Mitigating & Adapting to Climate change: Extreme Weather Events, a Worldwide Energy Revolution and Geoengineering options

Week 6: May 1st , 2017

Part A: Nuclear Power (fission and fusion)

Part B: Storage and Grid Options

EXTRAS

Paul Belanger, Ph.D.

EXTRAS

LINKS

- Stanford http://thesolutionsproject.org/infographic/
- http://www.iea.org/newsroom/news/2017/april/statistics-key-electricity-trends-2016.html
- http://www.noaanews.noaa.gov/stories2016/012516-rapid-affordable-energy-transformation-possible.html

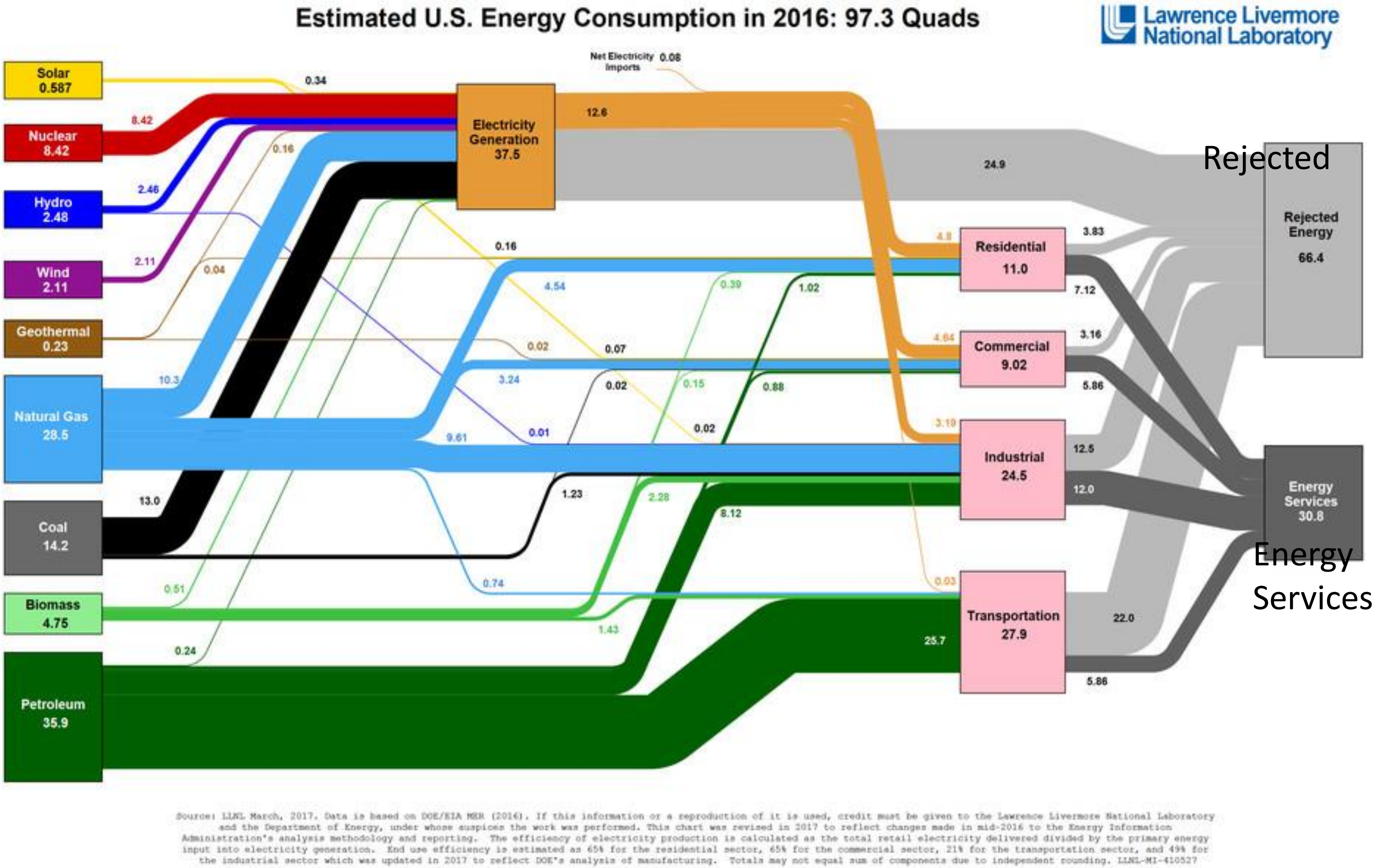
- Commonwealth club of California – Environment & Natural Resources chair
- https://www.ourchildrenstrust.org/
- https://www.ourchildrenstrust.org/us/federal-lawsuit/

- Other videos: https://www.youtube.com/channel/UCr81EUb2qVJVfmmlJMxEHVw/videos

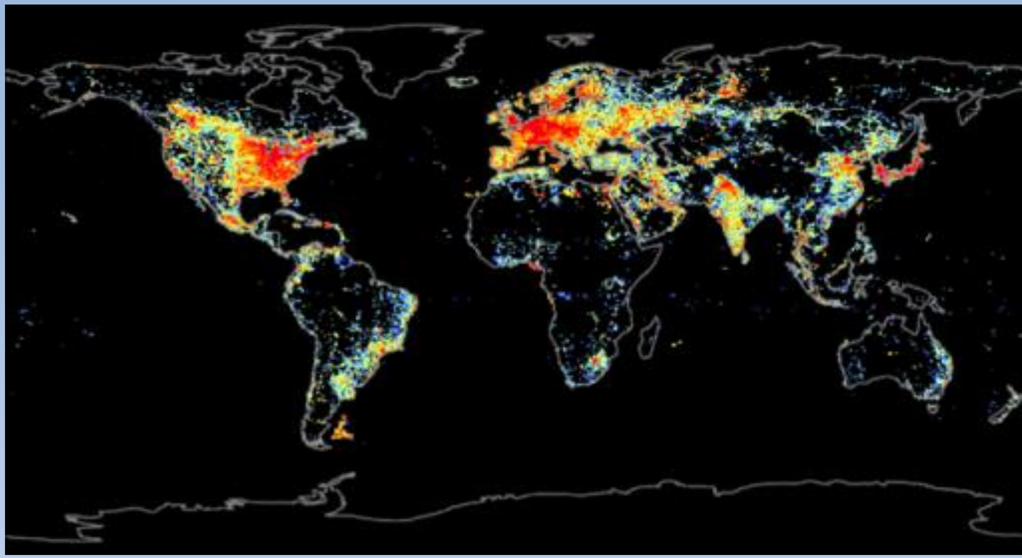
OTHER LINKS

- https://www.eia.gov/
- https://www.eia.gov/totalenergy/
- https://www.eia.gov/energyexplained/
- https://www.eia.gov/tools/faqs/
- https://www.eia.gov/environment/

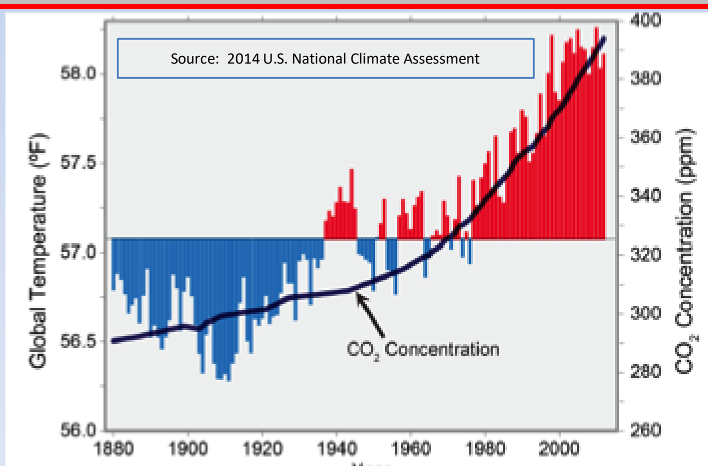
Energy in the U.S. in 2016 – Sources, What it is used for, and how much of it is wasted – a bit of a mind-blower Vox.com April 2017

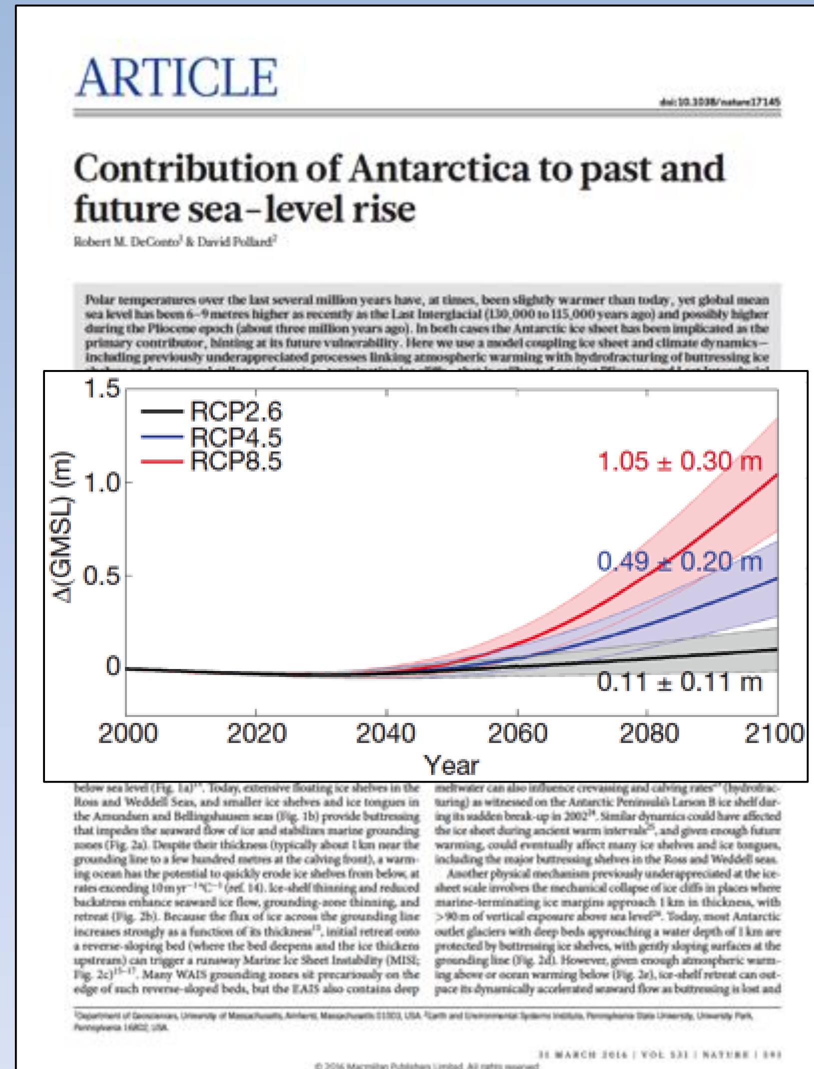


Motivation is Clear – Energy Needs vs. CO_2

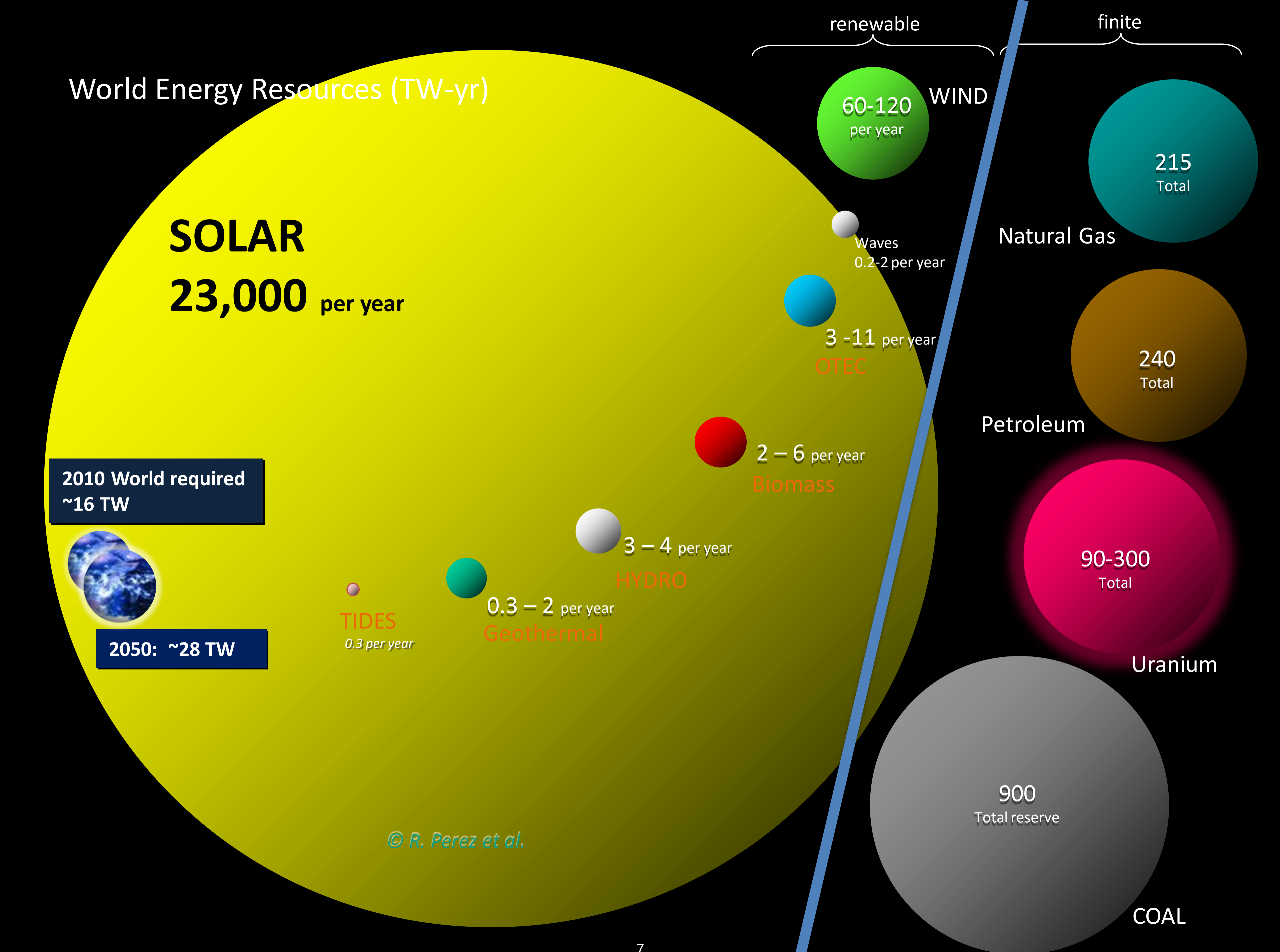


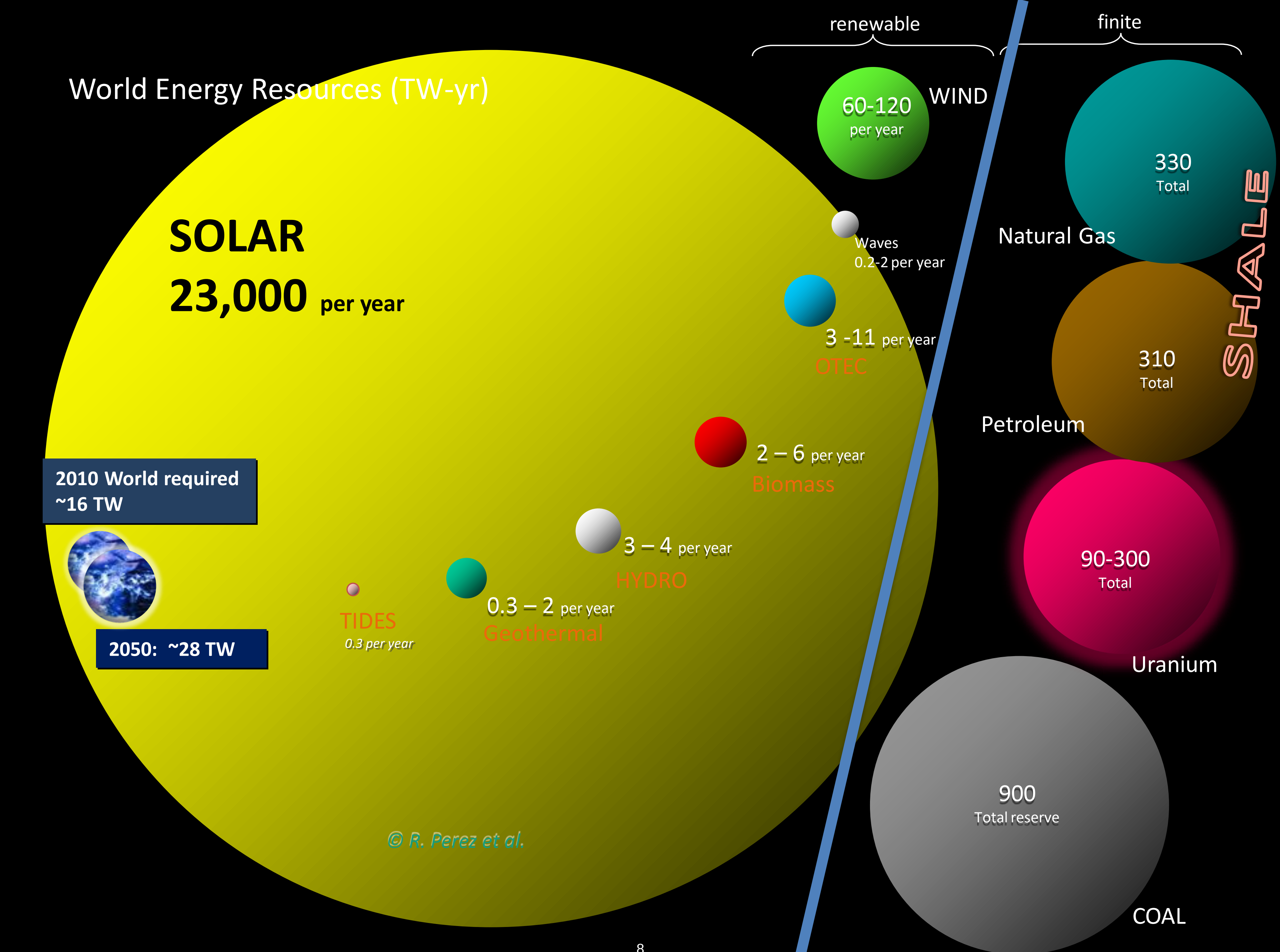
- **Humanity requires ~6 TW of electrical generating capacity, ~2/3 from fossil fuels.**
- **$[CO_2]$ ~402 ppm and rising.**





Nature - 31 March, 2016


World Energy Resources (TW-yr)
renewable
finite
SOLAR
23,000 per year
60-120 per year
WIND
Waves
0.2-2 per year
3 -11 per year
OTEC
2 – 6 per year
Biomass
3 – 4 per year
HYDRO
0.3 – 2 per year
Geothermal
TIDES
0.3 per year
2010 World required ~16 TW
2050: ~28 TW
215 Total
Natural Gas
240 Total
Petroleum
90-300 Total
Uranium
900 Total reserve
COAL
© R. Perez et al.



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© R. Perez et al.
330
Total
Natural Gas
310
Total
Petroleum
SHALE
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ENERGY CONSUMPTION:
PRESENT AND FUTURE PROJECTIONS

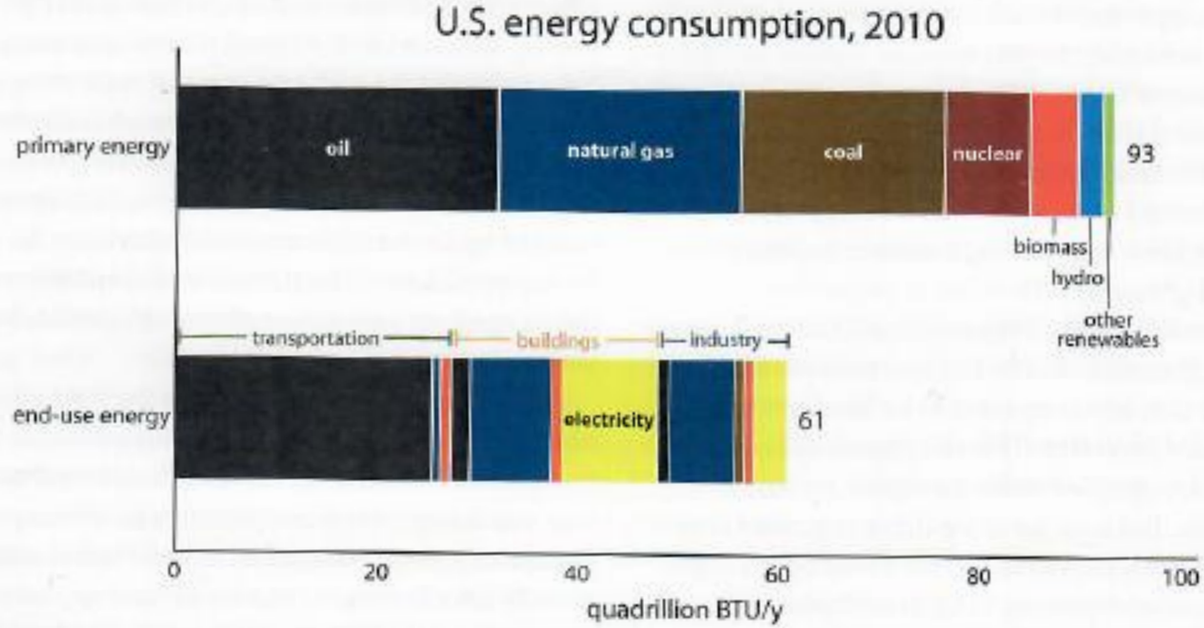
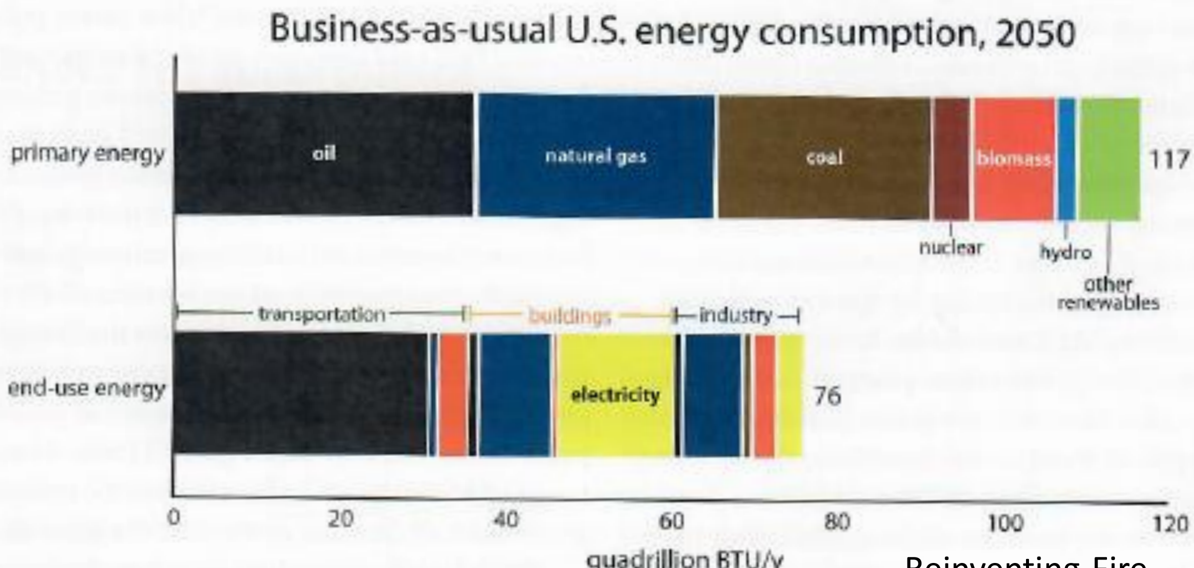


FIG. 1-4. U.S. energy use in 2010, measured in the U.S. in "quads" or quadrillion BTU (million billion British thermal units) and in the rest of the world as a 5.5% larger number of EJ (exajoules, or billion billion joules)[46]



Reinventing Fire…, Lovins, A. 2011

FIG. 1-5. RMI's extrapolation to 2050 from the Energy Information Administration's 2010 forecast of U.S. energy supply and use to 2035.[47]

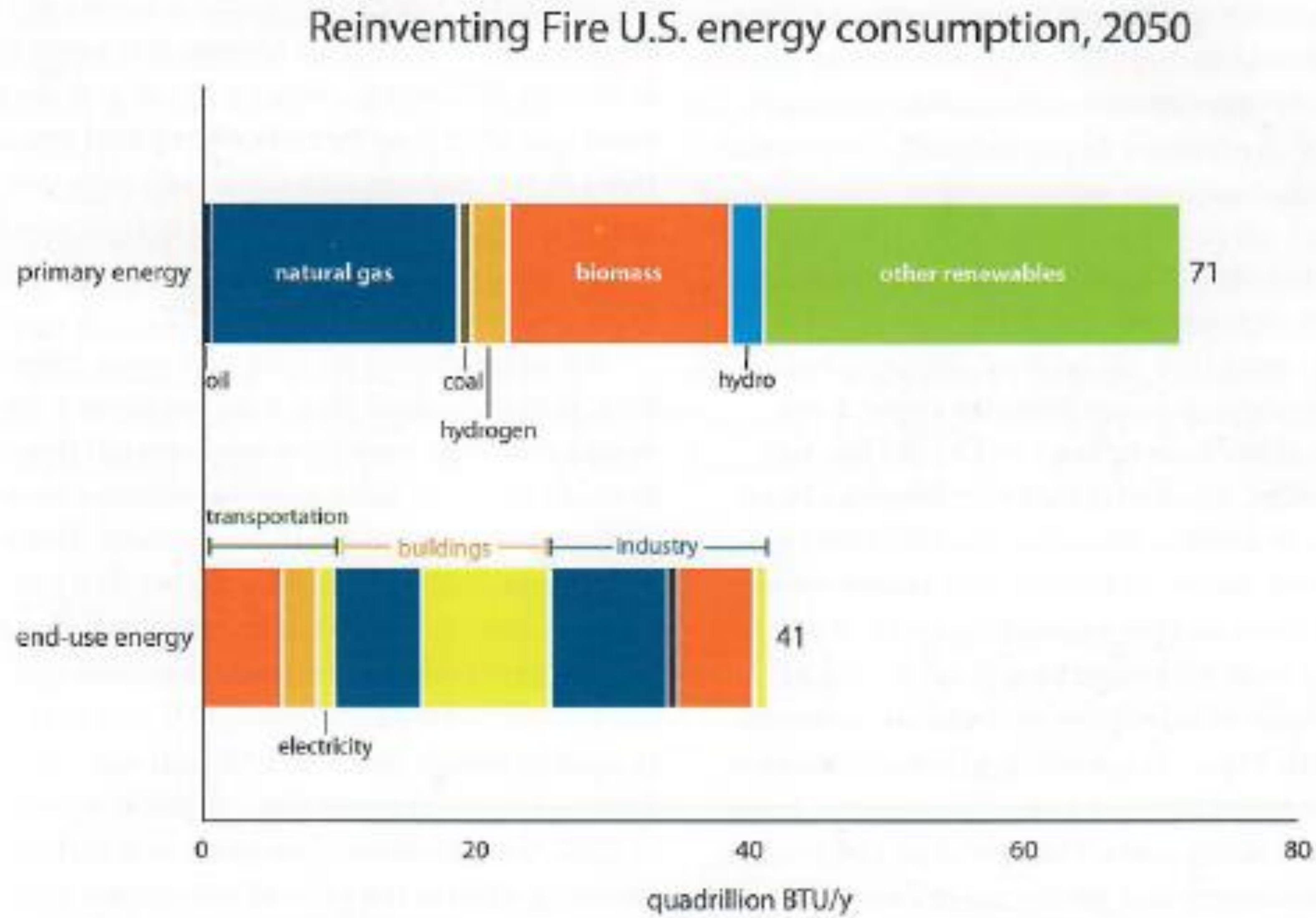


FIG. 1-6. The following chapters will show how we can run the same 2050 economy as in figure 1-5, but with half the delivered energy, with less risk, and for $5 trillion less (in 2010 net present value).[48]

Reinventing Fire…, Lovins, A. 2011

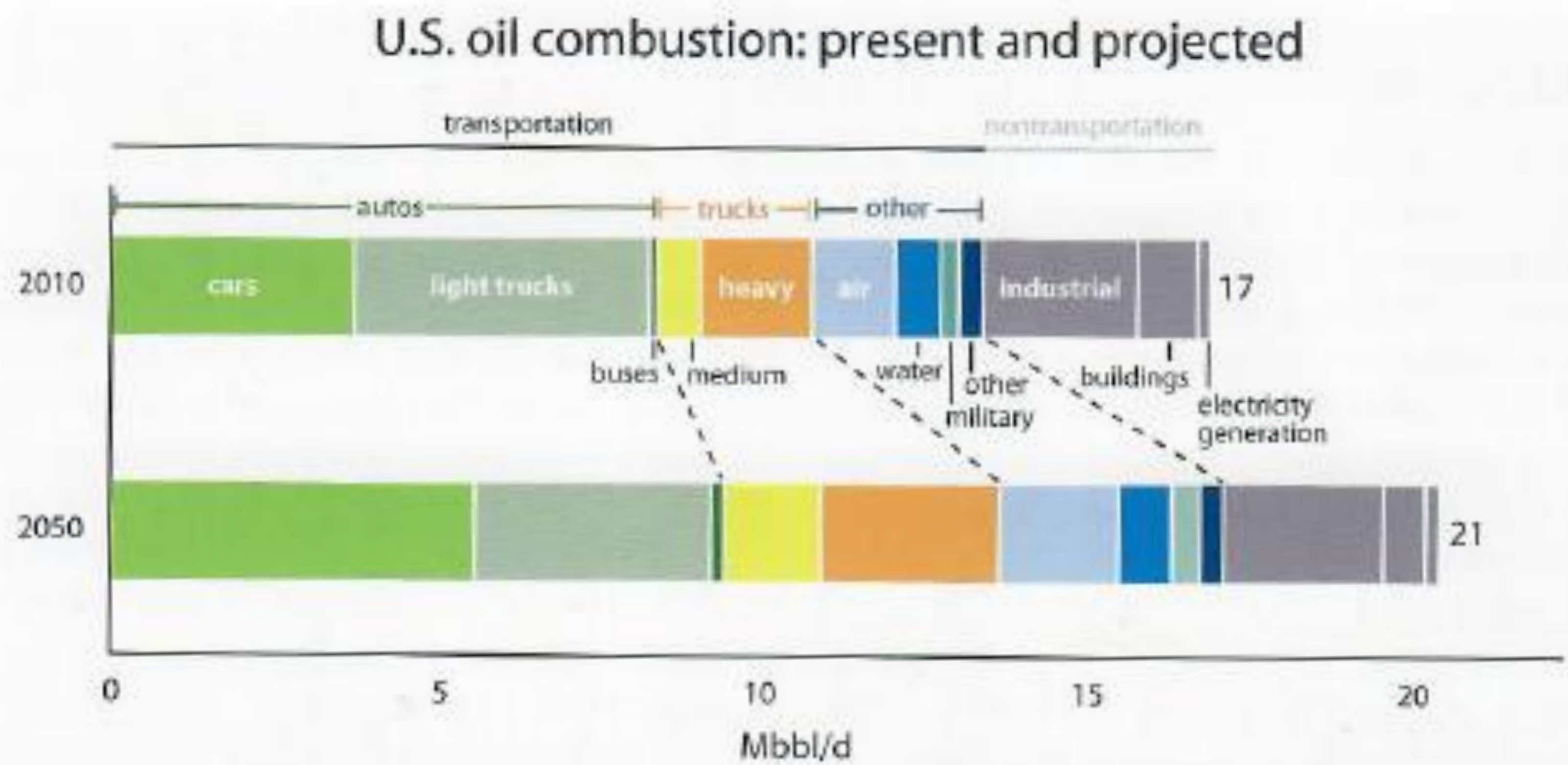


FIG. 2-2. U.S. oil use in 2010 and the U.S. Energy Information Administration's 2035 projection extrapolated to 2050 (our base case). (Only uses that burn oil are shown—not uses of oil as a raw material.) In 2010, transportation used 71% of U.S. oil and was 94% oil-fueled; the rest was 3% biofuels and 3% natural gas to run gas pipelines. Later chapters describe how to eliminate oil's nontransportation uses.[52]

Reinventing Fire…, Lovins, A. 2011

SUBSIDIES and TAX BREAKS

Cumulative Historical Federal Subsidies

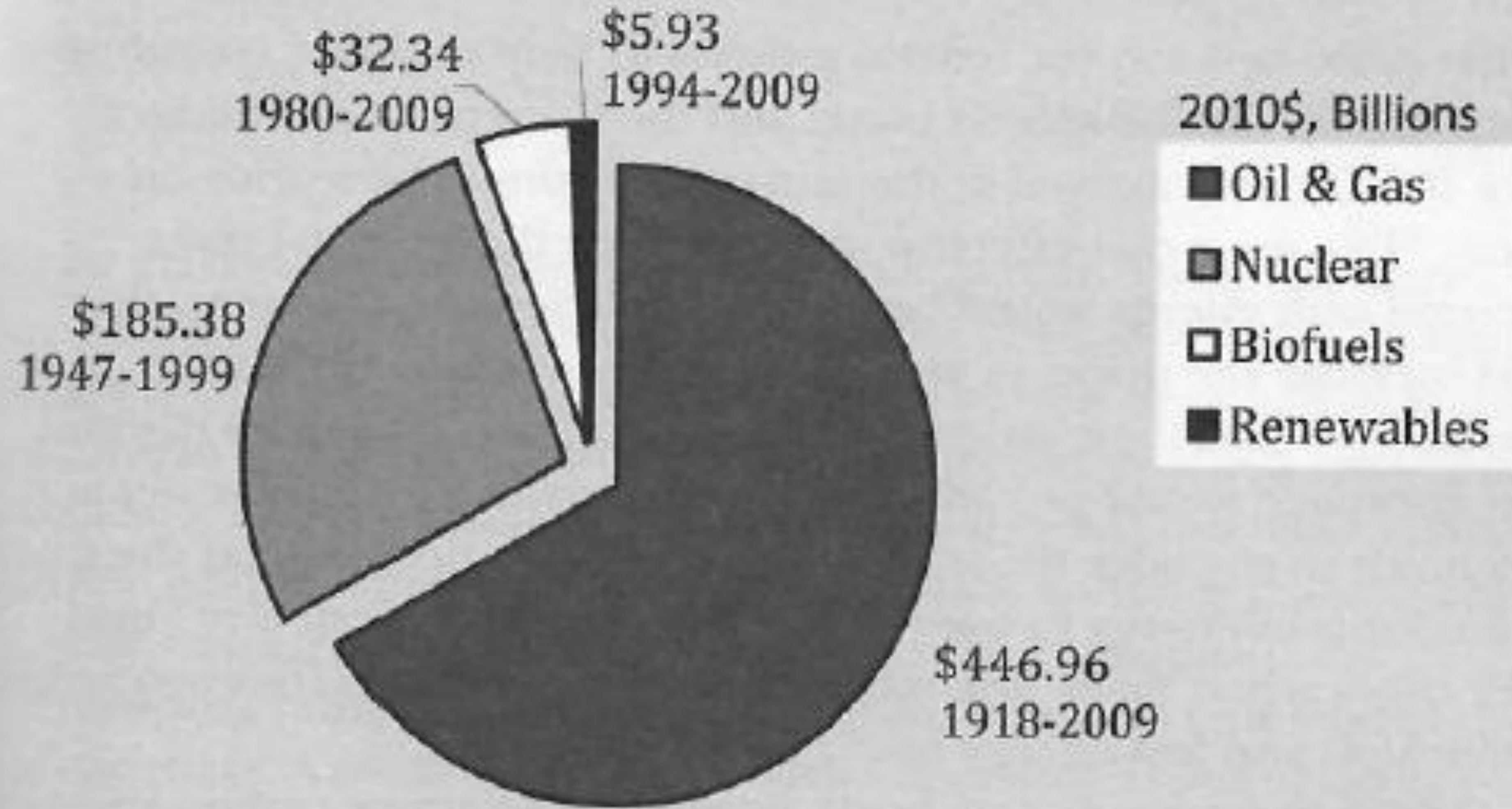


Chart from "What Would Jefferson Do? The Historical Role of Federal Subsidies in Shaping America's Energy Future." Nancy Pfund and Ben Healey, September 2011

Powering Forward, Ritter, 2016

Top 10 Energy Subsidies

Climate change has been called the biggest market failure in history. The failure has been caused in part by government policies that distort energy prices. Here are the 10 most distortionary policies, according to subsidy expert Doug Koplow of Earth Track Inc.:

1. The absence of charges on greenhouse gas emissions.
2. The failure of oil prices to reflect the cost of protecting supplies.
3. Liability caps for power companies on accidents at nuclear plants.
4. Mandates and tax incentives for the production of ethanol and biodiesel fuels.
5. Cross subsidies in electricity markets; the practice of charging some customers more to allow low prices for other customers.
6. Domestic subsidies for energy consumption.
7. Government assumption of risks associated with storing high-level nuclear waste.
8. Tax exemptions for petroleum used in air and water transportation.
9. Free cooling water for thermal power plants.
10. Feed-in tariffs and purchase mandates for renewable energy.

Note that in the context of reducing carbon emissions, some of these are constructive while others are perverse.

Powering Forward, Ritter, 2016

Why We Should Care

Because every nation's greenhouse gas emissions have worldwide impacts, all nations have an interest in global reforms of energy subsidies.

The United States is second only to China in the amount of money spent on direct and indirect energy subsidies, according to the IMF. In 2009, President Barack Obama proposed and won approval from G-20 nations to phase out inefficient fossil energy subsidies "in the mid-term." Little progress has been reported. In each of his annual budget proposals to Congress, Obama has called for cutting taxpayer subsidies for the largest oil, gas, and coal companies by $40 billion over 10 years. Congress has rejected the President's requests.

Subsidy reforms have been accomplished or attempted in Brazil, France, Ghana, North Sudan, Malaysia, India, Indonesia, Iran, Poland, and Senegal, according to the Global Subsidies Initiative at the International Institute for Sustainable Development.

In several countries, consumers have responded with protests. However, energy subsidies have proven to be inefficient. The IEA estimates that the bottom 20 percent of the world population in regard to income receives only 8 percent of the value of fuel subsidies. There are better ways to remedy the regressive nature of energy costs, including carefully targeted direct cash payments to low-income consumers.

Powering Forward, Ritter, 2016

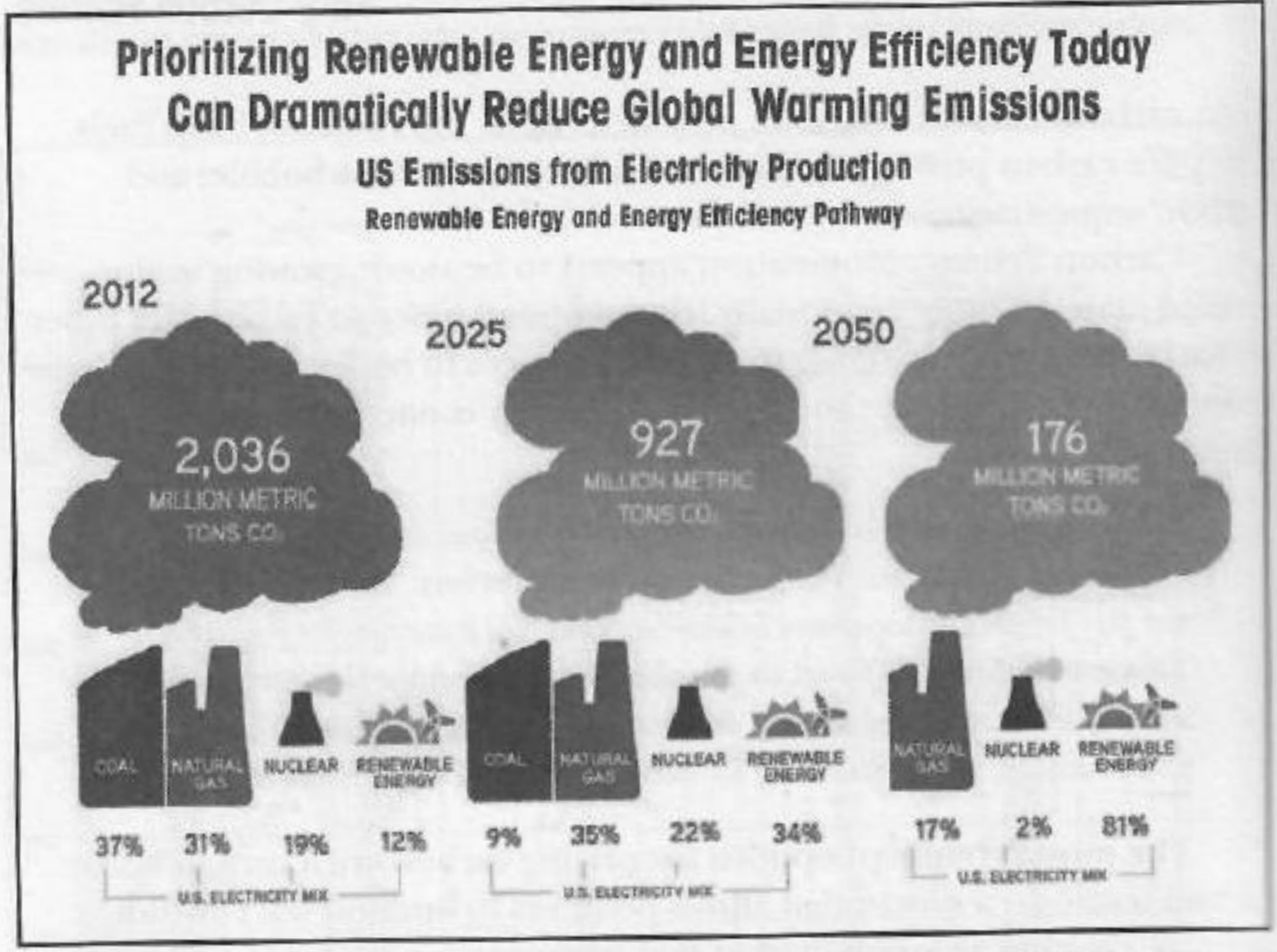


Figure 14.6

The carbon budget requires a dramatic global decline in the use of fossil fuels to generate electricity. Nevertheless, there is a wide disparity between different projections of what the nation's energy mix will be decades from now. These two charts show the disparity between the projections of the Union of Concerned Scientists (UCS) (Figure 14.6) and the EIA (Figure 14.7). The UCS projects that coal must disappear from America's power industry by mid-century and the use of natural gas must decline to 17 percent. Renewable

Powering Forward, Ritter, 2016

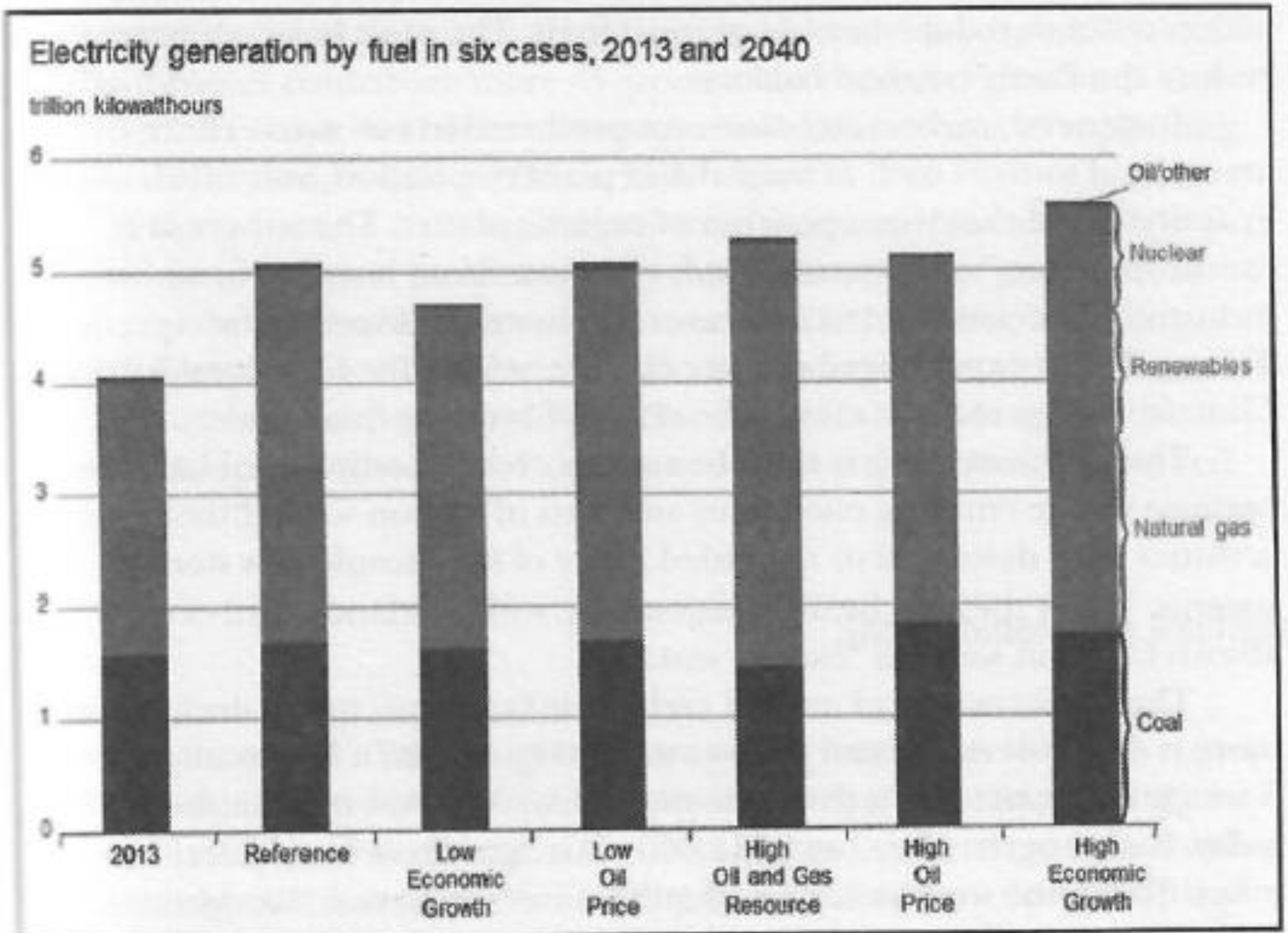


Figure 14.7

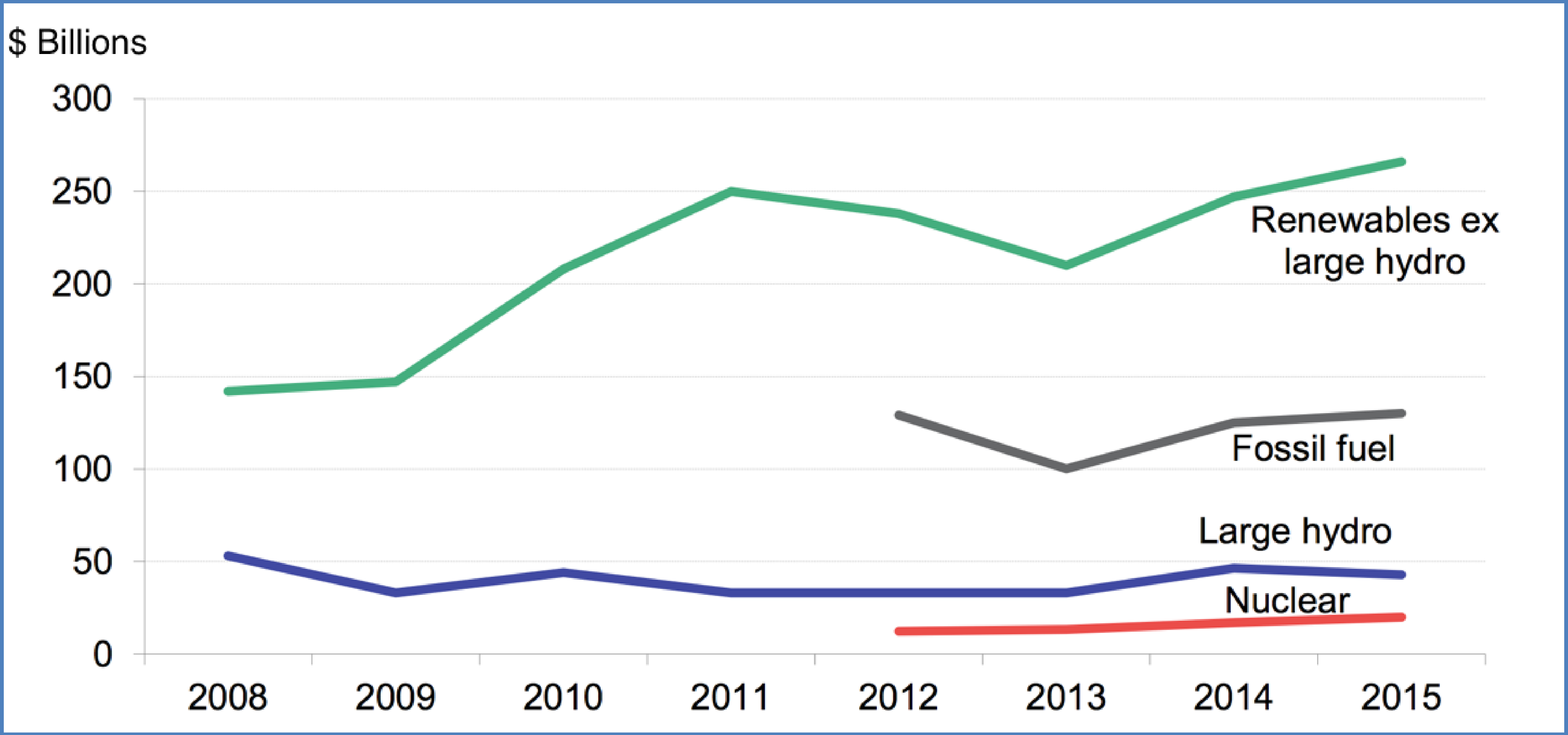
resources would produce the overwhelming majority of power (81 percent). This scenario agrees with analysis by the DOE's National Renewable Energy Laboratory that, with sufficient investment, renewable resources could provide 80 percent of the nation's electricity by 2050. On the other hand, EIA projects that coal and natural gas will still be significant sources of electric power by 2040. EIA's "reference case" assumes no changes in current policies. (Source: Union of Concerned

Powering Forward, Ritter, 2016

New Capacity and Jobs

Renewables are beating fossil fuels 2 to 1

Bloomberg News, by Tom Randall



Investment in World Power Capacity, 2008-2015

Bloomberg New Energy Finance, UNEP 6 Apr 2016.

We're adding record amounts of wind and solar — and we're still not moving fast enough

Washington Post, 25 Oct 2016

Renewable energy projects surpassed all other sources of new electricity added to the global supply last year, says a new report released this week by the International Energy Agency. In 2015, renewables made up more than half of all new installed capacity, with the greatest gains seen in onshore wind and solar.

That said, renewable energy sources still only account for about 23 percent of the electricity actually produced worldwide, the report notes. The agency predicts that this share will increase to 28 percent by the year 2021, making renewables the fastest-growing source of electricity generation in the world.

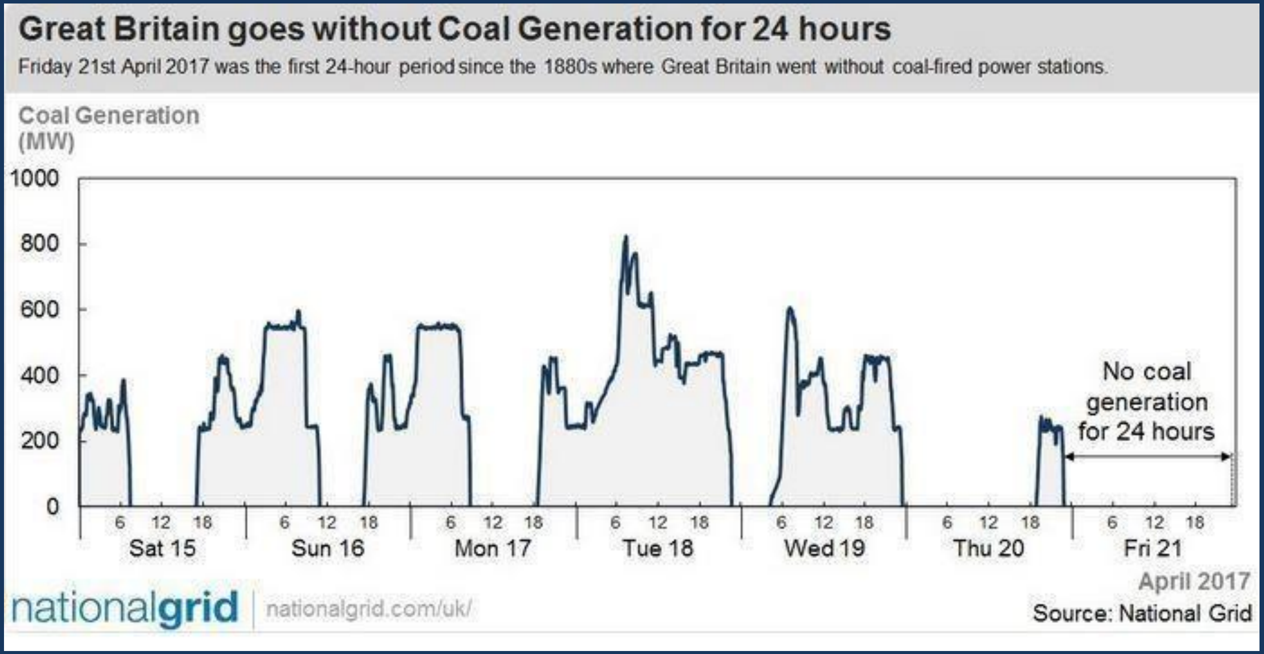
The report predicts that the U.S. will commission 107 gigawatts of new renewable additions — mostly wind and solar — by 2021, a 50 percent increase from 2015. The report attributes the U.S. success to a long-term extension of federal tax credits for renewables…

A general view shows solar panels used to produce renewable energy at the photovoltaic park during its official 2015 inauguration in Cestas, southwestern France. (Reuters/Regis Duvignau)

Historic Day in Britain: First Coal-Free Day Since 1882

Andy Rowell, Ecowatch 21 April 2017

The UK's energy provider, the National Grid, called it a "watershed" moment and it is seen as a significant step towards the UK Government's plans to phase out coal generating power plants by 2025.



Britain is not alone in phasing out coal, either. Earlier this month, a coalition of European energy companies announced that there would be no new coal plants built throughout the European Union after 2020.

UNITS

POWER

SI = Watt = J/s

Other units – see white board:

kW, GW, TW

Kilo- 10^3,

giga- 10^9,

tera- 10^{12})

BTU

QUADS (10^{15} BTUs)

ENERGY

SI = J = power-time

Or Watt-s

Or what you are used to getting billed for:

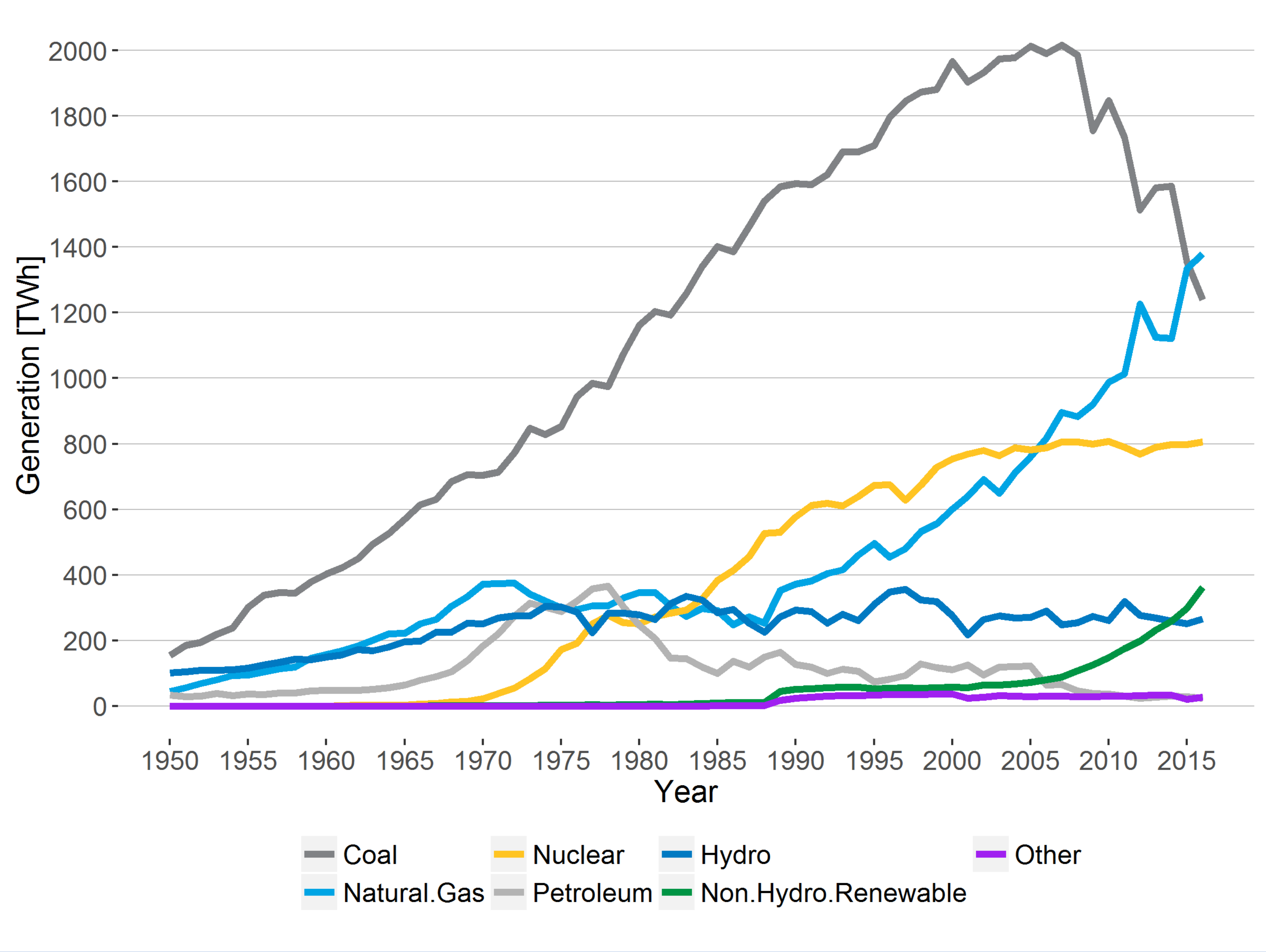
kWh @ ~0.11/kWh

Gt C = Gt CO2/3.67
(mass 44/mass 12 C)
32.7/3.67 = 8.91 Gt C

EXTRAS – Outline from David Mooney presentation BCRES 4/ 2017 – see video at CRES YouTube

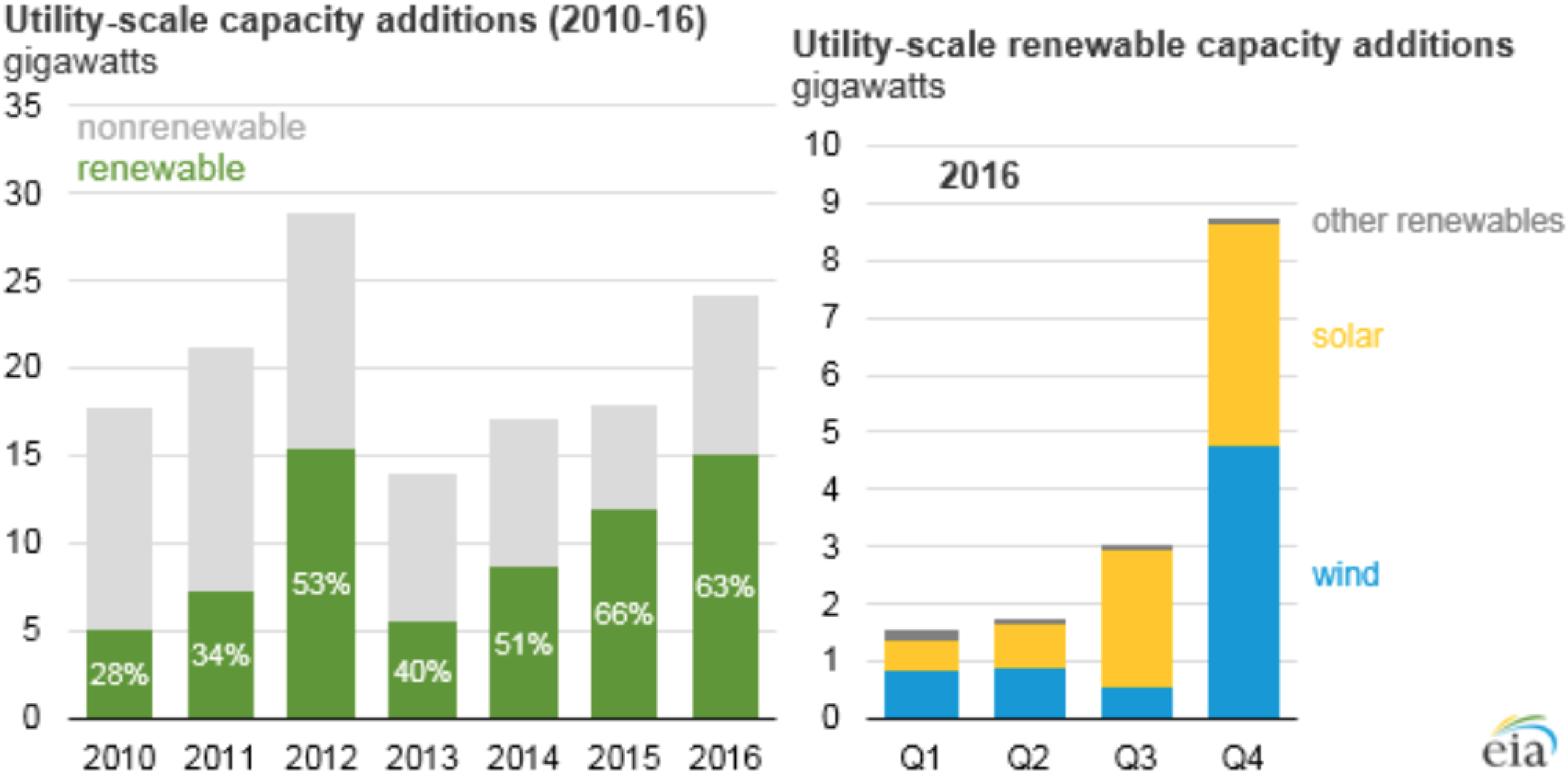
- Global Renewable Energy Markets Update
- Technology Overviews
  - Wind and Solar
    - Market Segments
    - Global and US Markets
    - Cost Trends
    - Status in Colorado
- A Changing Power System
- Jobs in the Energy Sector

Trends in the U.S. Power System

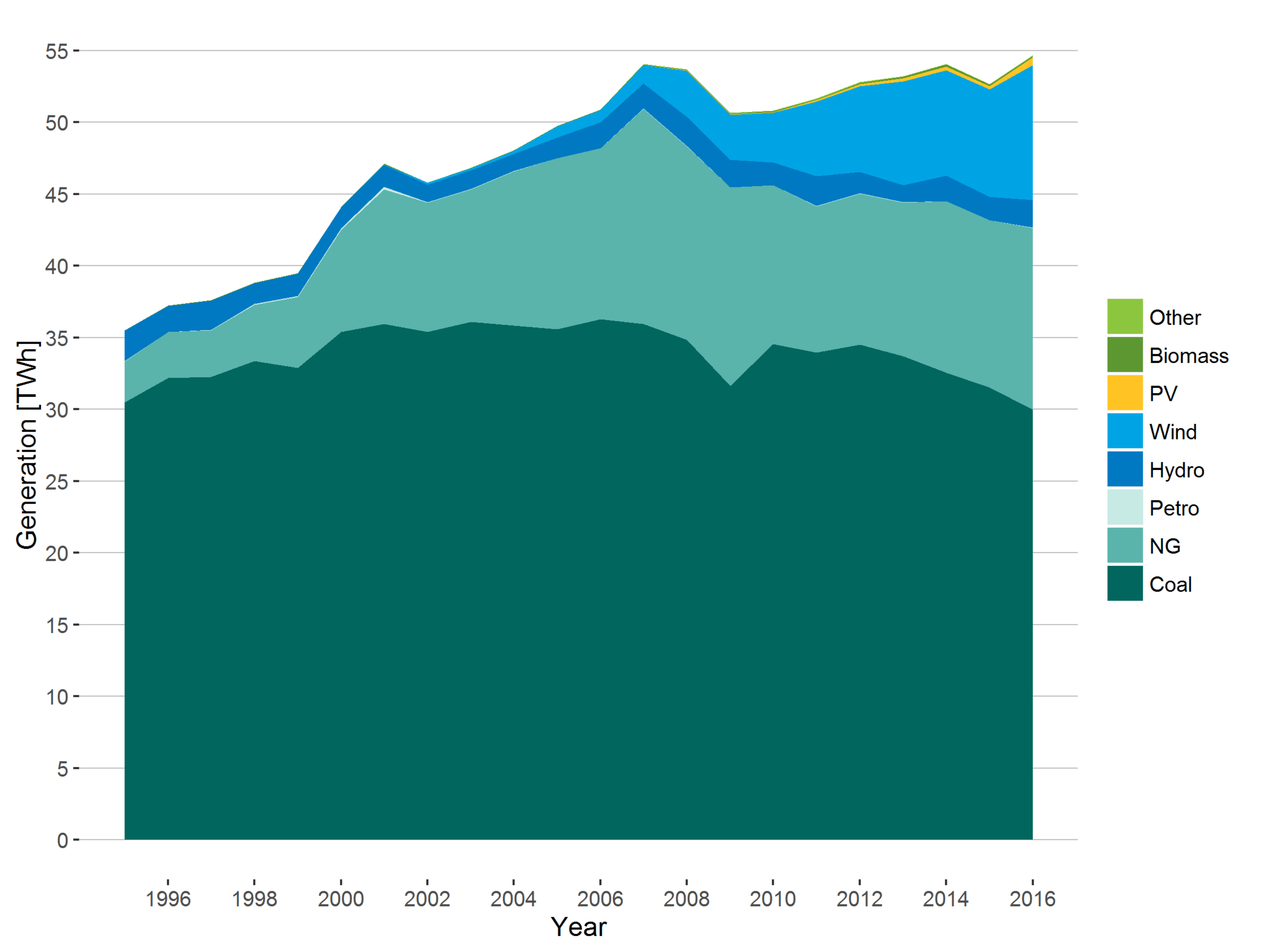


Source: EIA – Electric Power Annual

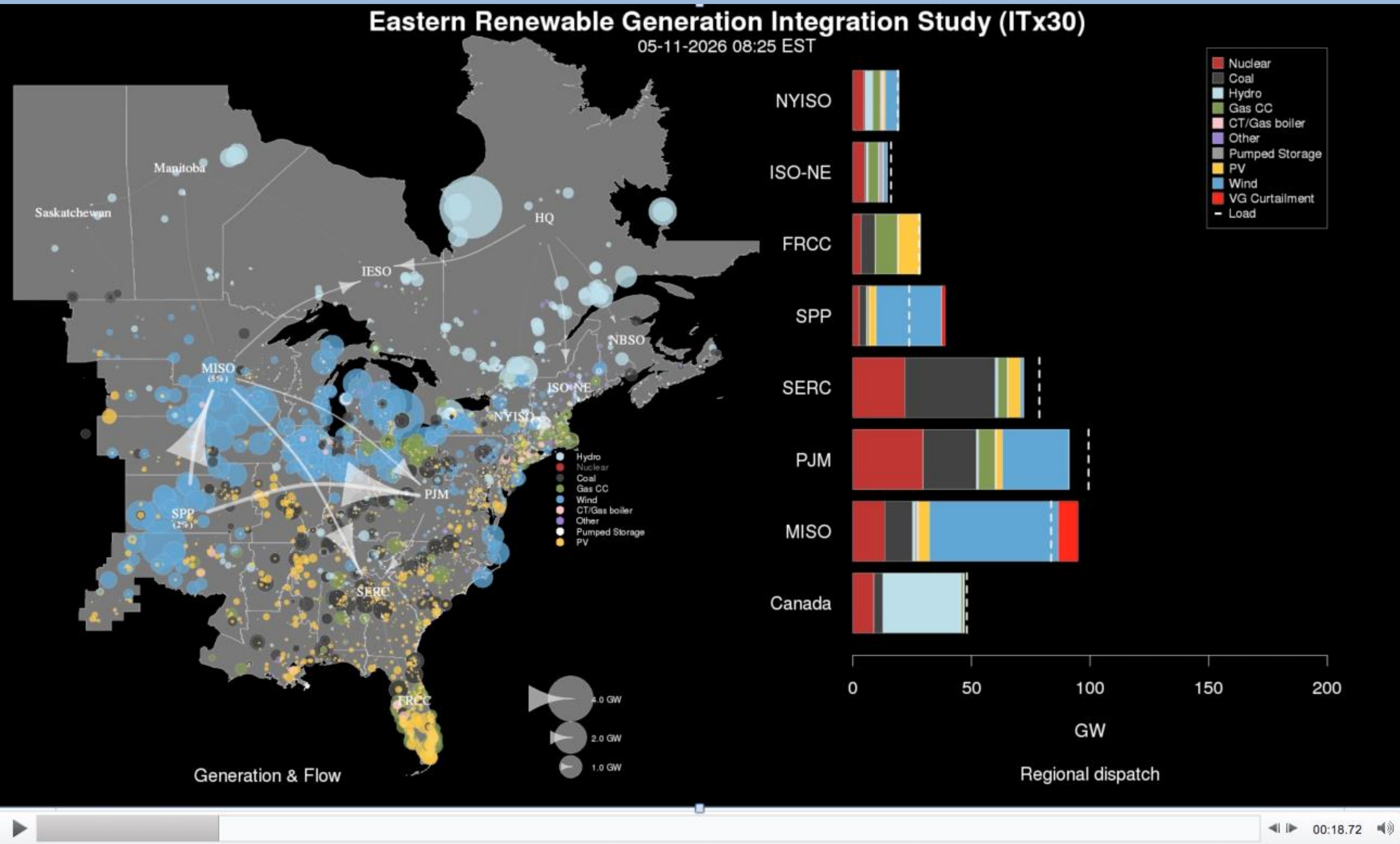
Trends in the U.S. Power System



Trends in the Colorado Power System



Source: EIA-923; Steinberg 2016 – Colorado and the Clean Power Plan, Presentation to the CDPHE



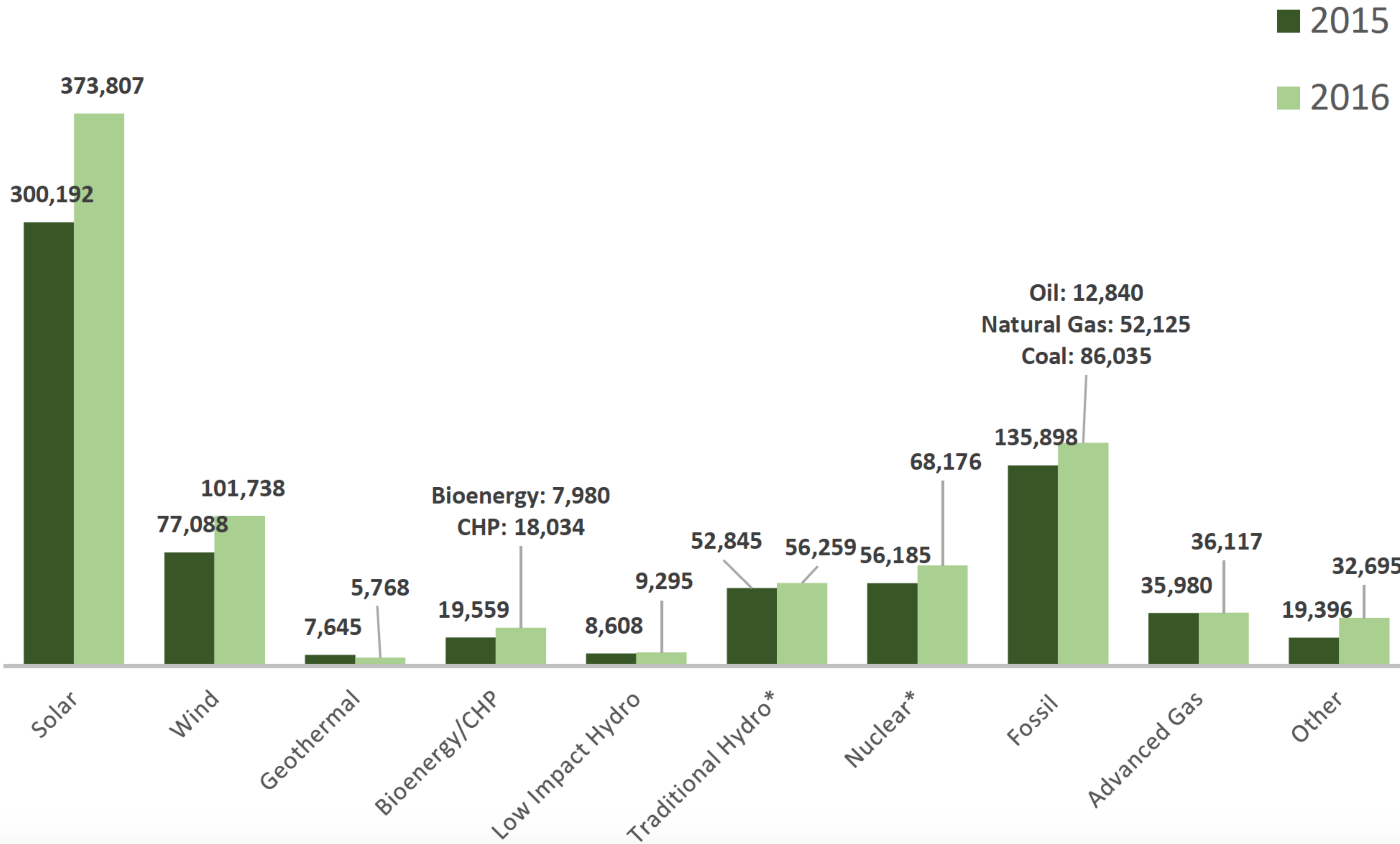
Eastern Renewable Generation Integration Study (ITx30)
05-11-2026 08:25 EST
Manitoba
Saskatchewan
HQ
IESO
NBSO
MISO
ISO-NE
NYISO
PJM
SPP
SERC
FRCC
Hydro
Nuclear
Coal
Gas CC
Wind
CT/Gas boiler
Other
Pumped Storage
PV
4.0 GW
2.0 GW
1.0 GW
Generation & Flow
NYISO
ISO-NE
FRCC
SPP
SERC
PJM
MISO
Canada
Nuclear
Coal
Hydro
Gas CC
CT/Gas boiler
Other
Pumped Storage
PV
Wind
VG Curtailment
Load
0
50
100
150
200
GW
Regional dispatch
00:18.72

ERGIS Visualization

Outline

- Global Renewable Energy Markets Update
- Technology Overviews
  - Wind and Solar
    - Market Segments
    - Global and US Markets
    - Cost Trends
    - Status in Colorado
- A Changing Power System
- Jobs in the Energy Sector

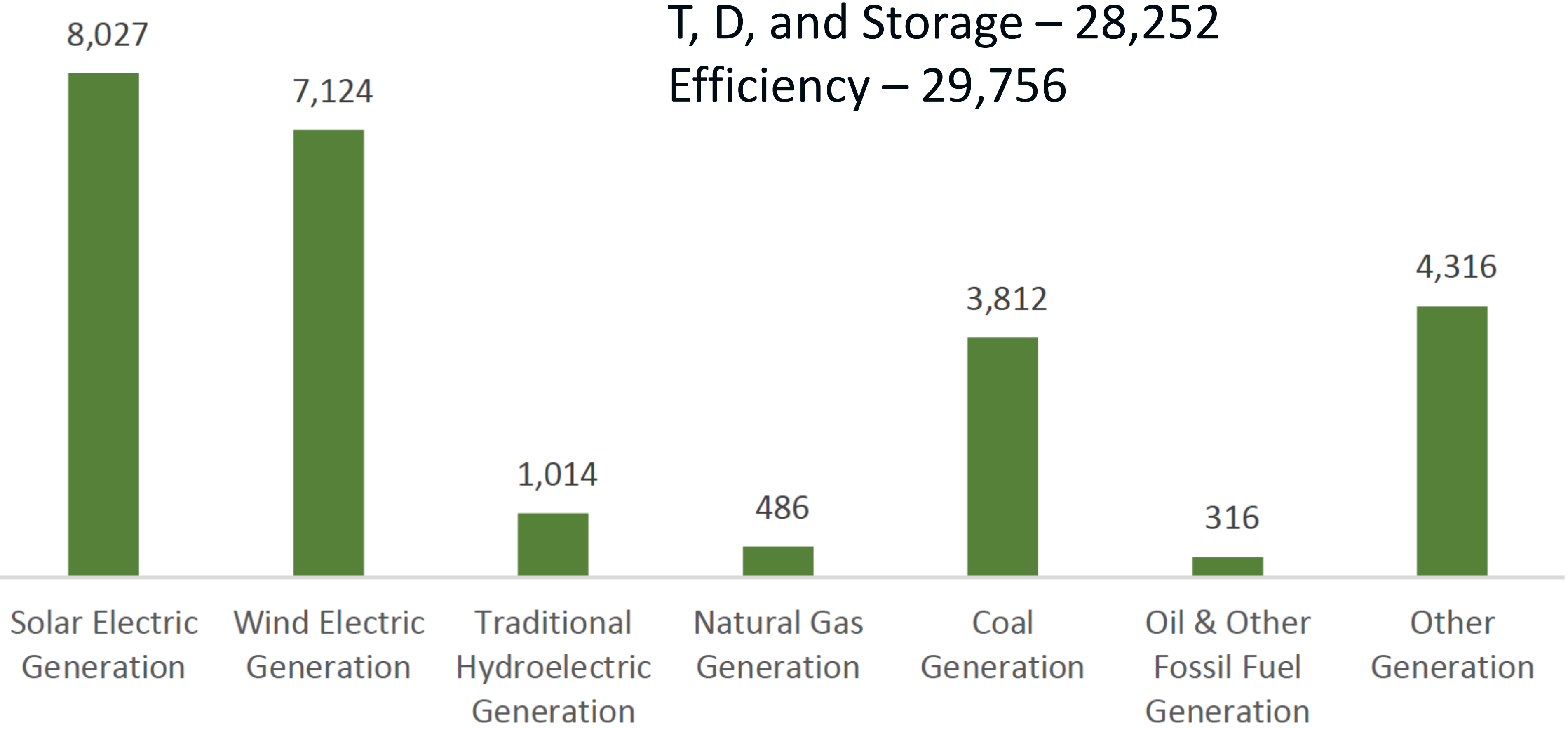
US Electricity Generation Jobs



Source: US DOE Energy and Employment Report

Colorado Electricity Generation Jobs - 2016

Electricity Gen – 25,095
Fuels – 36,765
T, D, and Storage – 28,252
Efficiency – 29,756



Source: US DOE Energy and Employment Report

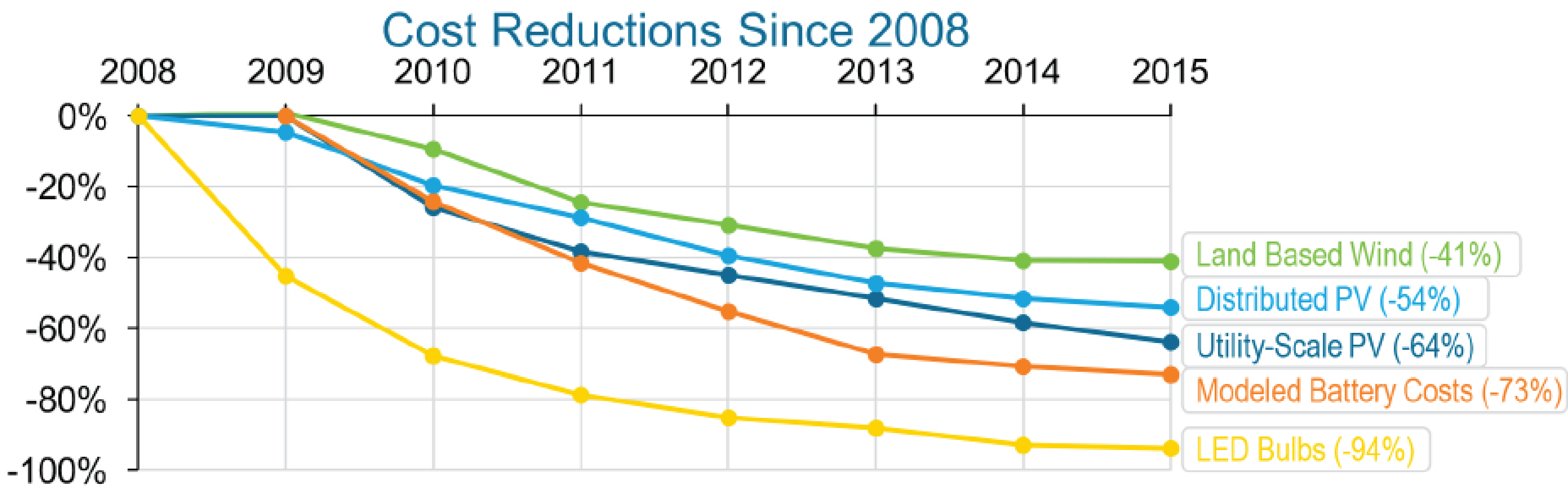
Thanks!
david.mooney@nrel.go v

www.nrel.gov

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

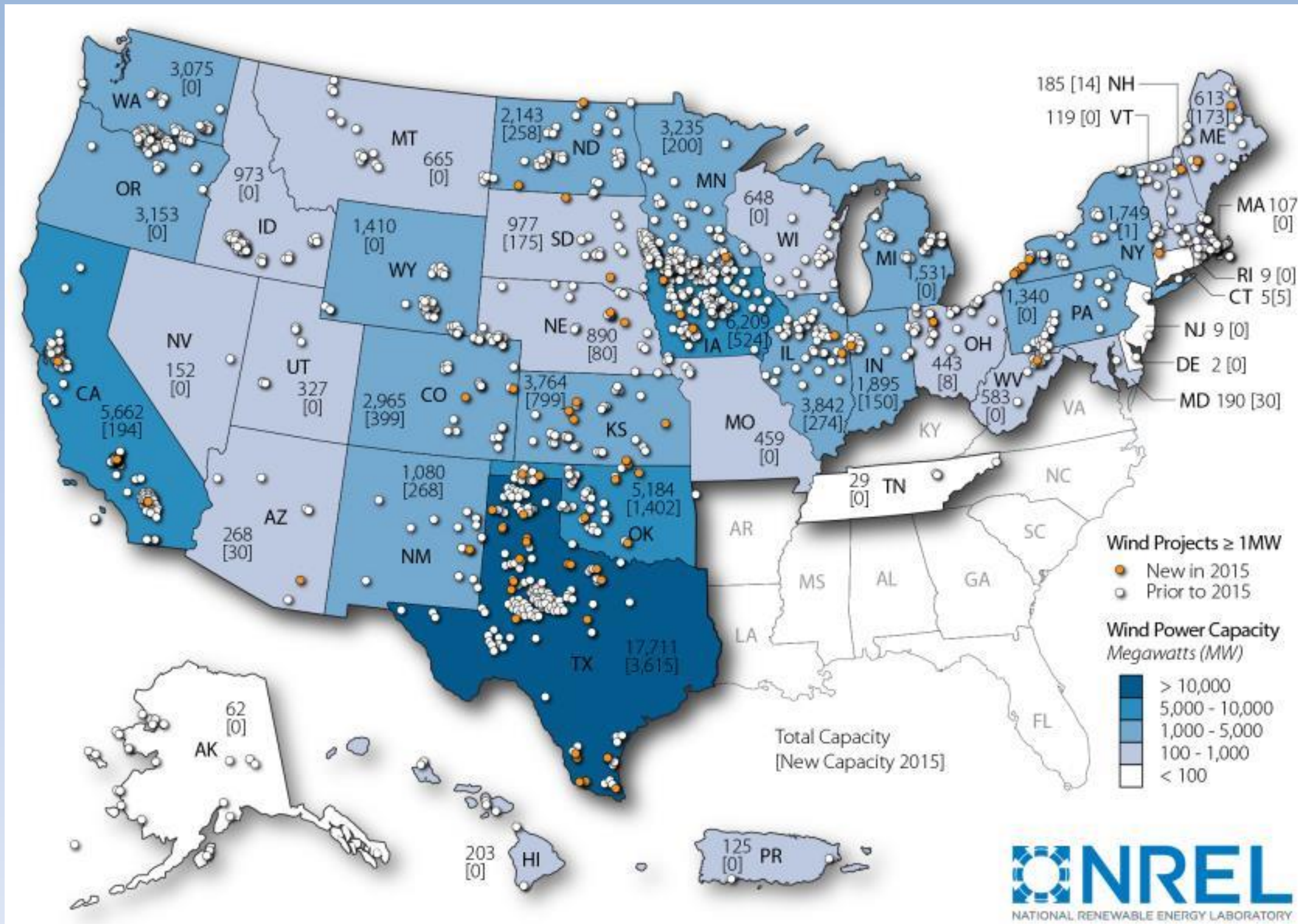
Additional Slides

Renewable Technology Cost Reductions



Notes: Land based wind costs derived from levelized cost of energy from representative wind sites from references [1] and [2]. Distributed PV is average residential installed cost from reference [3]. Utility-Scale PV is median installed cost for utility-scale PV systems from reference [4]. Modeled battery costs are at high-volume production of battery systems, derived from DOE/UIS Advanced Battery Consortium PHEV Battery development projects. LED bulbs are for A-type bulbs from reference [5].

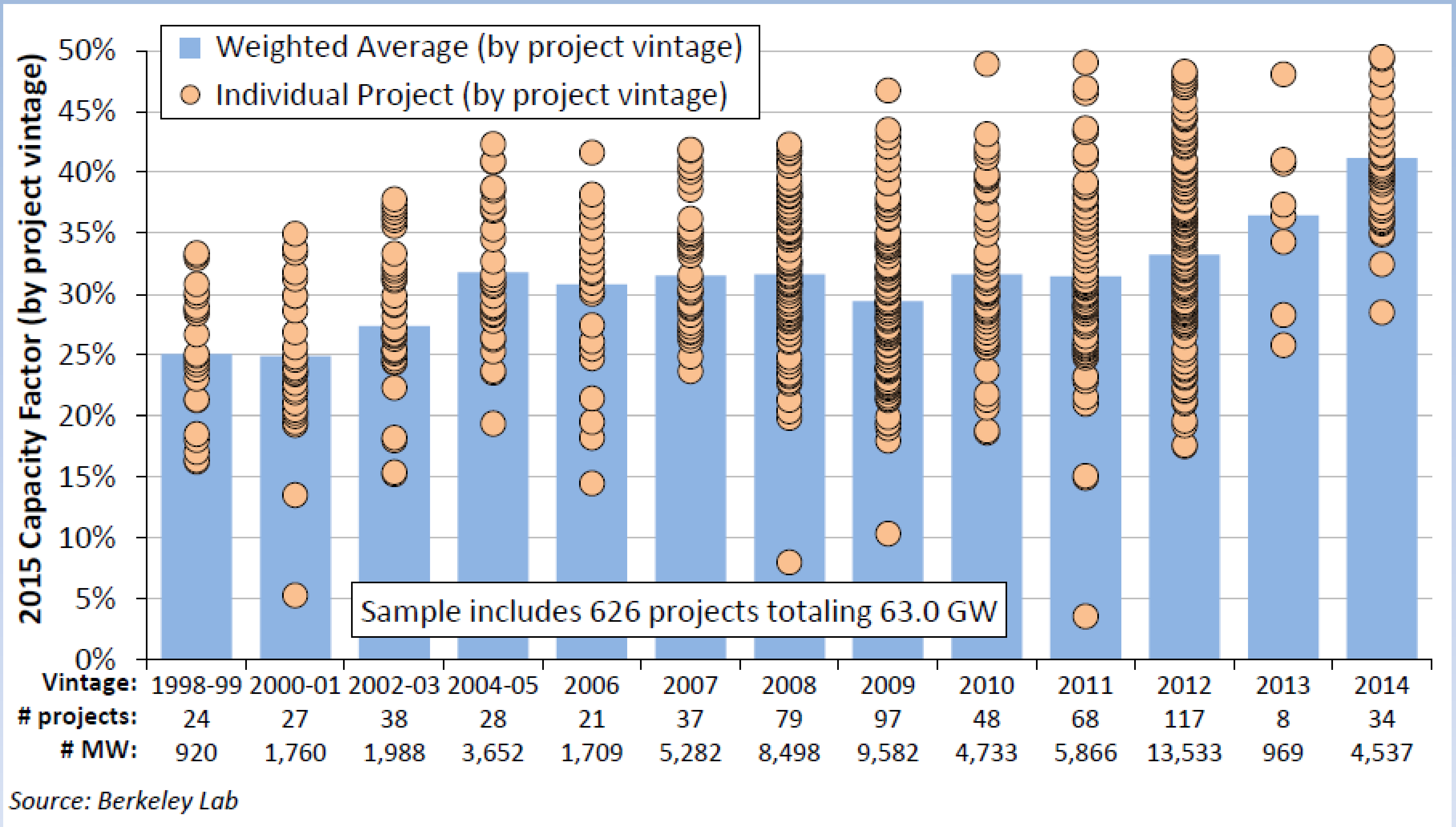
Geographic Distribution of Wind Plants



Trends in Wind Power

- Wind capacity in the U.S. has tripled since 2008
- In 2015:
  - Wind comprised 41% of all new capacity added
  - 8.6 GW added, representing $14.5 billion invested
  - GE and Vestas captured 73% of U.S. market in 2015
- Performance improvements due to increasing *capacity, hub height, and rotor diameter* of turbines
- Installed costs continue to fall: current costs $1,690/kW
- National average PPAs have fallen to $20/MWh

Calendar year 2015 capacity factors by project vintage



PV Module Prices