"ETP 2015 demonstrates that strategic action on clean energy technologies at national, regional and international levels has the capacity to move the world closer to shared goals for climate change mitigation while delivering benefits of enhanced energy security and sustainable economic development. Unfortunately, this report also shows that the current pace of action is falling short of the aim of limiting climate change to a global temperature rise of 2°C (ETP modeling, the 2° Scenario or 2DS). Indeed, despite positive signs in many areas, for the first time since the IEA started monitoring clean energy progress, not one of the technology fields tracked is meeting its objectives. As a result, our ability to deliver a future in which temperatures rise modestly is at risk of being jeopardized, and the future that we are heading towards will be far more difficult unless we can take action now to radically change the global energy system. "

Source: "Tracking Clean Energy Progress," IEA, 2015

Why Are We Lagging Behind Targets?

- Global Externality Problems Involving Such Large Costs and Potential Wealth Transfers are Inherently Difficult
- Too Much Wishful Thinking
- Too Little Hard-Nosed Analysis of Mitigation Costs, Incentives, Human and Organizational Behavior
- Too Little Long-Term R&D and Innovation
- Reinforced By Bad Domestic and International Public Policies

Domestic and International Public Policies

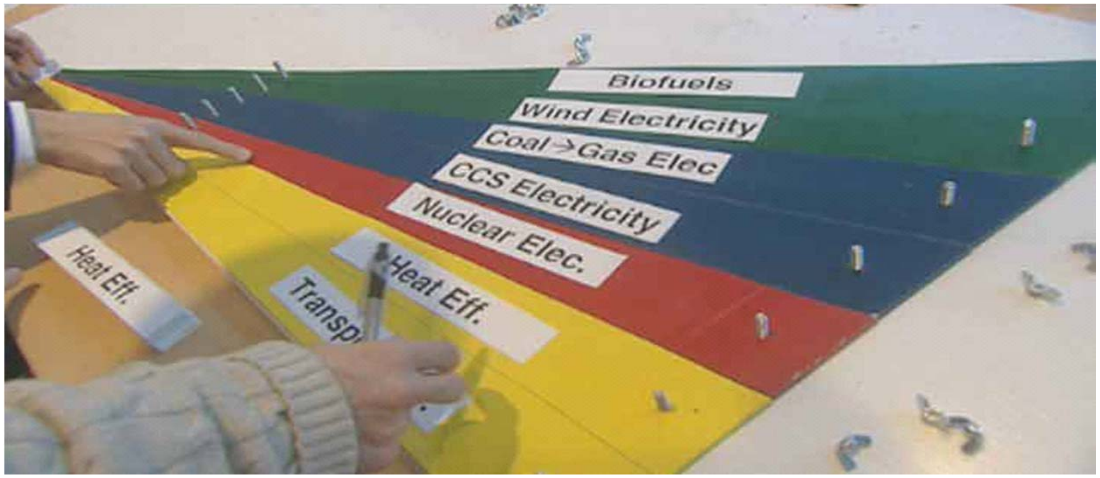
- Marginal Cost of Mitigation with Current Policies Varies Widely Across Applications (-$X - $1000/ton CO2 Avoided)
  - Solar in Northern Ontario vs. Solar in Mexico
- The Most Economical Long-Term Mitigation Innovations Are Very Uncertain and Cry Out for Broad Rather than Narrow Incentives
- Picking "Favorite" Technologies to Subsidize is a Loser
- Subsidies Are Very Difficult to Remove Once They Are Made Available
- Complementary Policies Receive Inadequate Attention (e.g. Electric and Gas Transmission)
- Costs of Meeting 2050 Mitigation Goal Using Current Technologies are Enormous Making the Likelihood of Achieving Goal Very Low

Domestic and International Public Policies

- International "Pledge and Verify Strategy" is Not Credible
- Incentive Structure is Wrong in the Short Run and Long Run (Innovation)
- Need Commitment to Uniform Global GHG Price Trajectory Equal to Best Estimate of the (PDV) of the Marginal Damages from Emissions
- Cap and Trade with International Trading is the Most Realistic Approach
  - Good luck with a global tax on carbon emissions
- Need a Different Mechanism to Allocate R&D Funds That Takes a Broad Long-Term Perspective (e.g. ARPA-E)
- Hard to Make an International "Deal" with 195 Countries

Stabilization Wedges

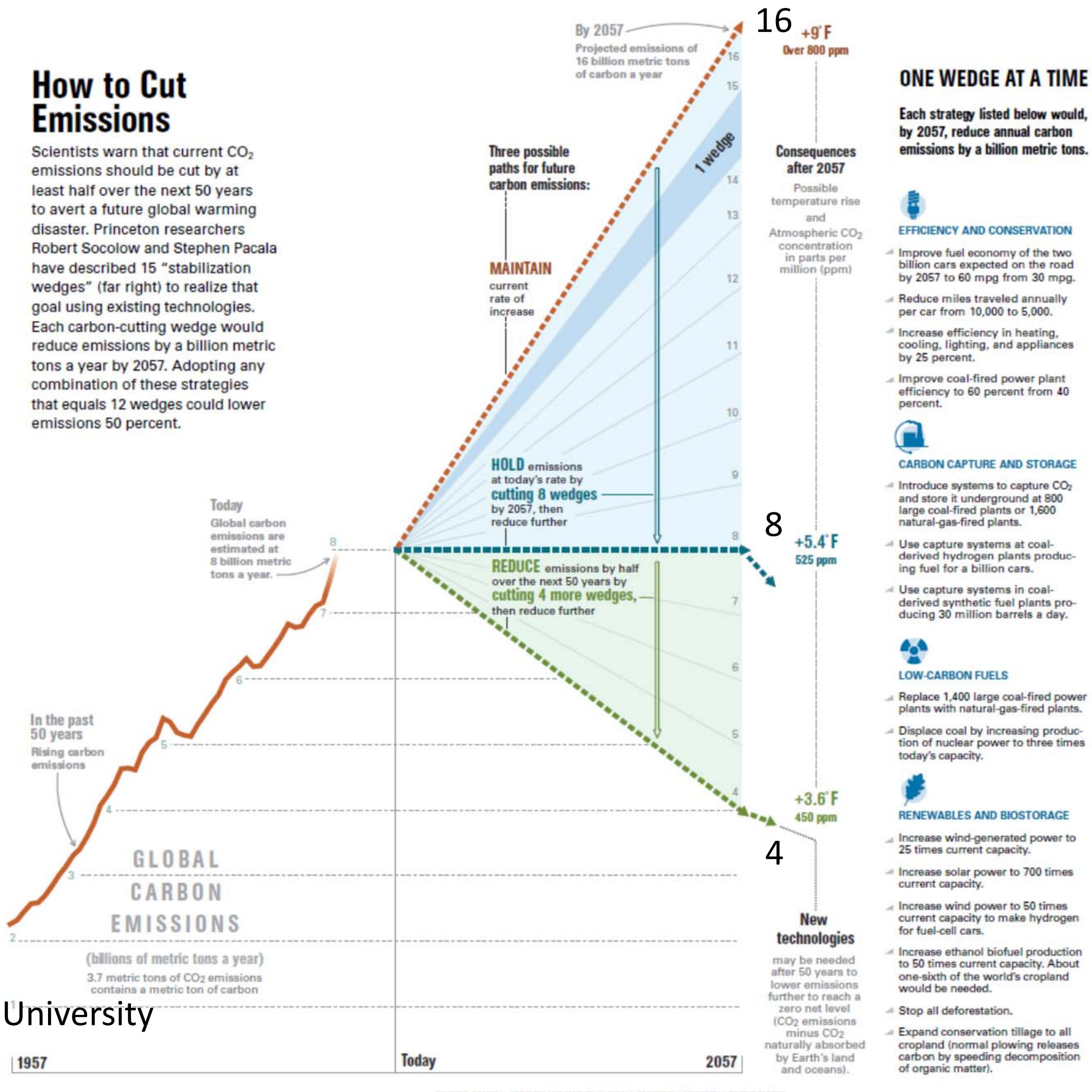
Tackling the Climate Problem with Existing Technologies



This presentation is based on the “Stabilization Wedges” concept first presented in

"Stabilization Wedges: Solving the Climate Problem for the next 50 Years with Current Technologies,” S. Pacala and R. Socolow, Science, August 13, 2004.

Please credit the Carbon Mitigation Initiative, Princeton University



Carbon Mitigation Initiative, Princeton University

Wedge Strategies Currently Available

The following pages contain descriptions of 15 strategies already available that could be scaled up over the next 50 years to reduce global carbon emissions by 1 billion tons per year, or **one wedge.** They are grouped into four major color-coded categories:

Efficiency & Conservation

- Increased transport efficiency
- Reducing miles traveled
- Increased building efficiency
- Increased efficiency of electricity production

Fossil-Fuel-Based Strategies

- Fuel switching (coal to gas)
- Fossil-based electricity with carbon capture & storage (CCS)
- Coal synfuels with CCS
- Fossil-based hydrogen fuel with CCS

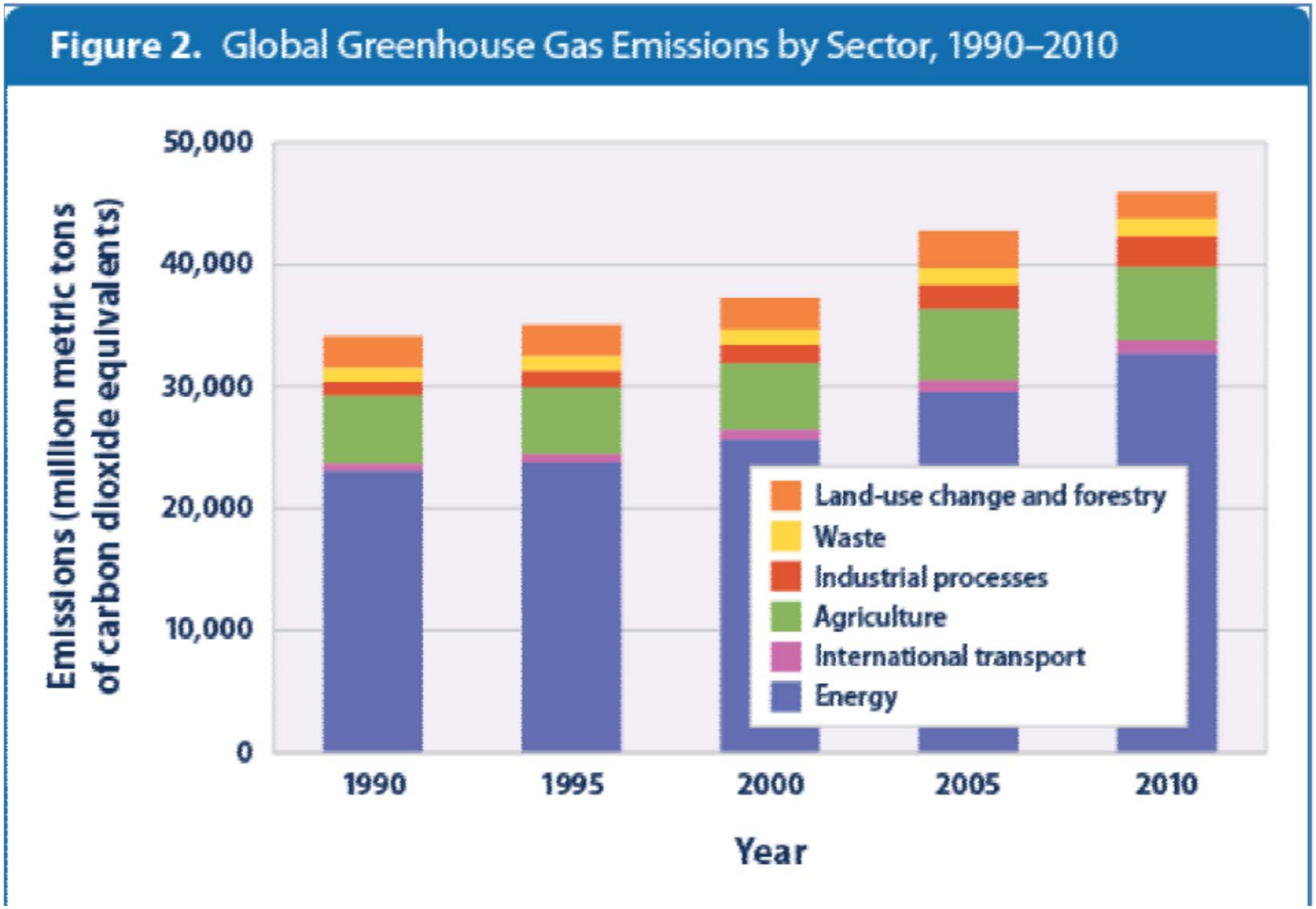
Nuclear Energy

- Nuclear electricity

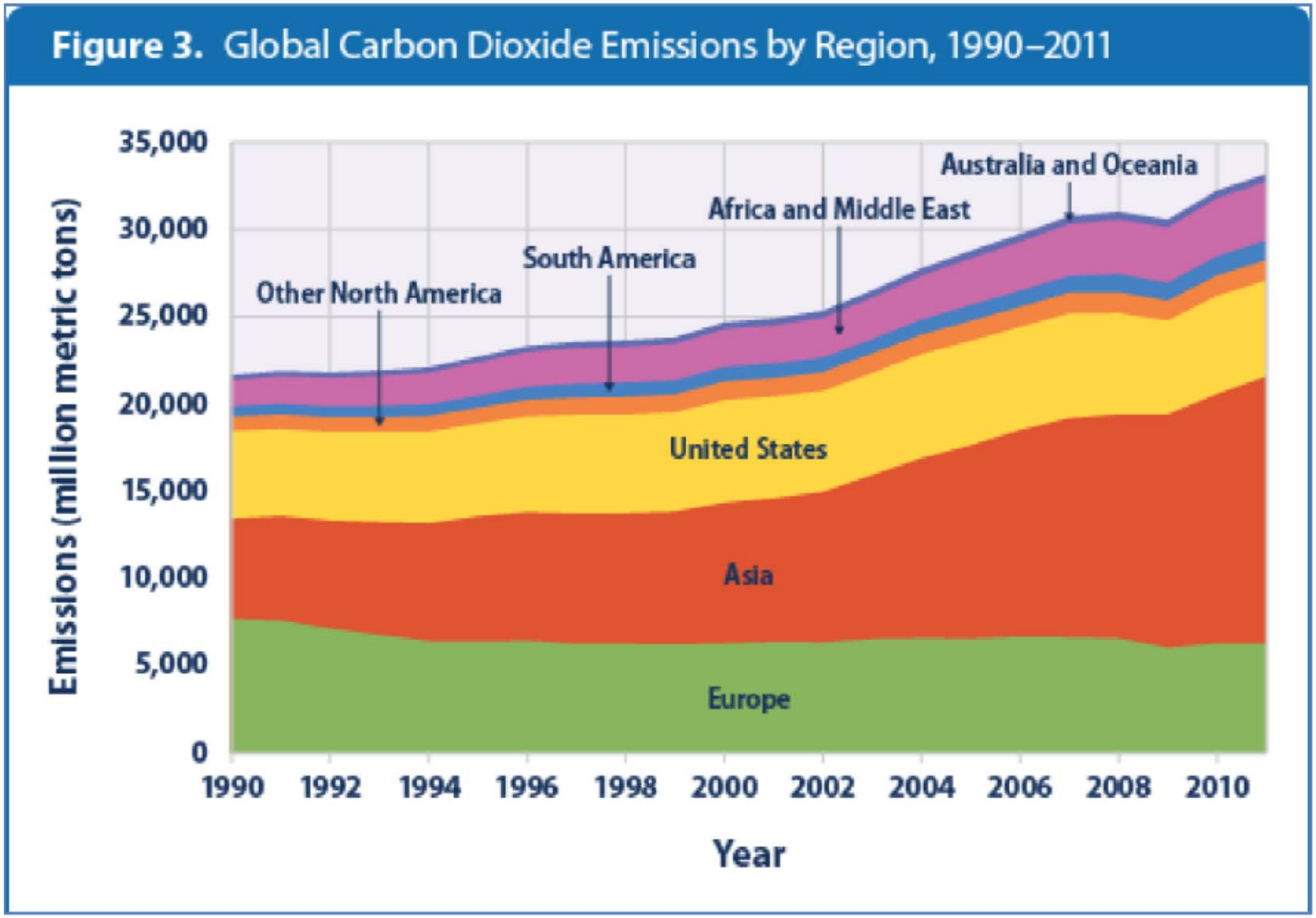
Renewables and Biostorage

- Wind-generated electricity
- Solar electricity
- Wind-generated hydrogen fuel
- Biofuels
- Forest storage
- Soil storage

Carbon Mitigation Initiative, Princeton University



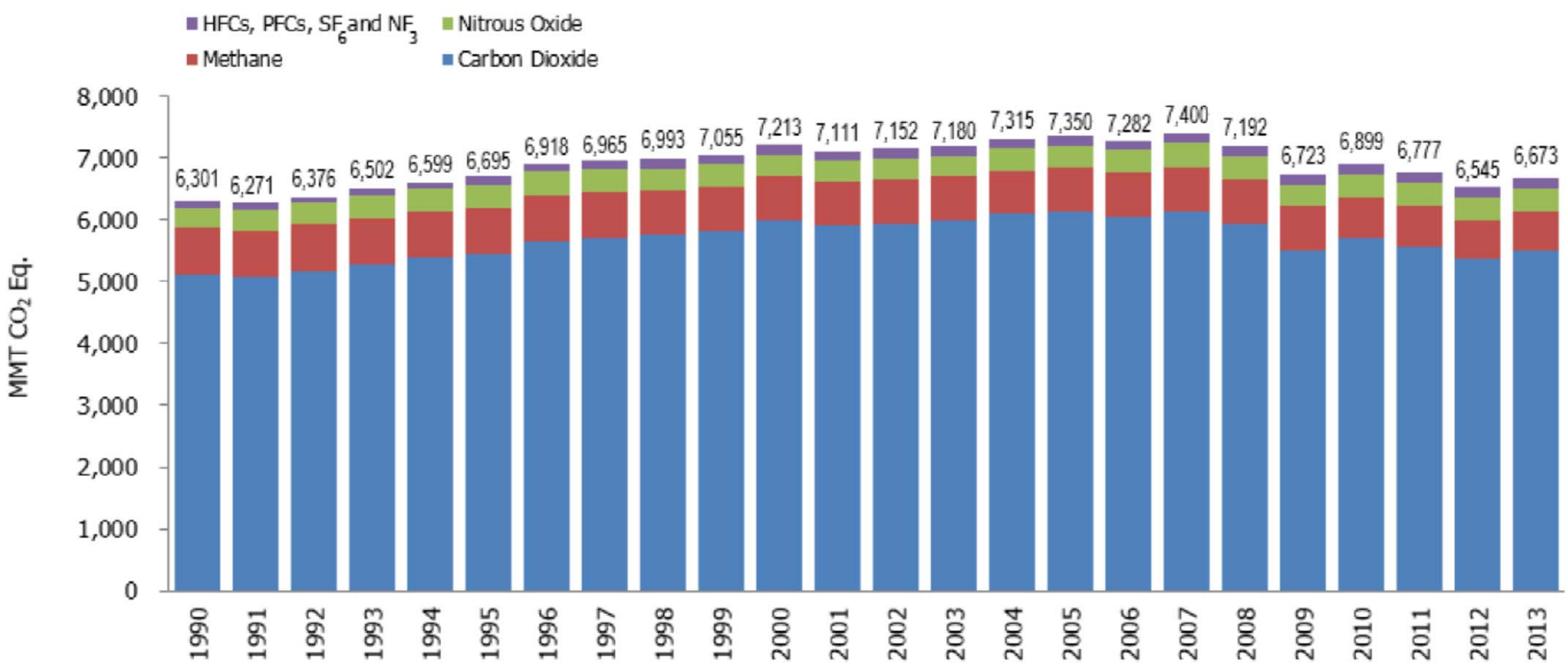
U.S. EPA Updated May 2014



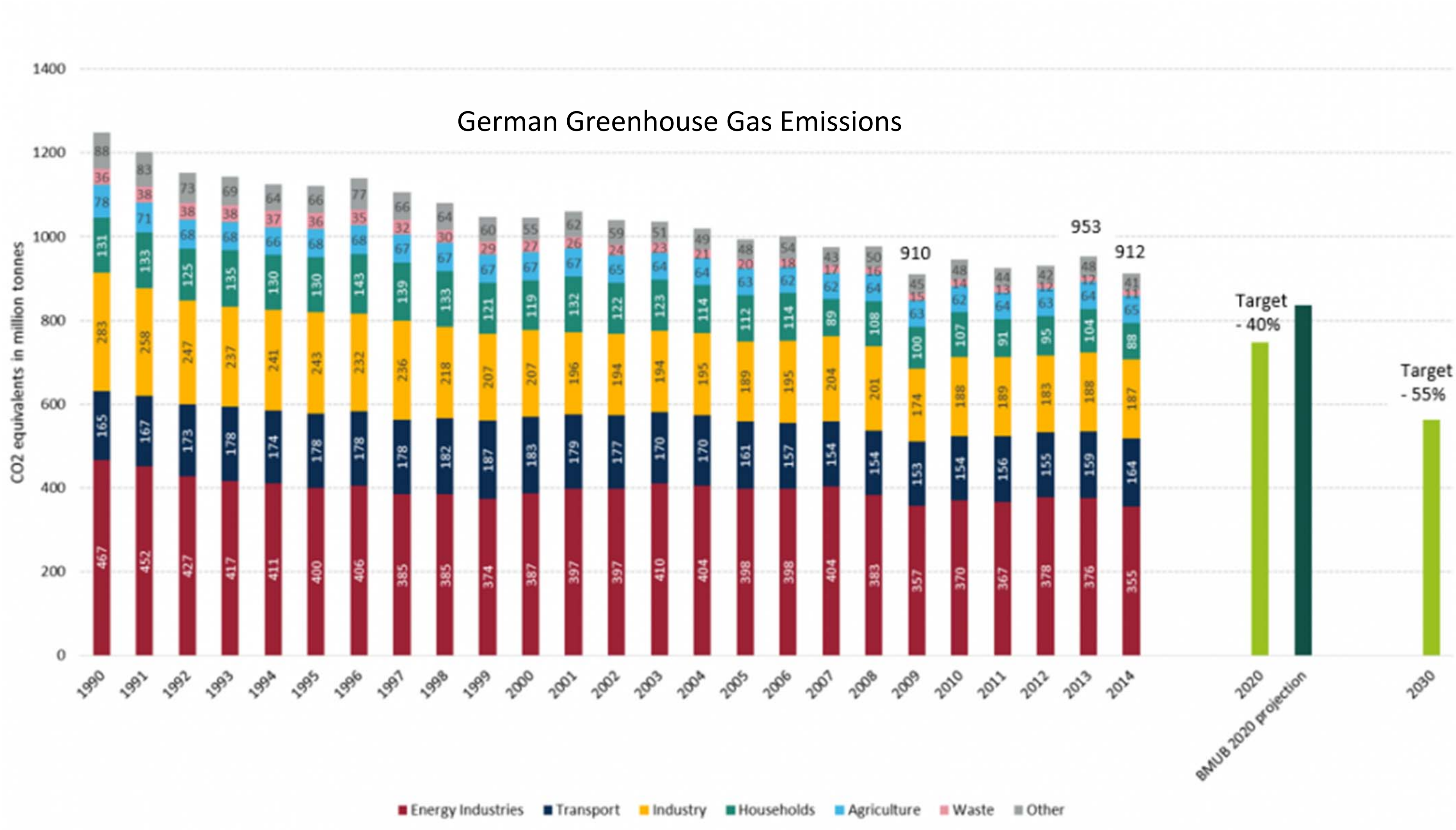
U.S. EPA Updated May 2014

Figure ES-1: U.S. Greenhouse Gas Emissions by Gas

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.



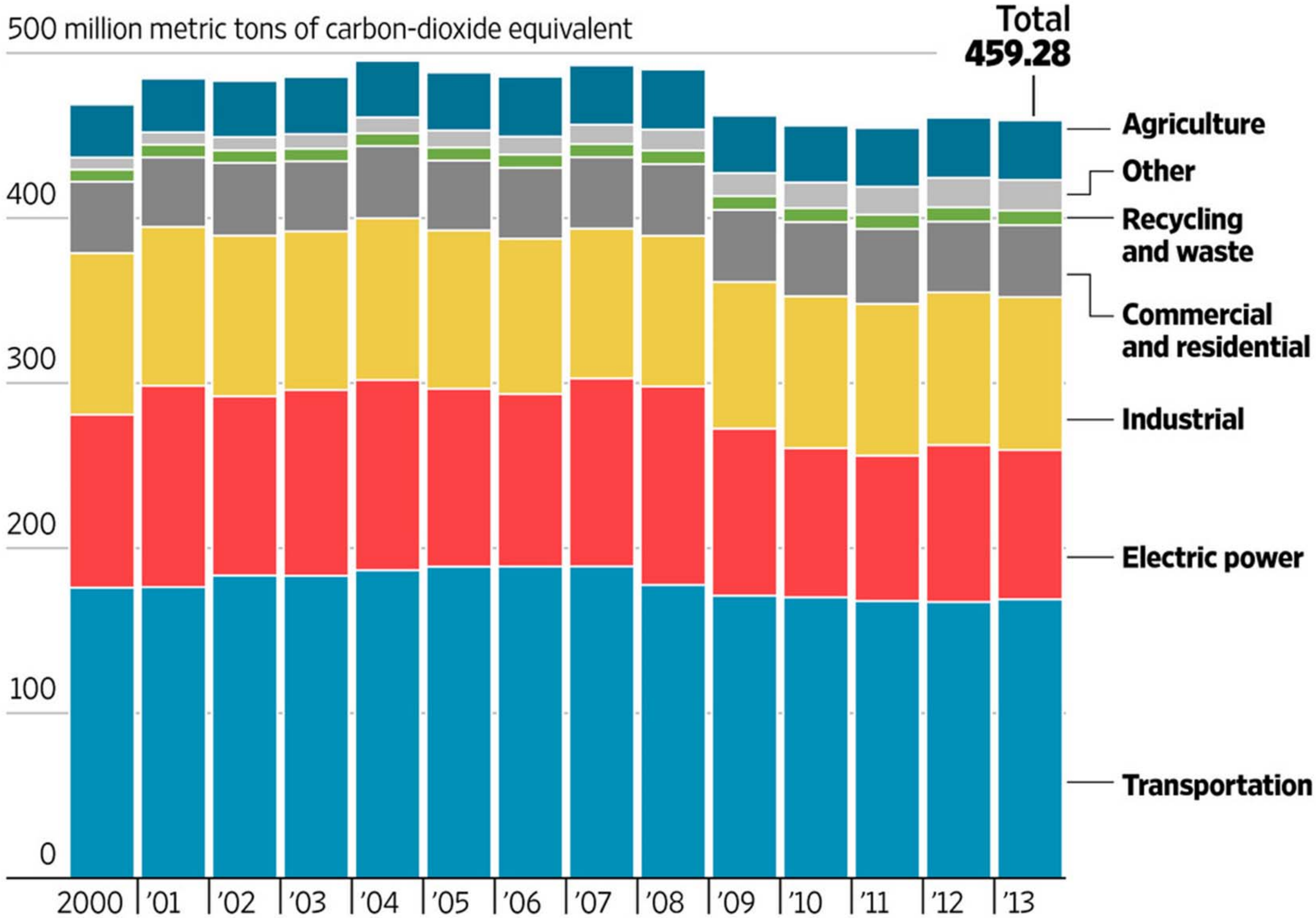
U.S. EPA Updated May 2014



Clean Energy Wire, May 9, 2015

From Farms to Roads

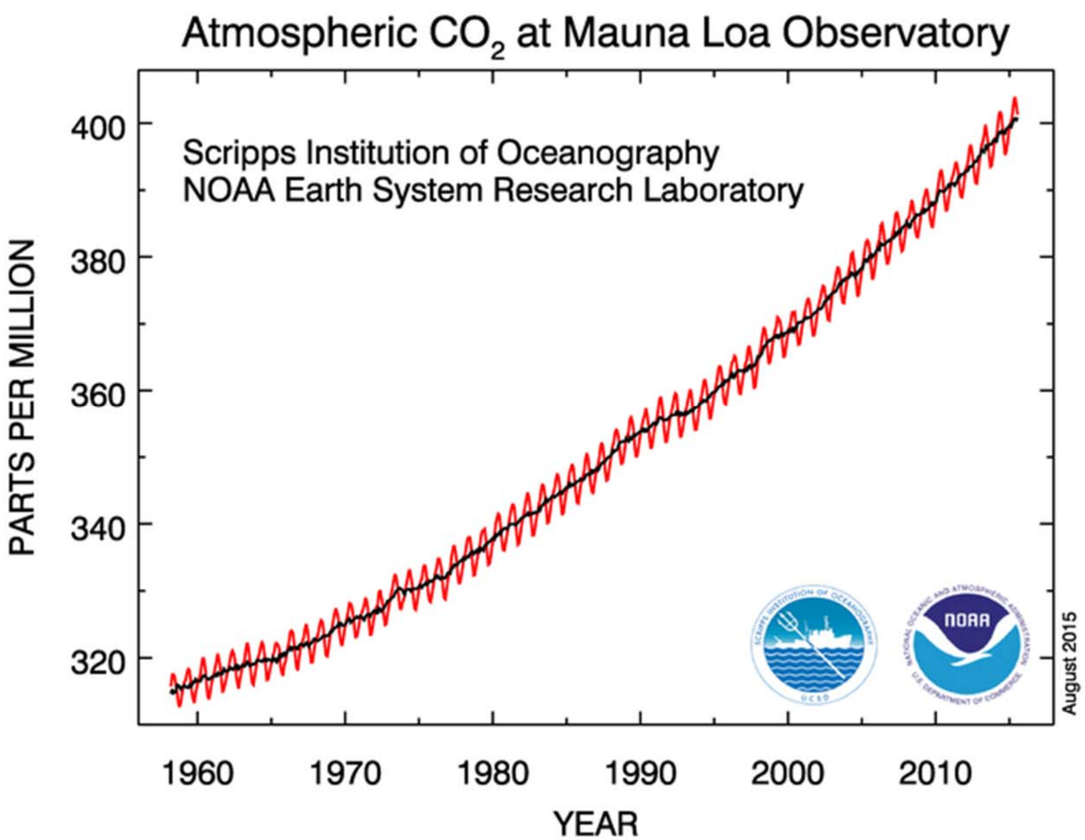
New legislation would aim to sharply reduce petroleum fuels used in transportation, the biggest source of California's greenhouse-gas emissions.



Source: California Air Resources Board

THE WALL STREET JOURNAL.

9/5/15


Atmospheric CO_2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
PARTS PER MILLION
400
380
360
340
320
1960
1970
1980
1990
2000
2010
YEAR
August 2015

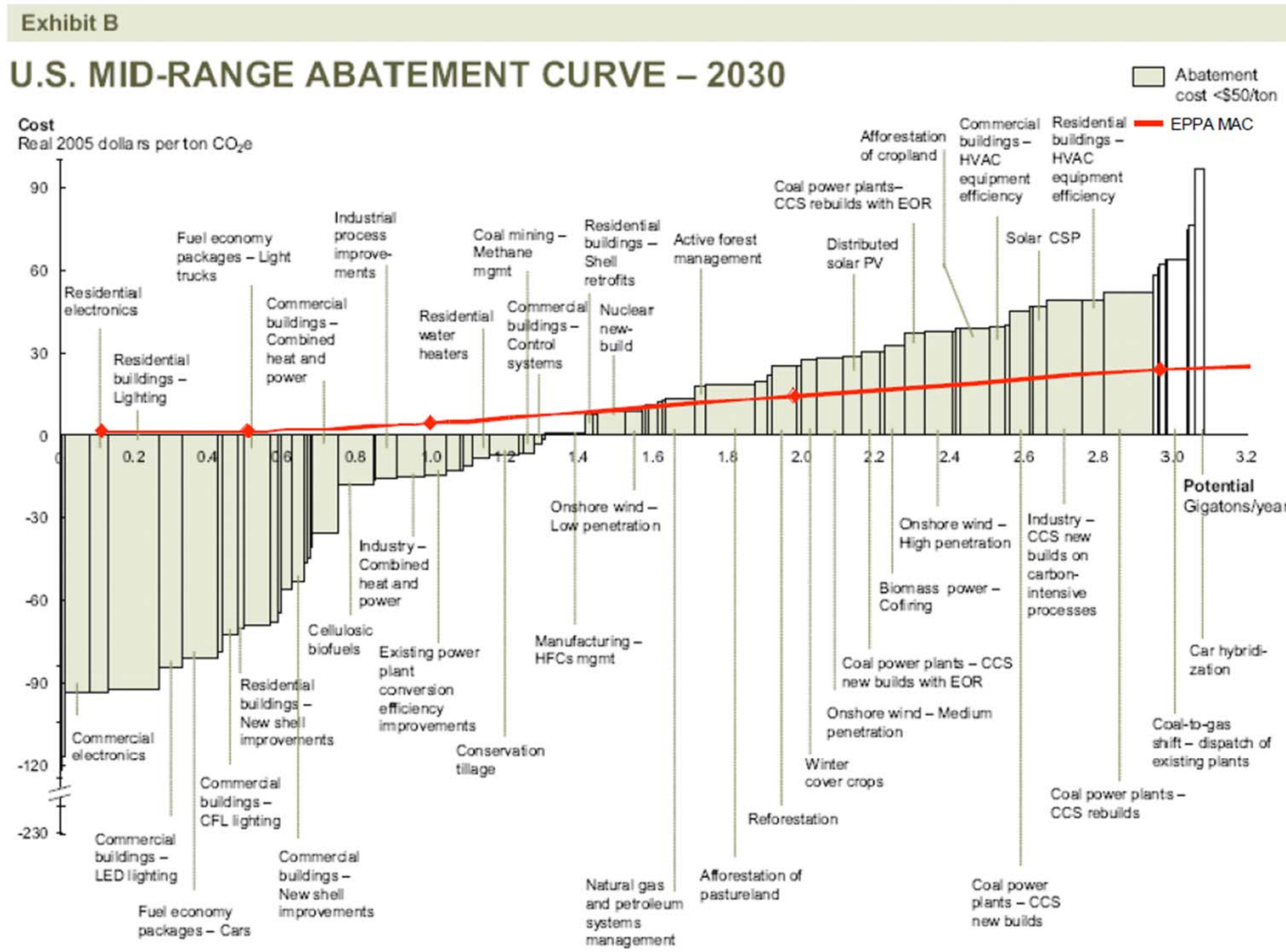


Figure B1 McKinsey and EPPA Abatement Cost Curves for USA in 2030 (all GHGs).

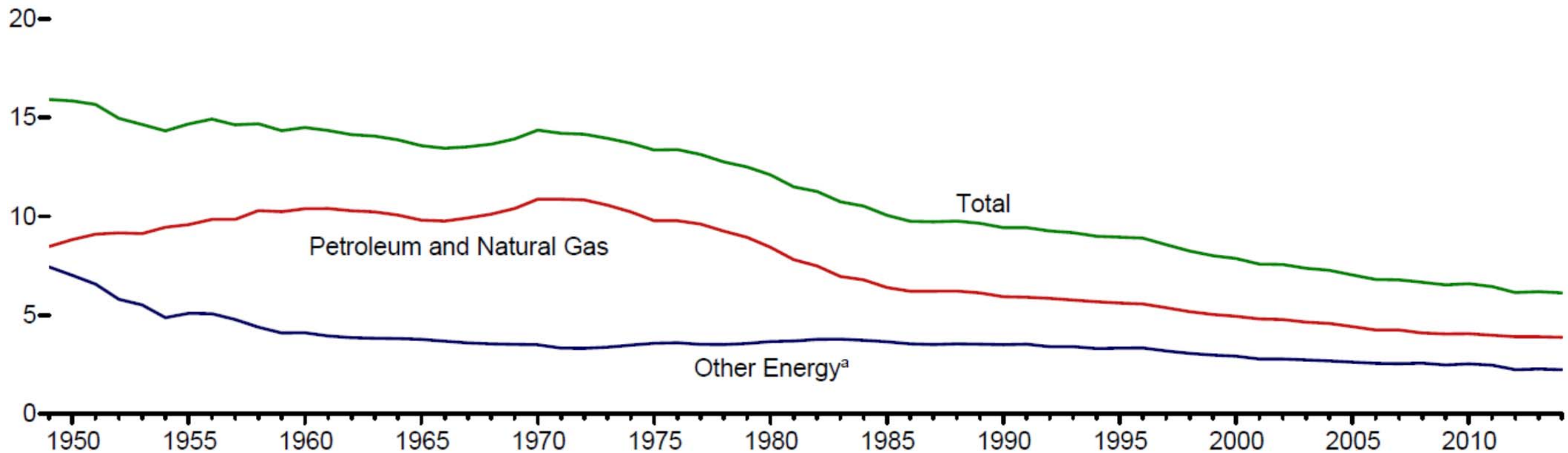
Appendix B: Comparison of U.S. Marginal Abatement Cost Curves from a McKinsey & Co. Study with Results from the MIT EPPA Model*

Jennifer Morris, Sergey Paltsev, John Reilly, Henry Jacoby

MIT Joint Program Report #164

Figure 1.7 Primary Energy Consumption per Real Dollar of Gross Domestic Product, 1949–2014

(Thousand Btu per Chained (2009) Dollar)



Note: See "Real Dollars" in Glossary.
Web Page: http://www.eia.gov/totalenergy/data/monthly/#summary.
Source: Table 1.7.

U.S. EIA

Figure 19. Energy use per capita and per 2009 dollar of gross domestic product, and carbon dioxide emissions per 2009 dollar of gross domestic product, in the Reference case, 1980-2040 (index, 2005 = 1.0)

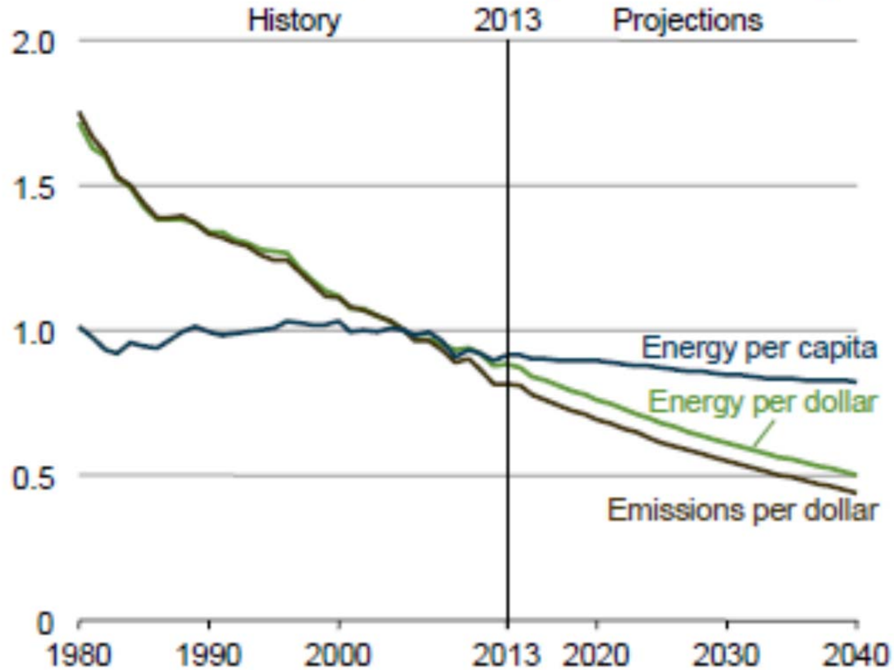
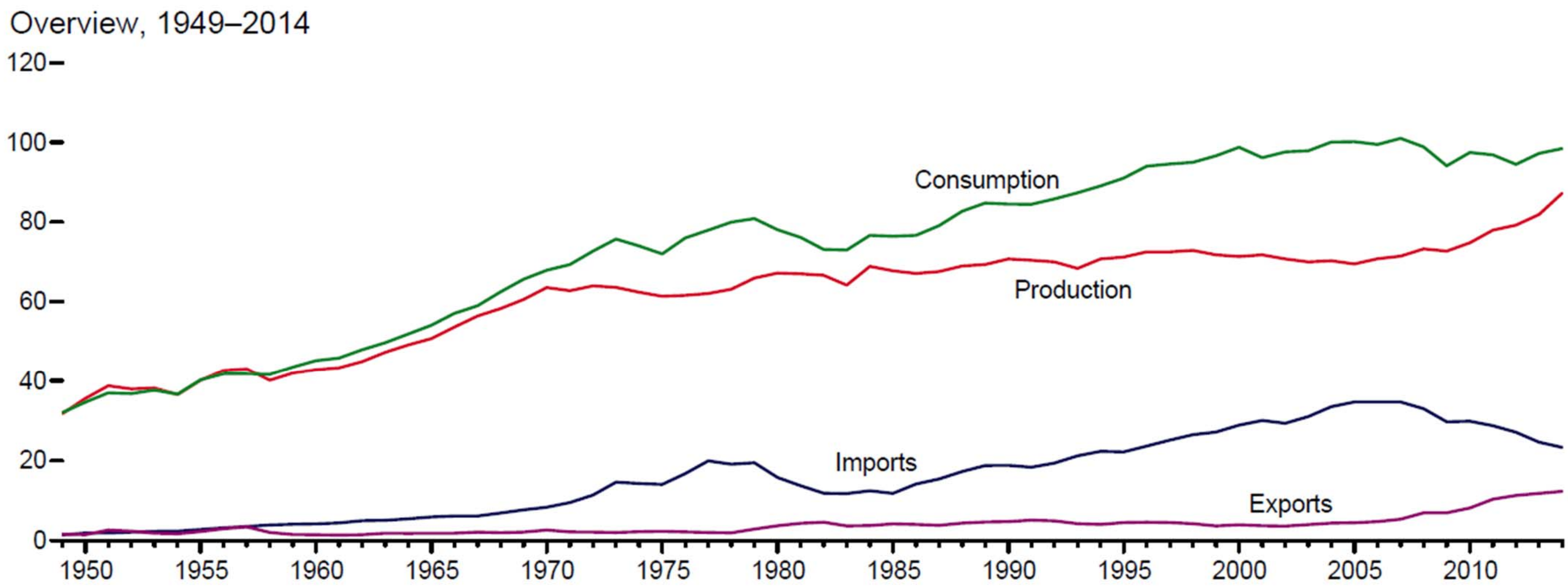


Figure 1.1 Primary Energy Overview
(Quadrillion Btu)



U.S. EIA 2015

Figure 18. Primary energy consumption by fuel in the Reference case, 1980-2040 (quadrillion Btu)

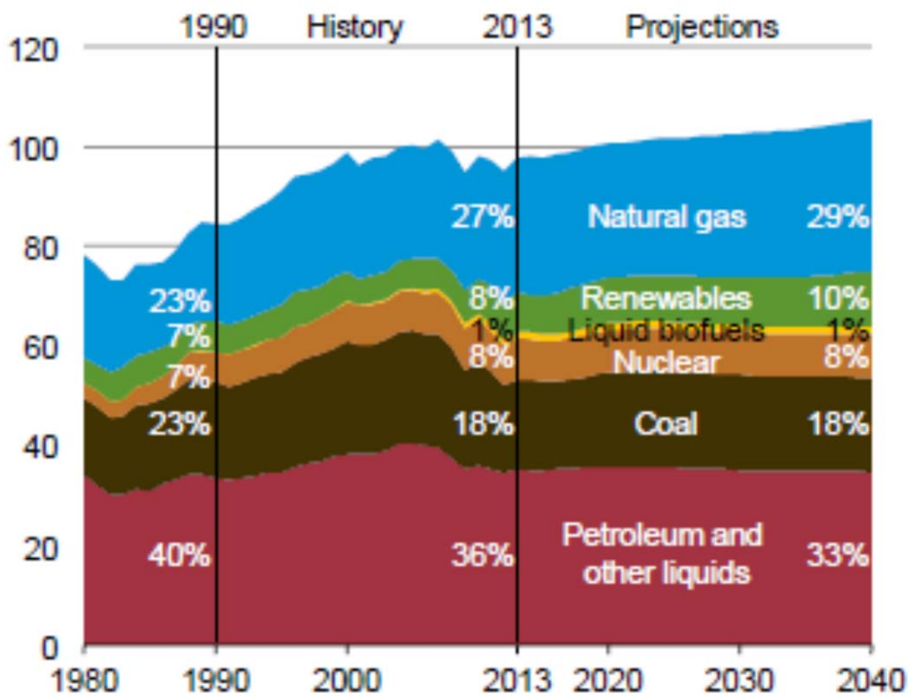
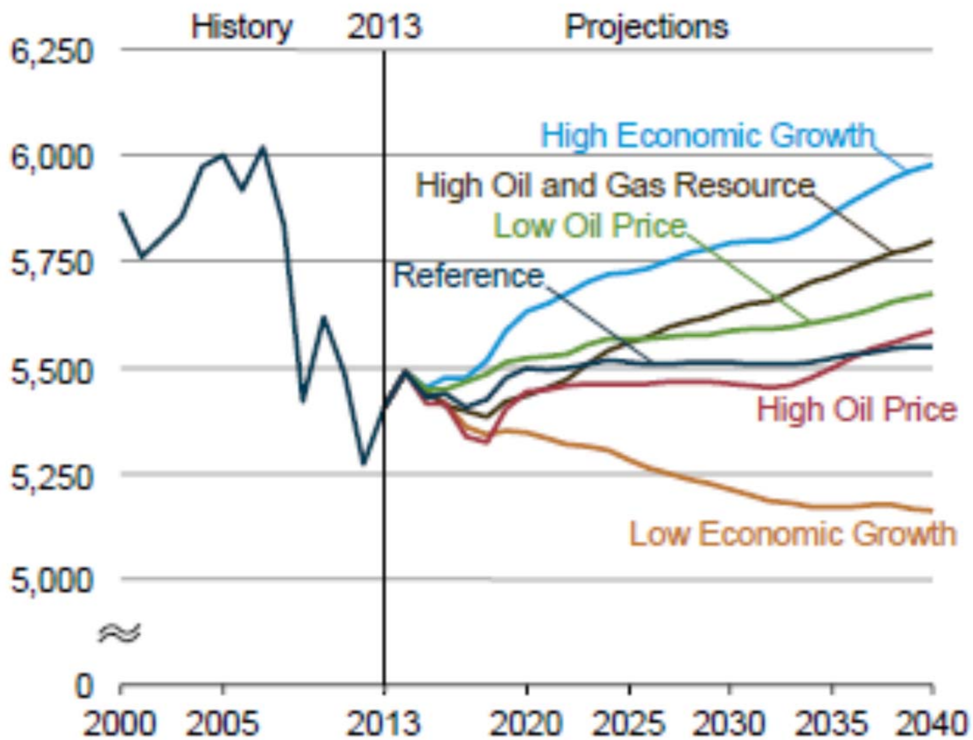


Figure 36. Energy-related carbon dioxide emissions in six cases. 2000-2040 (million metric tons)



Efficiency

Produce today's electric capacity with double today's efficiency

Average coal plant efficiency is 32% today

Double the fuel efficiency of the world's cars <u>or</u> halve miles traveled

There are about 600 million cars today, with 2 billion projected for 2055

Use best efficiency practices in all residential and commercial buildings

Replacing all the world's incandescent bulbs with CFL's would provide 1/4 of one wedge

Carbon Mitigation Initiative
Princeton University

E, T, H / $

Sector s affected:

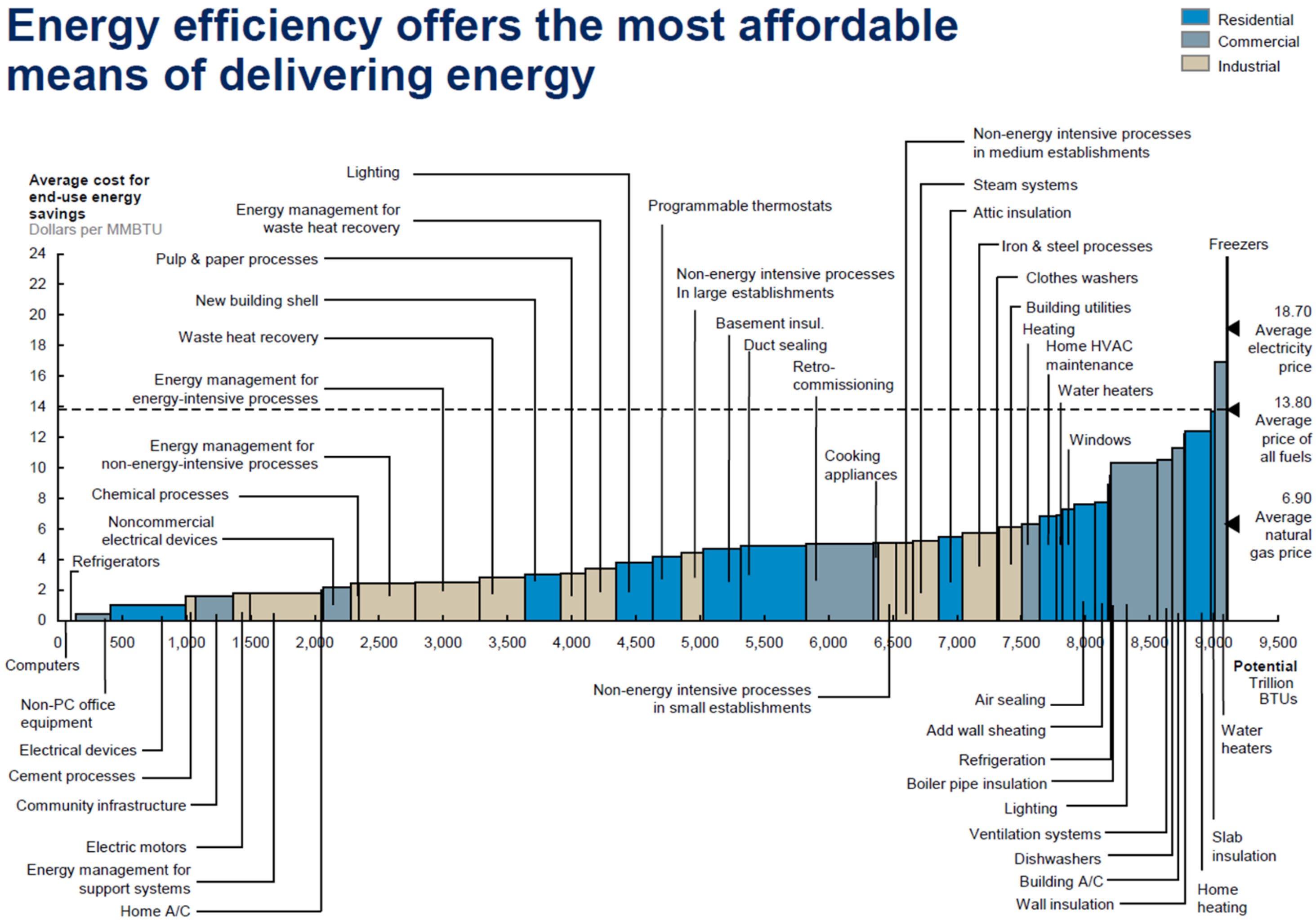
E = Electricity, T =Transport,

H = Heat

Cost based on scale of \$ to \$\$\$

Photos courtesy of Ford Motor Co., DOE, EPA

Energy efficiency offers the most affordable means of delivering energy



Source: EIA AEO 2008, McKinsey analysis

Time horizon	Ex ante projections (NEAT) (1)	Empirical estimates (2)
Panel A: Private internal rate of return		
10 years	7.0%	-10.5%
16 years	11.8%	-2.2%
20 years	12.8%	0.3%
Panel B: Private internal rate of return, adding avoided emissions damages		
10 years	11.3%	-8.8%
16 years	15.5%	-0.8%
20 years	16.4%	1.5%
Panel C: Social internal rate of return		
10 years	-1.0%	-20.0%
16 years	5.4%	-9.5%
20 years	7.0%	-6.1%
Panel D: CO_2 abatement cost - 3 percent discount (\$/ton CO_2)		
10 years	$29	$552
16 years	-$19	$329
20 years	-$35	$255

Fowlie, Greenstone and Wolfram, E2e Working Paper 20, 2015

Measuring the Welfare Effects of Energy Efficiency Programs

Hunt Allcott and Michael Greenstone*

July 11, 2015

Abstract

Energy efficiency programs are typically evaluated with engineering-style approaches that use simulated energy savings instead of empirical estimates and ignore non-monetary benefits and costs. We formalize an alternative welfare framework based on revealed preferences and apply it a 100,000-household randomized field experiment at a Better Buildings energy efficiency program in Wisconsin. Average simulated savings are 56 percent larger than the actual empirical estimates, and investment takeup decisions imply large non-monetary benefits and costs. If evaluated only on monetary factors (i.e. energy cost and externality reductions and investment costs), the Wisconsin and national Better Buildings programs had negative one to negative six percent social internal rates of return. Our revealed preference welfare approach suggests that the Wisconsin program reduced welfare, because subsidies substantially exceeded externality damages.

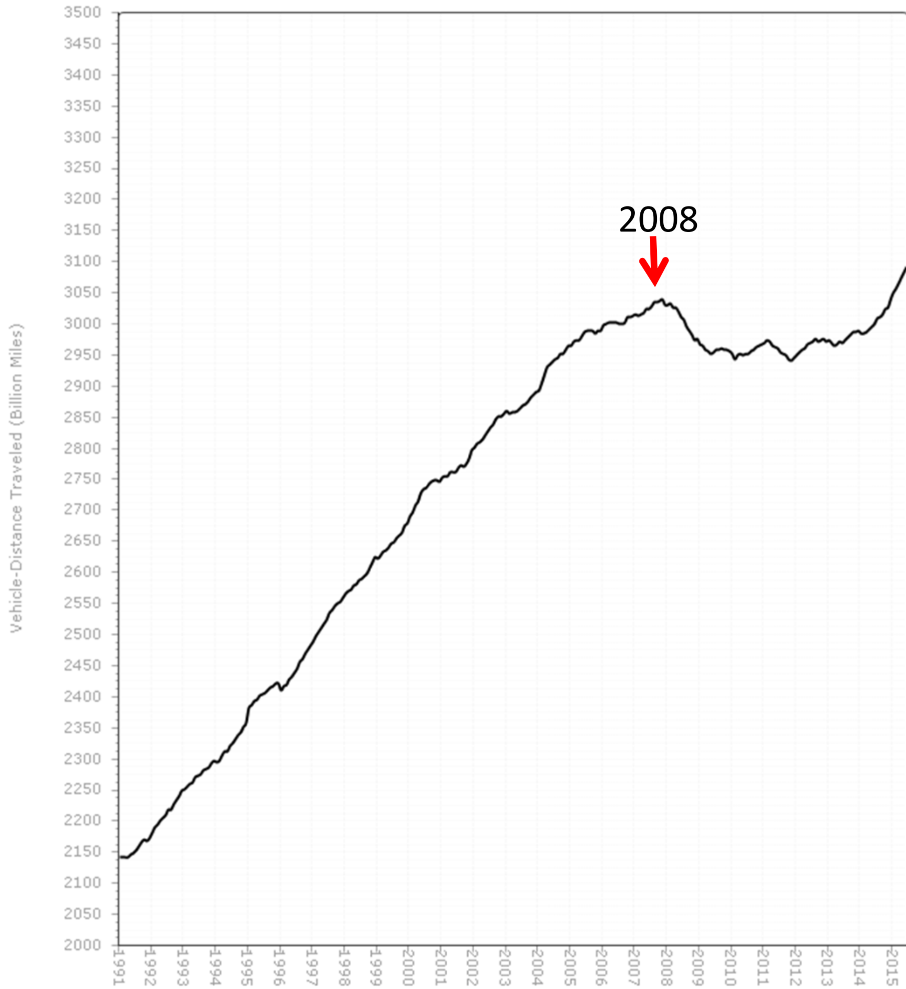
Miles apart

Below are models whose overall gas mileage in our tests fell 3 or more mpg below what the window sticker promises.

Model	EPA combined mpg	CR overall mpg	Difference (mpg)	Difference (percent)
Lincoln MKZ Hybrid	45	34	**11**	24.4
Ford C-Max Hybrid	47	37	**10**	21.3
Ford Fusion Hybrid	47	39	**8**	17.0
Volkswagen Jetta Hybrid	45	37	**8**	17.8
Toyota Prius C	50	43	**7**	14.0
Toyota Prius	50	44	**6**	12.0
Honda Civic Hybrid	44	40	**4**	9.1
Infiniti M35h	29	25	**4**	13.8
Lexus ES 300h	40	36	**4**	10.0
Toyota Avalon Hybrid	40	36	**4**	10.0
Buick LaCrosse (eAssist)	29	26	**3**	10.3
Honda Insight	41	38	**3**	7.3
Hyundai Sonata Hybrid	36	33	**3**	8.3
Lexus RX 450h	29	26	**3**	10.3

Consumer Reports Magazine, August 2013

VMT 1991-2015

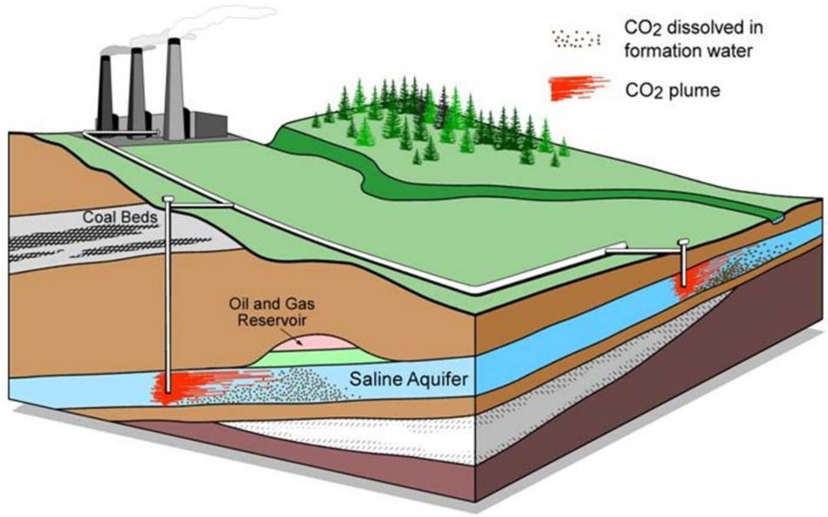


U.S. Federal Highway Administration

Carbon Capture & Storage

Implement CCS at

- **800 GW coal electric plants or**
- **1600 GW natural gas electric plants or**
- **180 coal synfuels plants or**
- **10 times today's capacity of hydrogen plants**



Graphic courtesy of Alberta Geological Survey

There are currently three storage projects that each inject 1 million tons of CO_2 per year – by 2055 need 3500.

E, T, H / $$

Carbon Mitigation Initiative, Princeton University

Nuclear Electricity

Graphic courtesy of NRC

Triple the world's nuclear electricity capacity by 2060

The rate of installation required for a wedge from electricity is equal to the global rate of nuclear expansion from 1975-1990.

E/ $$

Carbon Mitigation Initiative, Princeton University

Fuel Switching

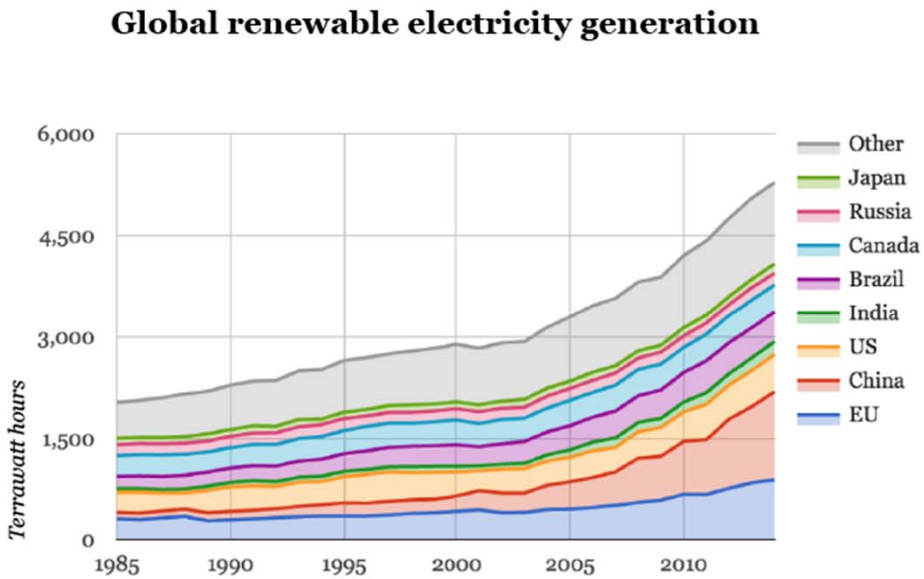
Substitute 1400 natural gas electric plants for an equal number of coal-fired facilities

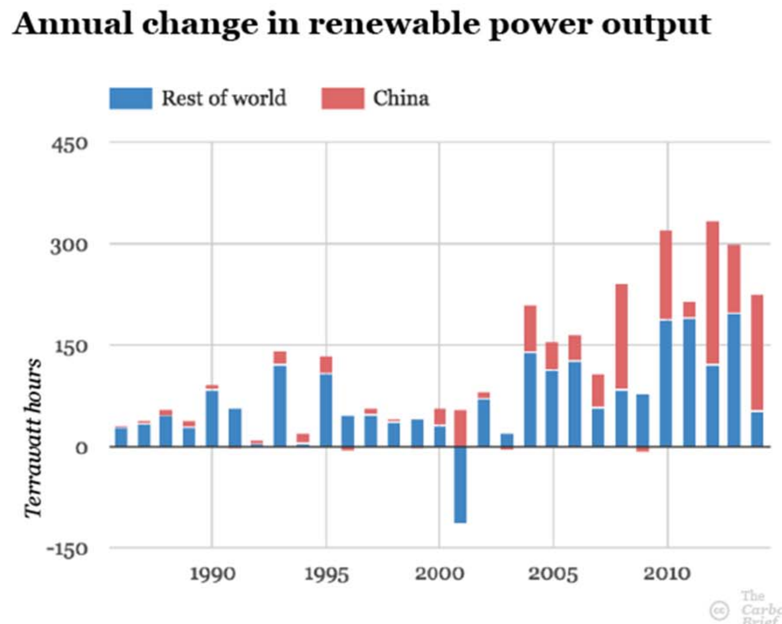
Photo by J.C. Willett (U.S. Geological Survey).

A wedge requires an amount of natural gas equal to that used for all purposes today

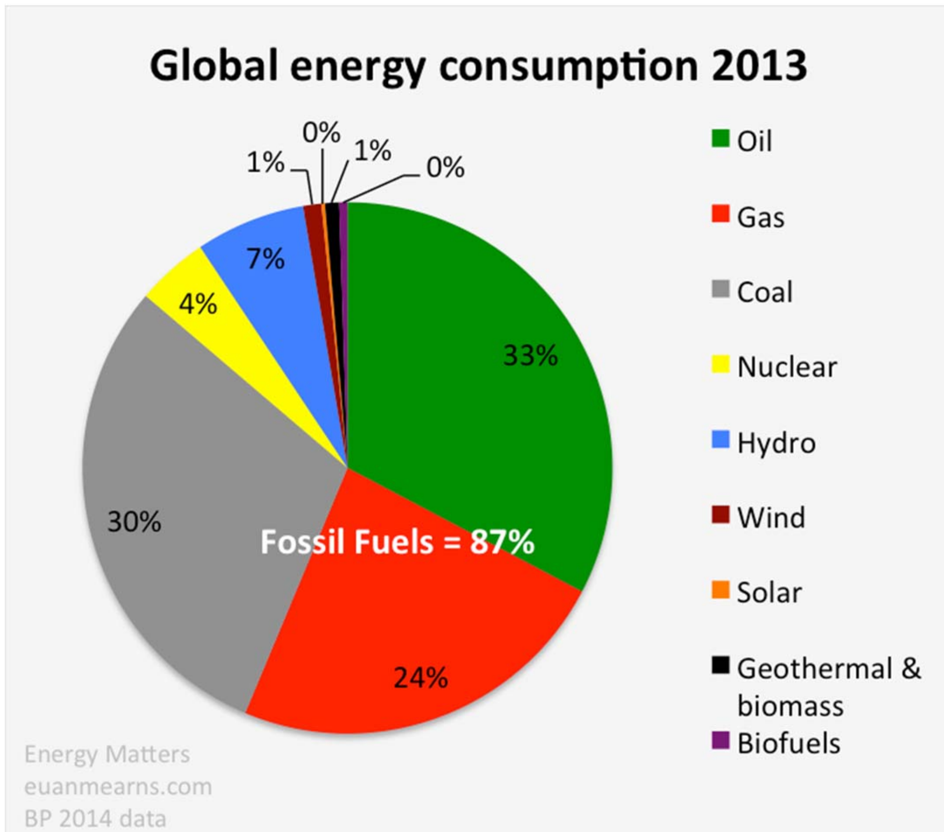
E, H / $

Carbon Mitigation Initiative, Princeton University





BP Statistical Review of World Energy 2015


Global energy consumption 2013
0%
1%
1%
0%
7%
4%
33%
30%
Fossil Fuels = 87%
24%
Oil
Gas
Coal
Nuclear
Hydro
Wind
Solar
Geothermal & biomass
Biofuels
Energy Matters
euanmearns.com
BP 2014 data

Wind Electricity

Photo courtesy of DOE

Install 1 million 2 MW windmills to replace coal-based electricity,

OR

Use 2 million windmills to produce hydrogen fuel

A wedge worth of wind electricity will require increasing current capacity by a factor of 10

E, T, H / $-$$

Carbon Mitigation Initiative, Princeton University

Figure 31. Electricity generation by fuel in the Reference case, 2000-2040 (trillion kilowatthours)

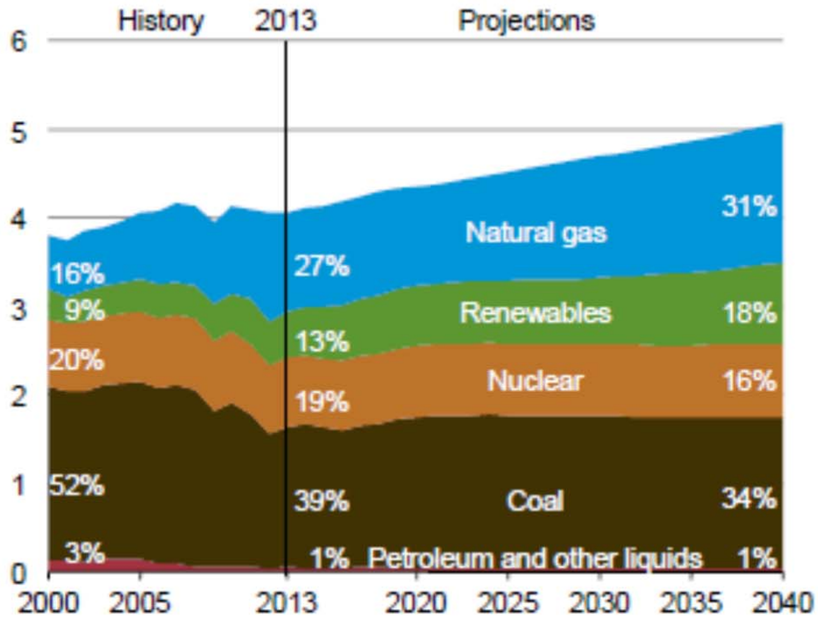
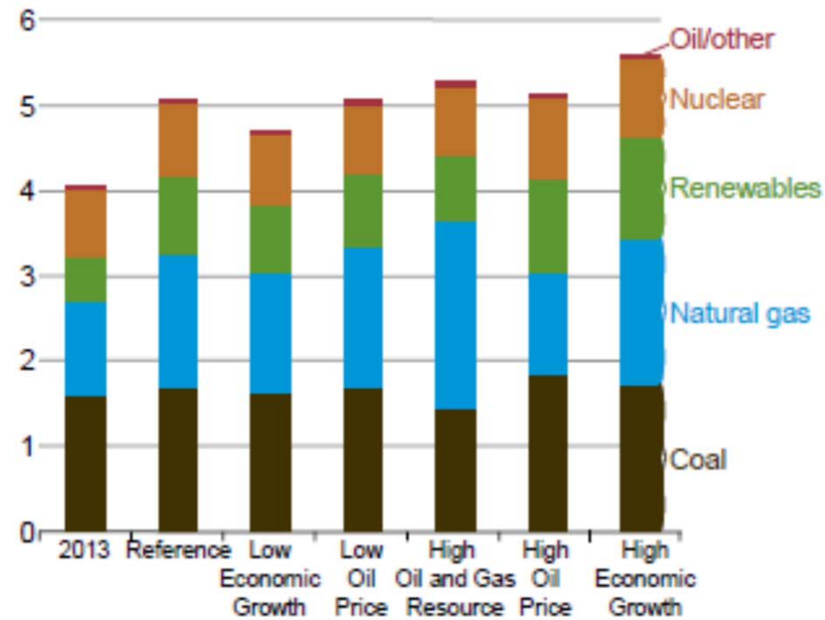
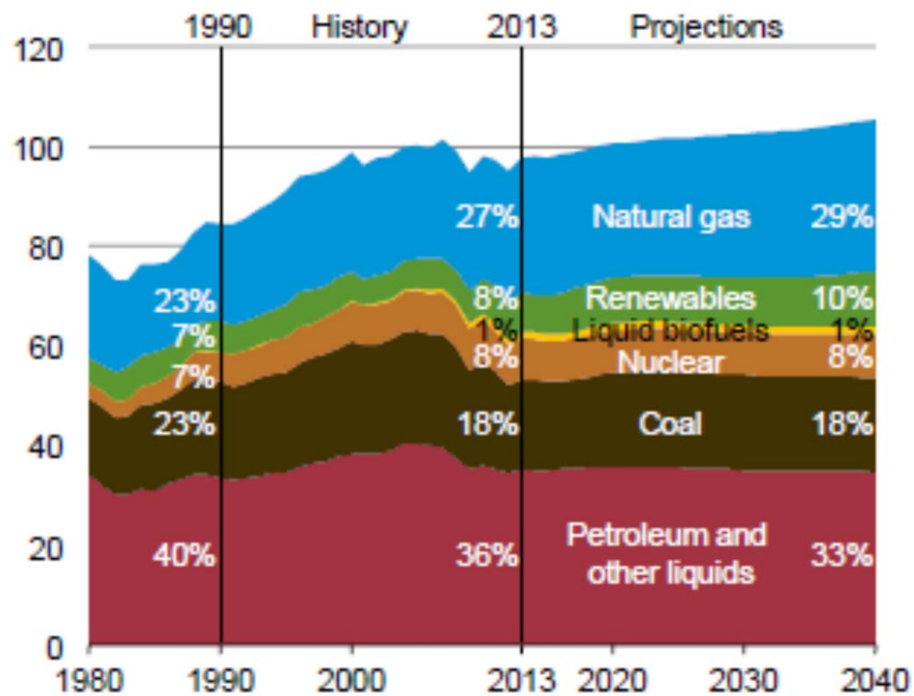


Figure 32. Electricity generation by fuel in six cases, 2013 and 2040 (trillion kilowatthours)

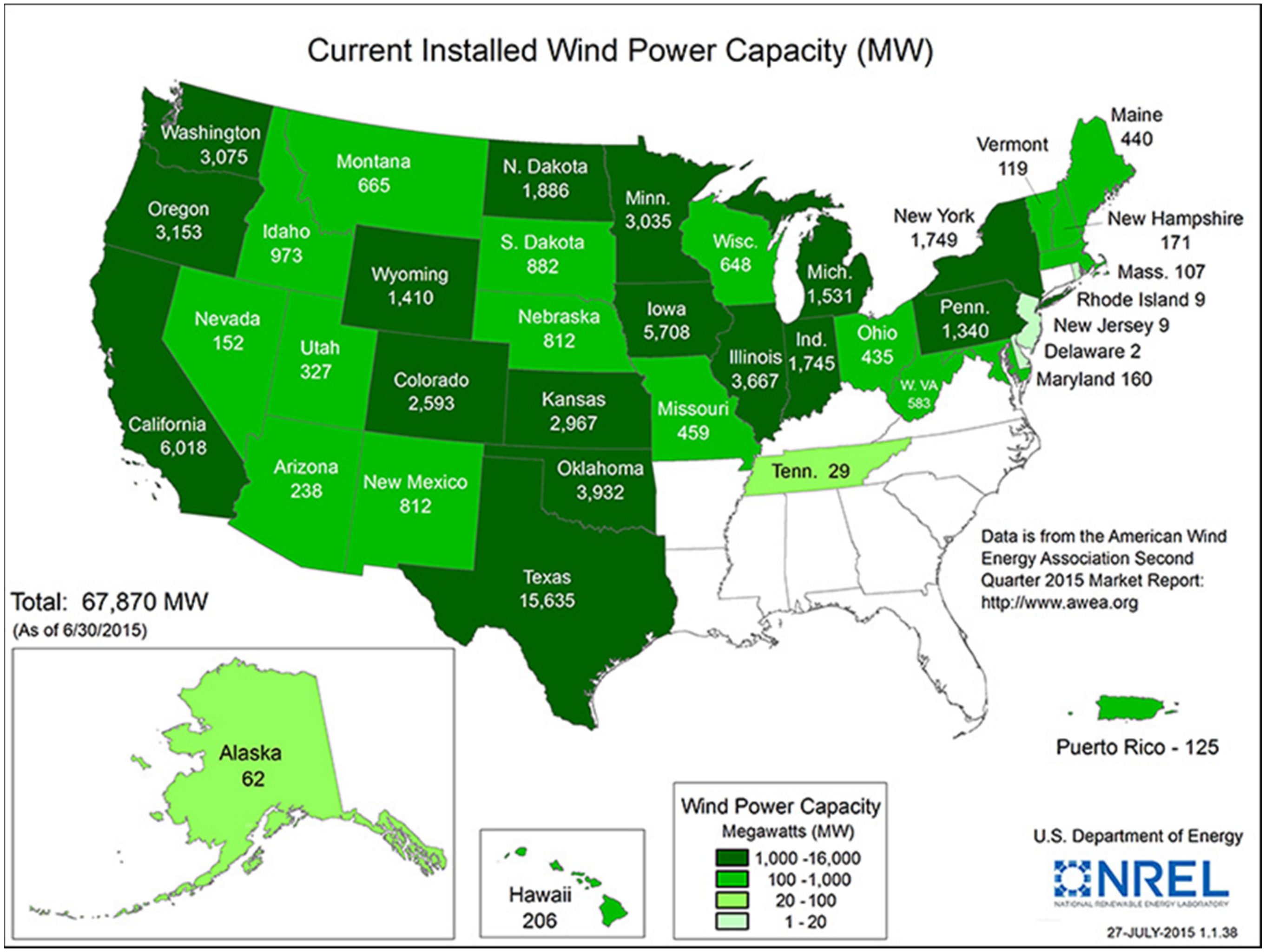


U.S. EIA

Figure 18. Primary energy consumption by fuel in the Reference case, 1980-2040 (quadrillion Btu)



U.S. EIA


Current Installed Wind Power Capacity (MW)
Washington 3,075
Oregon 3,153
California 6,018
Idaho 973
Montana 665
Nevada 152
Utah 327
Arizona 238
Wyoming 1,410
Colorado 2,593
New Mexico 812
N. Dakota 1,886
S. Dakota 882
Nebraska 812
Kansas 2,967
Oklahoma 3,932
Texas 15,635
Minn. 3,035
Iowa 5,708
Missouri 459
Wisc. 648
Illinois 3,667
Mich. 1,531
Ind. 1,745
Ohio 435
W. VA 583
Tenn. 29
Penn. 1,340
New York 1,749
Vermont 119
Maine 440
New Hampshire 171
Mass. 107
Rhode Island 9
New Jersey 9
Delaware 2
Maryland 160
Data is from the American Wind Energy Association Second Quarter 2015 Market Report: http://www.awea.org
Total: 67,870 MW
(As of 6/30/2015)
Alaska 62
Hawaii 206
Puerto Rico - 125
Wind Power Capacity
Megawatts (MW)
1,000 -16,000
100 -1,000
20 - 100
1 - 20
U.S. Department of Energy
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
27-JULY-2015 1.1.38

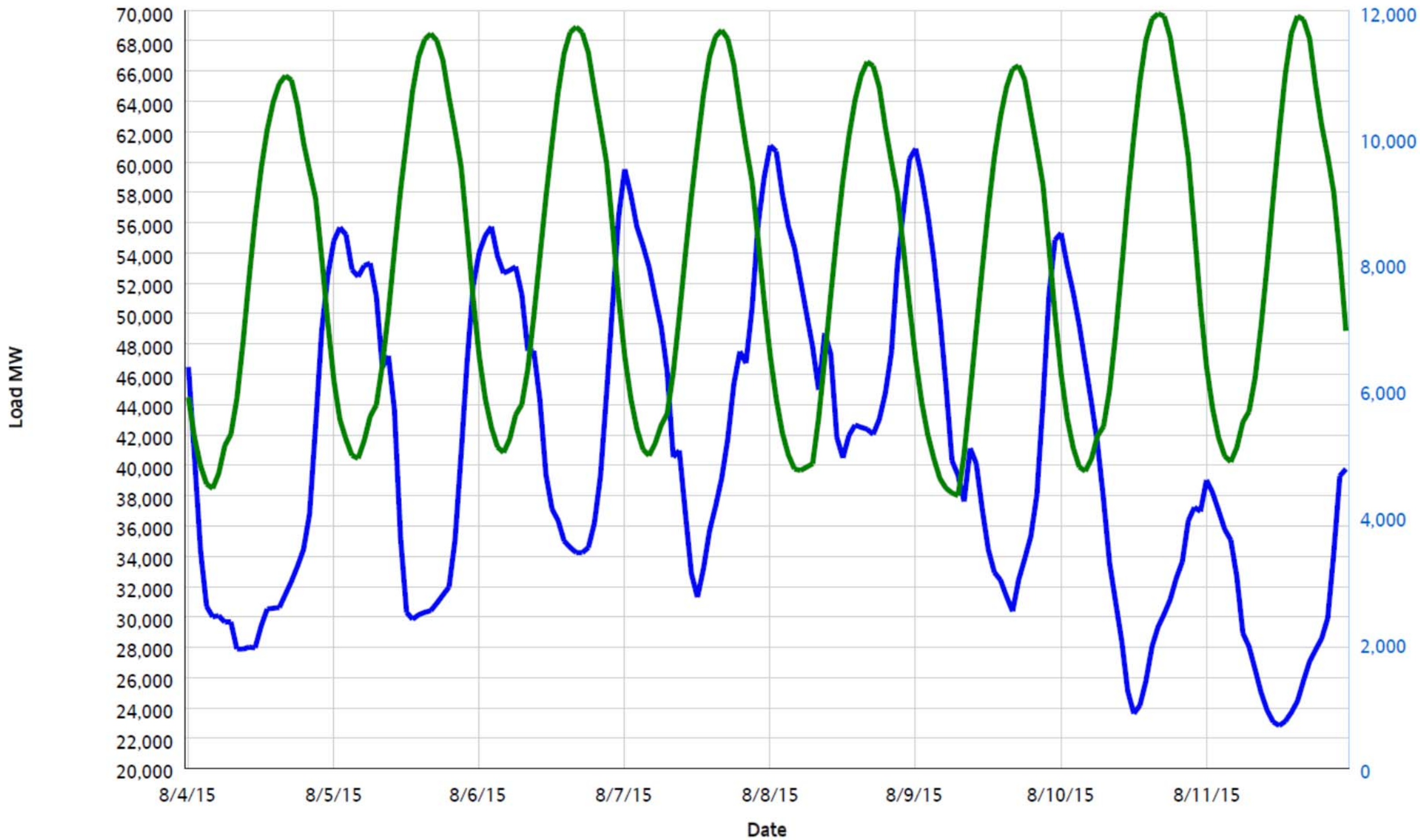
ERCOT Grid Operations

Wind Integration Report : 08/11/2015

Peak Load	69,625 MW
Load Peak Hour (HE)	16
Wind Over Peak	1,066 MW
Wind Record 02/19/15	11,154 MW
Max Wind Value*	4,961 MW
Wind Peak Time	22:54
Wind Integration %	9.55 %

ERCOT Load vs. Actual Wind Output

08/04/2015 - 08/11/2015



Solar Electricity

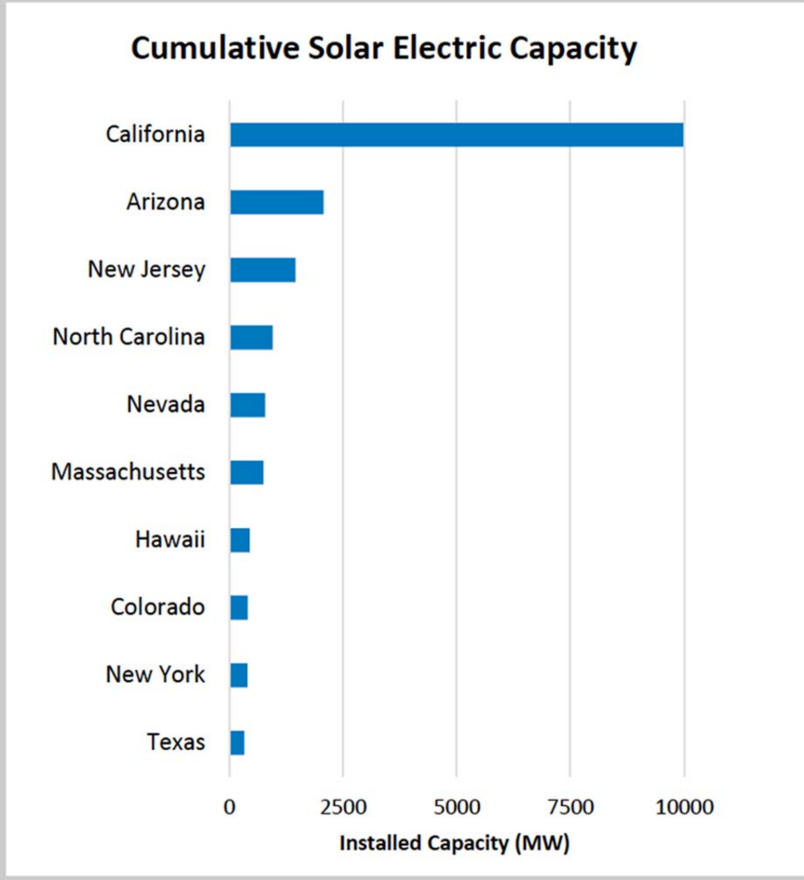
Install 20,000 square kilometers for dedicated use by 2060

A wedge of solar electricity would mean increasing current capacity 100 times

E / $$$

Carbon Mitigation Initiative, Princeton University

Photos courtesy of DOE Photovoltaics Program

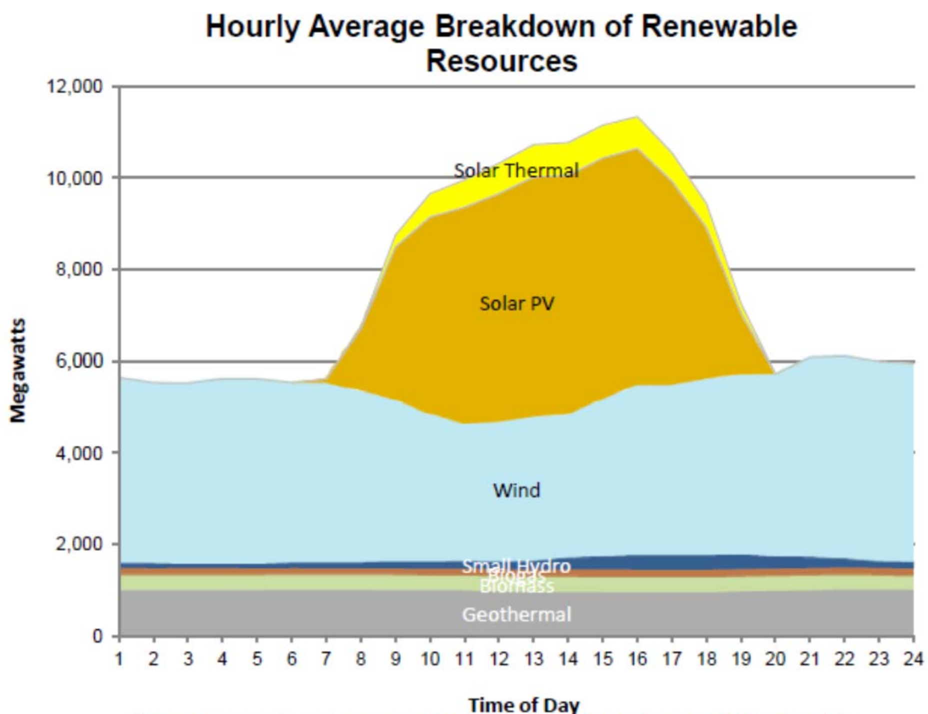


Cumulative Solar Electric Capacity
California
Arizona
New Jersey
North Carolina
Nevada
Massachusetts
Hawaii
Colorado
New York
Texas
0
2500
5000
7500
10000
Installed Capacity (MW)

24-Hour Renewables Production

Renewable Resources	Peak Production Time	Peak Production (MW)	Daily Production (MWh)
Solar Thermal	14:22	721	6,252
Solar	14:53	5,493	48,690
Wind	21:05	4,452	90,049
Small Hydro	17:26	340	4,834
Biogas	23:54	197	4,463
Biomass	6:27	304	7,011
Geothermal	21:36	1,023	23,874
Total Renewables			**185,174**

Total 24-Hour System Demand (MWh): *781,787*



This graph shows the production of various types of renewable generation across the day.

System Peak Demand (MW) *one minute average	**40,767**
Time:	**16:55**

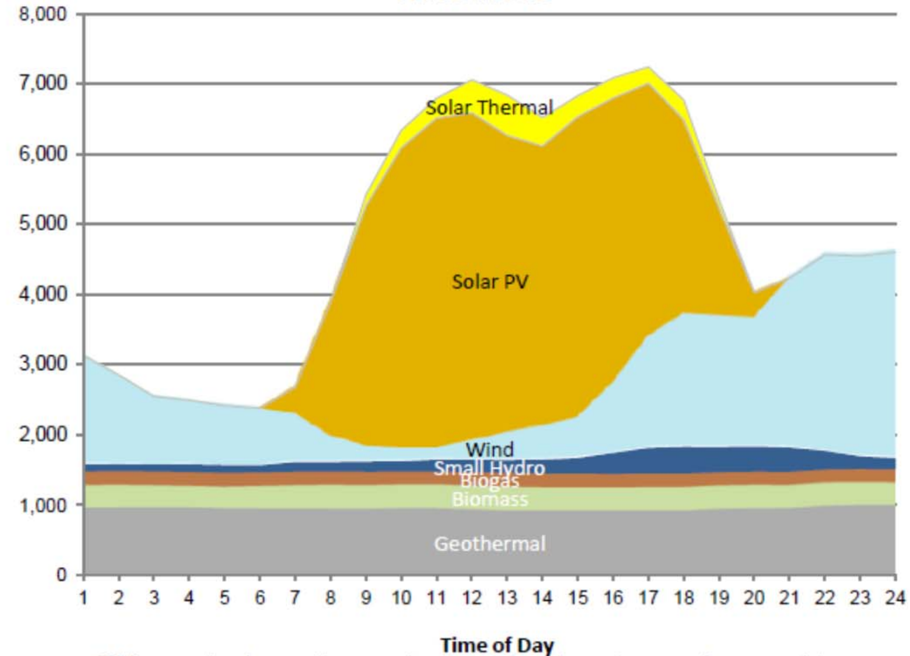
CAISO, August 18, 2015

24-Hour Renewables Production

Renewable Resources	Peak Production Time	Peak Production (MW)	Daily Production (MWh)
Solar Thermal	12:17	634	3,364
Solar	11:04	4,886	44,164
Wind	23:18	3,010	28,972
Small Hydro	17:22	380	4,771
Biogas	14:18	204	4,729
Biomass	11:42	337	7,753
Geothermal	23:04	995	22,812
Total Renewables			**116,563**

Total 24-Hour System Demand (MWh): *817,408*

Hourly Average Breakdown of Renewable Resources



This graph shows the production of various types of renewable generation across the day.

System Peak Demand (MW) *one minute average	**42,058**
Time:	**15:24**

CAISO, June 30, 2015

Biofuels

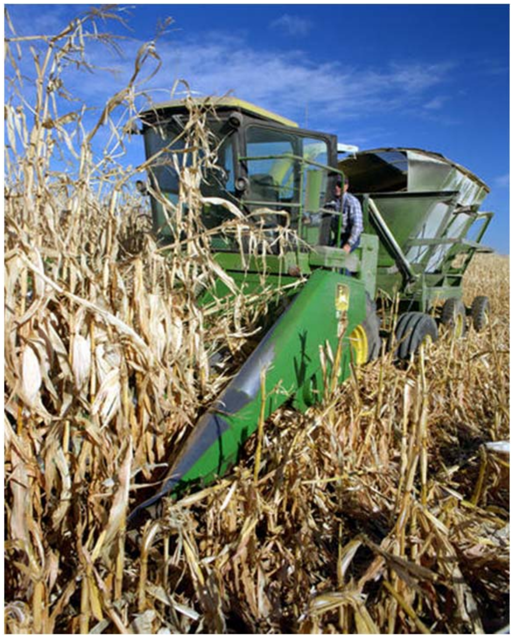


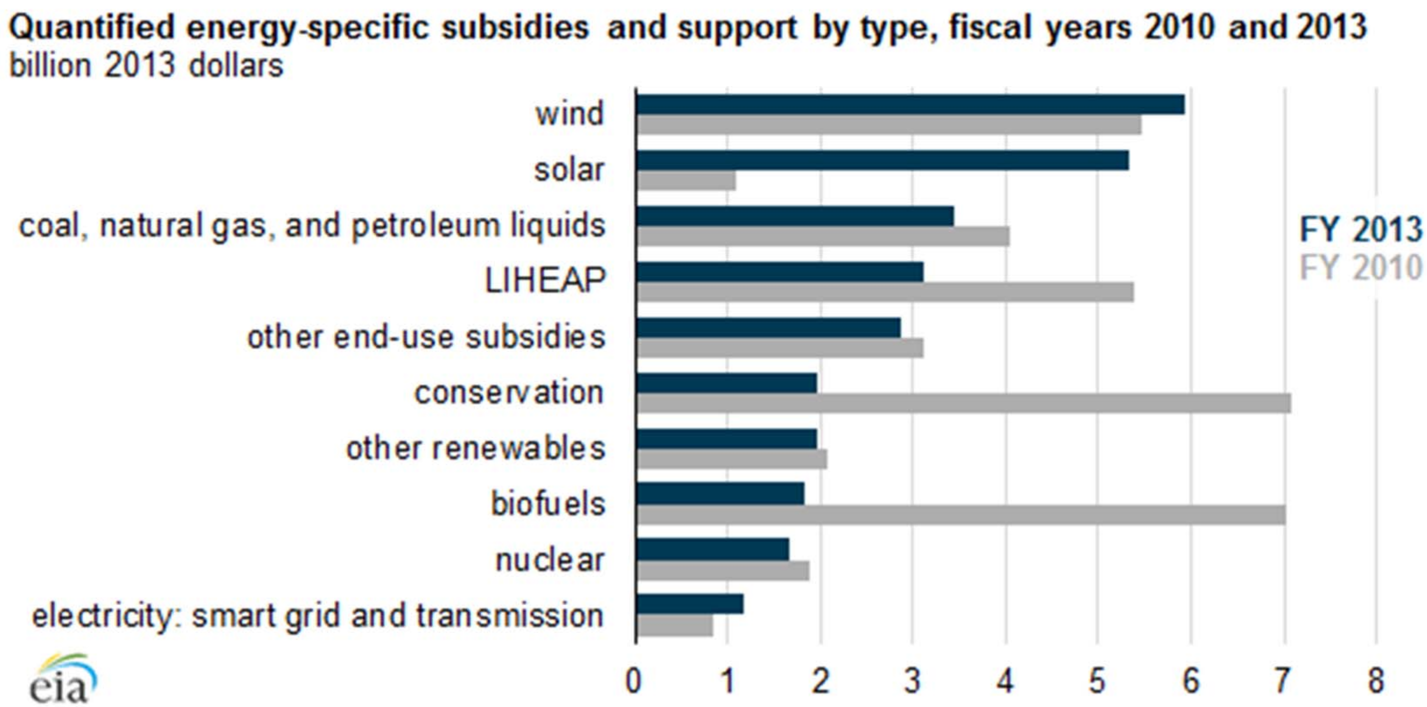
Photo courtesy of NREL

Scale up current global ethanol production by ~12 times

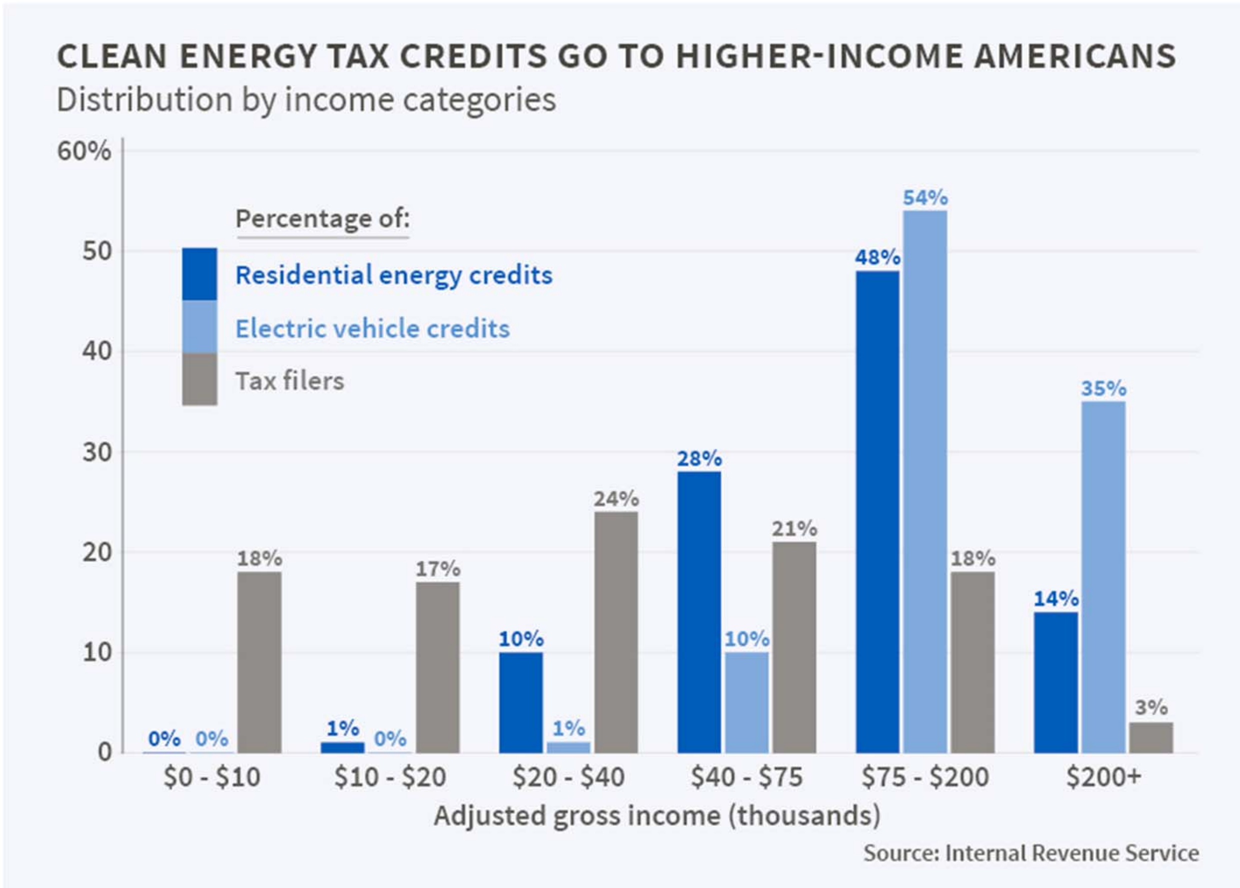
Using current practices, one wedge requires planting an area the size of India with biofuels crops

T, H / $$

Carbon Mitigation Initiative, Princeton University



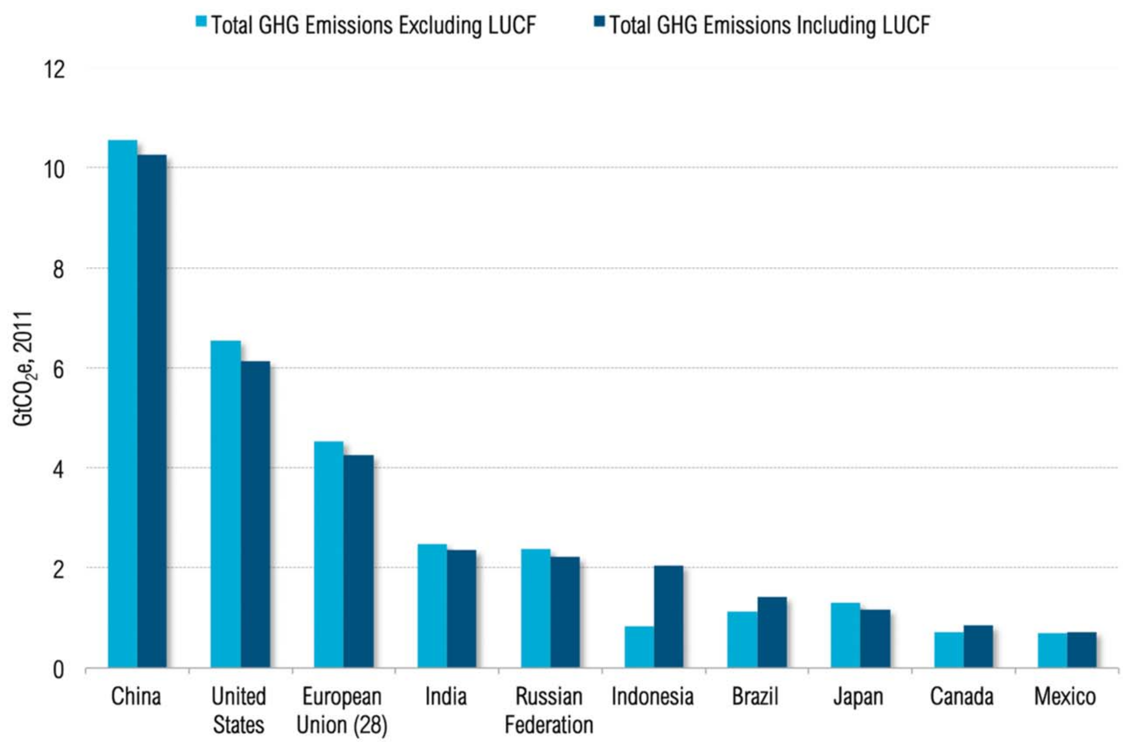
LIHEAP = Low Income Energy Assistance Program



Borenstein and Lucas, NBER WP21342, 2015

Top 10 Emitters

2011



http://bit.ly/11SMpjA

WORLD RESOURCES INSTITUTE