

A PV Powered Earth by 2040



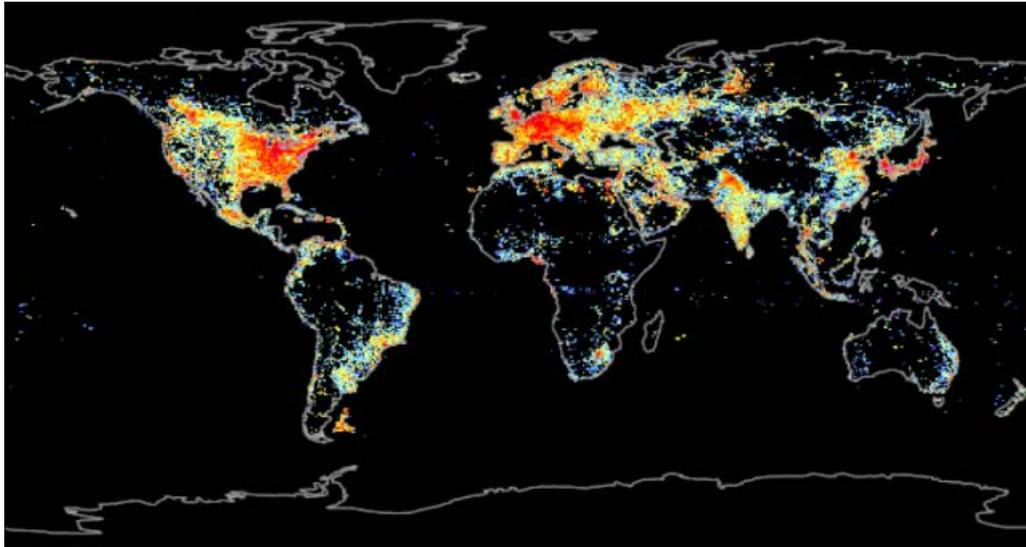
2014 SunShot Summit

Greg Wilson

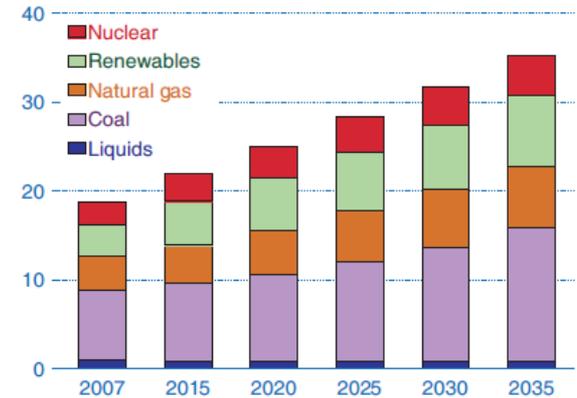
Director, National Center for Photovoltaics
National Renewable Energy Laboratory
Golden, Colorado - USA

21 May, 2014

An Energy & Climate Change Challenged World



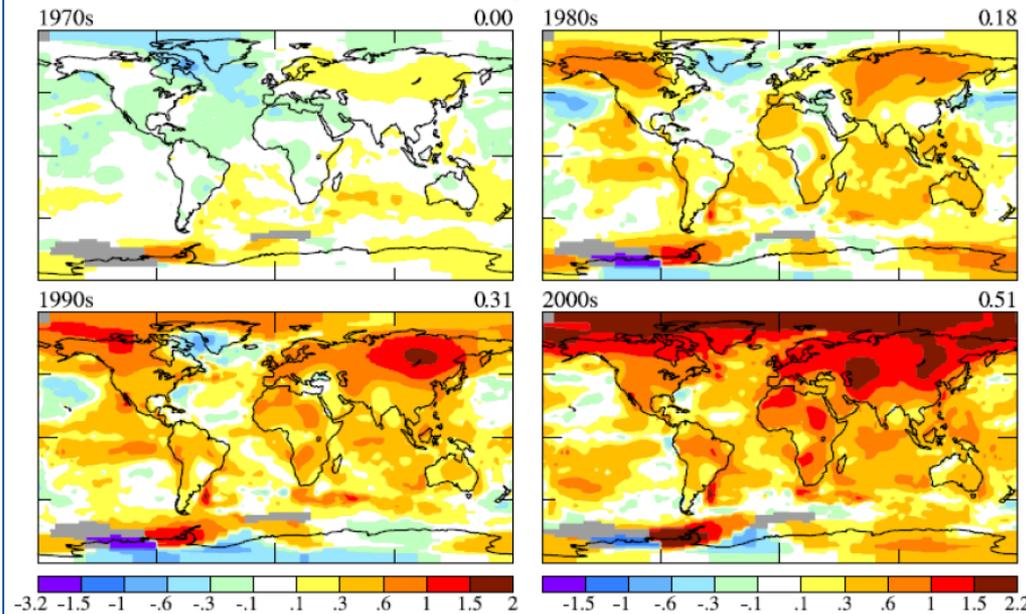
Trillion Kilowatt-hours



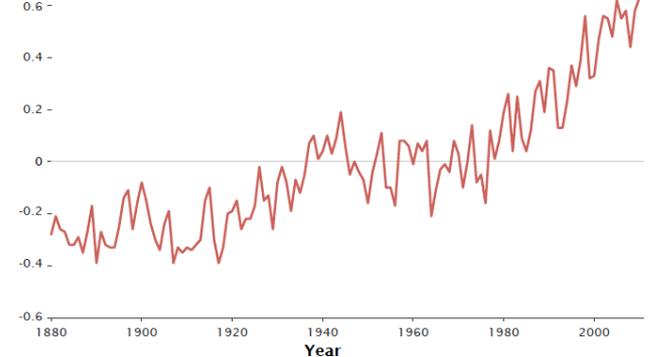
Source: 2010 DOE-EIA International Energy Outlook

- ~21 trillion kWhrs of electricity, ~2/3 from fossil fuels.
- Earth at 400ppm CO₂.

Decadal Surface Temperature Anomalies (°C)



Global Temperature Anomalies (°C)

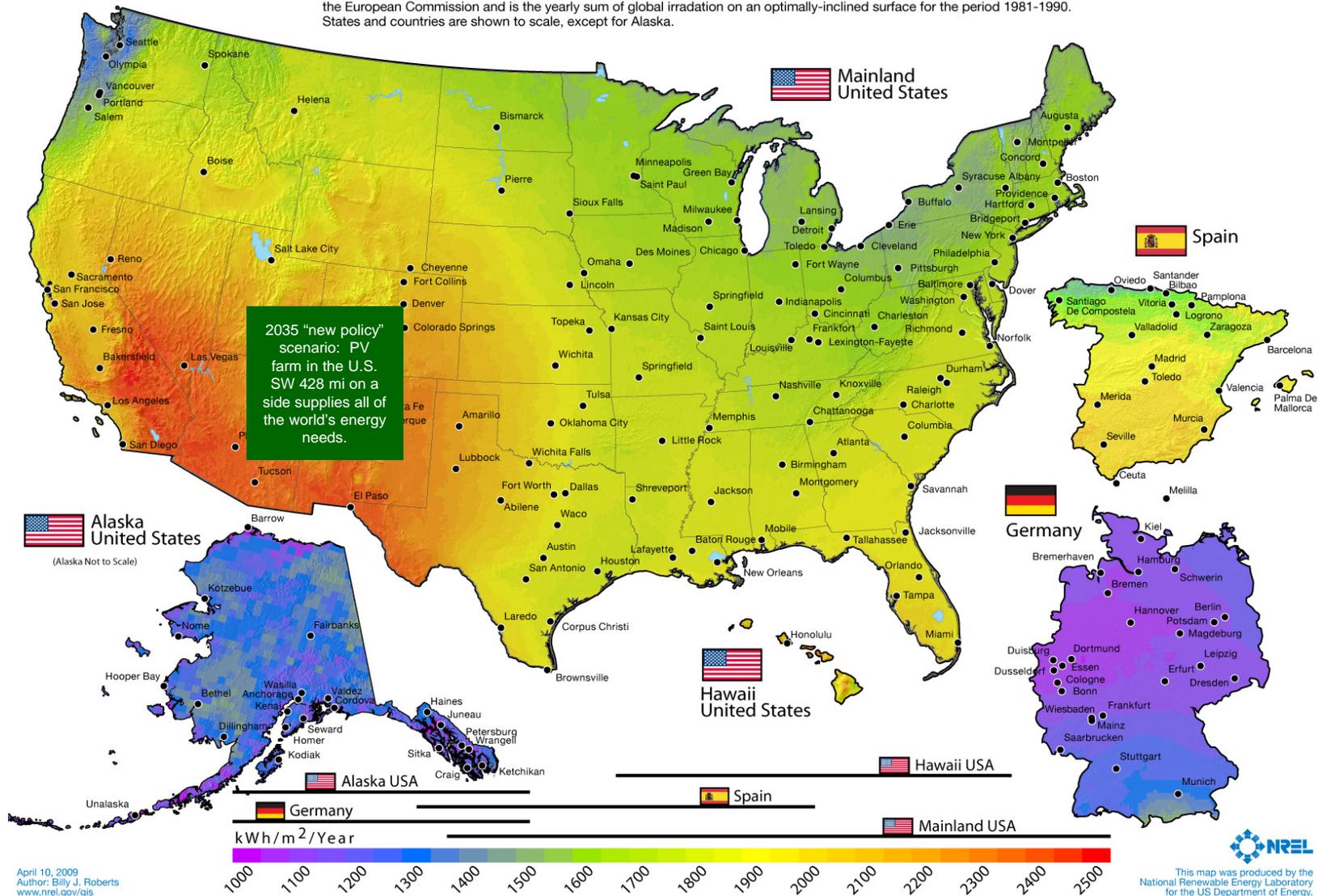


Source: NASA-GISS

PV Energy for Planet Earth

Photovoltaic Solar Resource: United States - Spain - Germany

Annual average solar resource data are for a solar collector oriented toward the south at a tilt = local latitude. The data for Hawaii and the 48 contiguous states are derived from a model developed at SUNY/Albany using geostationary weather satellite data for the period 1998-2005. The data for Alaska are derived from a 40-km satellite and surface cloud cover database for the period 1985-1991 (NREL, 2003). The data for Germany and Spain were acquired from the Joint Research Centre of the European Commission and is the yearly sum of global irradiation on an optimally-inclined surface for the period 1981-1990. States and countries are shown to scale, except for Alaska.



April 10, 2009
 Author: Billy J. Roberts
 www.nrel.gov/gis

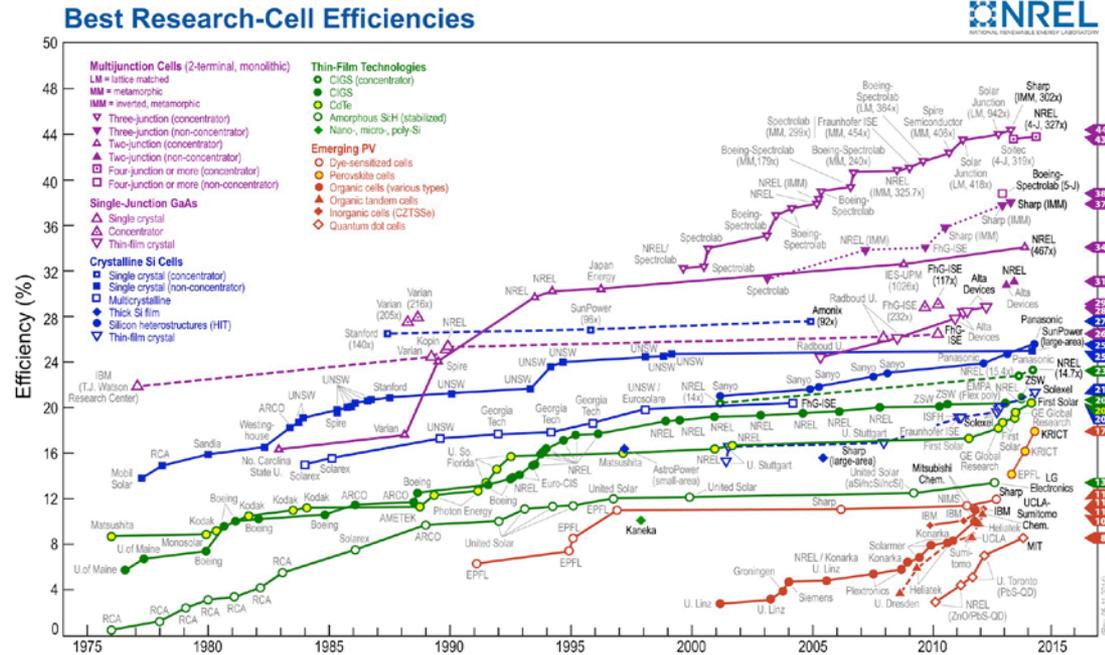
This map was produced by the
 National Renewable Energy Laboratory
 for the US Department of Energy.



PV in 2040

- The combination of a climate change challenged world and the emergence of PV as one of the lowest cost generation sources will create large demand pull that will drive PV technology innovation.

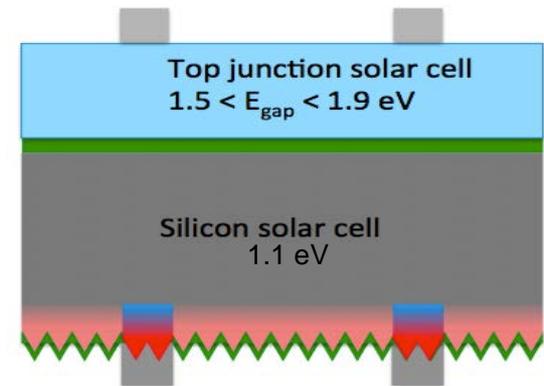
- The market for PV systems will have expanded to cover a wide range of system efficiencies, service lives and aesthetic features (for BIPV systems).



- This market will be highly segmented and highly competitive, much like today's automobile market.

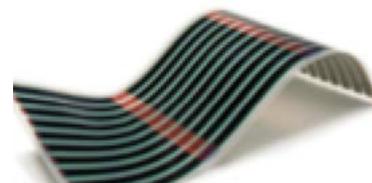
PV in 2040: High η from Columns III-IV-V

- The highest efficiency ground mounted cSi systems installed in the next few years will be nearing the end of their service lives.
- Lower efficiency systems will have already been replaced by a new generation of low-cost, 25 – 35% efficient systems based on multi-junction PV technologies, and much of this will still use bottom cells made using single crystal Si.
- Another portion of this market will not use cSi at all and will utilize various III-V PV absorbers produced using very low cost epitaxy and next generation layer transfer and bonding technologies.



PV in 2040: Next Gen Thin Films

- Building integration of PV will be dominated by roofing systems that include PV cells that are matched both in cost and service life to the roofing system.
- Lower cost flexible roofing systems will use lower cost, shorter service life PV absorbers made from organic, organic-inorganic hybrid (perovskite?) and inorganic binaries, ternaries and quaternaries.

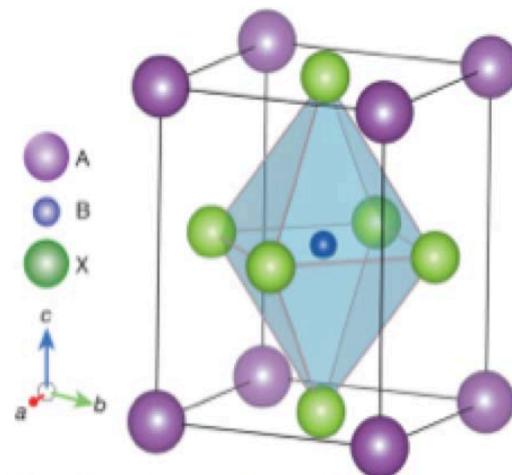


Organic-Inorganic Lead Halides Perovskite

$X = \text{Cl}^-, \text{Br}^-, \text{I}^-$

$B = \text{Pb}, \text{Sn}, \text{Ge}$

$A = \text{ORGANIC } (\text{CH}_3\text{NH}_3^+)$



Liu et. al., Nature 2013

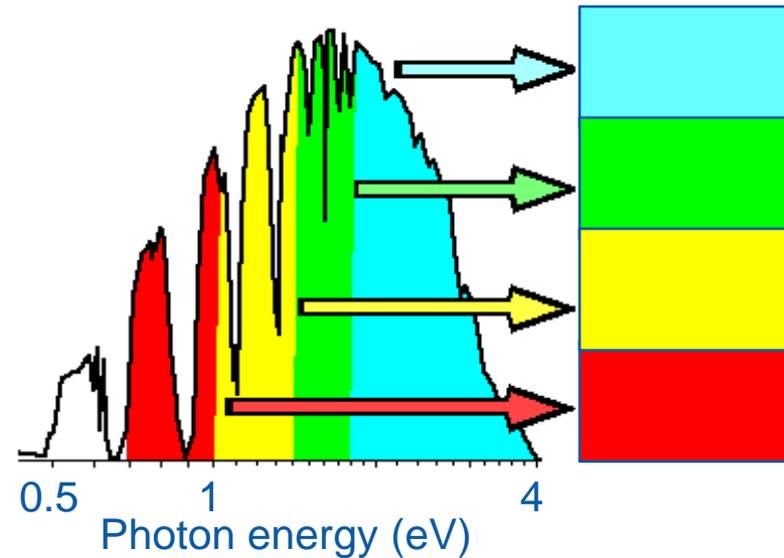
For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

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Ptable.com

PV in 2040: Building Integrated PV

- Higher cost, longer lifetime roofing systems will integrate higher efficiency PV technologies that may utilize either single or multi-junction cells.



- Silicon will still be a player (thin absorber, epitaxially grown on low-cost seeds) but it will be accompanied by III-Vs at the high end of the efficiency scale.
- The cost of integrating PV will have dropped to the point that PV is also integrated into building exterior walls and windows but again, efficiency, service life and aesthetics will determine which technologies win.



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Thank You

