbines	19.8%	1,192,000
5-MW offshore wind turbines	12.9	762,000
5-kW Res. roof PV systems	5.55	653 million
100-kW com/gov roof PV systems	5.97	35.3 million
50-MW Solar PV plants	42.3	497,000
100-MW CSP plants	7.67	15,500
100-MW geothermal plants	0.74	840
1300-MW hydro plants	4.38	0
1-MW tidal turbines	0.07	32,000
0.75-MW wave devices	0.72	496,000
	100%	

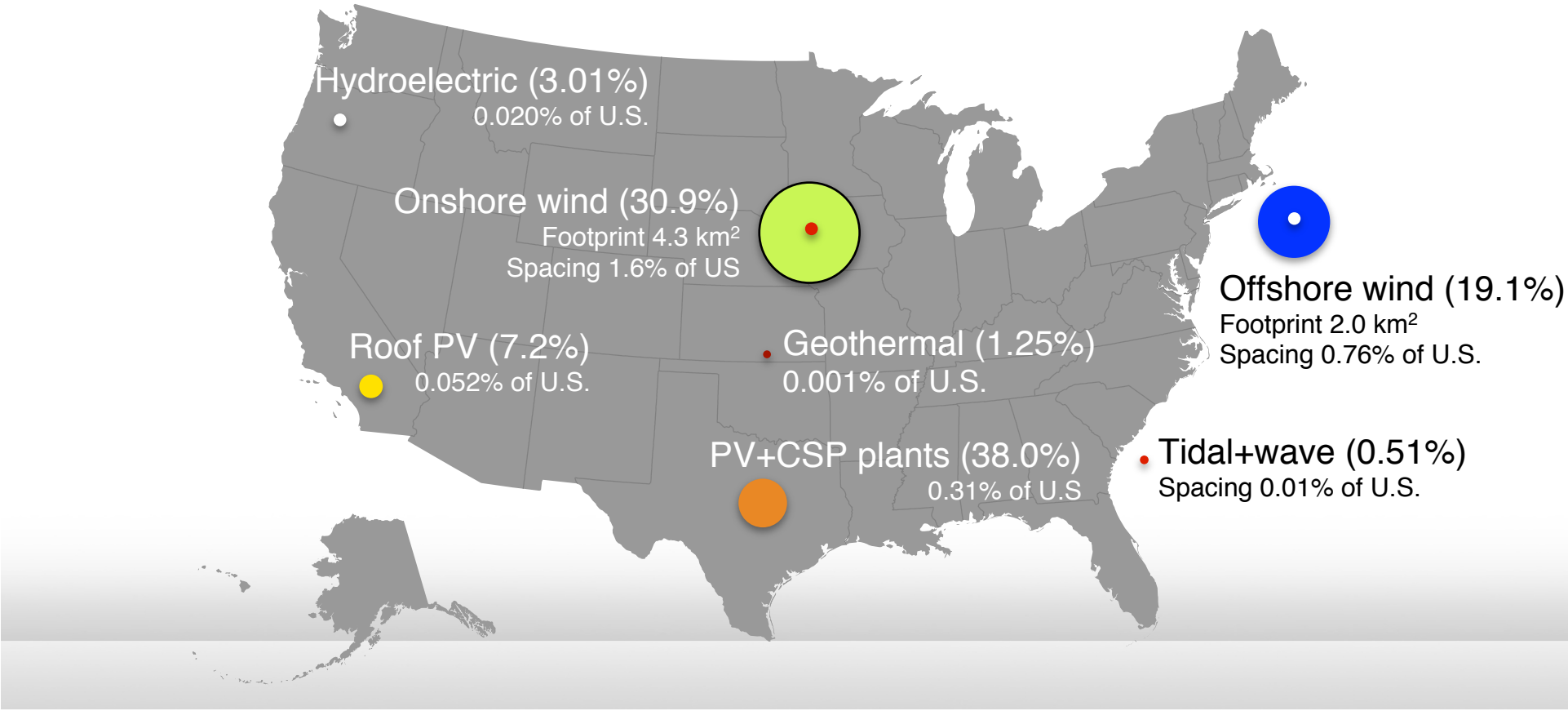
Area (Thousands of km^2) Beyond 2014 Installations to Power 100% of 139 Countries for all Purposes w/ WWS in 2050



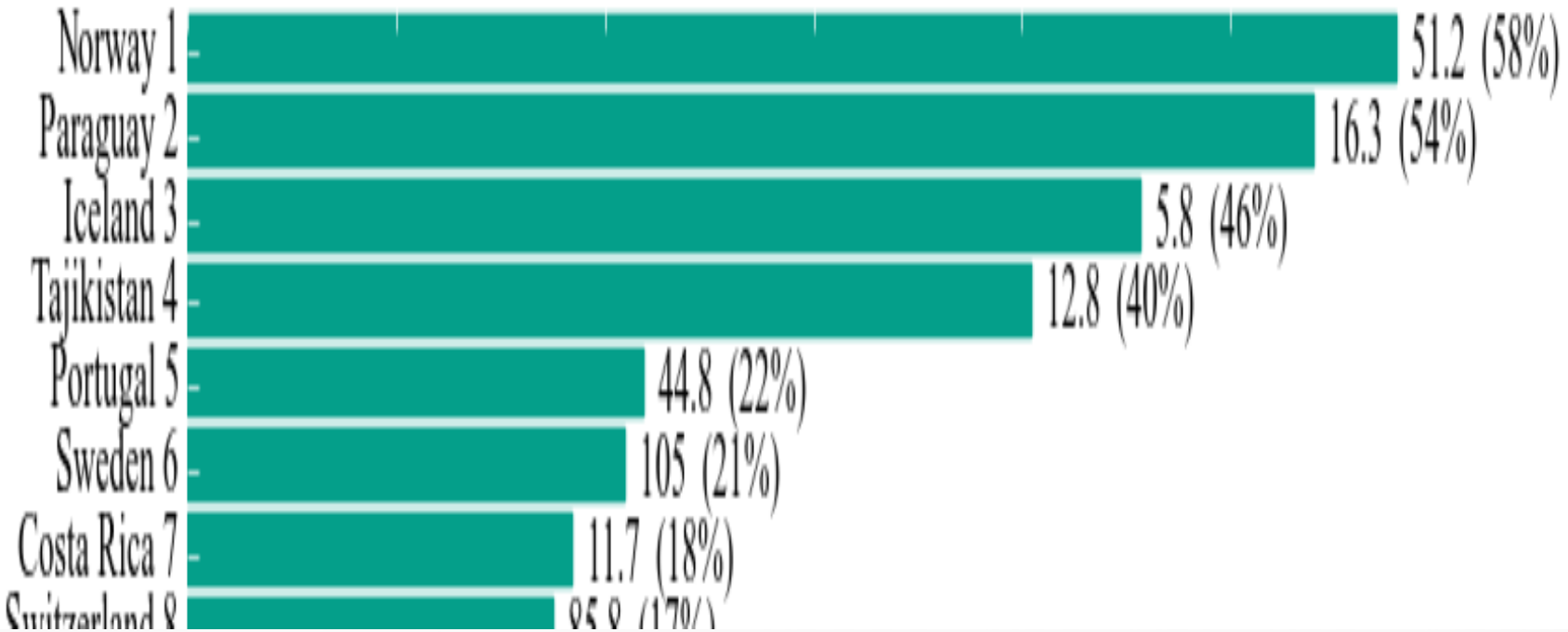
Number of New Plants to Power Canada for All Purposes

TECHNOLOGY	PCT SUPPLY 2050	NUMBER
5-MW onshore wind turbines	37.5%	39,200
5-MW offshore wind turbines	21.0	21,600
5-kW Res. roof PV systems	1.46	4.2 million
100-kW com/gov roof PV systems	1.69	35.3 million
50-MW Solar PV plants	17.7	243,000
100-MW CSP plants	0	0
100-MW geothermal plants	1.92	50
1300-MW hydro plants	16.5	0
1-MW tidal turbines	0.21	1,980
0.75-MW wave devices	2.0	27,300
	100%	

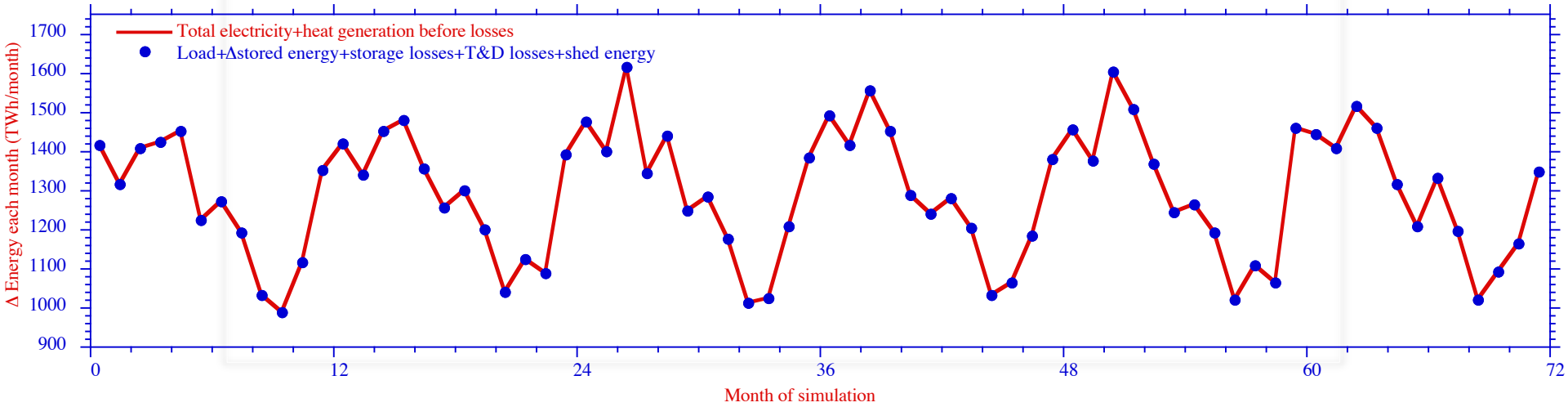
Additional Area Needed to Power 100% of 50 States for all Purposes With Wind, Water, & Solar in 2050



% of 2050 All-Sector WWS Already Installed



Matching 100% 2050-2055 U.S. Load With WWS for 6 Years

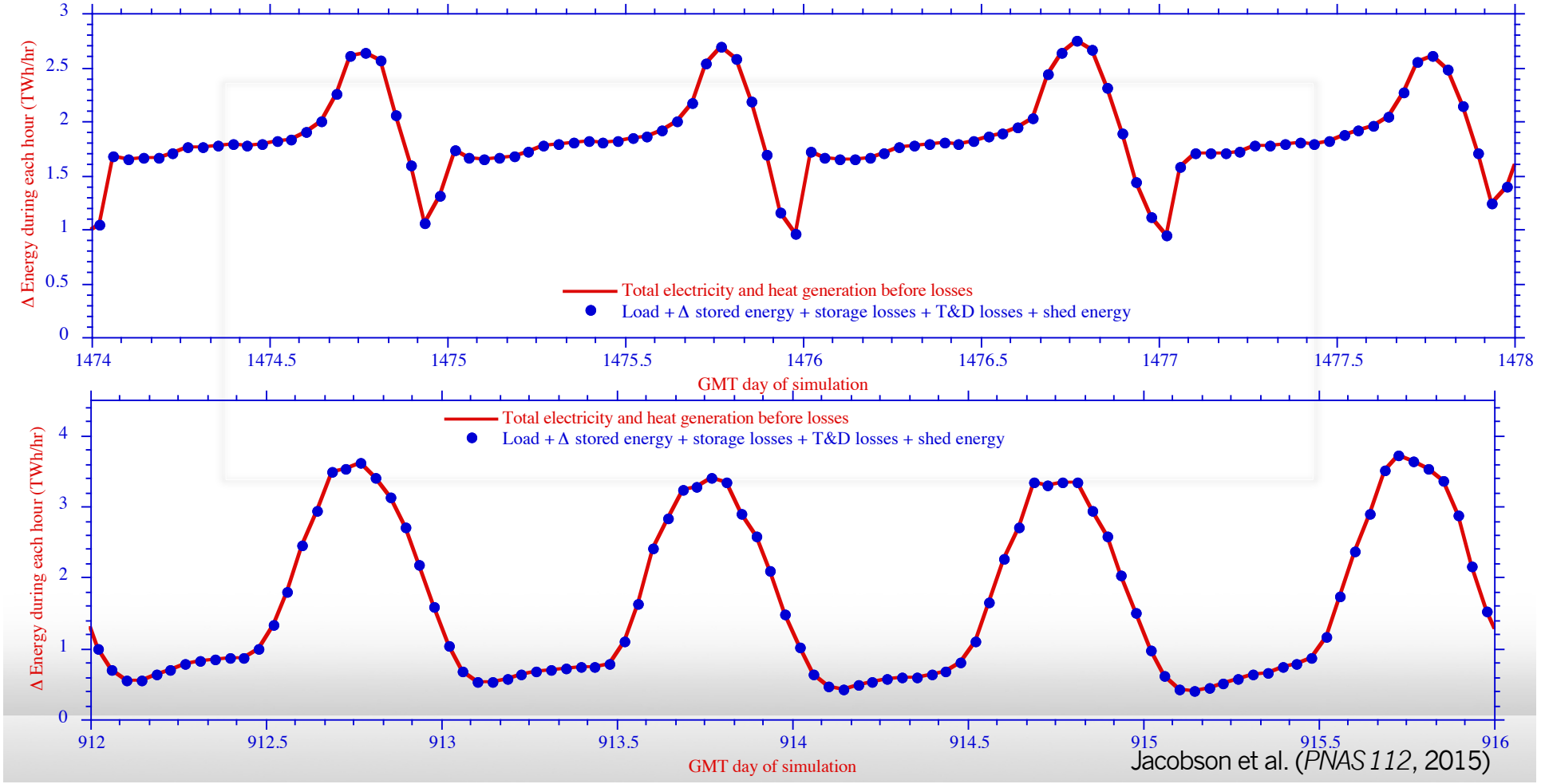


Red = Energy supply

Blue = Energy demand + change of storage + losses

Jacobson et al. (*PNAS 112*, 2015)

Matching 100% U.S. Load With WWS on Two Sets of Four Days

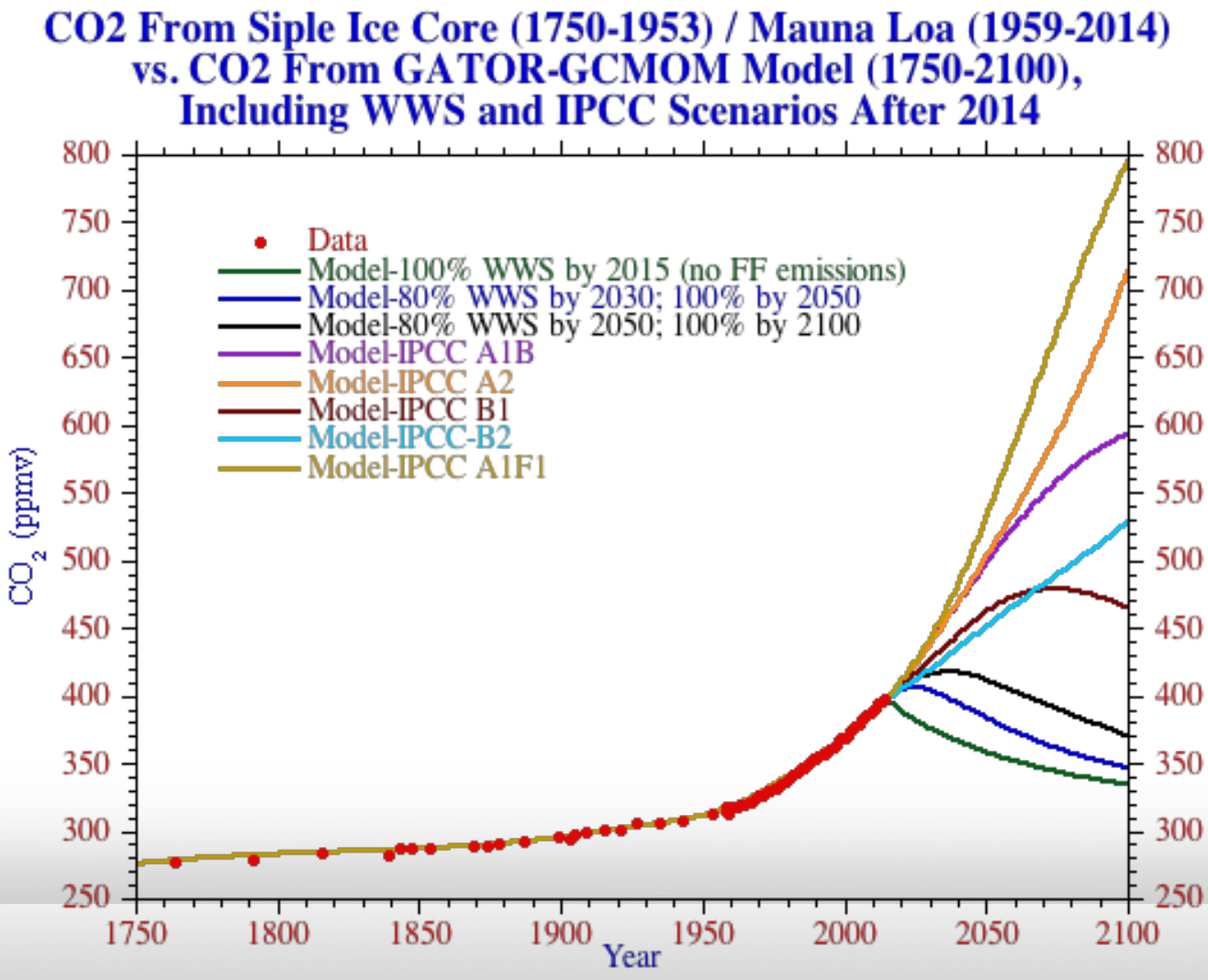


Jacobson et al. (*PNAS 112*, 2015)

2015 U.S. Unsubsidized Costs of Energy (¢/kWh)

Wind onshore	3.2	to 7.7
Wind offshore	11	to 19.4
Geothermal	8.2	to 11.7
Hydroelectric	4	to 6
CSP with 18 hr storage	11.9	to 18.1
Utility-scale solar PV	5.0	to 7.0
Community rooftop PV	7.8	to 13.6
Residential rooftop PV	18.4	to 30.0
Gas combined cycle	5.2	to 7.8
Gas peaking	16.5	to 21.8
Advanced pulverized coal	6.5	to 15.0
Nuclear	9.7	to 13.6

Lazard (2015)


CO2 From Siple Ice Core (1750-1953) / Mauna Loa (1959-2014)
vs. CO2 From GATOR-GCMOM Model (1750-2100),
Including WWS and IPCC Scenarios After 2014
Data
Model-100% WWS by 2015 (no FF emissions)
Model-80% WWS by 2030; 100% by 2050
Model-80% WWS by 2050; 100% by 2100
Model-IPCC A1B
Model-IPCC A2
Model-IPCC B1
Model-IPCC-B2
Model-IPCC A1F1
CO2 (ppmv)
Year
800
750
700
650
600
550
500
450
400
350
300
250
1750
1800
1850
1900
1950
2000
2050
2100

Summary–Converting 139 Countries to 100% WWS

- →Reduces 2050 139-country BAU power demand by ~39%
- → Eliminates ~4-7 million premature air pollution deaths per year (saving ~$25 trillion/yr ~7.9% of world GDP)
- →Eliminates up to ~$17 trillion/yr global climate costs 2050
- →Each person saves $170/yr fuel costs; $4800/yr health+climate costs
- →WWS w/storage+DRM gives 100% reliability @ ~11-12 ¢/kWh in US
- →Creates 22 million more jobs than are lost
- →Requires only 0.29% of land for footprint; 0.66% for spacing
- →Makes countries energy independent, reducing international conflict
- →Creates distributed power, reducing terrorism/catastrophic risk
- →Reduces energy poverty of up to 4 billion people worldwide

Barriers : up-front costs, transmission needs, lobbying, politics.

Materials are not limits

Papers / Graphics

Articles and data

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

Infographic maps

www.thesolutionsproject.org

100.org

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Thank you for being part of our *#energyhorizon!*

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