ECE 333 – GREEN ELECTRIC ENERGY

1. Introduction and Overview

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RENEWABLE ENERGY SYSTEMS

- We focus on the technical, economic and environmental aspects of renewable and alternative energy systems to obtain an understanding of their role in meeting society's electricity needs
- We analyze a wide range of renewable energy supply issues
- The course provides a basis to understand the distinctive scientific principles of renewable

RENEWABLE ENERGY SYSTEMS

energy and the ability to provide an assessment of the economics and environmental impacts of renewable energy

- The course covers the basics of energy generation from renewable sources, the needed thermodynamics background, the structure and nature of the electric transmission grid, the integration of renewable resources into the grid in terms of technical, environmental and economic aspects and the regulatory framework for electricity

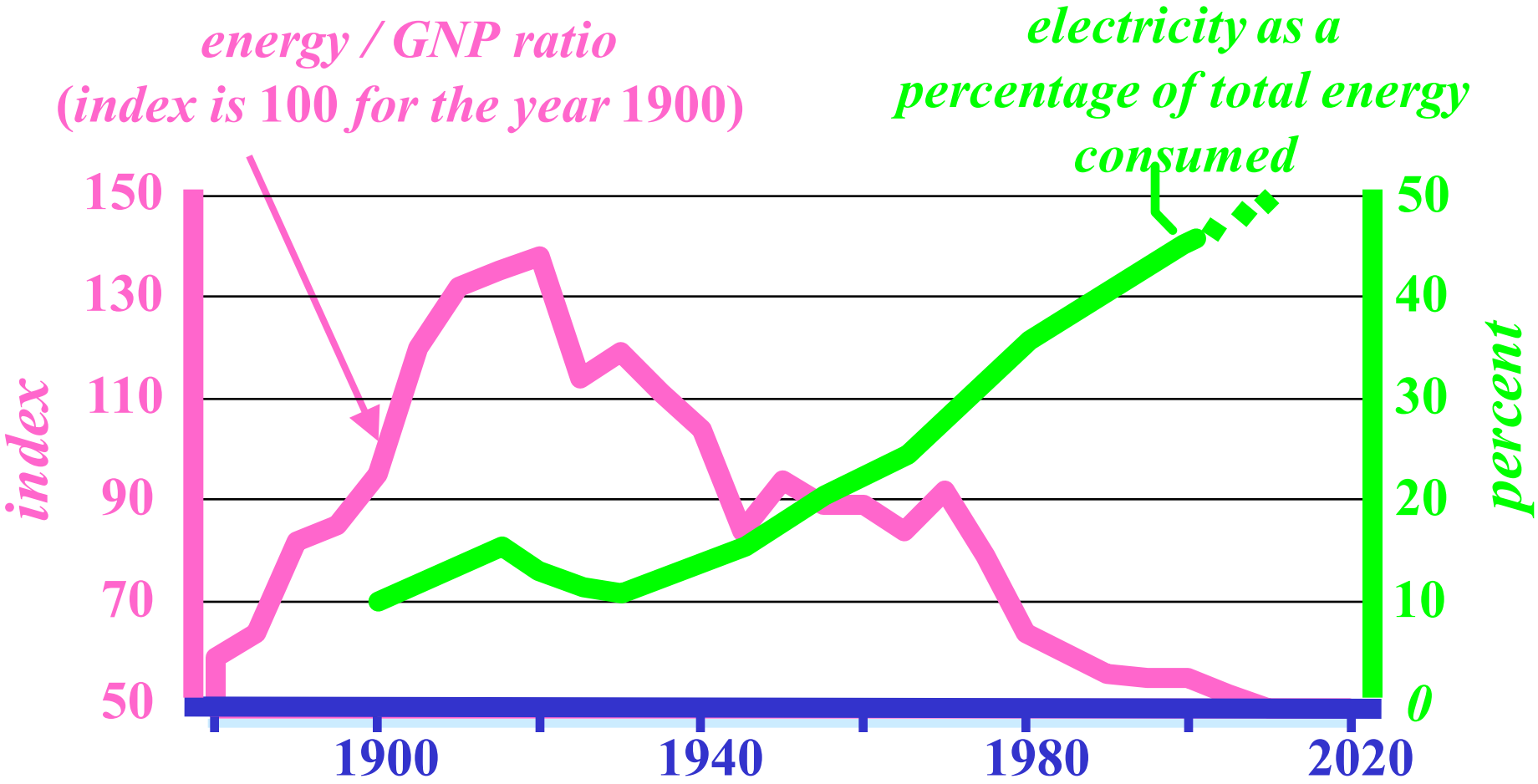
OUTLINE OF INTRODUCTION

- The importance of electricity
- The *US* electricity industry – past and present
- Electricity generation
- Nature of electric demand
- The energy supply and demand picture
- A brief overview of renewables
- Course outline

CRITICAL IMPORTANCE OF ELECTRICITY

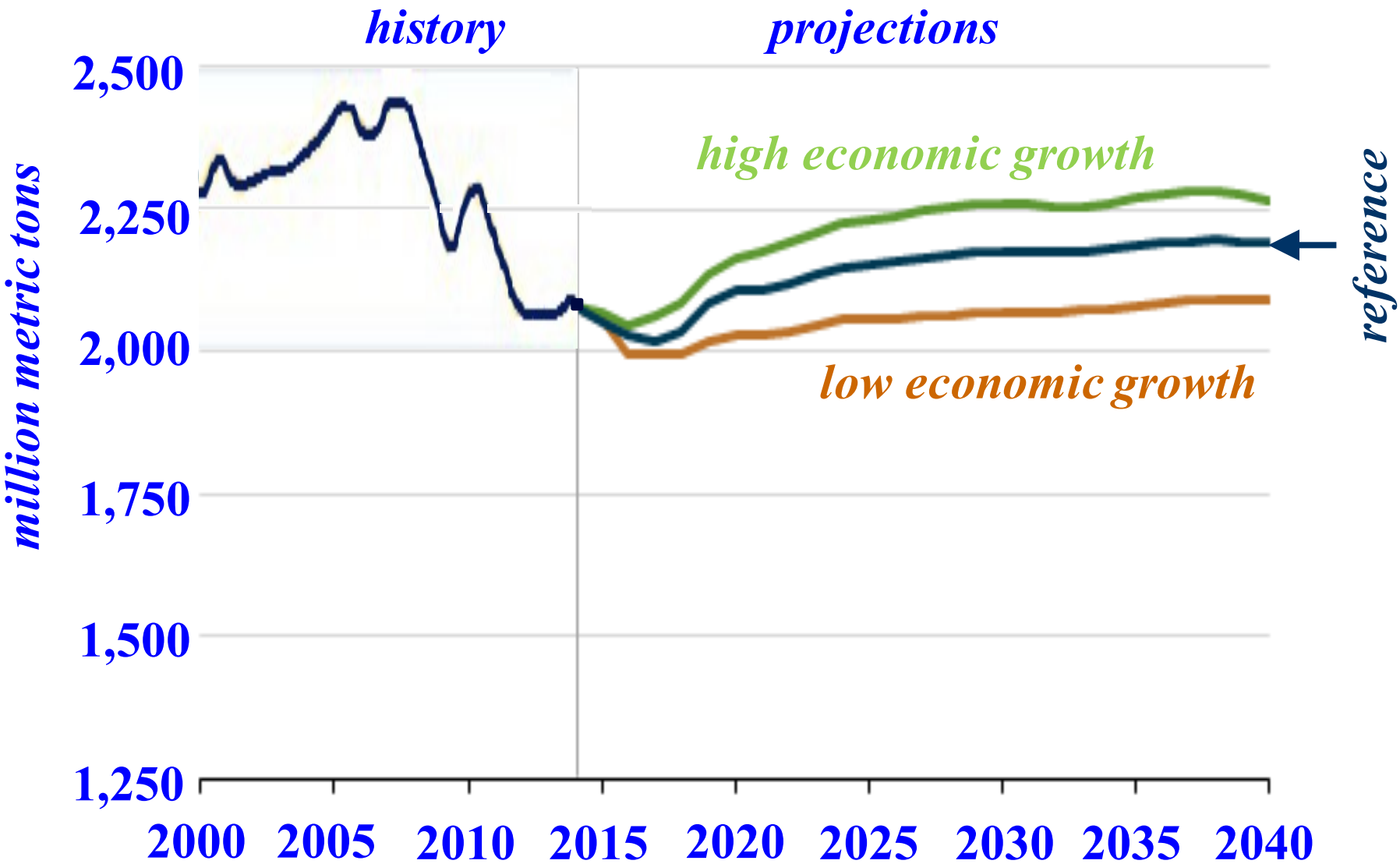
- Energy is the *lifeblood* of modern society
- The importance of electricity is on the rise
- Efficient and environmentally sensitive electricity services are key requirements for the nation's global competitiveness
- The electric power industry is one of the world's largest industrial sectors; the 2014 *US* revenues from retail sales were over *$ 389 billion*

ENERGY CONSUMPTION AND ELECTRICITY USE



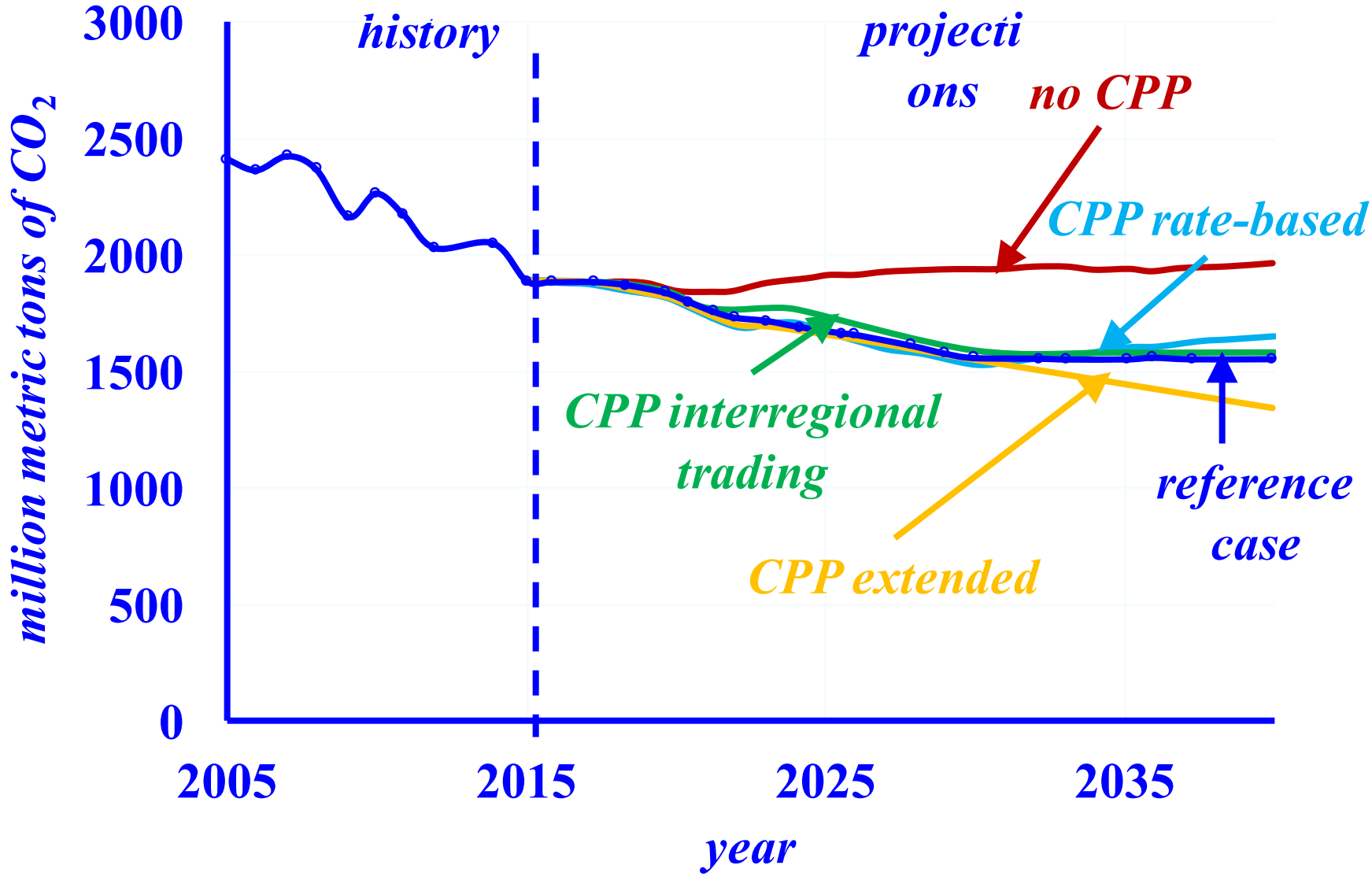
electricity will continue to substitute for less efficient and less productive energy forms

ELECTRIC POWER SECTOR CARBON DIOXIDE EMISSIONS



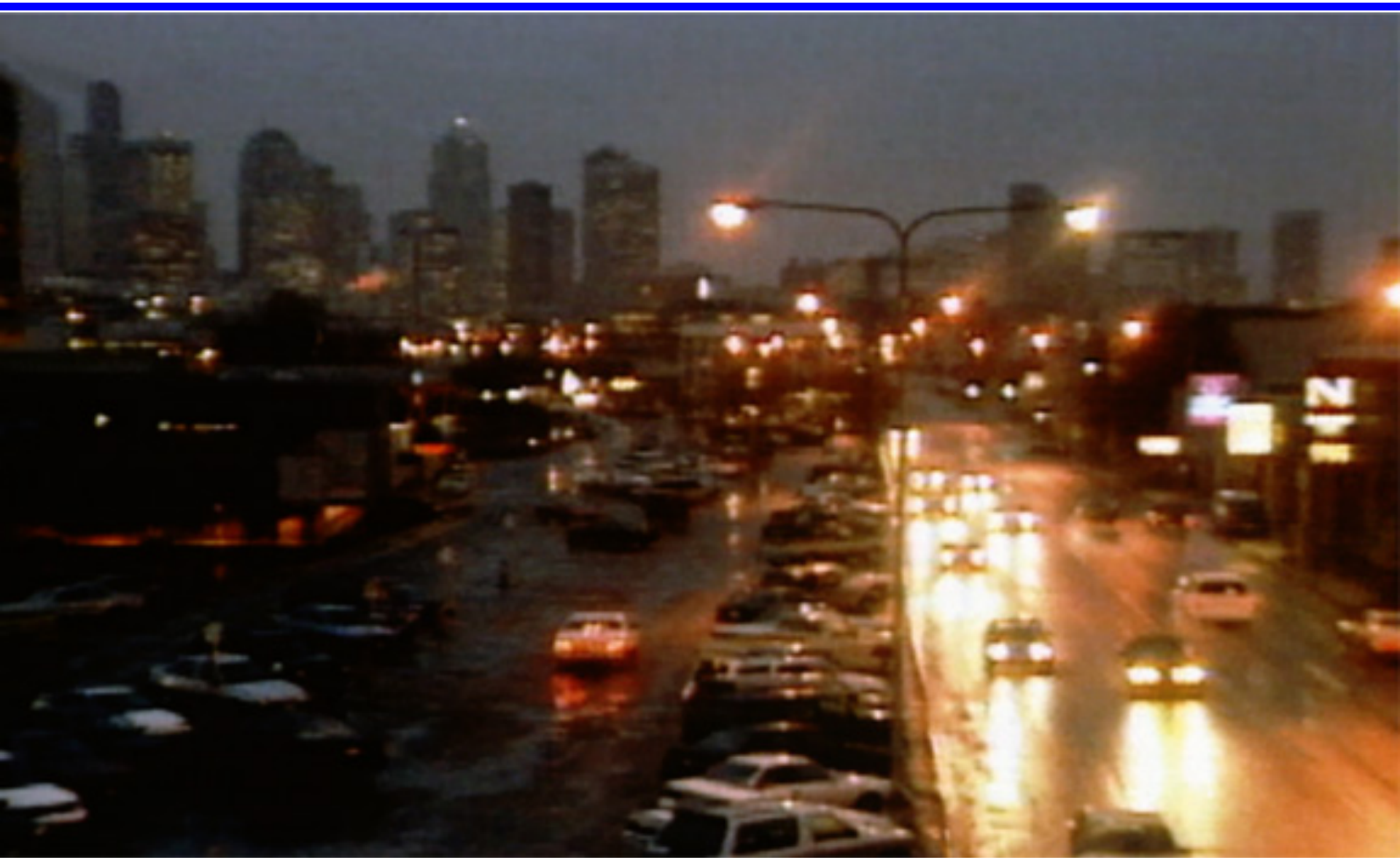
Source: http://www.eia.gov/todayinenergy/detail.cfm?id=21252; issued May 15, 2015
https://www3.epa.gov/climatechange/ghgemissions/sources/electricity.html ;issued April 2016

ELECTRIC POWER SECTOR CO_2 EMISSIONS



Source: https://www.eia.gov/electricity/annual/pdf/epa.pdf; issued November 2016

THE WORLD ECONOMIES RELY ON ABUNDANT AND AFFORDABLE ELECTRICITY



ELECTRICITY AND ENERGY

- While the main focus of the course is on green resources, we need to also understand both the energy context and the policy context, within which such resources are planned and operated
- Energy obtained from various sources is converted into electricity; electric energy is not used in

ELECTRICITY AND ENERGY

that form but is converted into other energy forms, such as light, sound and mechanical energy

- As more energy is consumed as electricity, the focus on the environmental impacts is driving the changes underway in the energy infrastructure, given the universal interest to effectively address the impacts of *climate change*

IMPACTS OF ELECTRICITY

- The National Academy of Engineering, the *US*'s most prestigious collection of outstanding engineers, named electrification – the development of the vast networks of electricity that power the world – the most important of the twenty engineering achievements that have had the greatest impact on the quality of life in the twentieth century

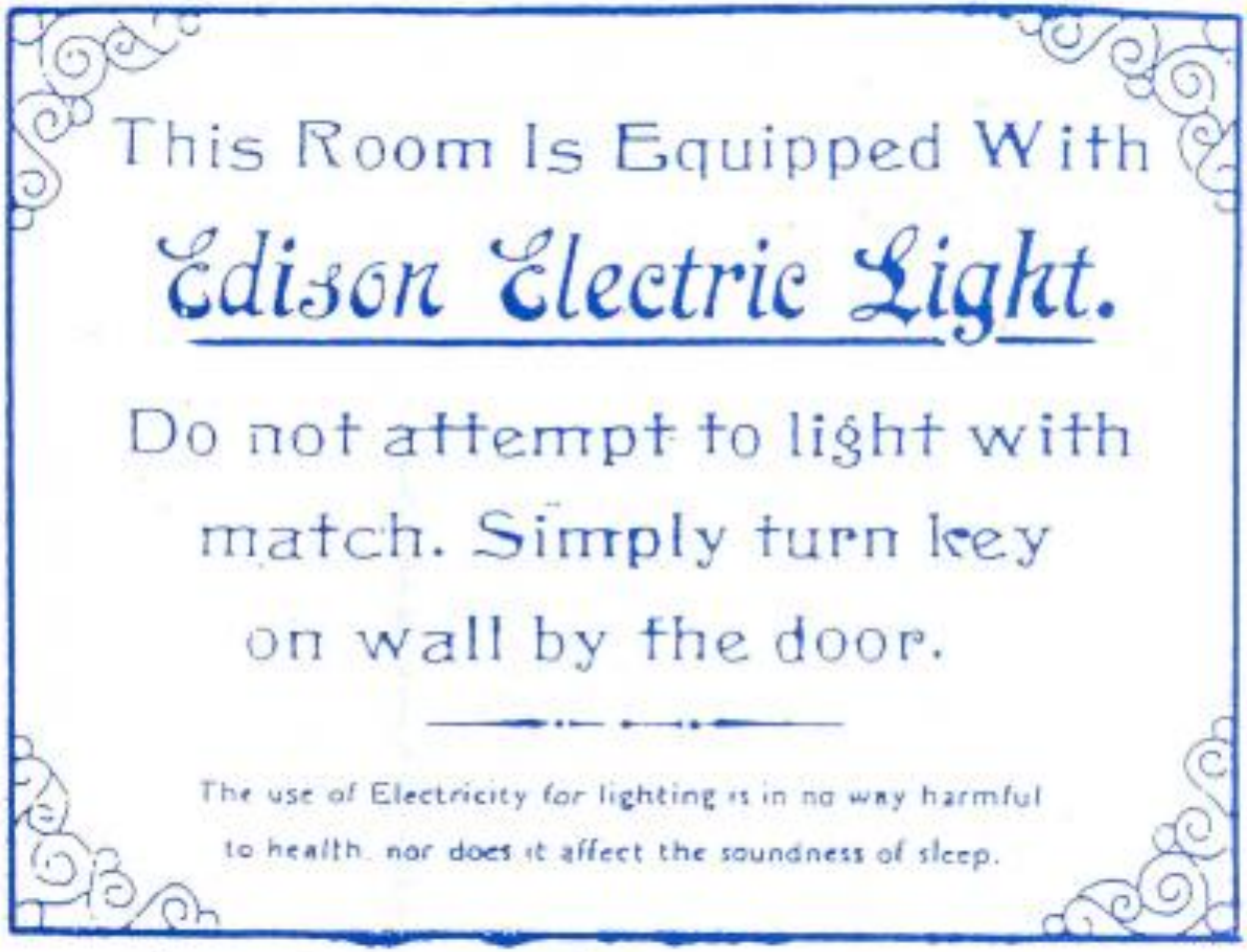
IMPACTS OF ELECTRICITY

- Electricity ranked ahead of the automobile, airplane, safe and abundant water, electronics, computers and space exploration
- The widespread electrification implemented in the twentieth century gave us energy for our cities, factories, farms and homes, forever changing the lives of people

THE BEGINNINGS

- Commercial use of electricity began in the late 1870's with the development of arc lamps for street lighting and lighthouse illumination
- The first complete electric power system, comprising a generator, cable, fuse, meter and loads, is considered to be *Edison's Pearl Street Station* in New York in 1882
  - DC system with a DC generator supply
  - 59 customers within a 1 – mile radius area

1882 EDISON POSTER ON ELECTRIC LIGHTING



Issued during the introduction of electricity supply to New York in 1882.

THE BEGINNINGS

- Actually, George Roe had founded in 1879 an electric company in San Francisco, which later became part of *PG&E*
  - this was the first entity in the nation to offer central station electric service to the public
  - two brush arc–light dynamos supplied 21 lights to serve from sundown to midnight – Sundays and holidays excluded – for $ 10 per lamp per week

MAJOR DEVELOPMENTS

- Frank Sprague developed *electrical motors* in 1884; within a short time, he incorporated them into the electricity system
- The major limitations of *DC* systems became apparent by 1886:
  - inability to deliver power over longer distances
  - need for high voltages for longer distance transmission so as to reduce the associated losses but, considerably lower voltages for generation and consumption

MAJOR DEVELOPMENTS

- Gaulard and Gibbs developed the *transformer* and AC transmission, the forerunners of the *AC* transmission systems in use today
- George Westinghouse immediately bought *US* rights to the Gaulard and Gibbs technology
- In 1889, the *first AC transmission line in North America* – a single phase 4–*kV*, 21–*km* line – was put into operation to link Willamette Falls to Portland

MAJOR DEVELOPMENTS

- A key and important development was Tesla's invention of induction motors and polyphase systems
  - Westinghouse purchased the rights to Tesla's inventions on AC motors, generators, transformers and transmission systems
  - Westinghouse was the key driver of the construction of the basis of today's AC grid

MAJOR DEVELOPMENTS

- *AC* won out over *DC* because
  - the ease of transformation of voltage levels thereby providing the flexibility to use diffe–rent voltage levels for generation/transmis–sion and consumption
  - the increased simplicity of *AC* over *DC* generators
  - the increased simplicity and lower costs of *AC* over *DC* motors
- *AC* replaced *DC* over a very brief time period

MAJOR DEVELOPMENTS

- In 1893, the first three–phase transmission line in North America went into service; it was a 2.3–*kV*, 12–*km* line in Southern California
- Niagara Falls was connected to Buffalo – a 30–*km* distance – using *AC* since *DC* was *not practical*

TECHNOLOGICAL DEVELOPMENTS

- Pressures to transmit larger amounts of power over larger distances led to higher voltages
  - early systems: 12, 44 and 66 *kV* (*RMS* line–to–line)
  - 1922: 165 *kV*
  - 1923: 220 *kV*
  - 1935: 287 *kV*
  - 1953: 330 *kV*
  - 1965: 500 *kV*
  - 1966: 735 *kV* (*Hydro Quebec*)
  - 1969: 765 *kV* (*American Electric Power*)

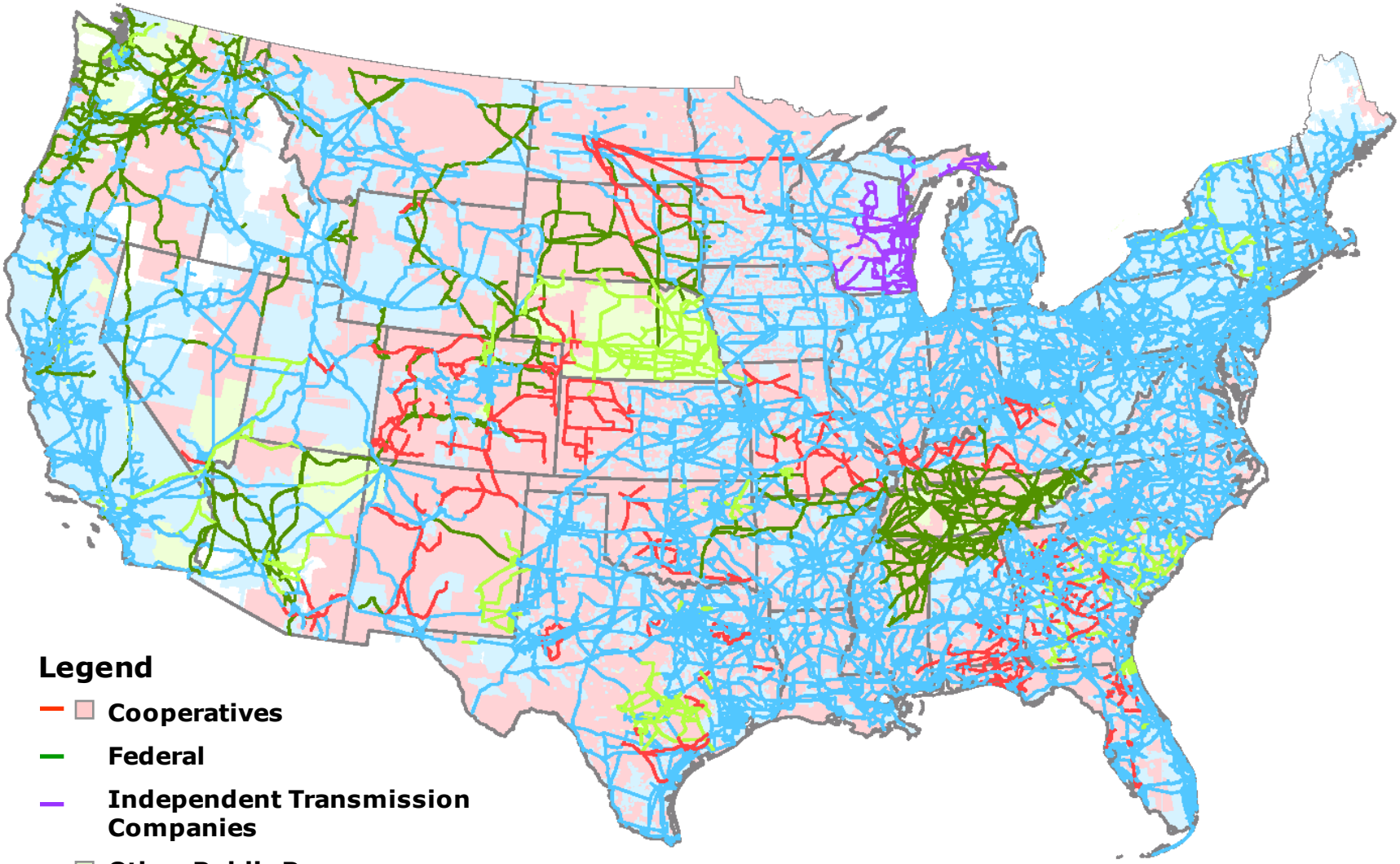
TECHNOLOGICAL DEVELOPMENTS

- Standardization of voltage levels led to voltage classifications
  - 115, 138, 161 and 230 *kV* are *high voltage* (*HV*)
  - 345, 500 and 765 *kV* are *extra high voltage* (*EHV*)
- The development of mercury arc valves in the early 1950's made *HVDC* economical in specific cases: transmission of larger blocks of power over longer distances

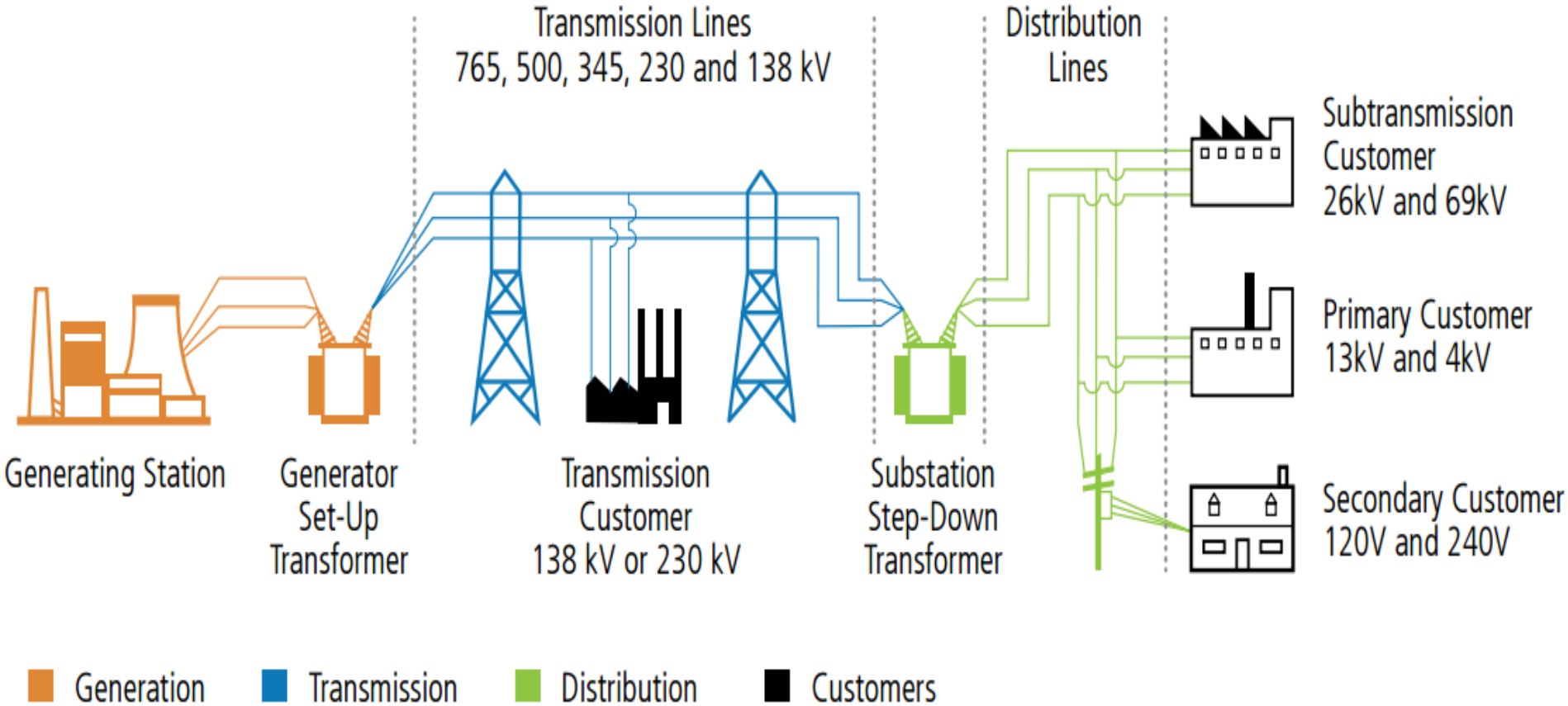
TECHNOLOGICAL DEVELOPMENTS

- Eventually, the various frequencies in use – 25, 50, 60, 125 and 133 *Hz* – became standardized to 60 *Hz* in North America; there are many parts of the world where the frequency is 50 *Hz* today
- *DC* becomes economic over *AC* for distances greater than
  - 500 *km* for overhead lines
  - 50 *km* for underground/submarine cables

THE *US* TRANSMISSION GRID



THE ELECTRIC POWER GRID



Source: EIA (2010-2013) http://www.eia.gov/electricity/monthly/current_year/february2014.pdf; pg 134; Issued April 2015

INDUSTRY STRUCTURE

- Brutal and inefficient competition was rife in electricity
  - 24 central station power companies were established in Chicago between 1887 and 1893
  - exhaustive duplication and fierce competition led to high costs

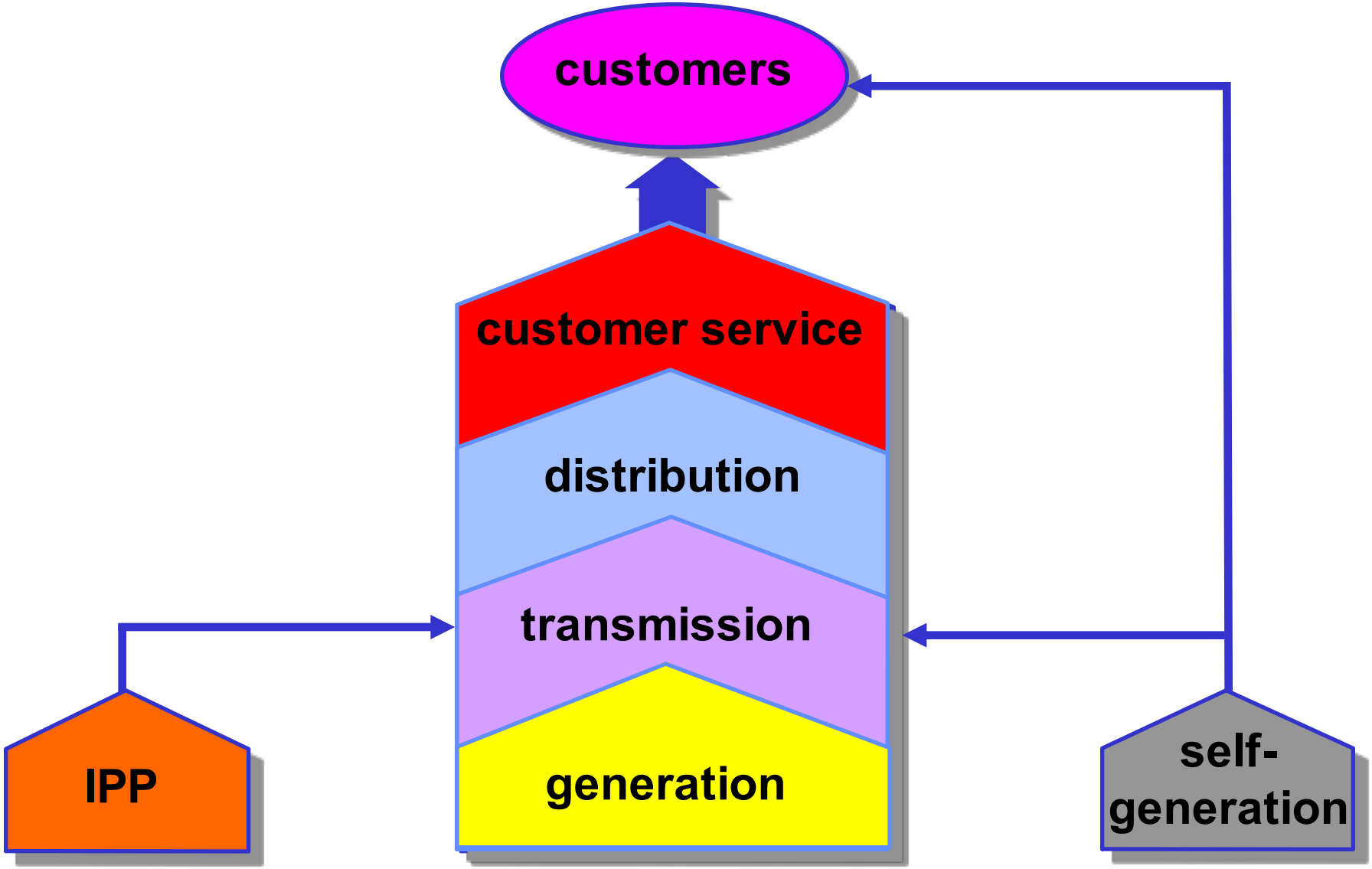
INDUSTRY STRUCTURE

- Samuel Insull built a monopoly over all central station production in Chicago and is considered the father of the regulated monopoly:

  "exclusive franchises should be coupled with the conditions of public control, requiring all charges for services to be based on a cost plus a reasonable profit"

- In 1907, New York and Wisconsin set up their regulatory commissions to regulate electricity

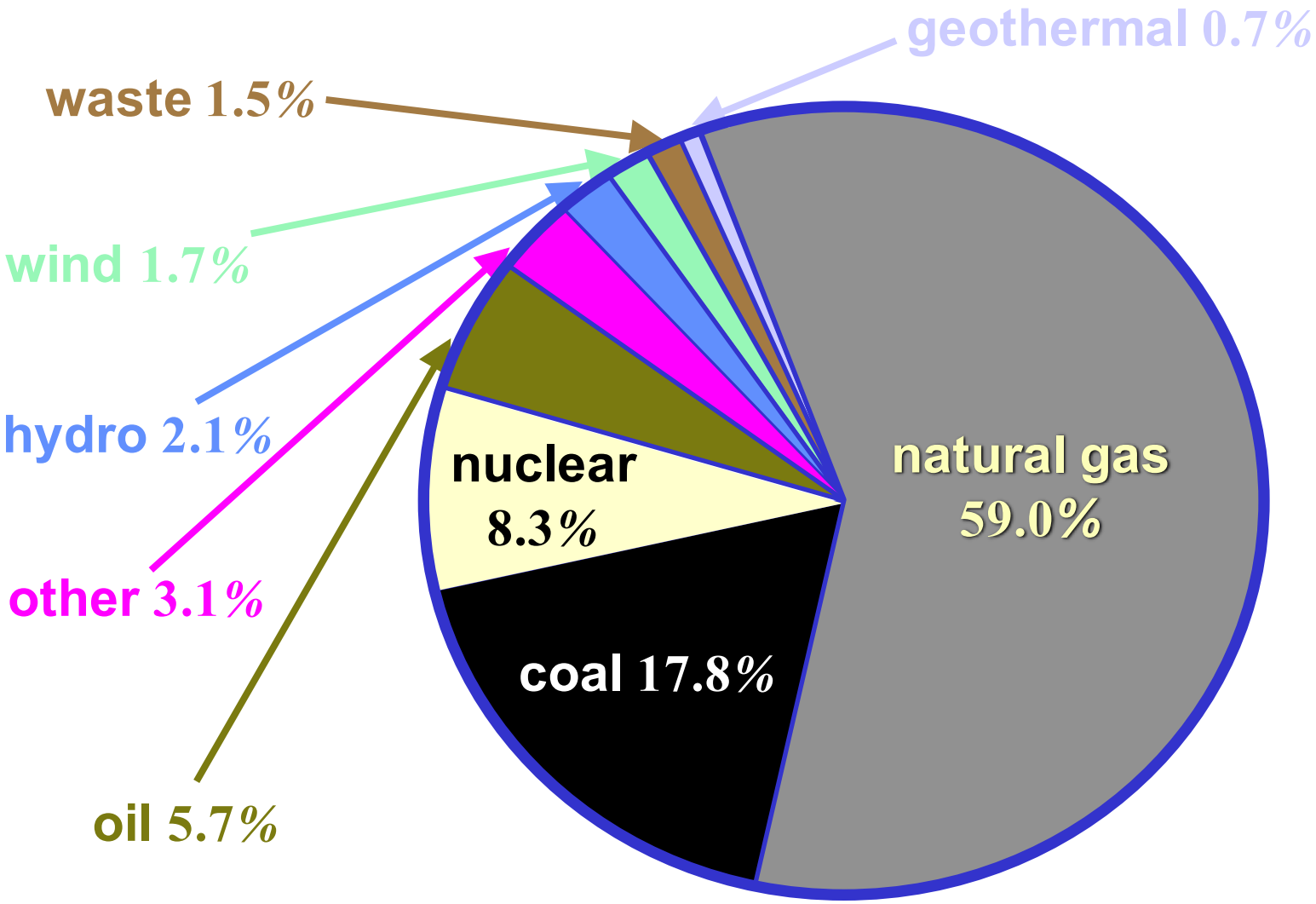
THE VERTICALLY INTEGRATED UTILITY INDUSTRY STRUCTURE



COMPETITION IN THE GENERATION MARKET

- The 1978 Public Utility Regulatory Policies Act (*PURPA*) unleashes competition through the introduction of qualifying facilities (*QF*s)
- *PURPA* mandates each investor–owned utility to purchase power at *avoided cost* from *QF*s located in its service territory
- *PURPA* implementation was left to individual states resulting in non-uniform implementations
- The once fledgling private power enterprises constitute today a *multibillion dollar* industry whose role in the electricity business is of paramount importance

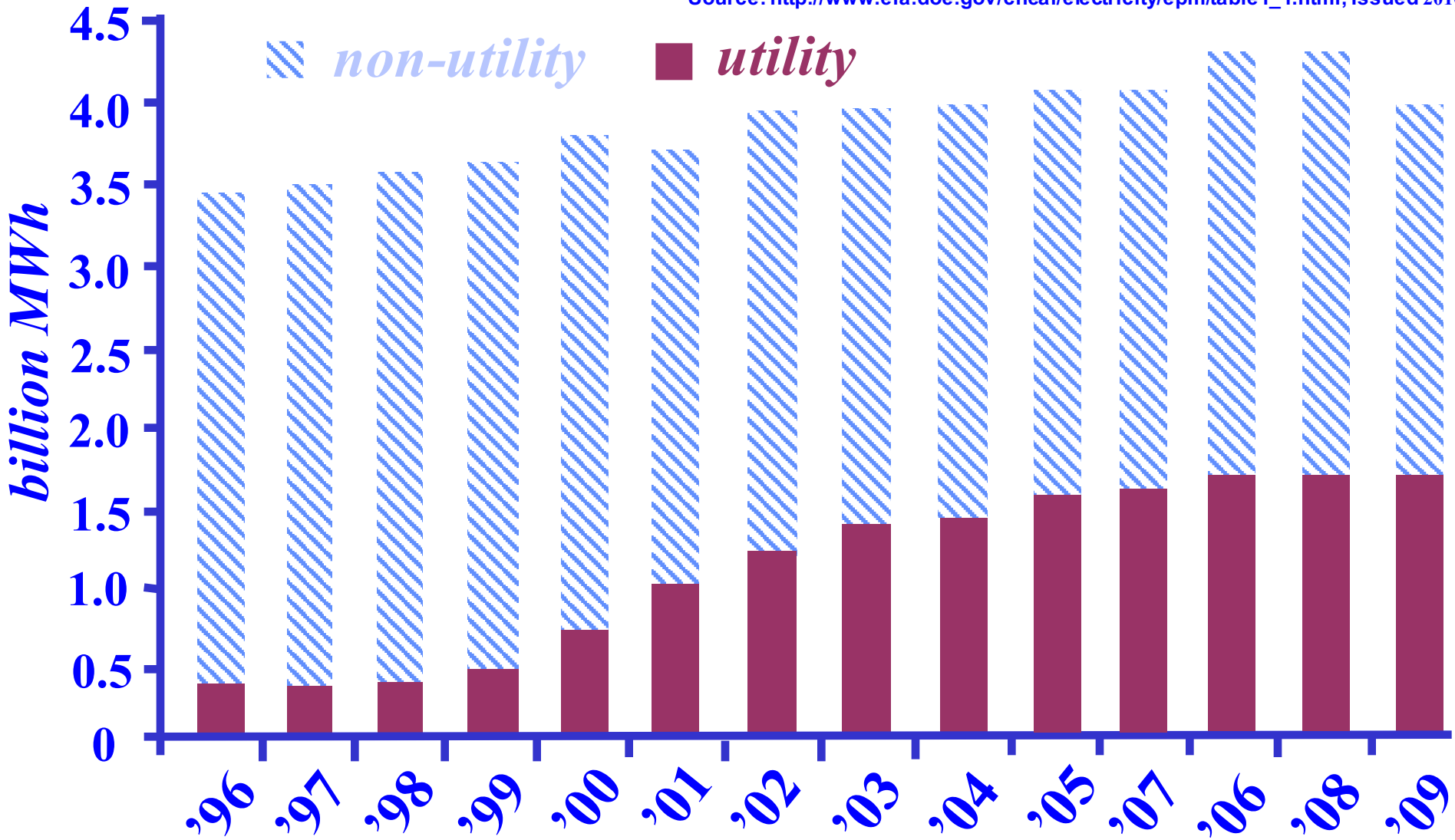
ENERGY SOURCES OF *NUG* CAPACITY



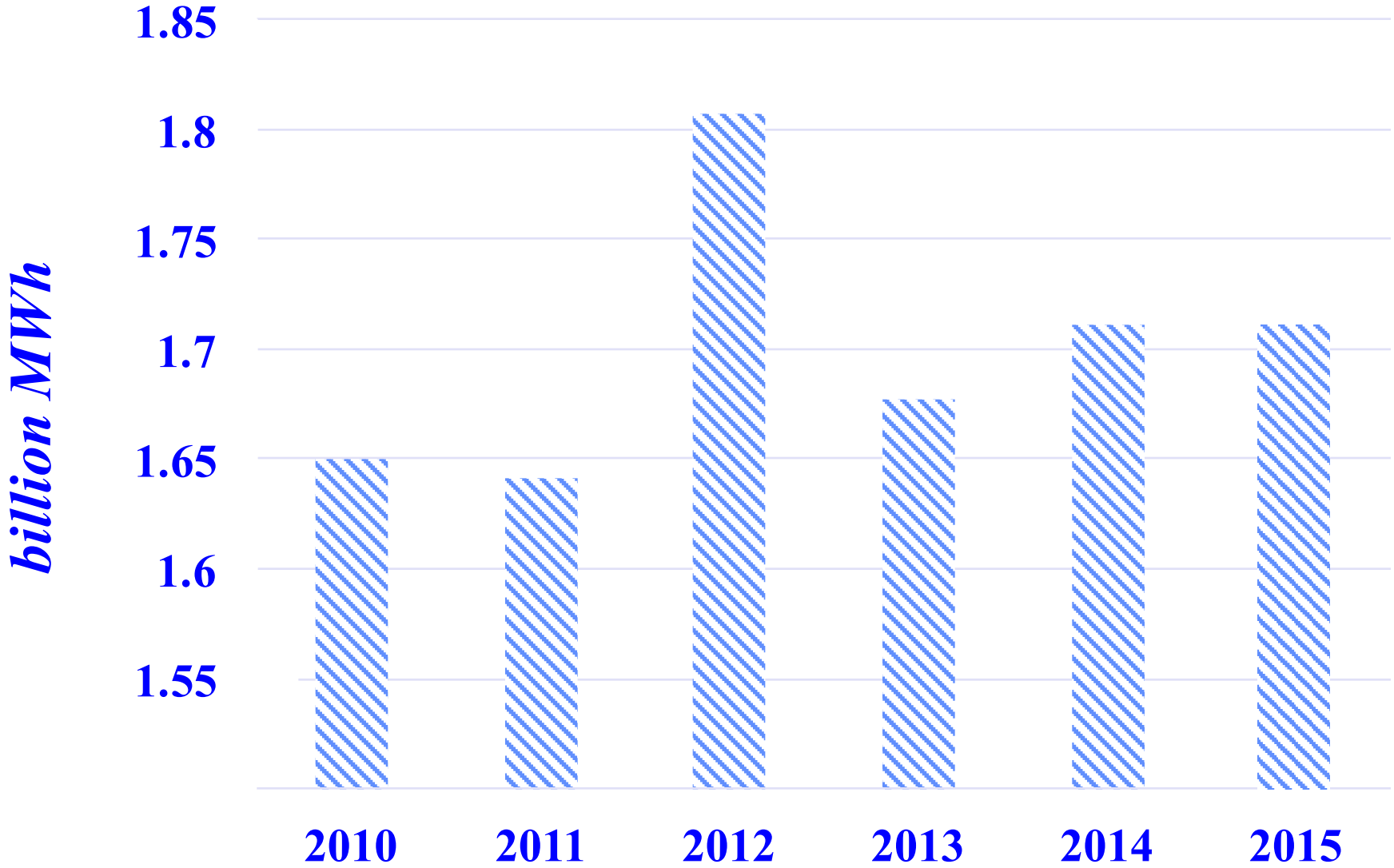
Source : 1993 Capacity and Generation of Non-Utility Sources of Energy, Edison Electric Institute

GROWING IMPACT OF *NUG* ENERGY

Source: http://www.eia.doe.gov/cneaf/electricity/epm/table1_1.html; Issued 2010

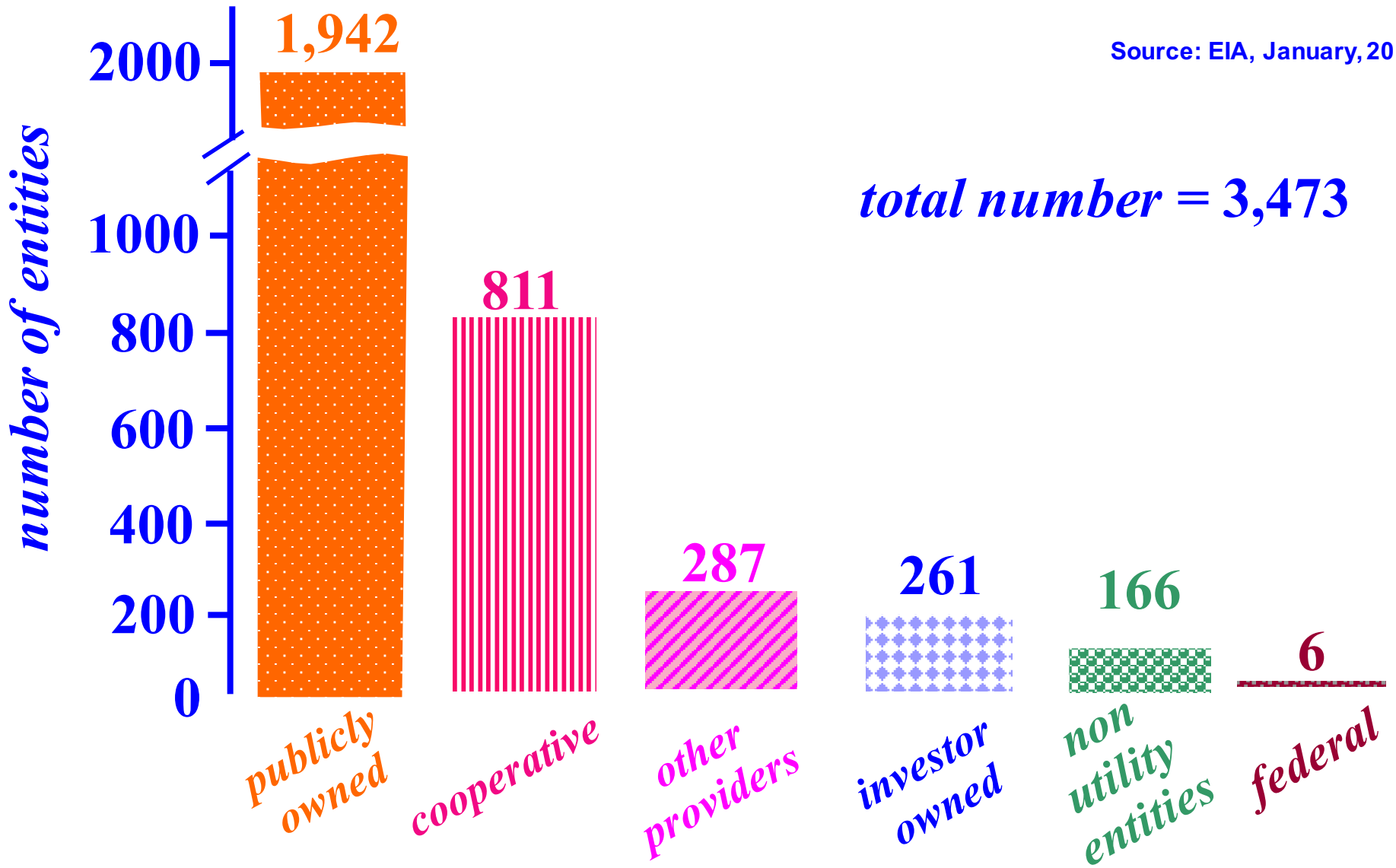


NUG ENERGY



Source: https://www.eia.gov/electricity/data.cfm#generation; Issued April 2016

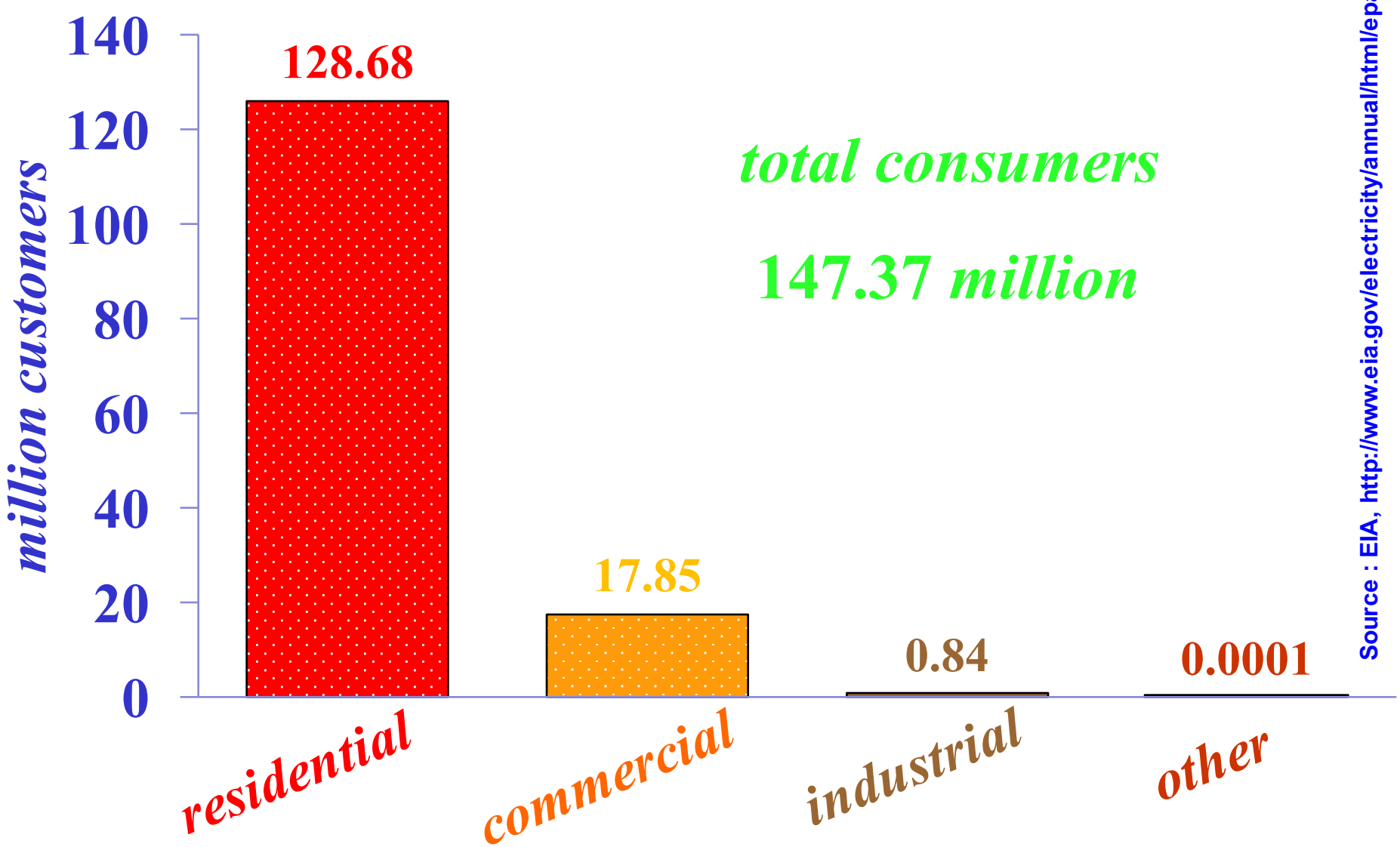
DIVERSITY OF THE *US* ELECTRICITY INDUSTRY



THE *US* ELECTRICITY INDUSTRY

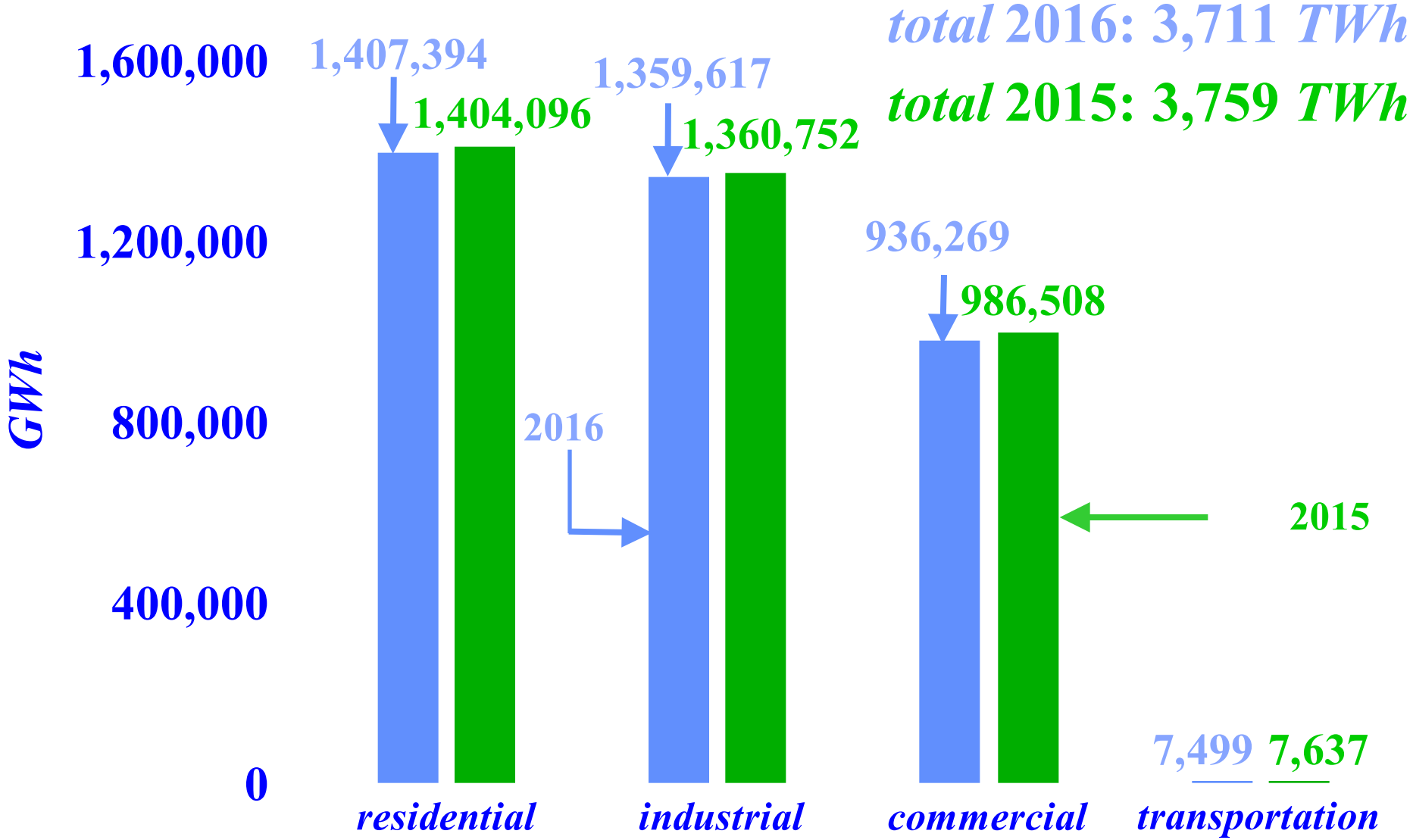
- The 811 rural electric coops stem from the *New Deal* years – a result of the drive to supply electricity to everyone and everywhere
- The 287 "other providers" include 89 "facilities" of co-generators and other industrial generators and 198 "other entities" of marketers – entities that sell delivery or energy services, but not both
- The 261 investor-owned utility companies (*IOU*s) represent the predominant part of the industry because nearly three fifths of all electricity sales come from these entities

US ELECTRICITY CUSTOMERS



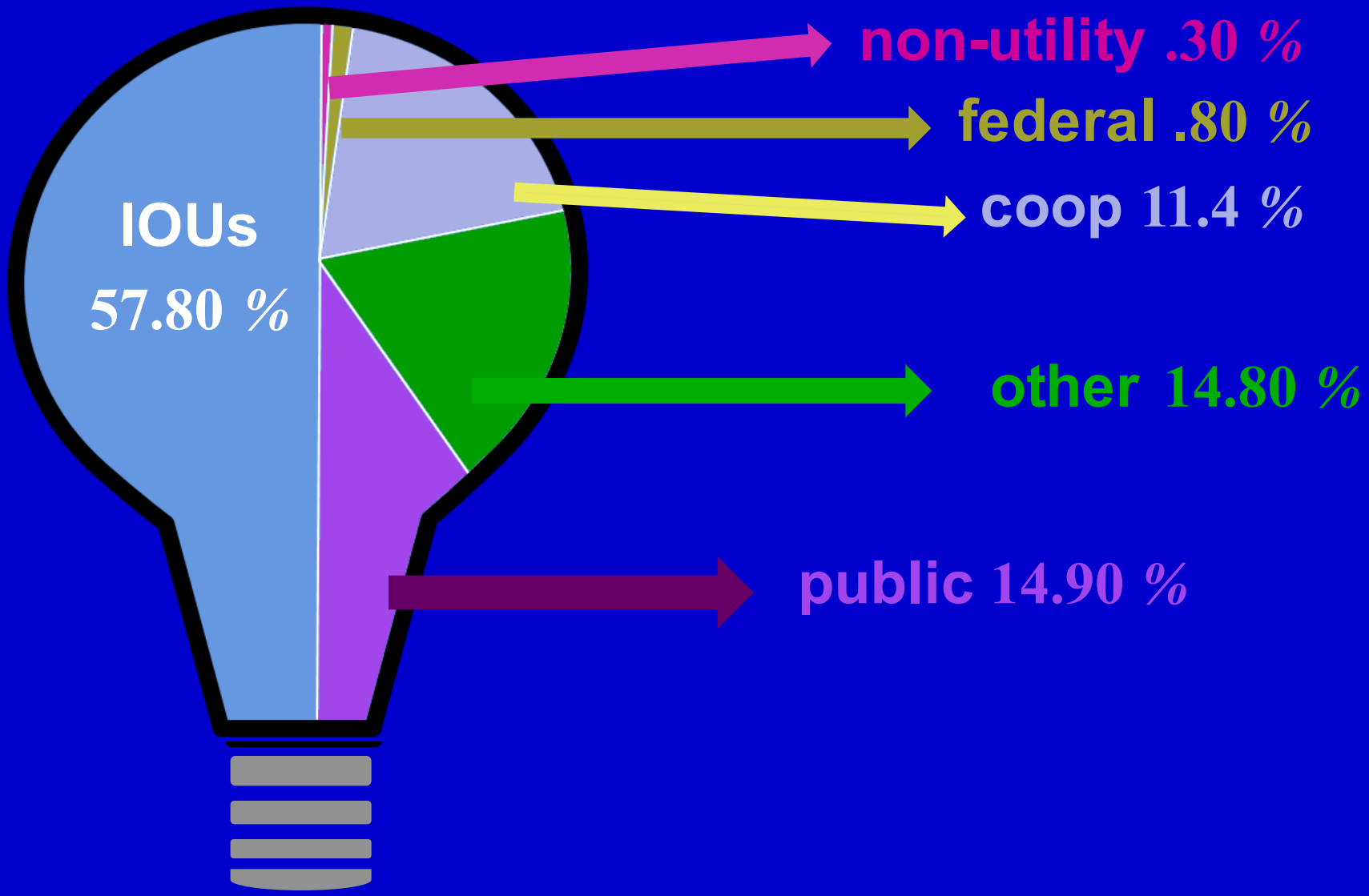
Source : EIA, http://www.eia.gov/electricity/annual/html/epa_01_02.html; Issued February 2016

RETAIL SALES OF ELECTRICITY TO END–USE SECTOR CUSTOMERS



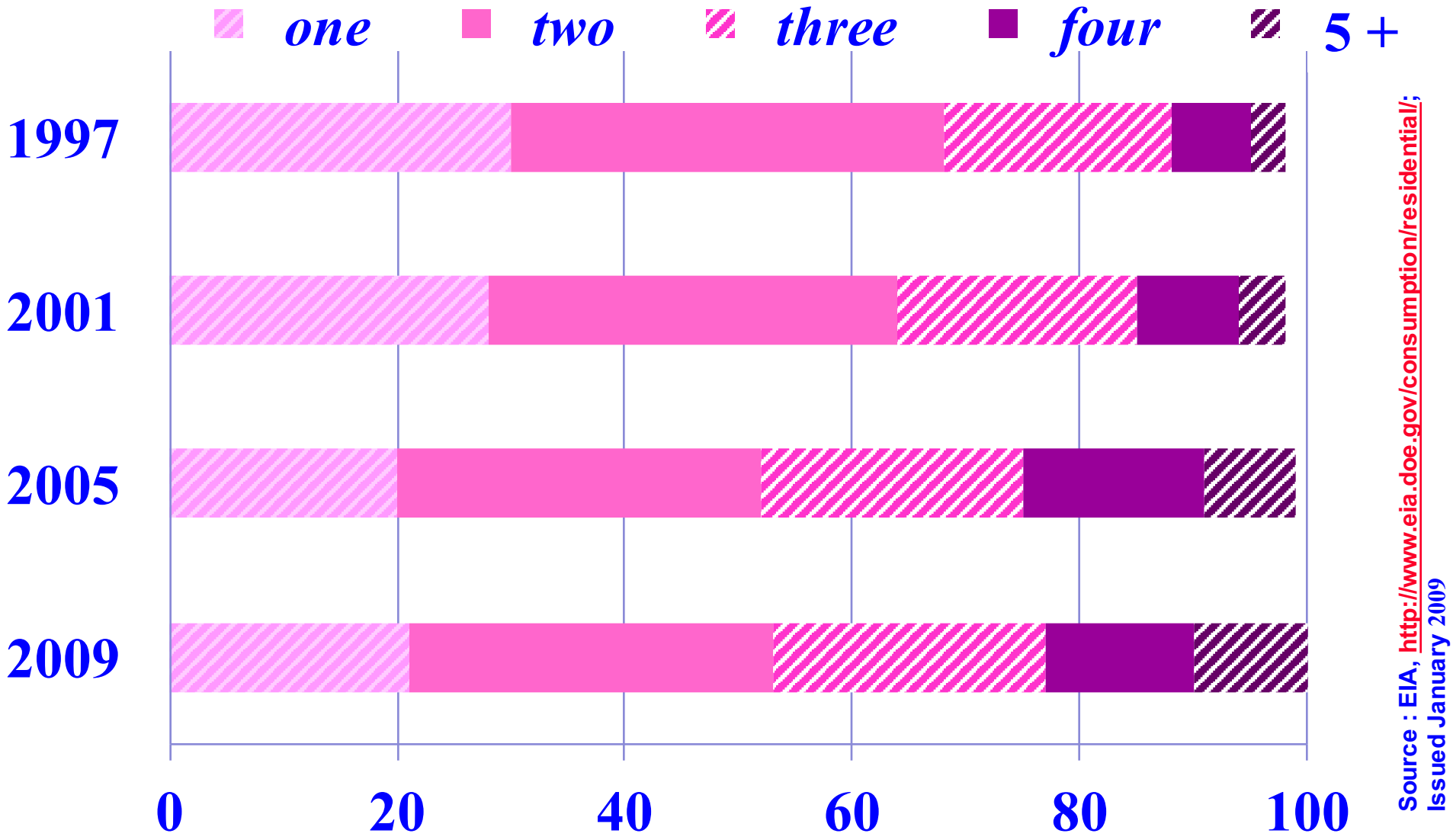
Source : EIA, Electric Power Monthly with data for January 2017, Table 5.1: *Sales of Electricity to Ultimate Customers*, March 2017.

PERCENT CUSTOMERS SERVED BY THE ELECTRICITY PROVIDERS

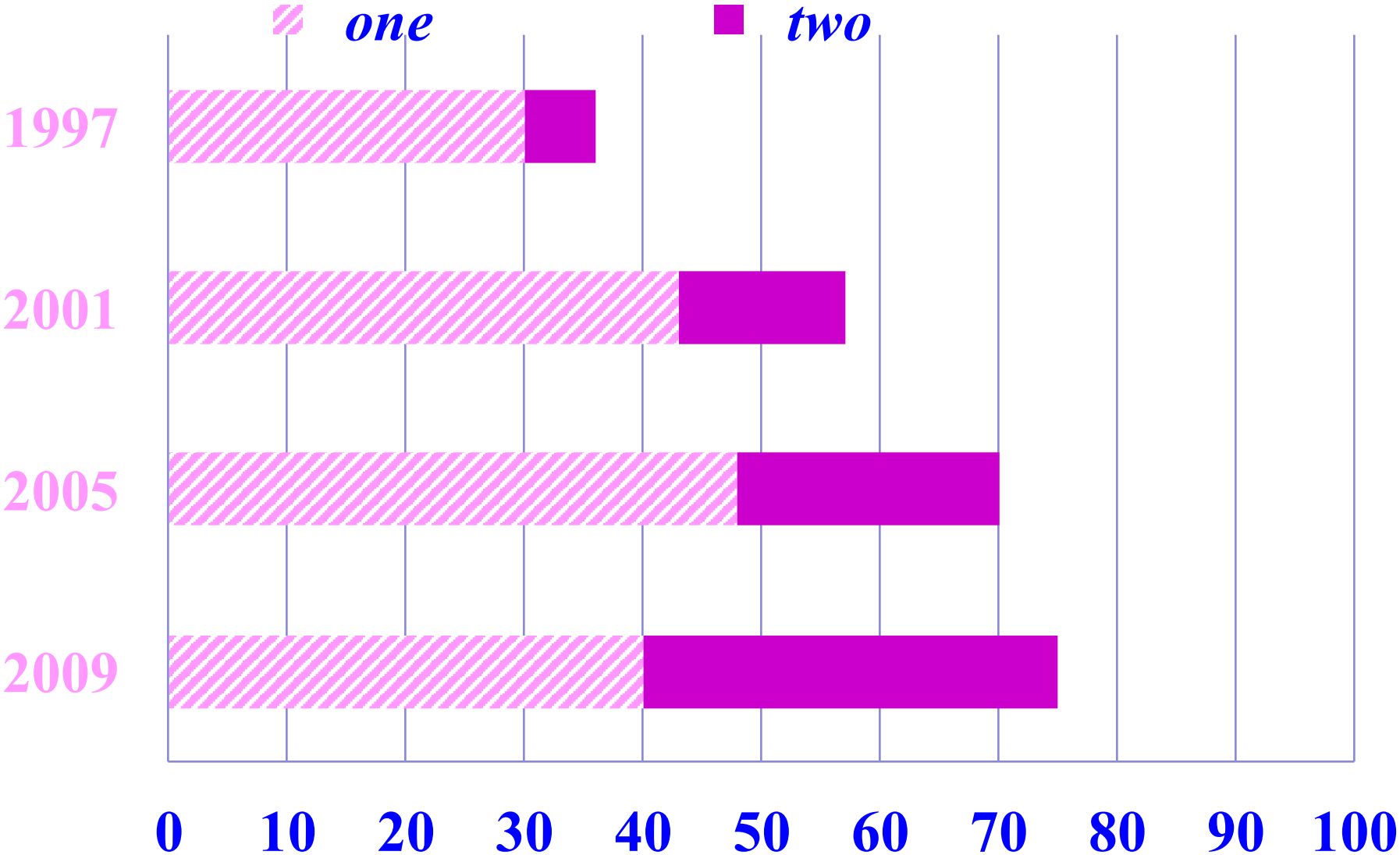


Source: http://www.eia.gov/electricity/state/unitedstates/Table 9

RISING NUMBER OF TELEVISIONS IN HOUSEHOLDS



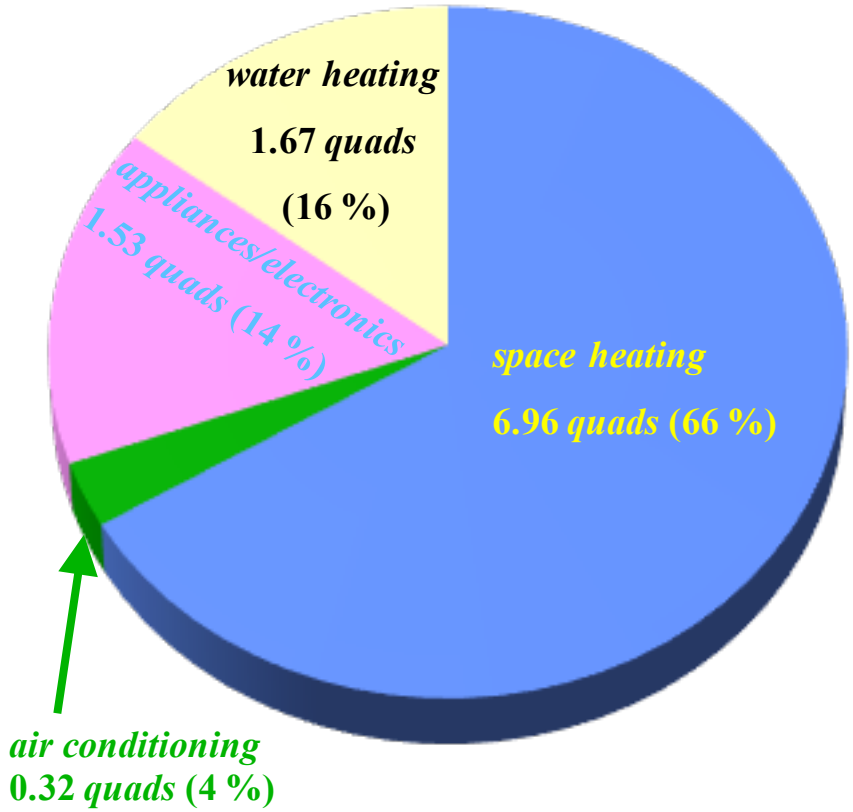
RISING NUMBER OF COMPUTERS IN HOUSEHOLDS



Source : EIA, http://www.eia.doe.gov/consumption/residential/; Issued January 2009

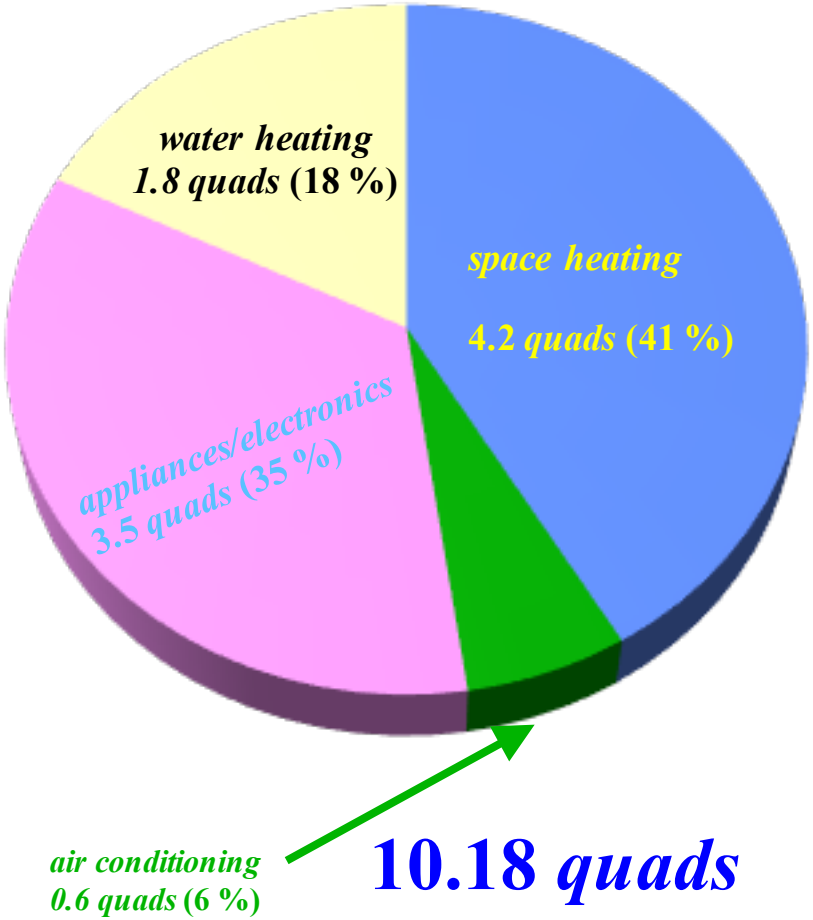
TOTAL RESIDENTIAL ENERGY USE

1978 usage



10.58 *quads*

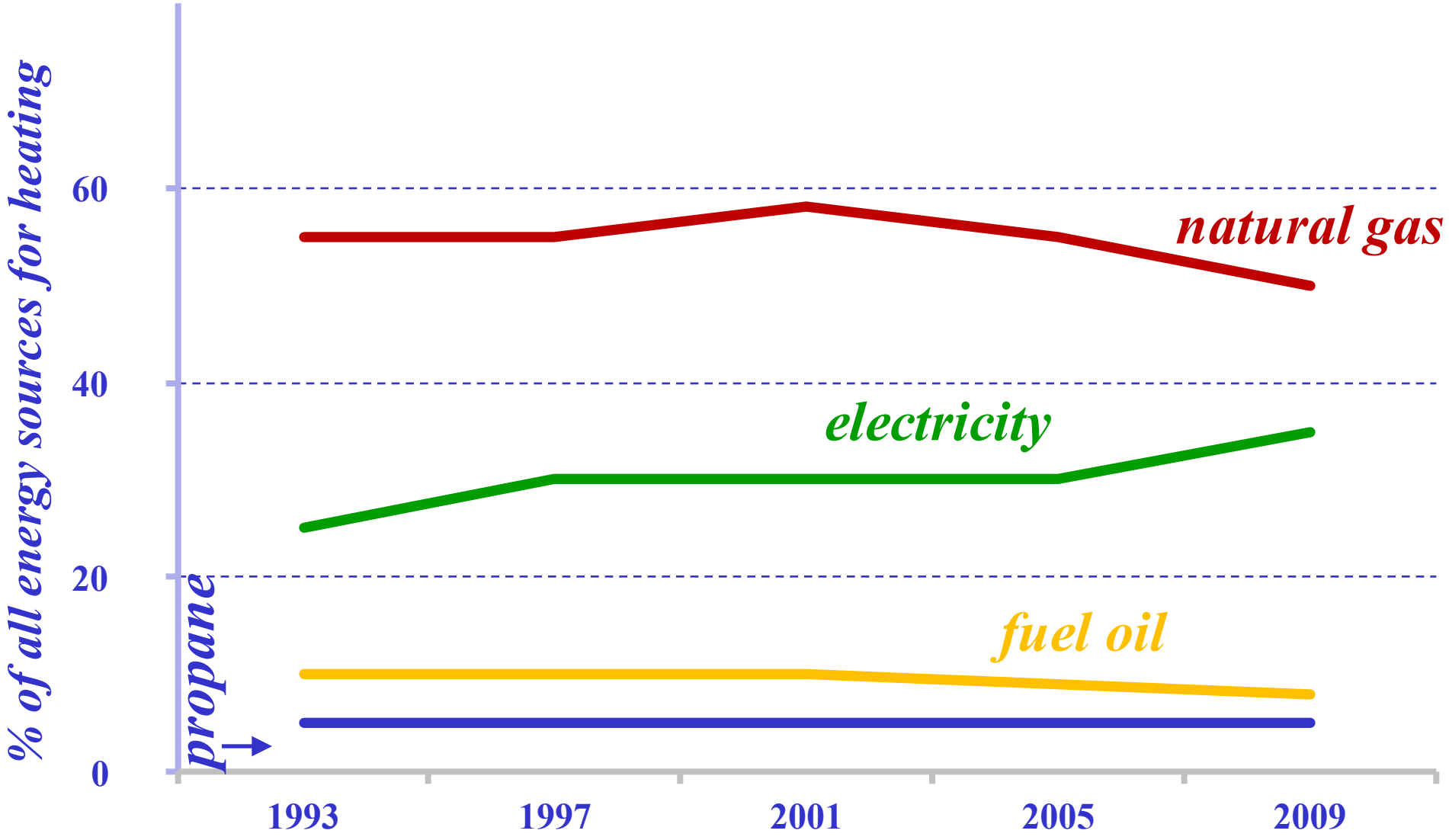
2009 usage



10.18 *quads*

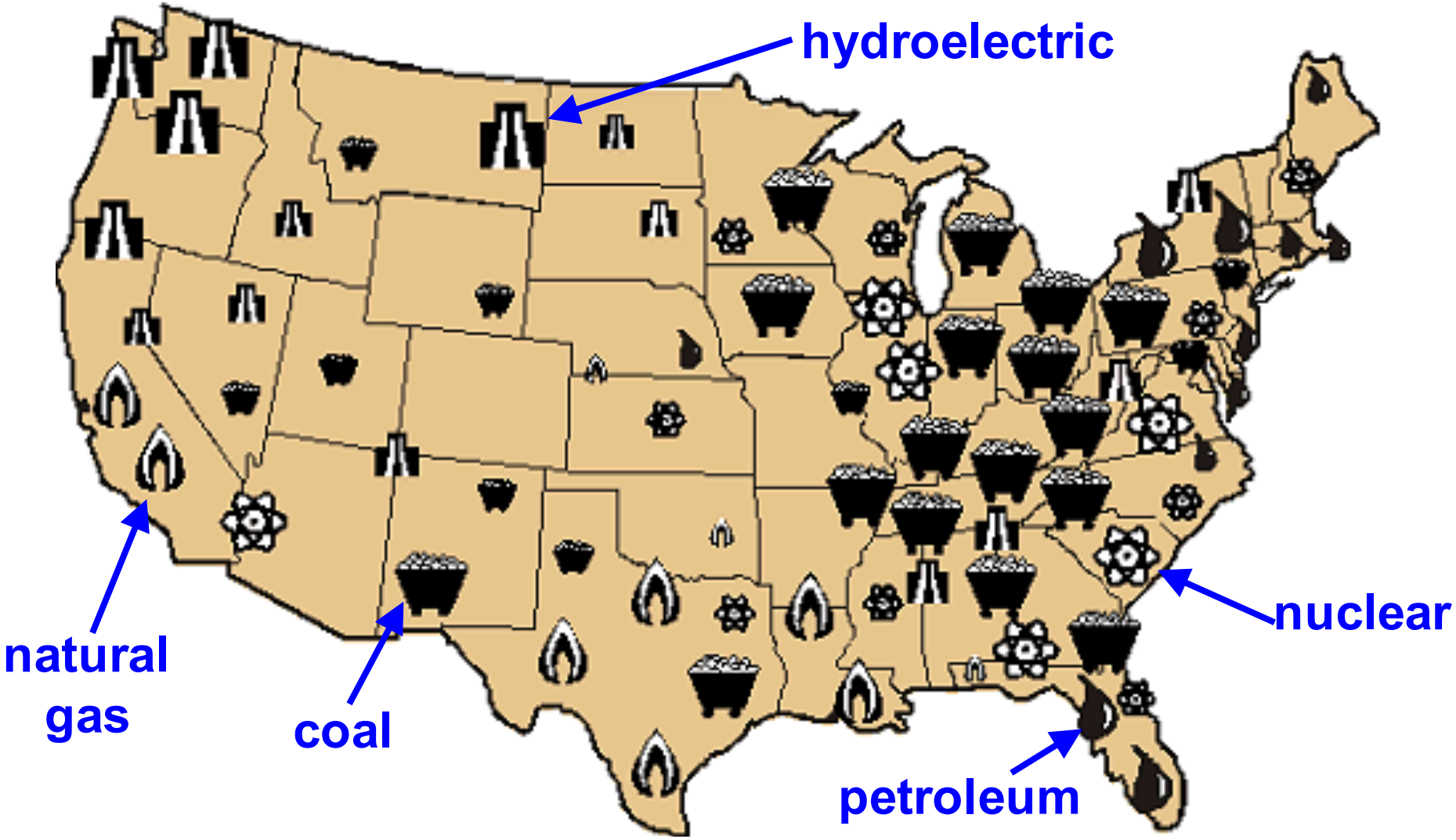
Source : EIA, http://www.eia.gov/consumption/residential/ ; Issued March 2013

PREVALENT HEATING SOURCES IN *US* HOUSEHOLDS



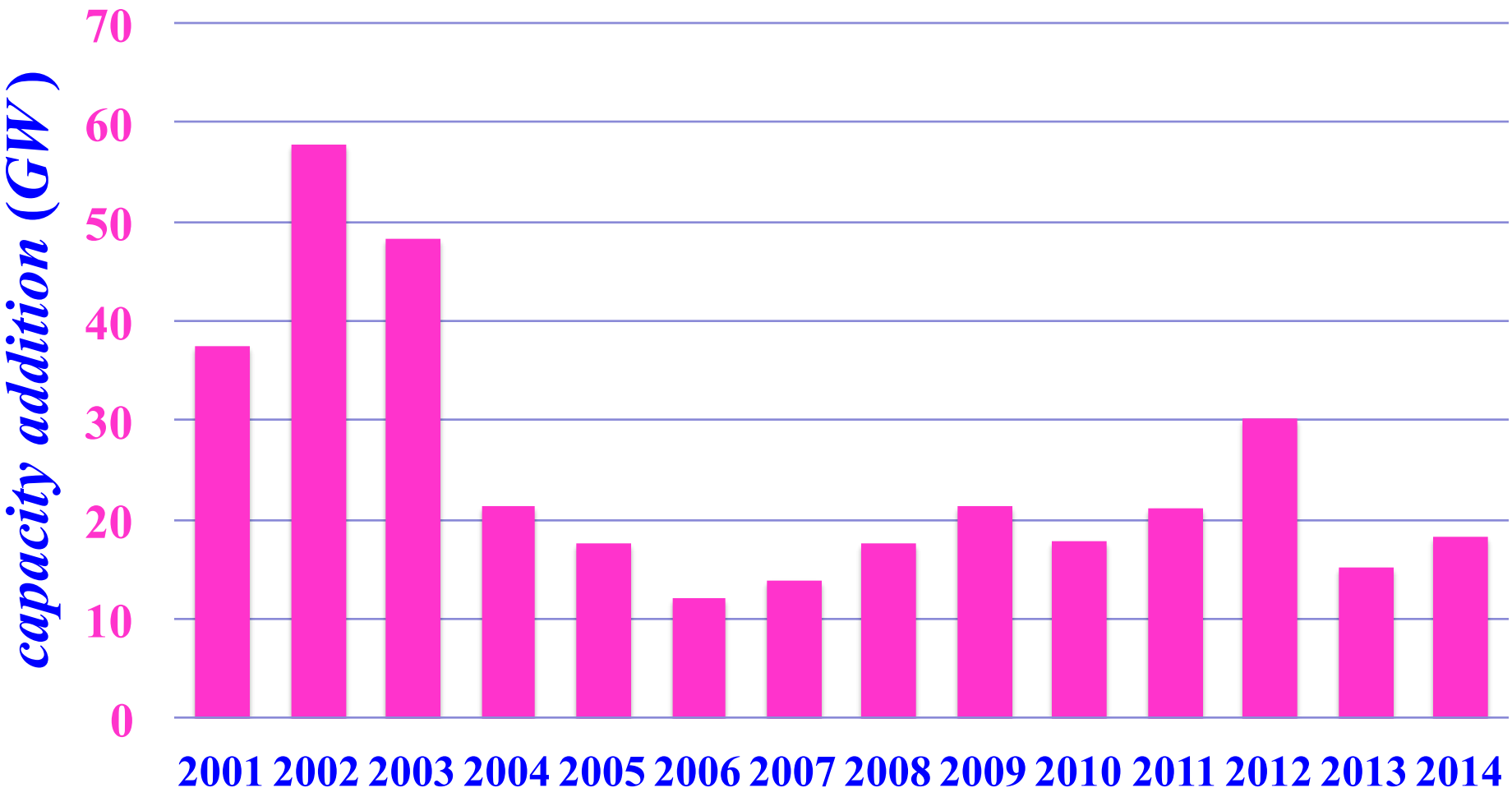
Source : EIA, http://www.eia.doe.gov/consumption/residential/; issued January 2009

US CONVENTIONAL ELECTRICITY GENERATION SOURCES



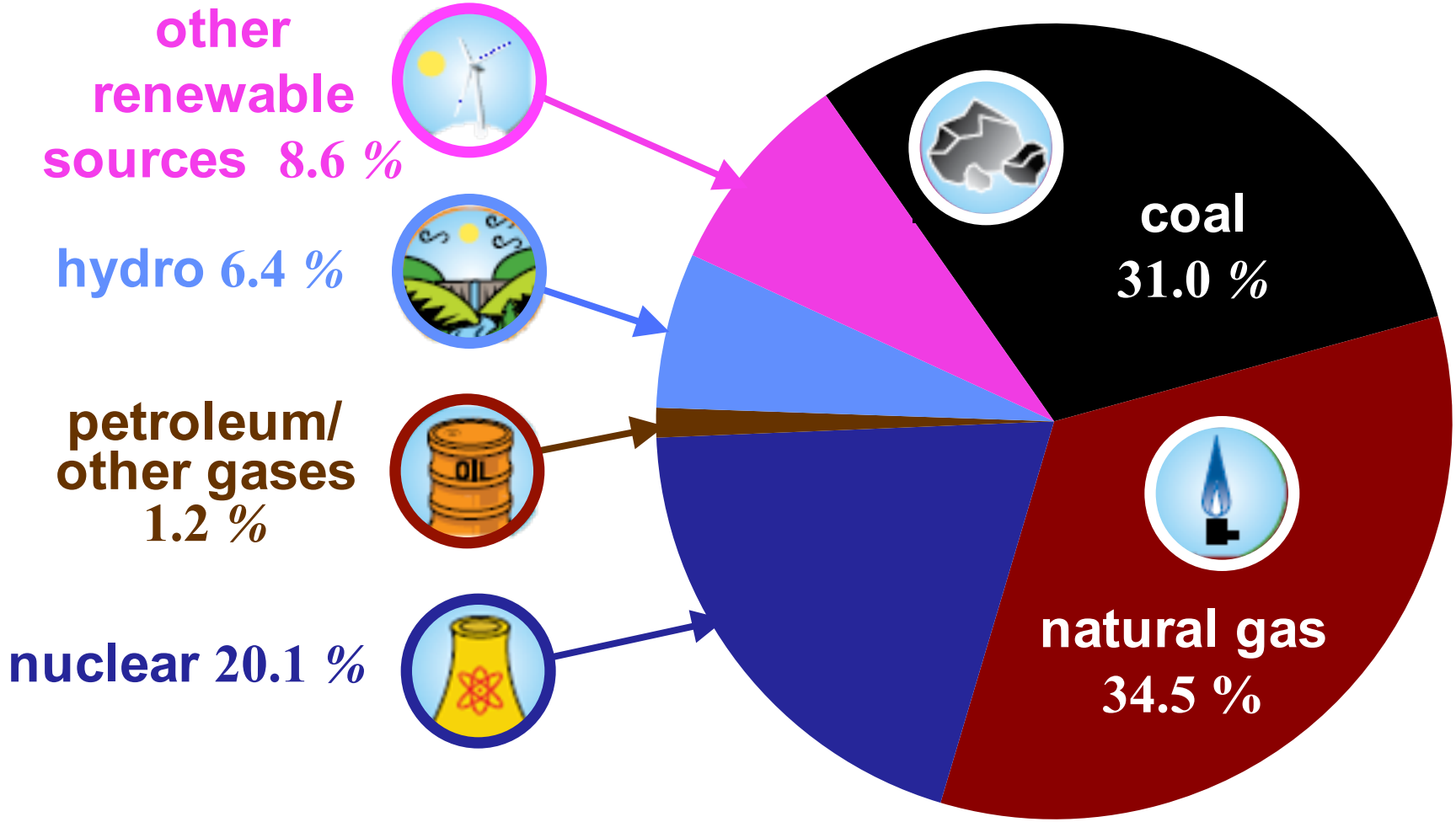
Source: The Changing Structure of the Electric Power Industry 2000*: An Update* (*EIA*, 2000)

2001 – 2014 GENERATION CAPACITY ADDITIONS



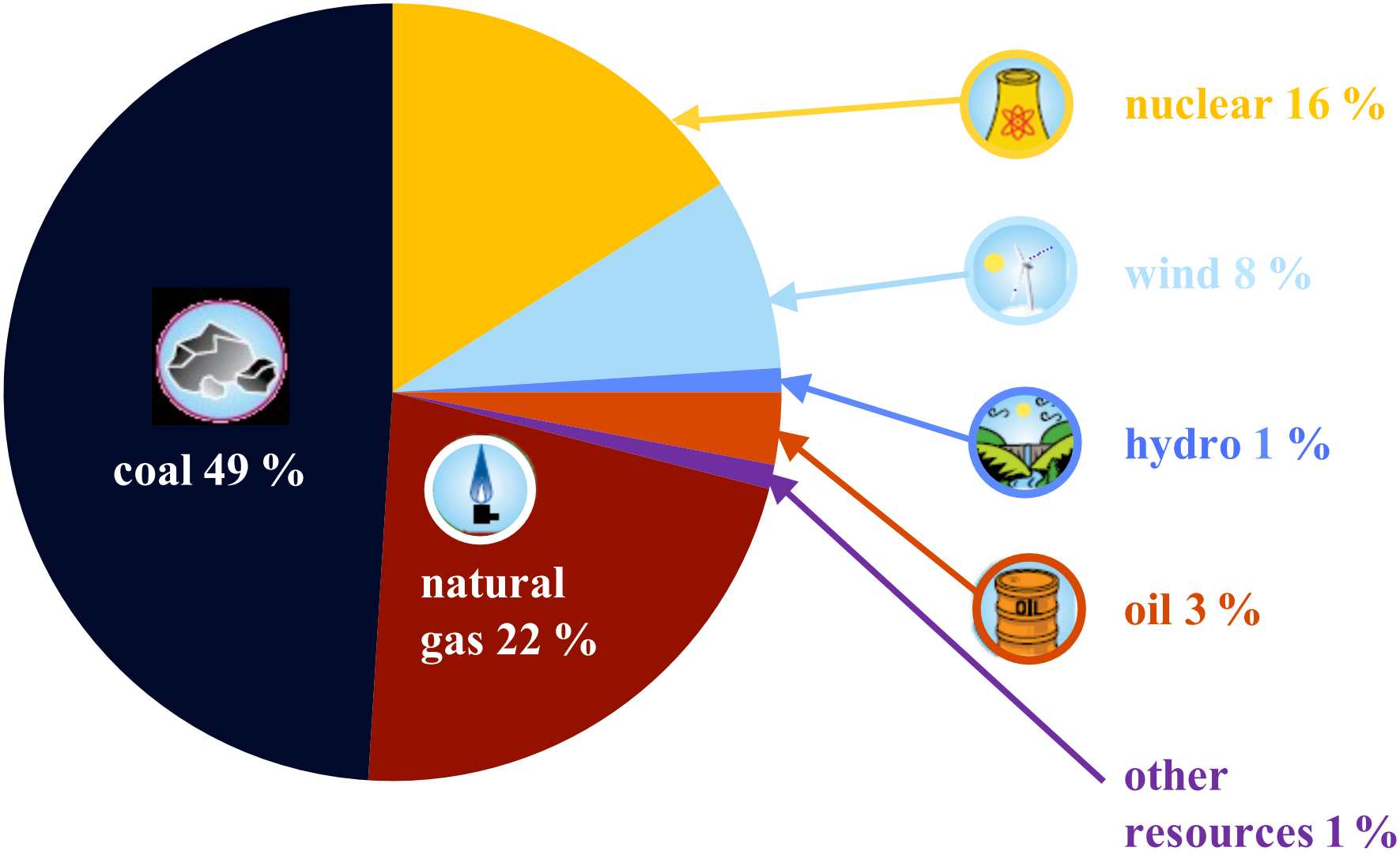
Source: EIA, http://www.eia.gov/electricity/annual/html/epa_04_06.html; issued February 2016

2016 GENERATION BY SOURCE



Source: http://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf; issued March, 2016

AMEREN ILLINOIS ENERGY SOURCES OF ELECTRICITY SUPPLIED IN 2016



Source: Ameren IP, December 2017

2015 *AMEREN ILLINOIS POWER* AVERAGE ELECTRICITY EMISSIONS / WASTE

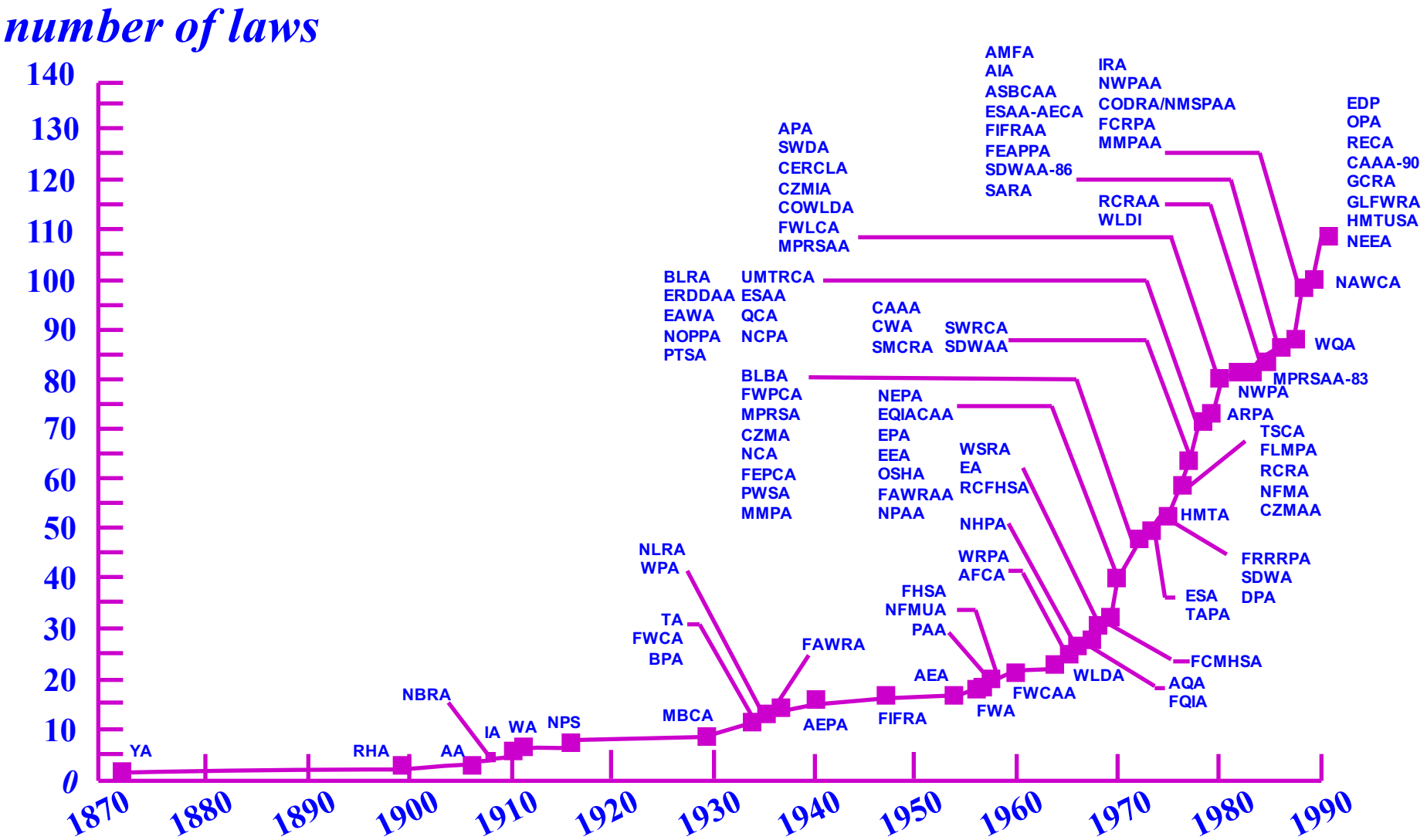
output	*average amount per MWh*
carbon dioxide	1,370 *lb*
nitrogen oxides	0.78 *lb*
sulfur dioxide	1.54 *lb*
high–level nuclear waste	0.0009 *lb*
low–level nuclear waste	0.0002 ft^3

Source: Ameren IP, data for the 12 months ending December 31, 2016

ENVIRONMENTAL ASPECTS

- The electricity industry is the most highly visible stationary source of pollution
- In big picture terms, the *US* electric power industry is responsible for
  - 3/4 of SO_X emissions
  - 1/3 of CO_2 and NO_X emissions
  - 1/4 of particulate matter and toxic heavy metals emissions

US LAWS ON ENVIRONMENTAL PROTECTION

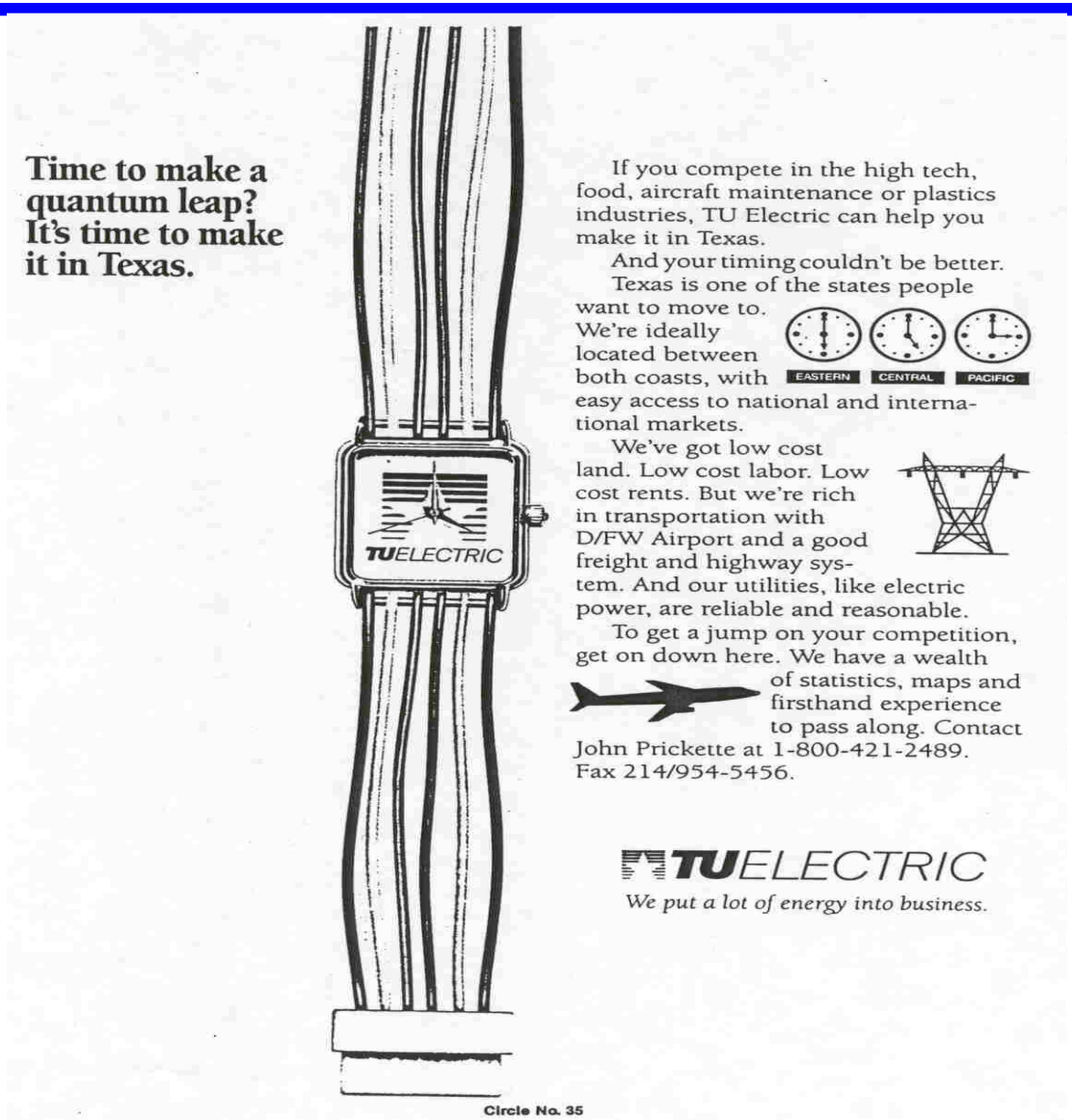


ACRONYM SOUP

- *NIMBY* : *Not In My Back Yard*
- *NOOS* : *Not on Our Street*
- *LULU* : *Locally Undesirable Land Use*
- *NOPE* : *Not on Planet Earth*
- *NIMTOO* : *Not in My Term of Office*
- *SLAPP* : *Strategic Lawsuits Against Public Participants*
- *CAVE* : *Citizens Against Virtually Everything*
- *BANANA* : *Build Absolutely Nothing Anywhere Near Anyone*

ENERGY EFFICIENCY

ECONOMIC DEVELOPMENT



THE ENERGY UNIT PREFIX

prefix	*symbol*	*value*	*exponent value*
kilo	*k*	*thousand*	10^{3}
Mega	*M*	*million*	10^{6}
Giga	*G*	*billion*	10^{9}
Tera	*T*	*trillion*	10^{12}
Peta	*P*	*quadrillion*	10^{15}
Exa	*E*	*quintillion*	10^{18}

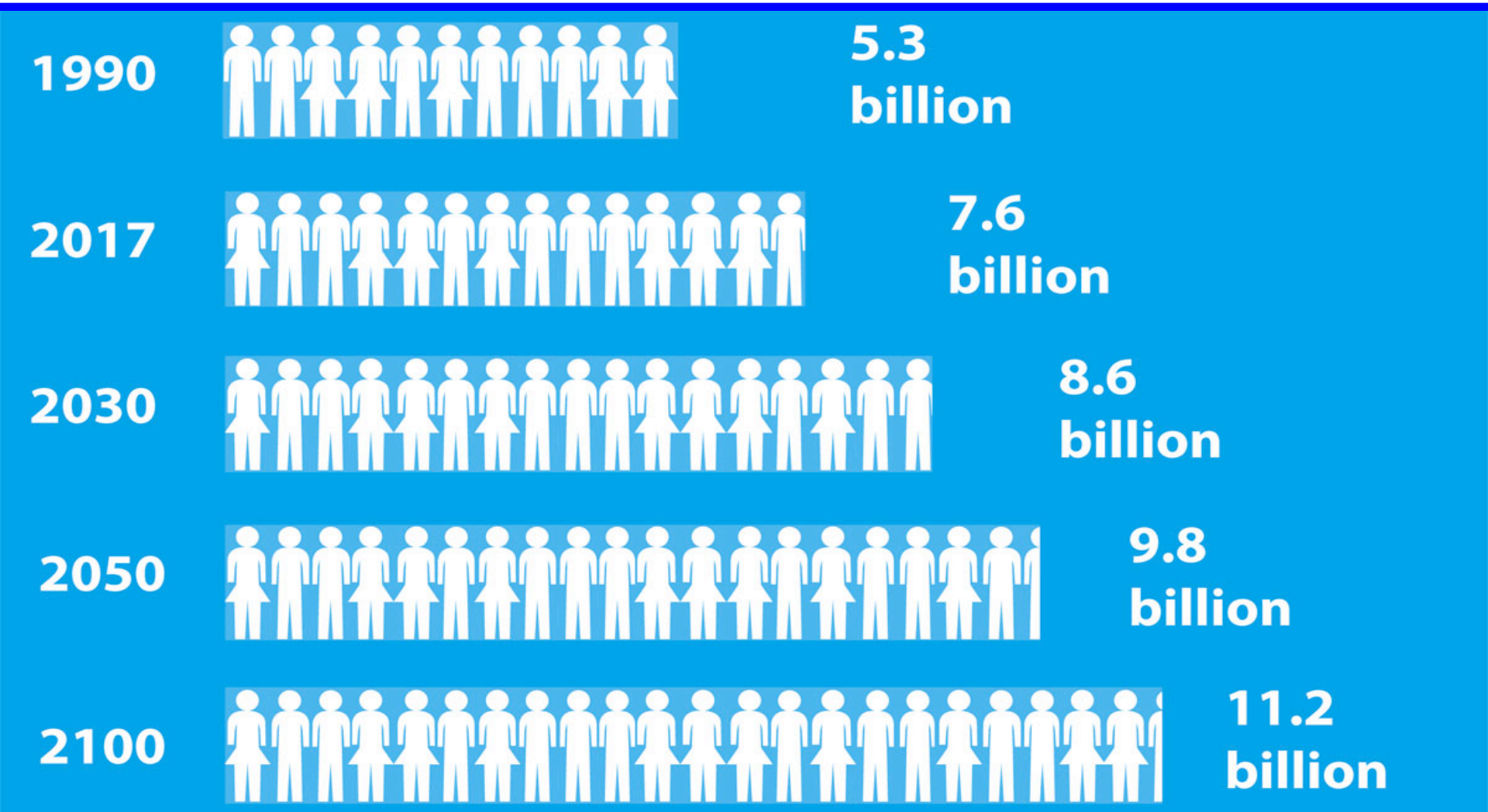
ENERGY AND POWER UNITS

- Energy is expressed in a wide variety of units:
  - *Joules*
  - *quads*
  - *Watt-hours*
  - *BTUs*
  - *calories*
- Fuel supply are expressed in *barrels*, *tons oil equivalent* (*toe*), *BTU*s, *calories* or *cubic feet* for gas and *acre feet* for water
- In round numbers
  - the *US* annually consumes 100 *quad*s of energy
  - the *US* installed electric generation capacity is about 1,000 *GW*
  - the Champaign electrical load is about 300 *MW*

THE GLOBAL ENERGY DEMAND

- We view the electric energy within the global energy context
- We discuss the key aspects of demand
  - population growth
  - future demand growth
- We examine the energy supply picture and the impacts on green house gases

WORLD POPULATION

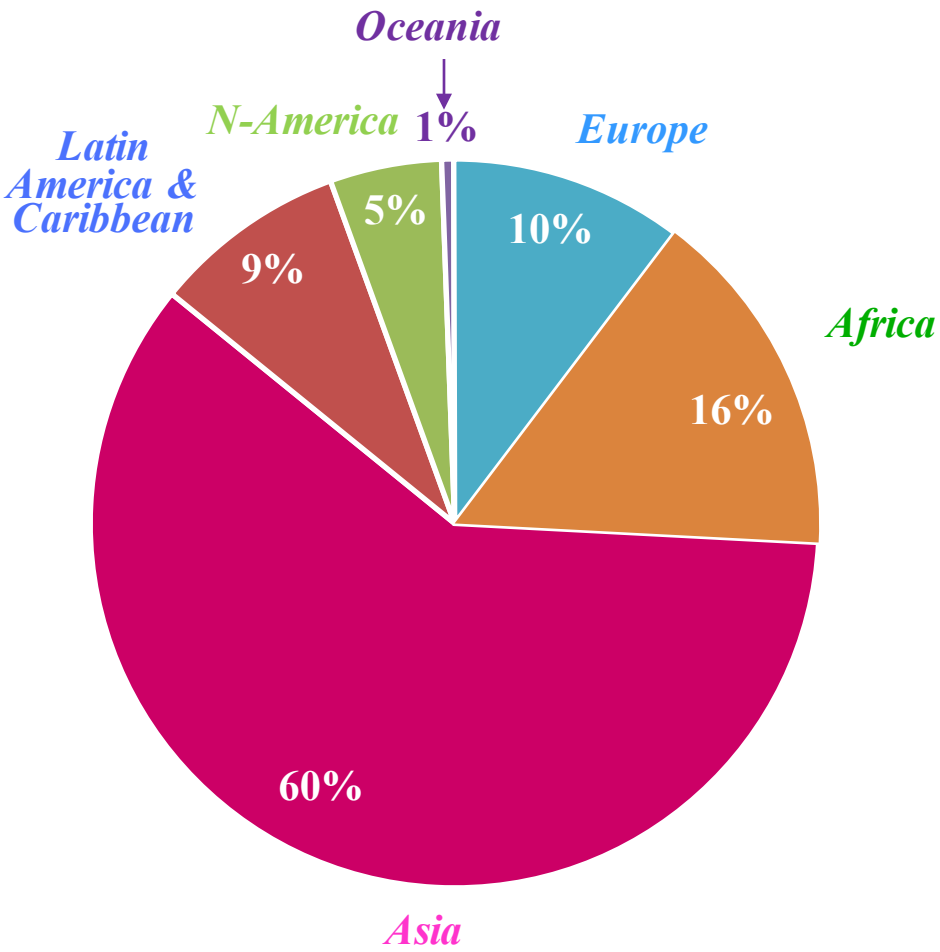


Source: United Nations Department of Economic and Social Affairs, Population Division, *World Population Prospects: The 2017 Revision*
Produced by: United Nations Department of Public Information

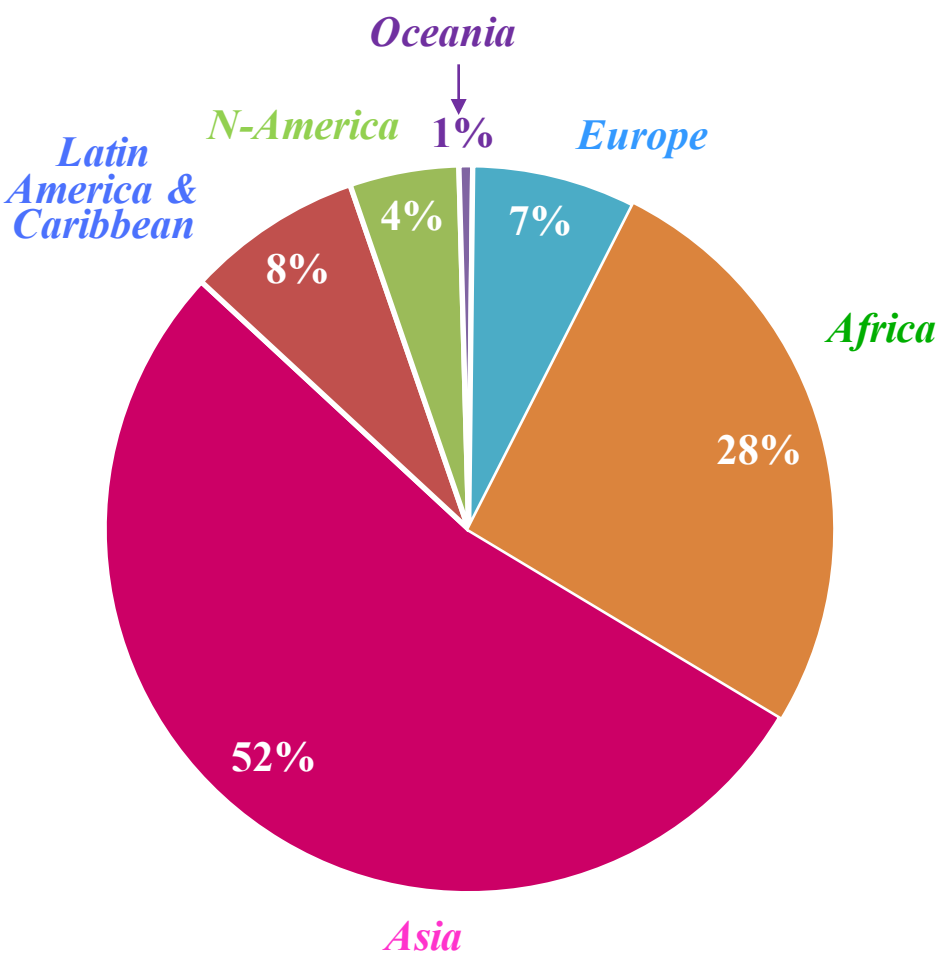
SUSTAINABLE DEVELOPMENT GOALS

DEMOGRAPHIC TRANSFORMATIONS

2015 – 7.35 *billion*

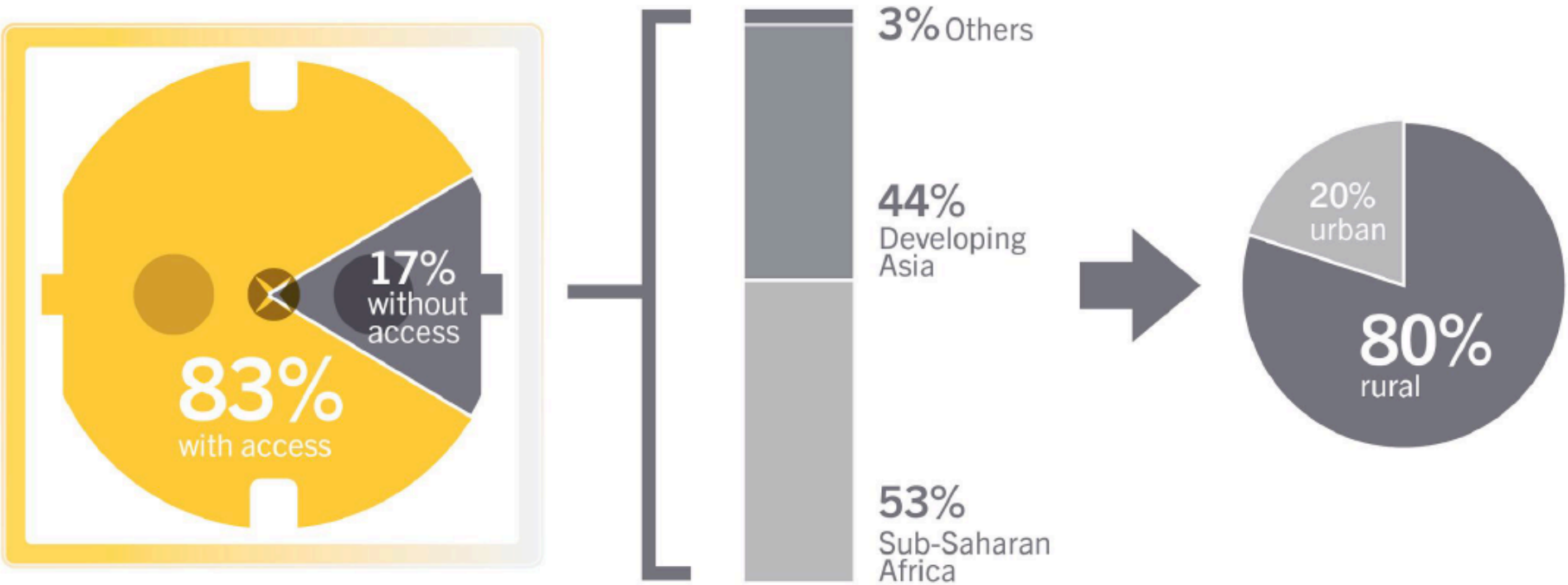


2060 – 10.18 *billion*



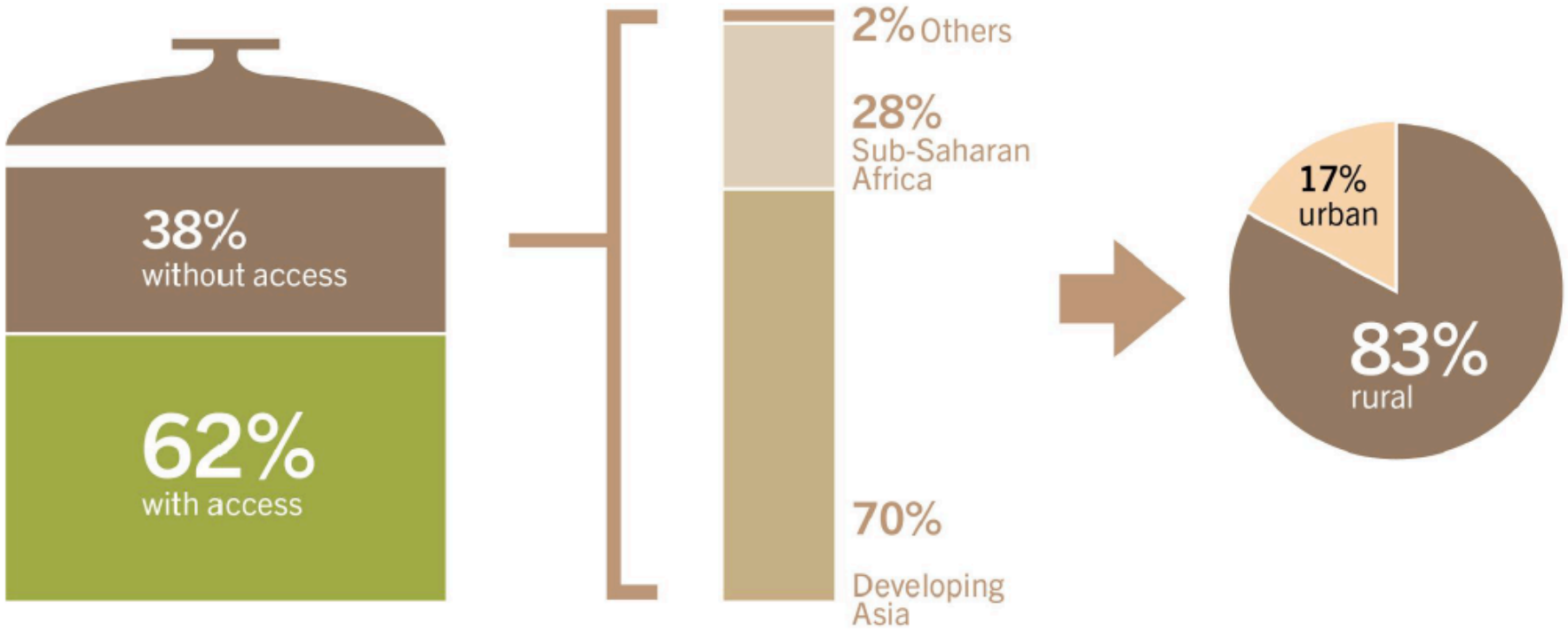
Source: UN, Population Division; http://esa.un.org/unpd/wpp/Excel-Data/population.htm

GLOBAL LACK OF ELECTRICITY ACCESS



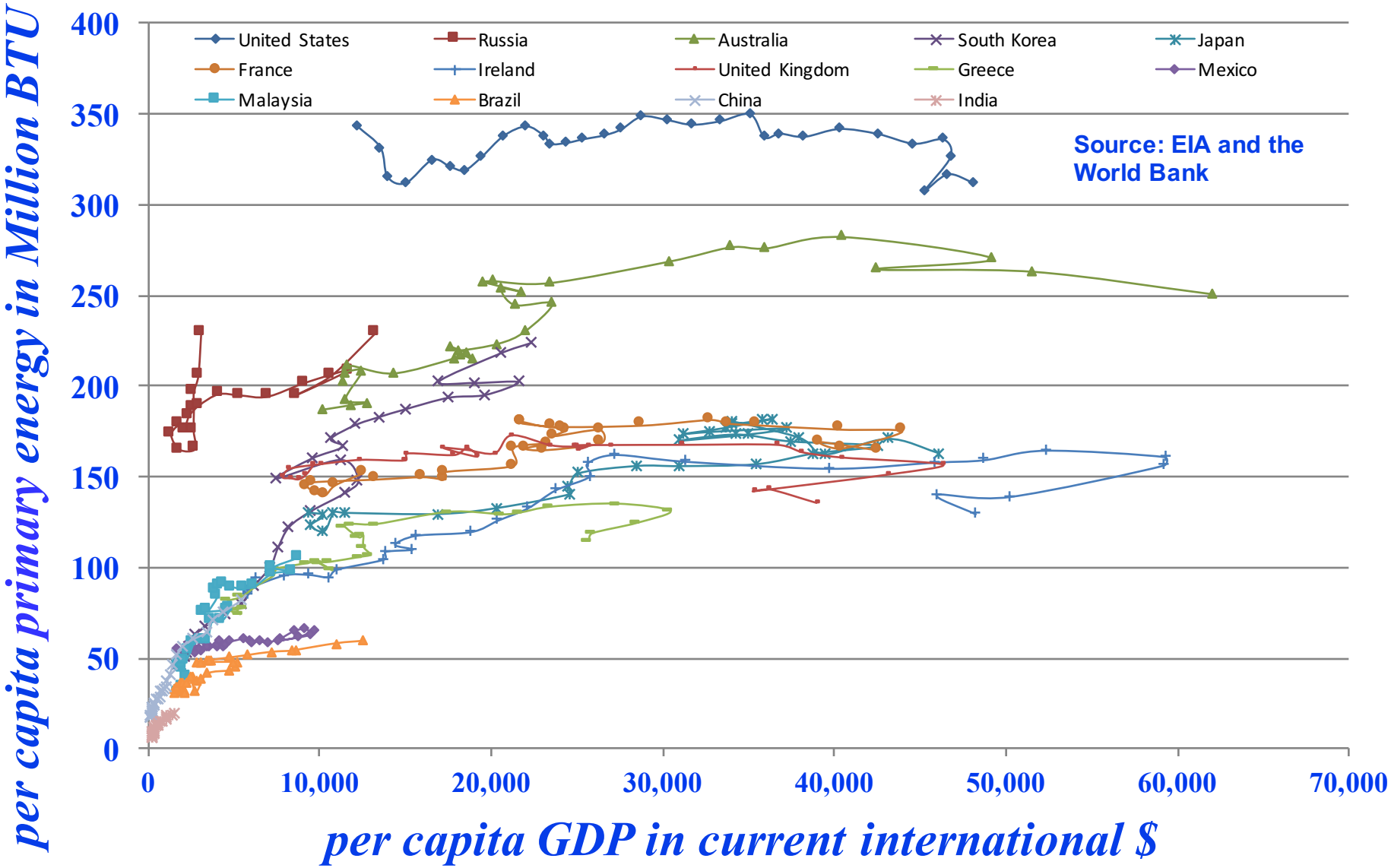
Source: REN 21

GLOBAL LACK OF CLEAN COOKING ACCESS

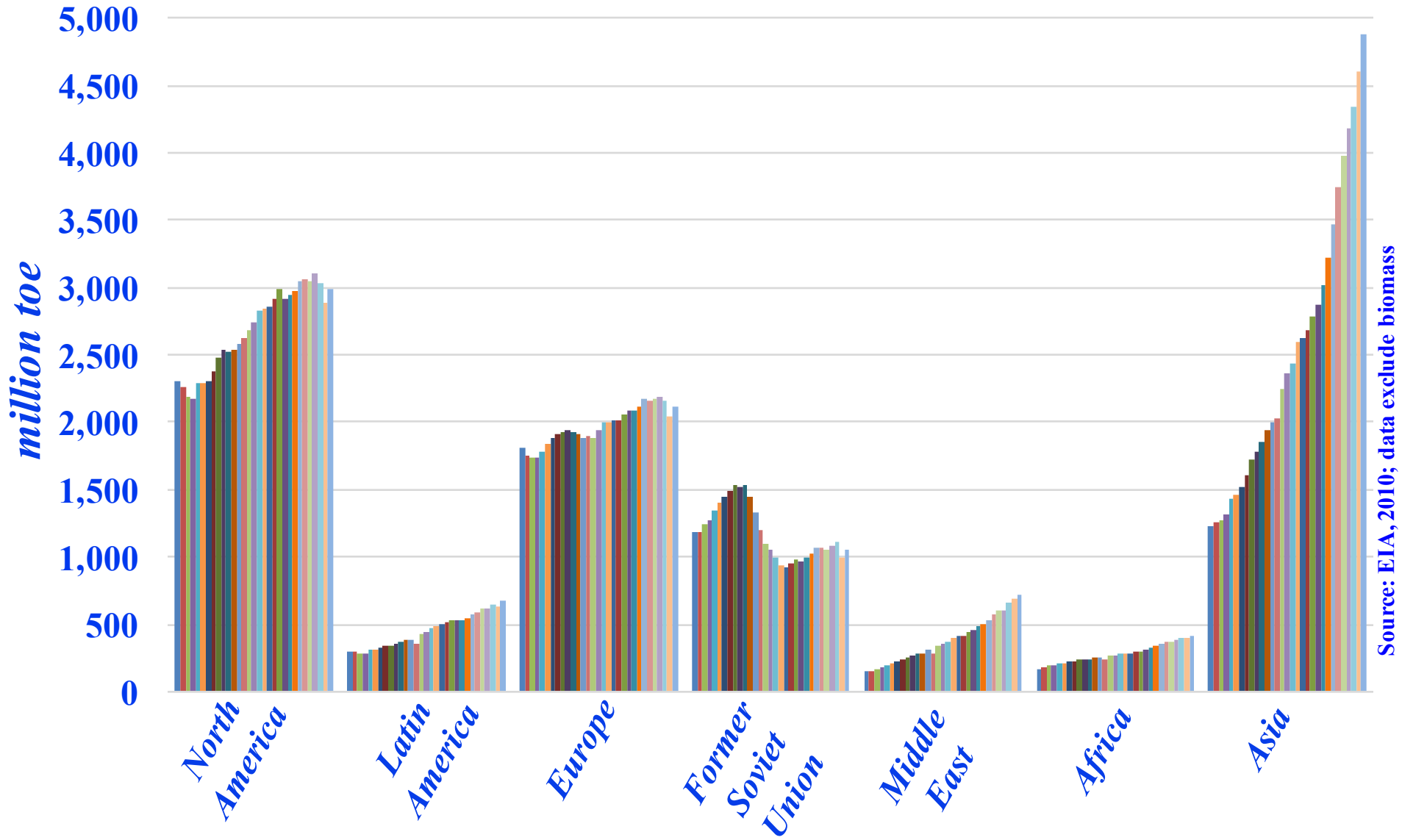


Source: REN 21

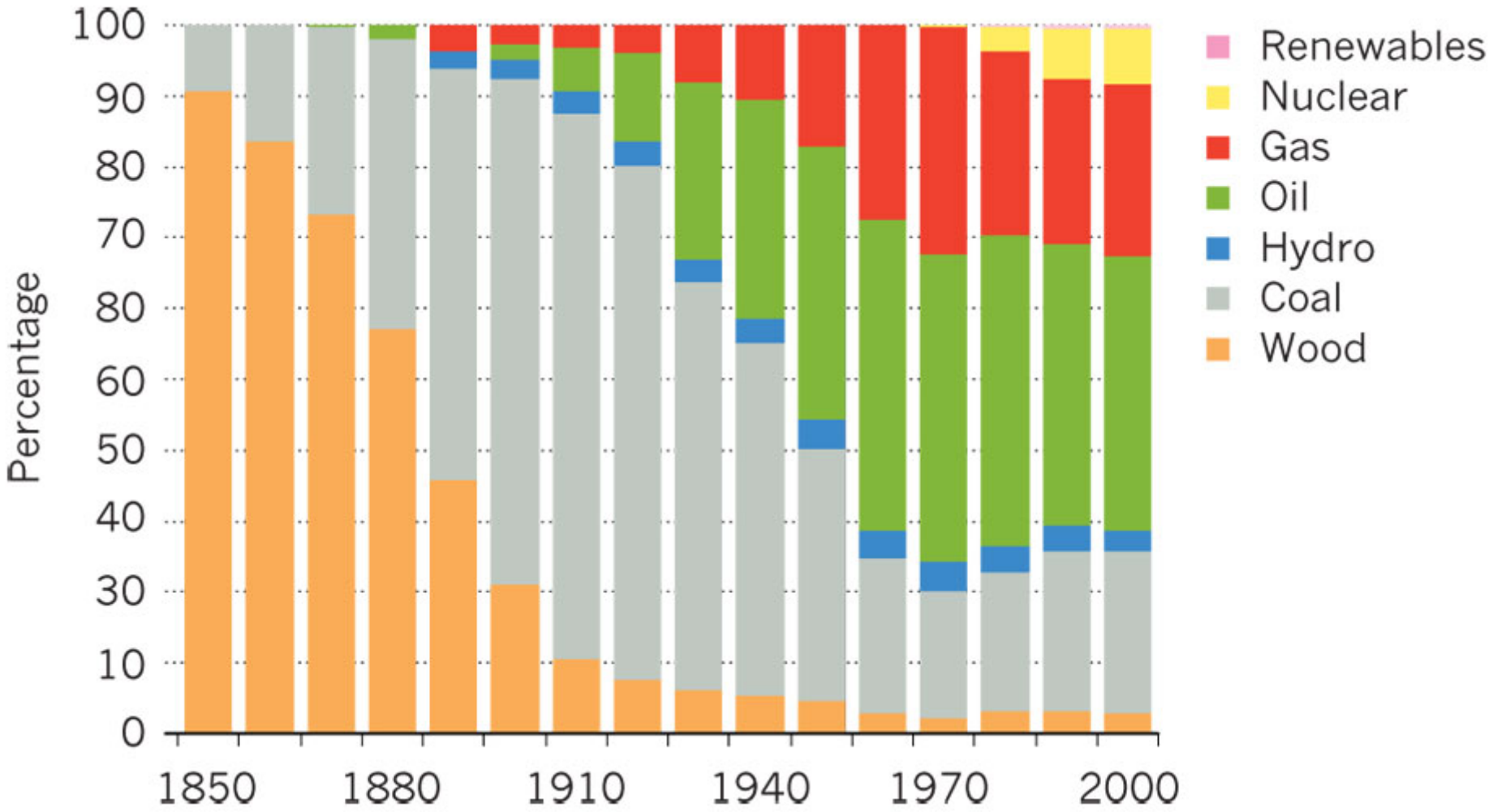
1980 – 2011 ENERGY DEMAND VS. *GDP PER CAPITA*



1980 – 2011 ENERGY DEMAND TRENDS

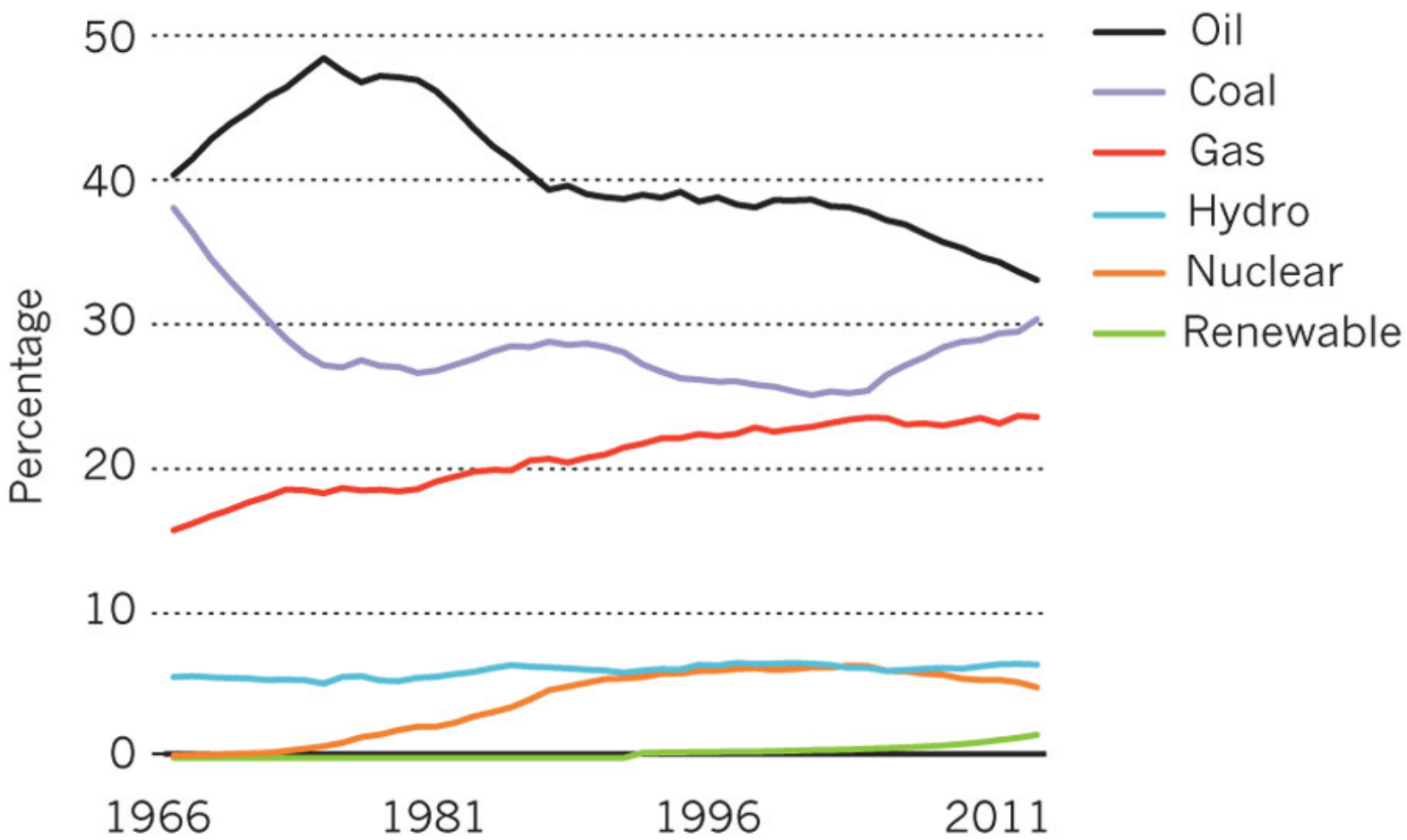


EVOLUTION OF THE MAIN SOURCES OF *US* ENERGY CONSUMPTION



Source: Steve Chu and Arun Majumdar, "Opportunities and challenges for a sustainable energy future," Nature, August 2012

WORLDWIDE SHARES OF PRIMARY ENERGY: 1966 – 2011



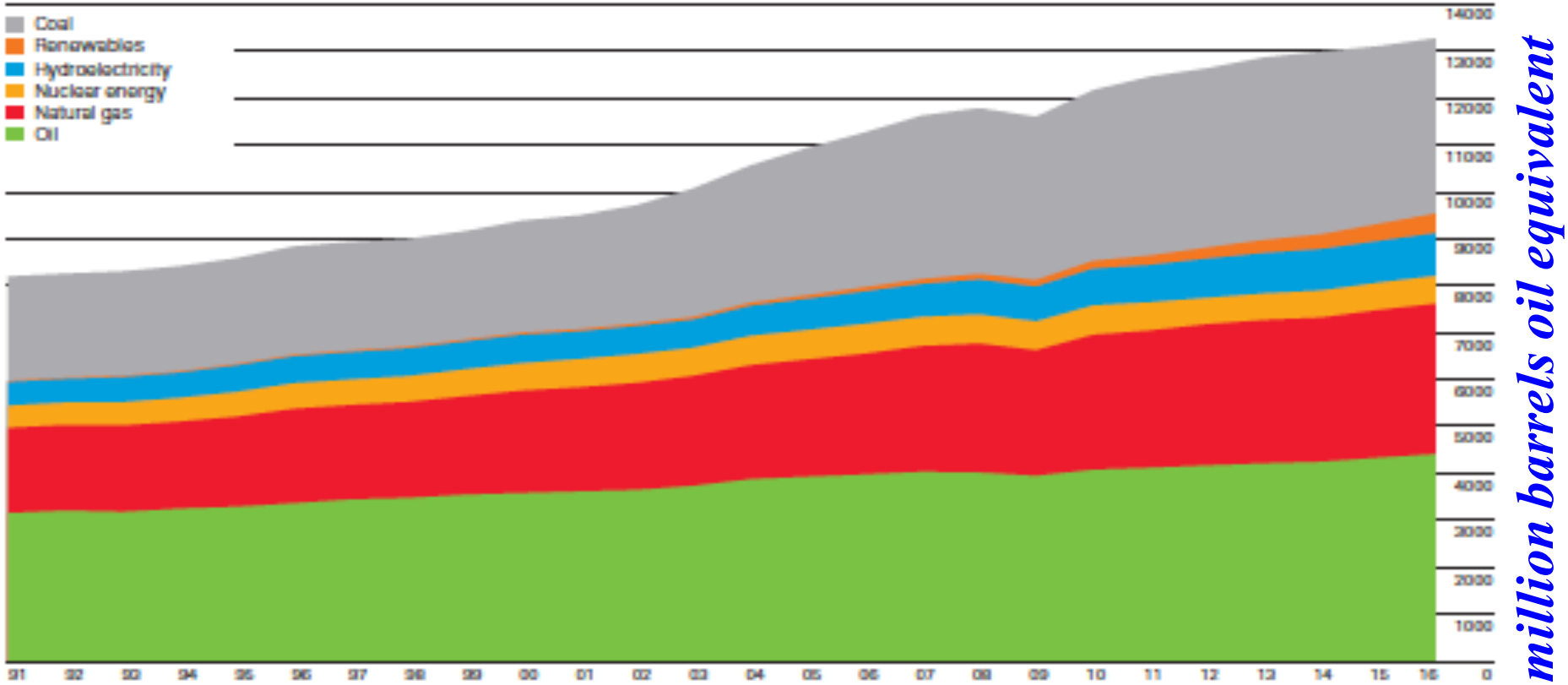
Source: Steve Chu and Arun Majumdar, "Opportunities and challenges for a sustainable energy future," Nature, August 2012

2012 WORLD PRIMARY ENERGY CONSUMPTION

source	*generation (PJ)*
solid fuels	156,171
liquid fuels	172,935
natural gas	125,063
hydroelectric power	34,796
nuclear power	23,462
total	522,370

Source: BP Statistical Review of the World 2013

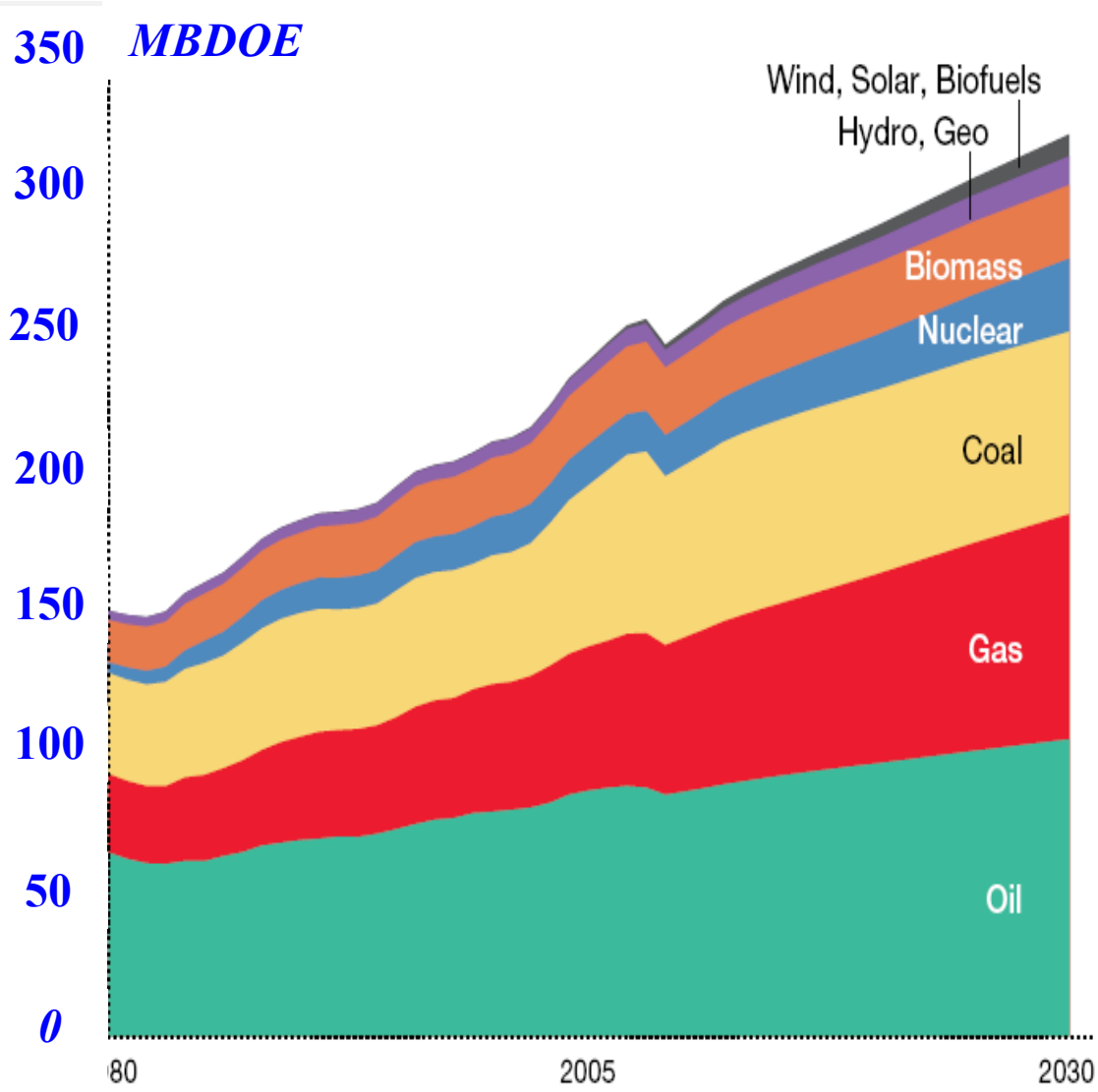
PREDOMINANCE OF OIL AND GAS

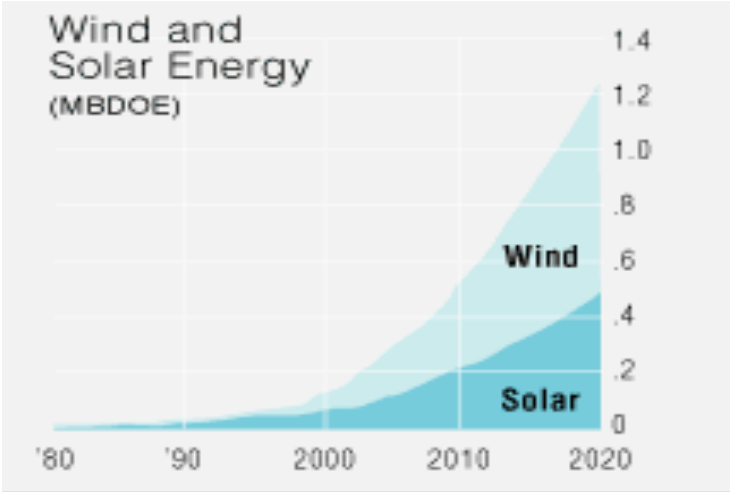


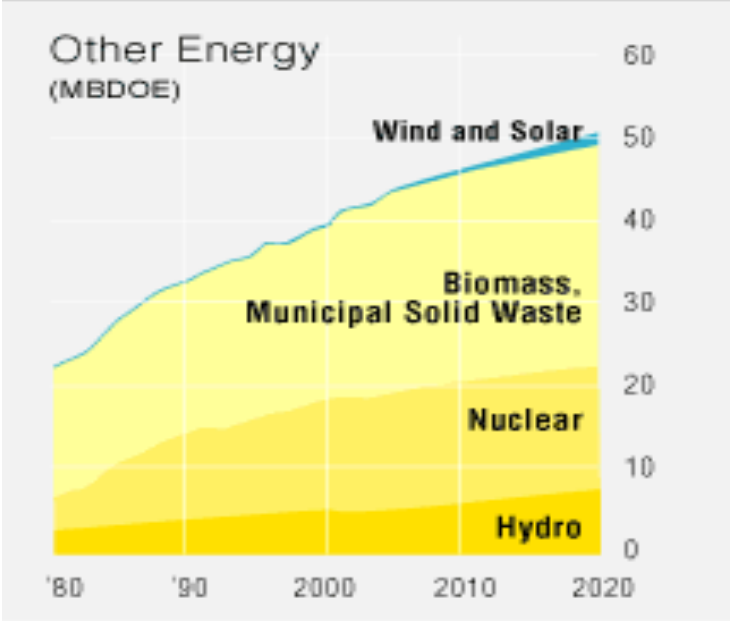
World primary energy consumption grew by 1.0% in 2016, well below the 10-year average of 1.6% and the third consecutive year at or below 1%. As was the case in 2015, growth was below average in all regions except Europe & Eurasia. All fuels except oil and nuclear power grew at below-average rates. Oil provided the largest increment to energy consumption at 77 million tonnes of oil equivalent (mtoe), followed by natural gas (57 mtoe) and renewable power (53 mtoe).

Source: BP Statistical Review o World Energy, 2017

PREDOMINANCE OF OIL AND GAS

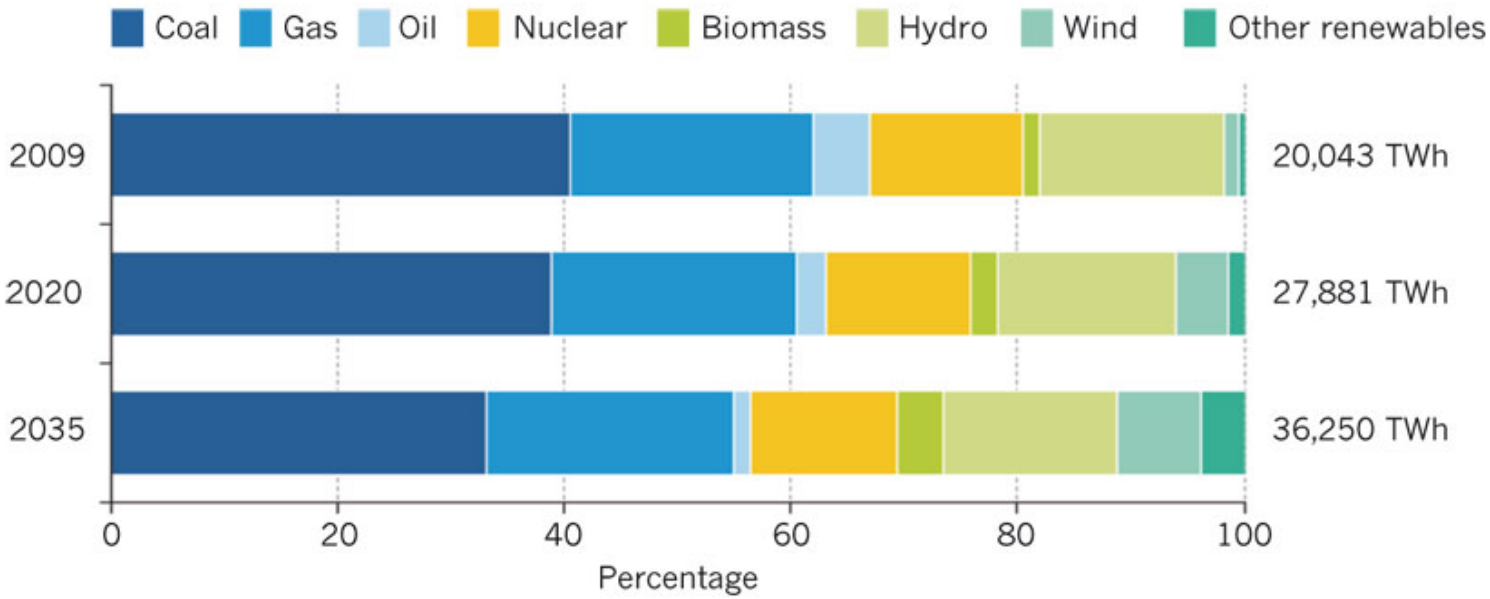


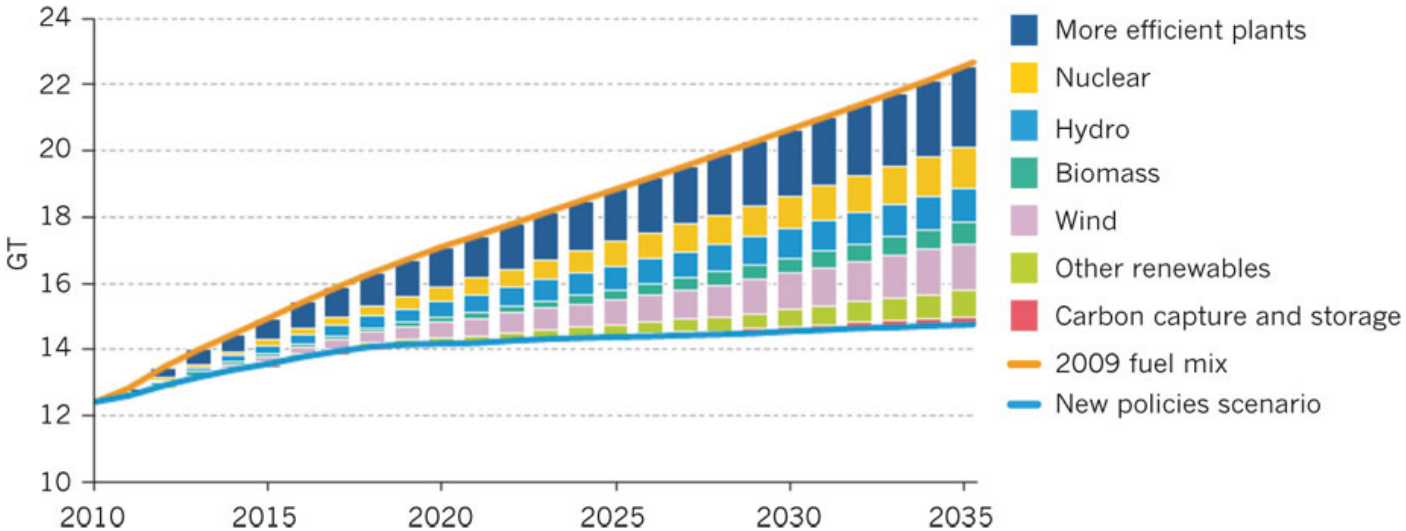




Source: http://www.exxonmobil.com/corporate/Newsroom/Publications/eTrendsSite/chapter1.asp

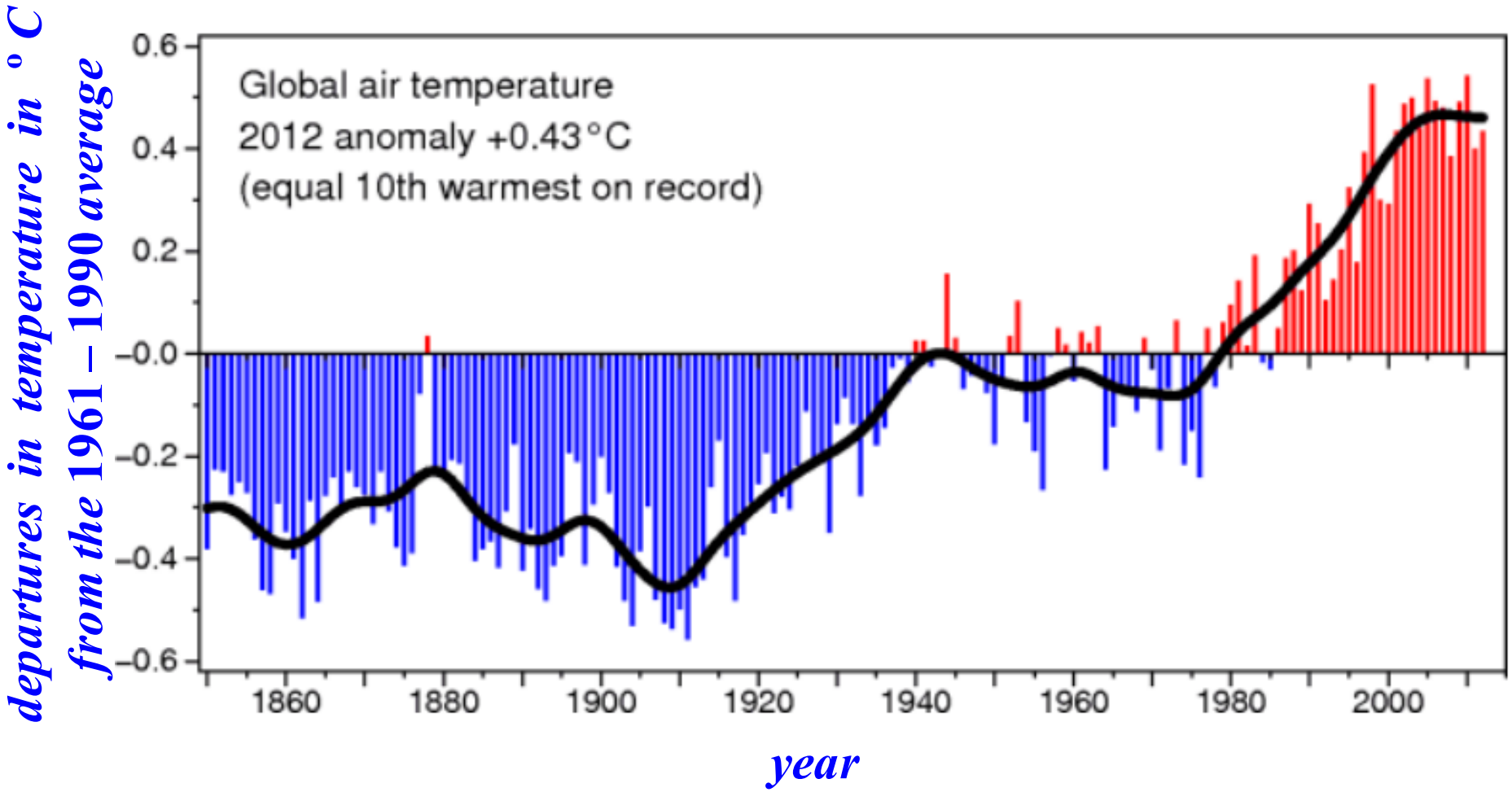
IEA ELECTRICITY GENERATION AND CO_2 FORECASTS





Source: Steve Chu and Arun Majumdar, "Opportunities and challenges for a sustainable energy future," *Nature*, August 2012

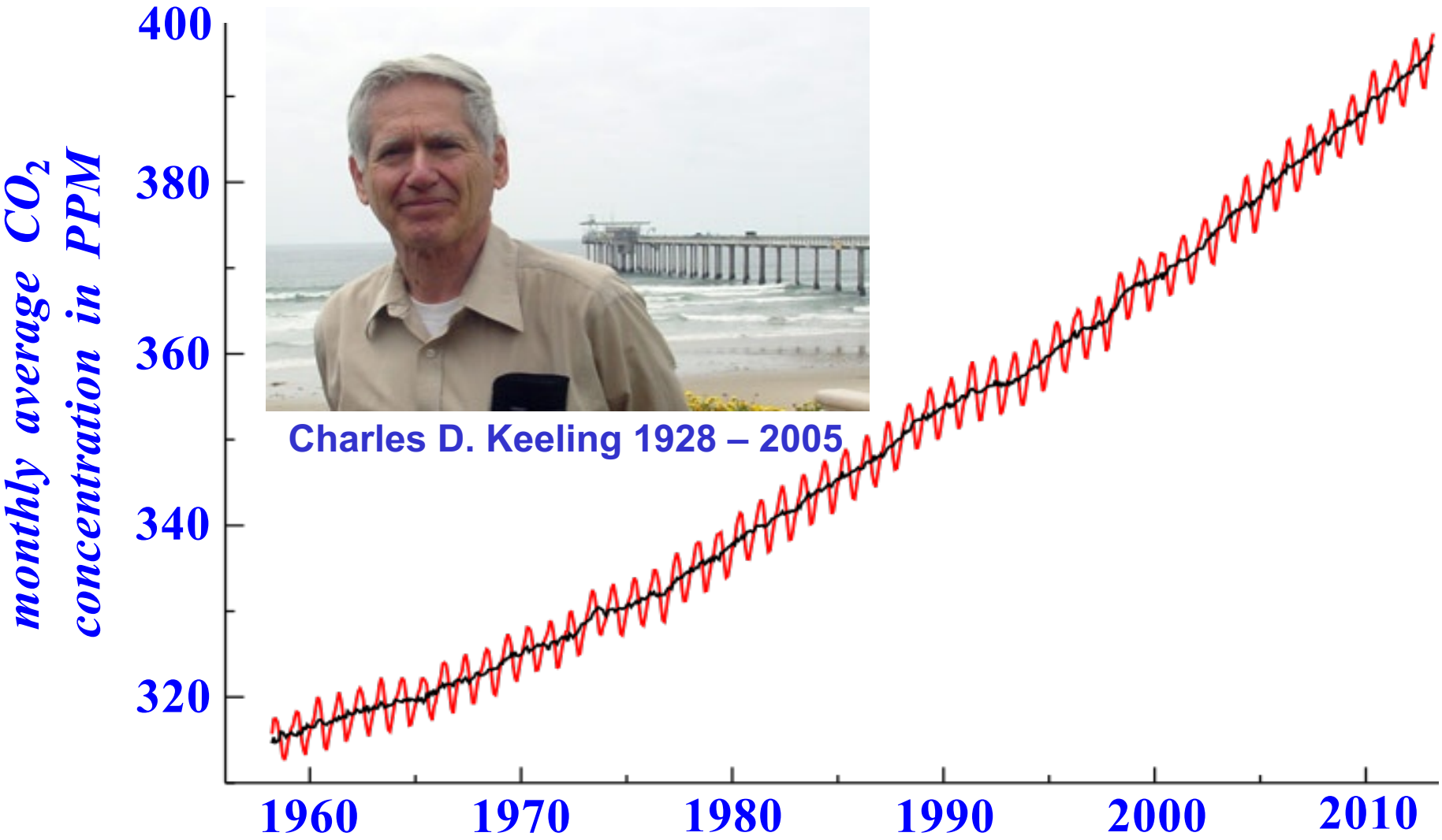
GLOBAL MEAN TEMPERATURE



the change over the period* 1860-2000 *is about* 0.7 ° *C

Source: IPCC Fourth Assessment Report

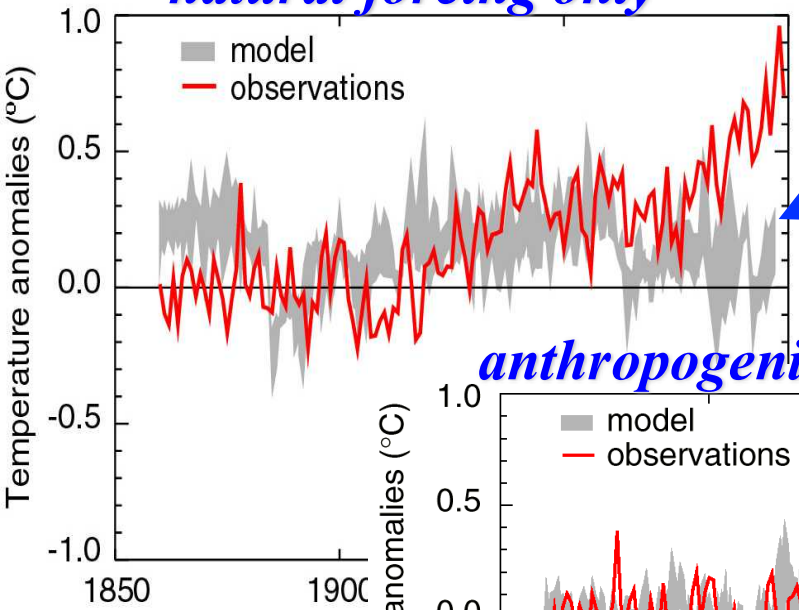
KEELING CURVE



Source: Mauna Loa Observatory, Hawaii

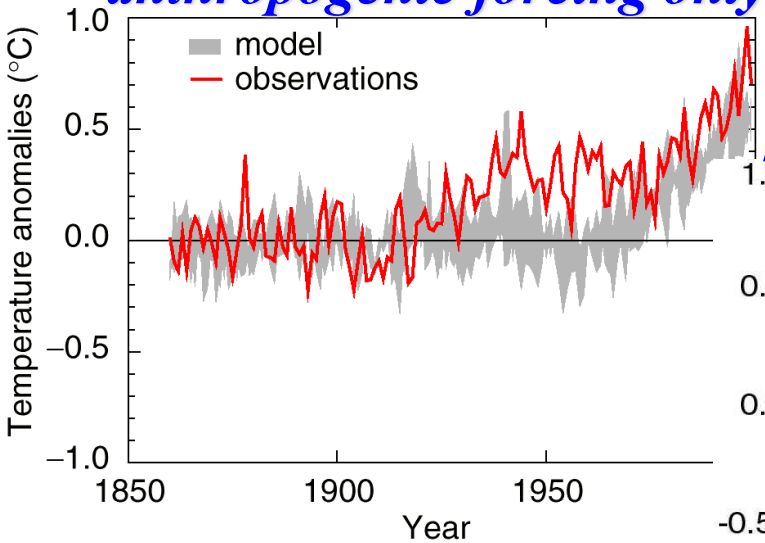
COMPELLING EVIDENCE

natural forcing only

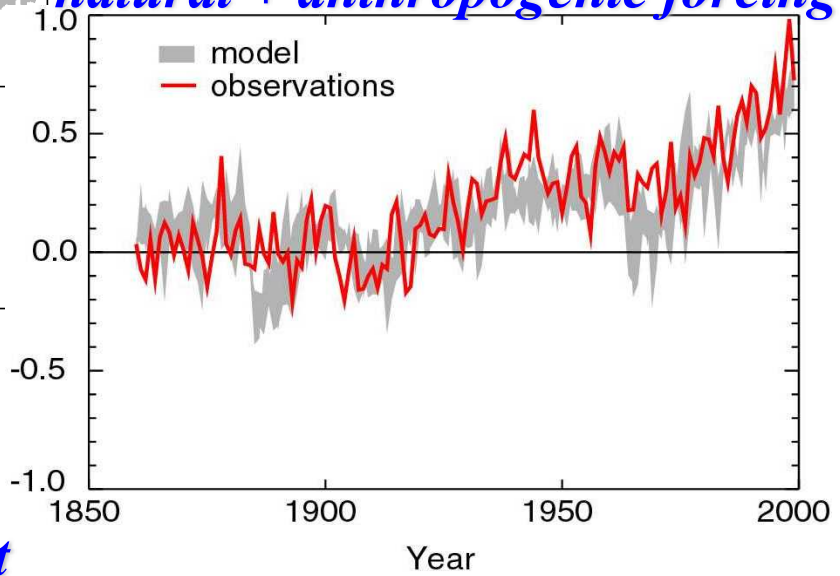


natural (solar + volcanic) forcing alone does not account for warming in the past 50 years

anthropogenic forcing only

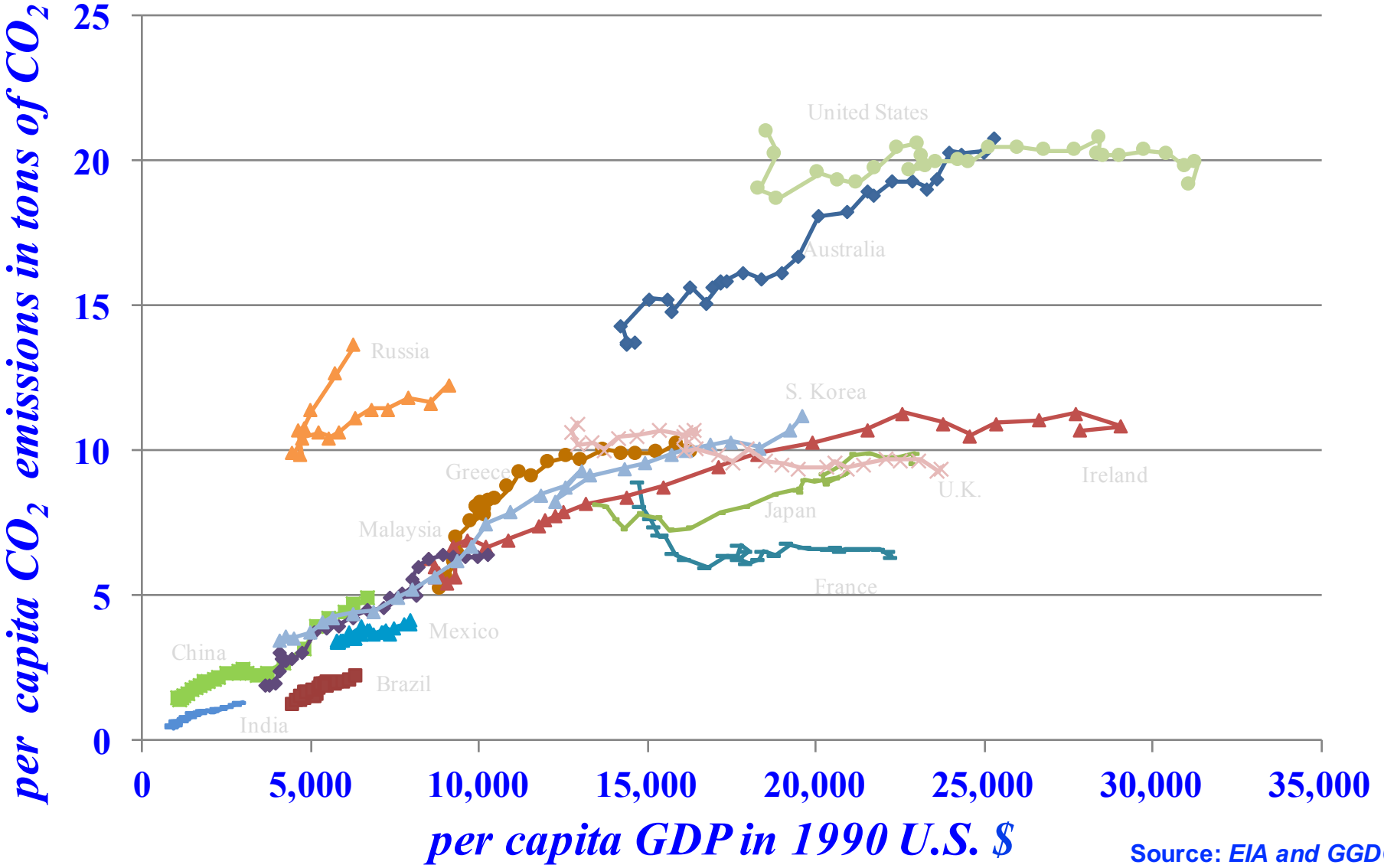


natural + anthropogenic forcing



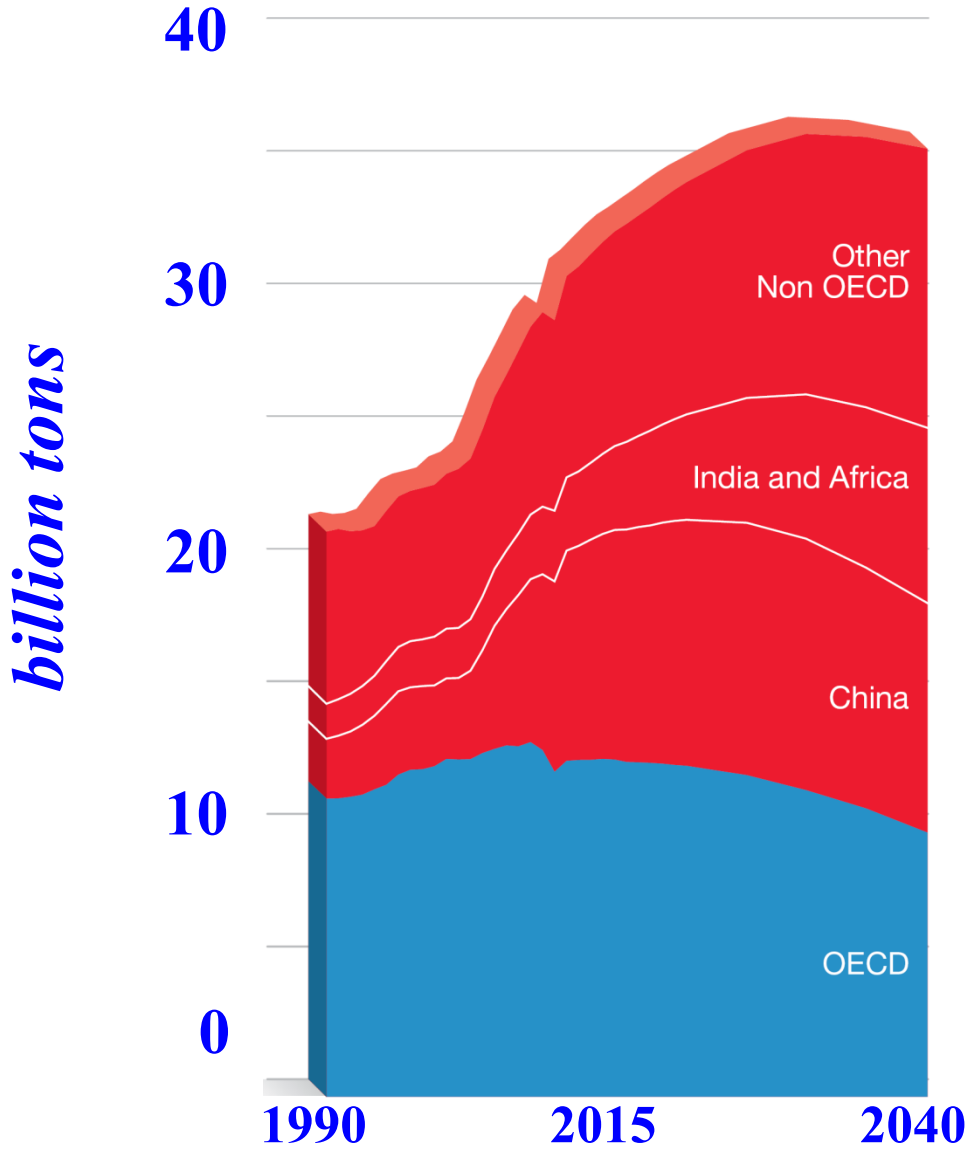
adding human influences (greenhouse gases + sulfate aerosols) brings the models and observations into pretty close agreement

1980 – 2008 CO_2 EMISSIONS VS. *GDP PER CAPITA*



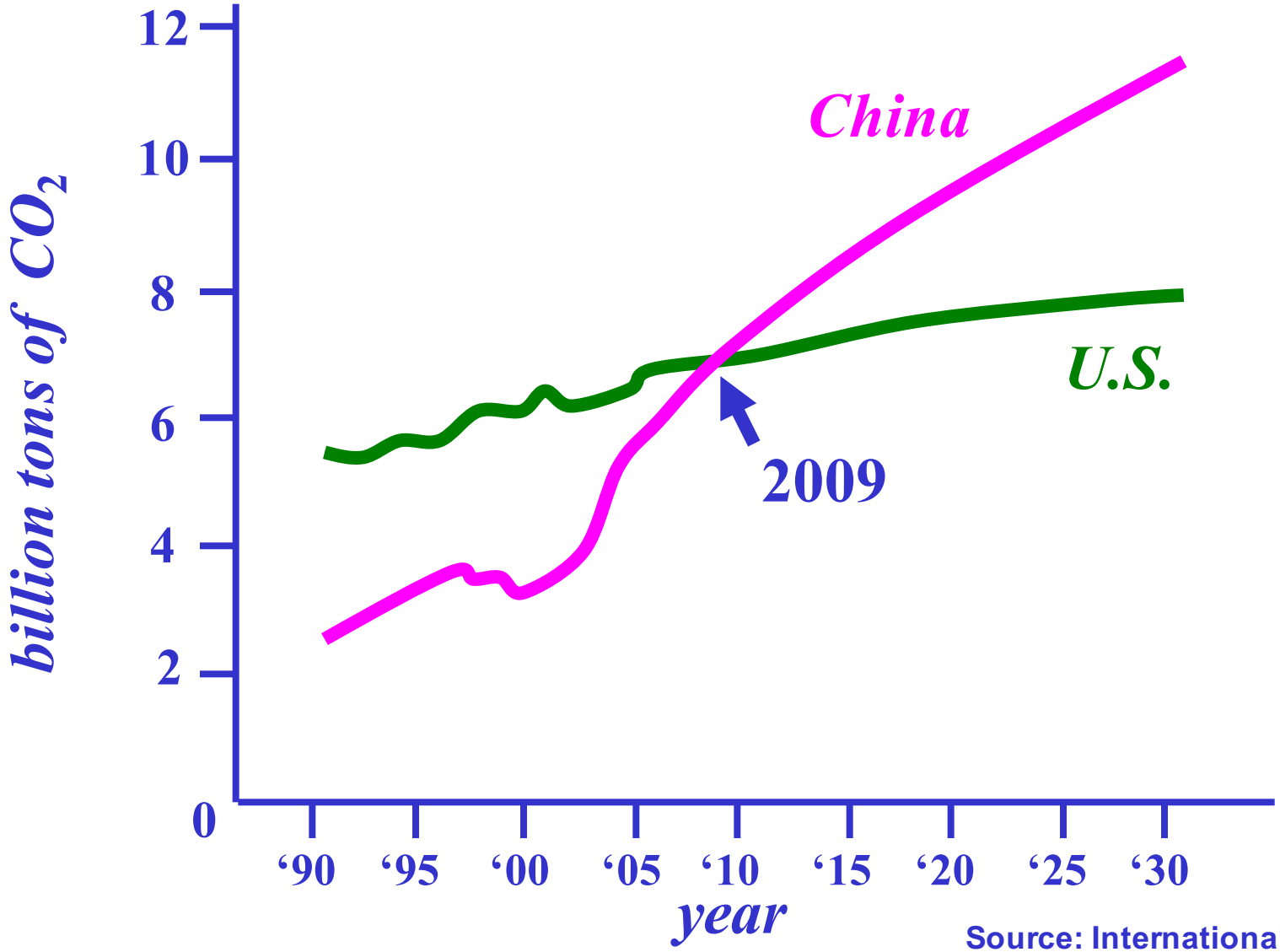
Source: *EIA and GGDC*

CO_2 EMISSIONS FORECAST



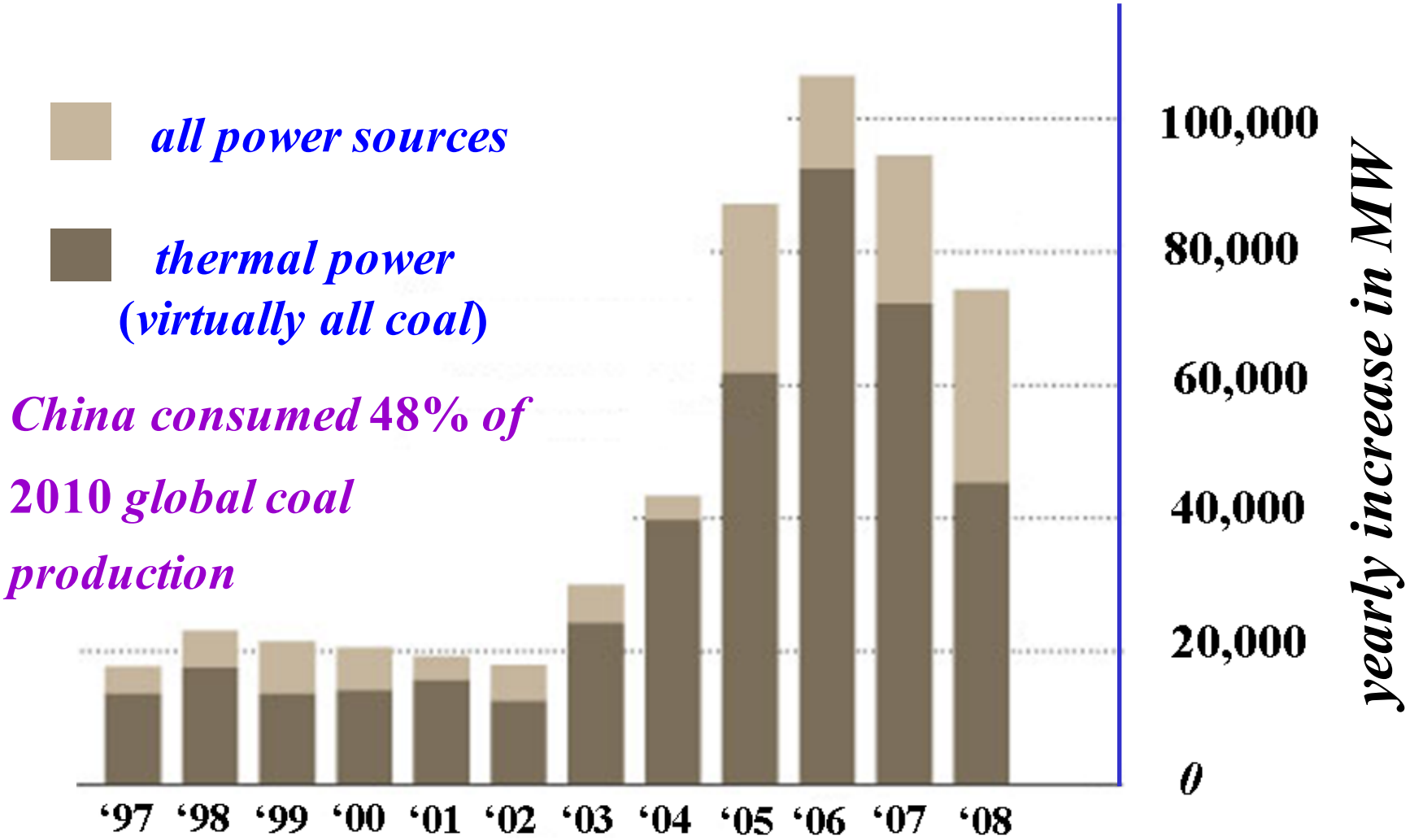
Source: The Outlook for Energy: A View to 2040, pg. 34

EMISSION HETEROGENEITIES



Source: International Energy Agency

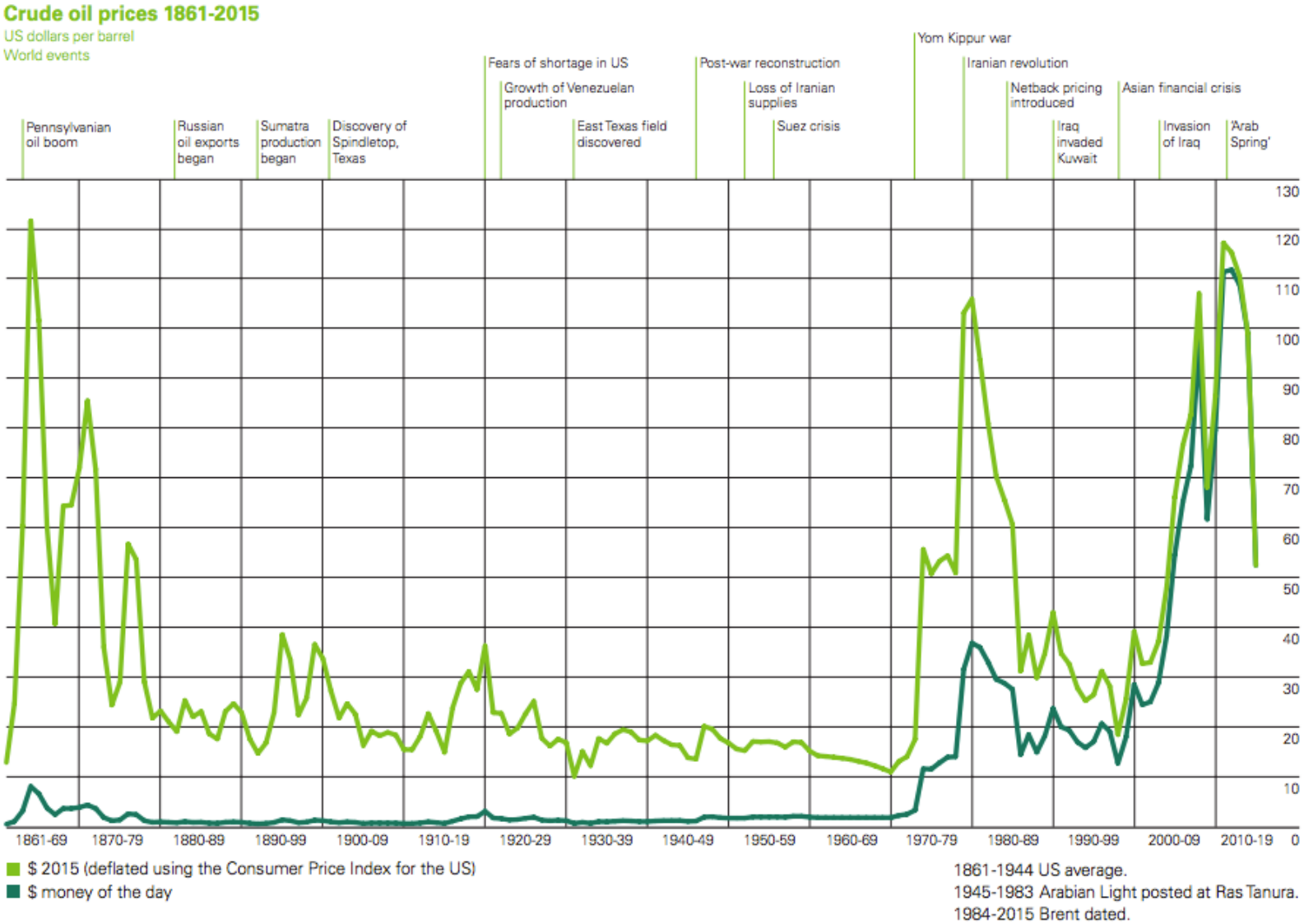
CHINA GENERATION CAPACITY



yearly increase in power generating capacity

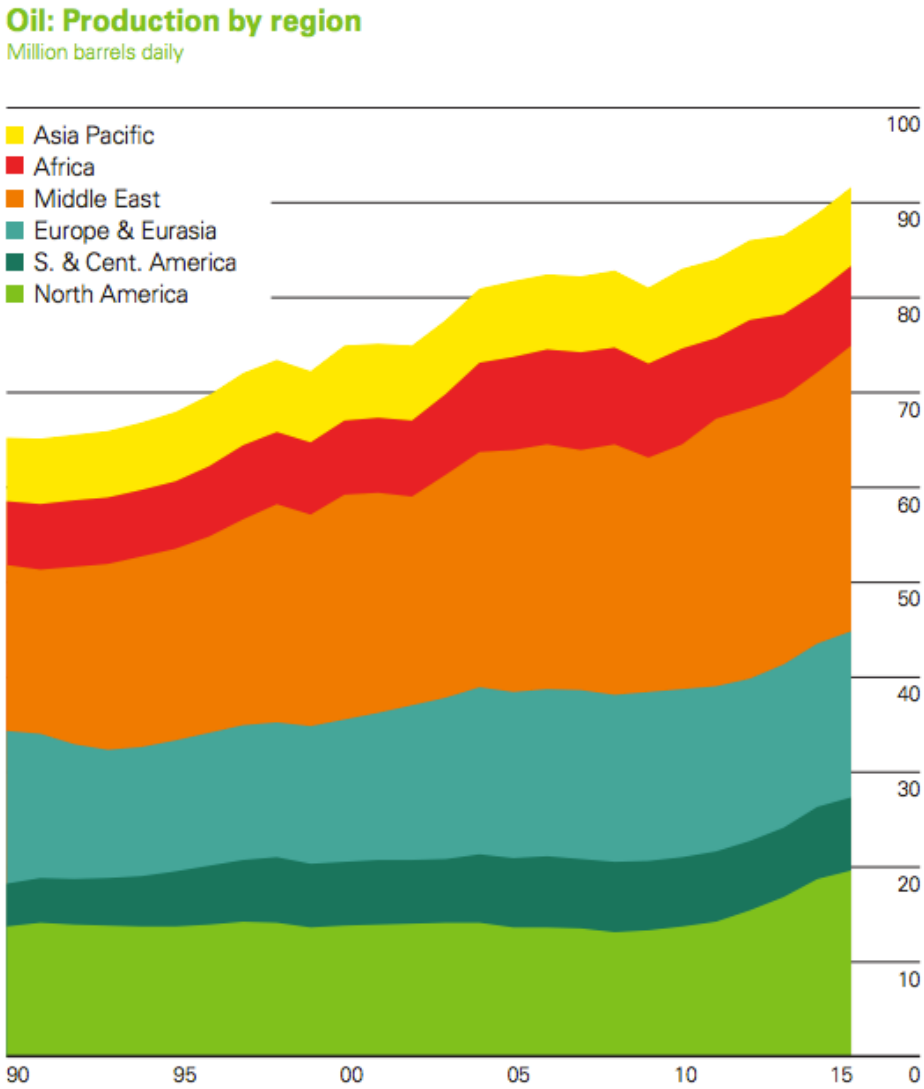
Sources: NYT article using China National Bureau of Statistics data; BP Statistical Review of World Energy 2011, pg. 5

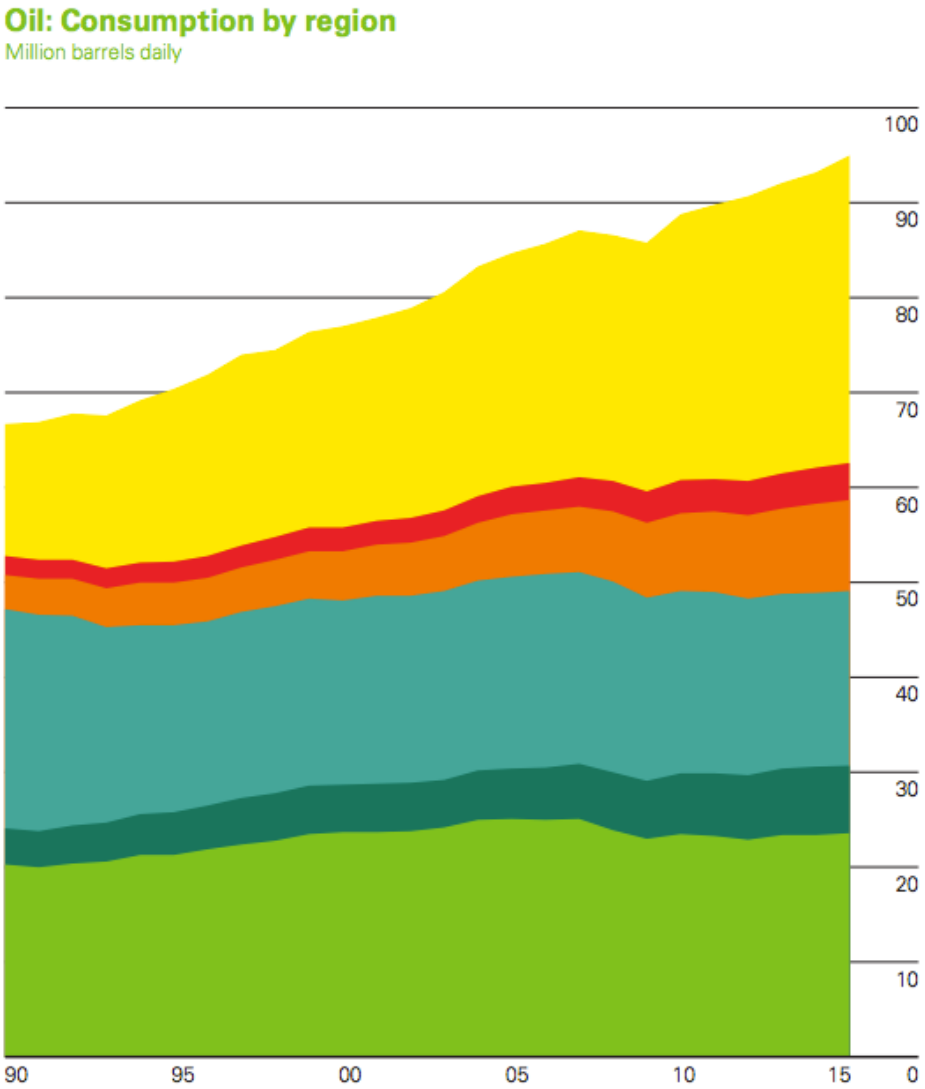
CRUDE OIL PRICES 1861- 2015



Source: BP Statistical Review of World Energy 2016, pg. 15

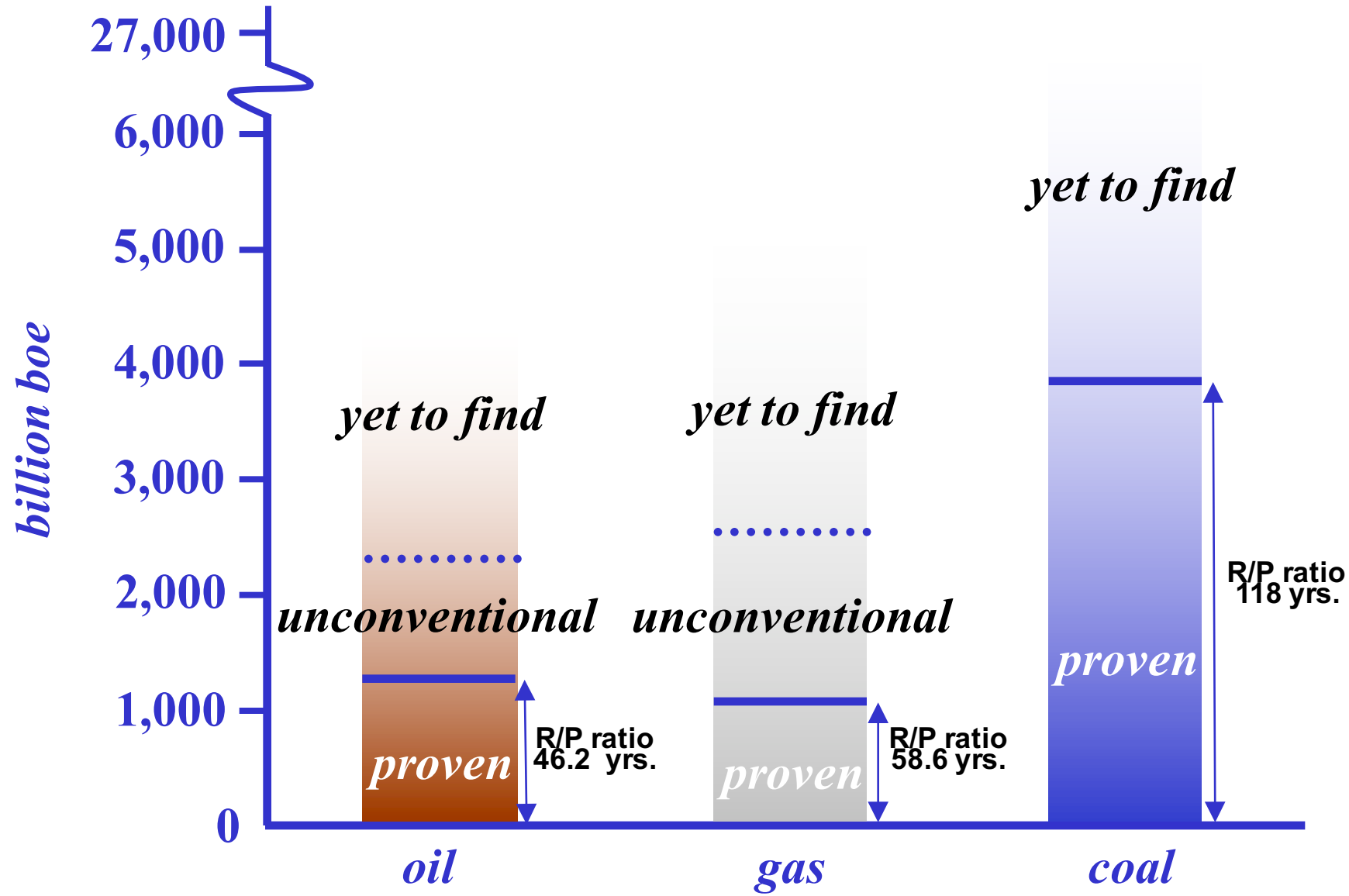
ANNUAL WORLD OIL PRODUCTION





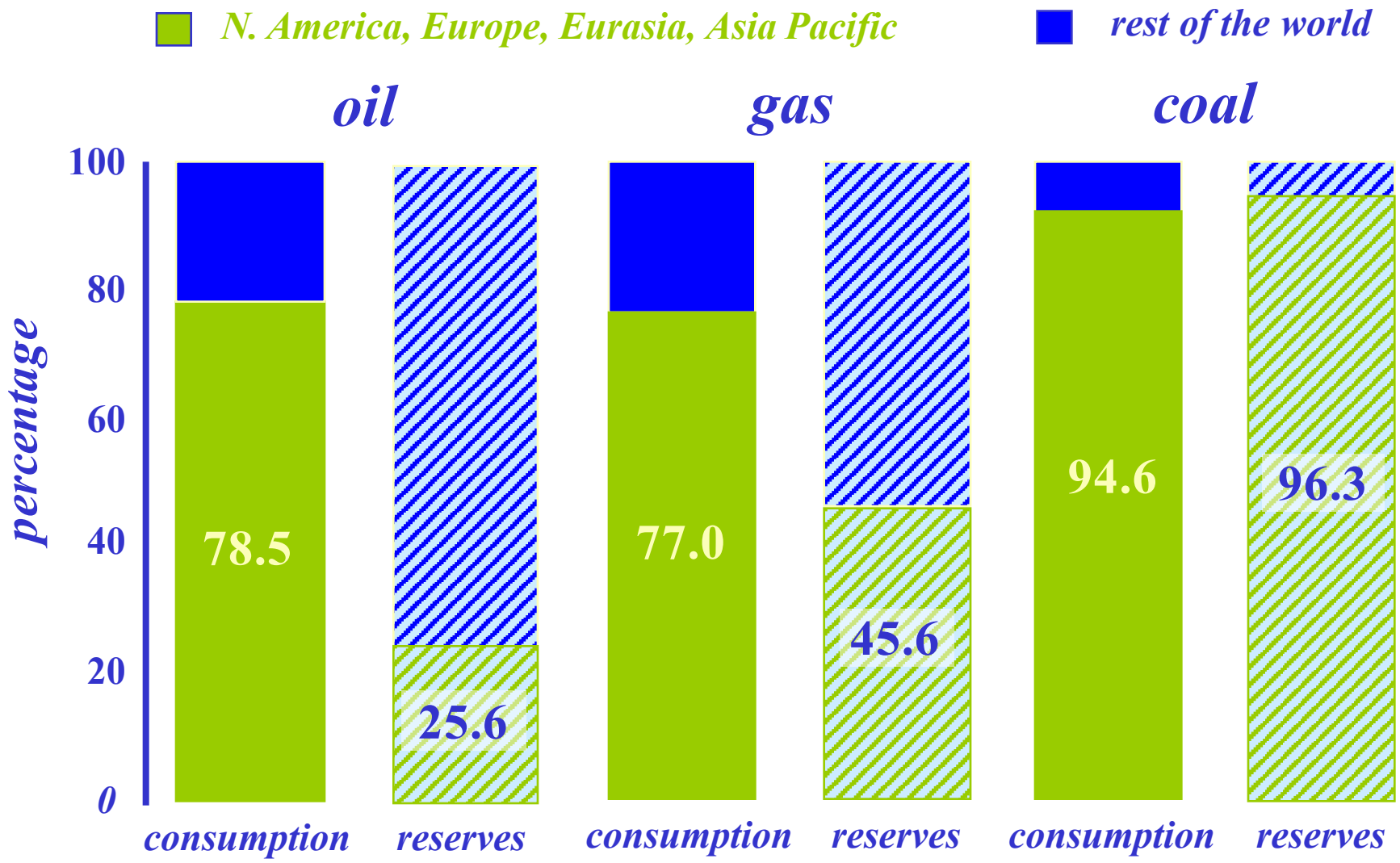
Source: BP Statistical Review of the World 2016

GLOBAL FOSSIL RESOUCE RESERVES



Source: World Energy Assessment, 2001; HIS; WoodMackenzie; BP Statistical Review, 2011

MISALIGNMENT OF SUPPLY AND DEMAND



Source: BP Statistical Review of World Energy, 2016

MAJOR CHALLENGES IN ENERGY

- **Energy security**: fuel supply resources for the future
- **Economic growth**: accommodation of the developing nations' needs
- **Environmental effects**: global warming and emission control
- **Electricity system reliability**: assurance of integrity of electric power infrastructure

SUSTAINABILITY

- Sustainable development refers to living, production and consumption in a manner and at a level that meets the needs of the present without unduly impacting the ability of future generations to meet their own needs
- The World Commission on Environment and Development set up by the *UN* issued a seminal report in 1987; the so-called Brundtland Report entitled *Our Common Future* established the concept and

SUSTAINABILITY

definition of sustainable development:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- *the concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and*
- *the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs."*

SUSTAINABILITY

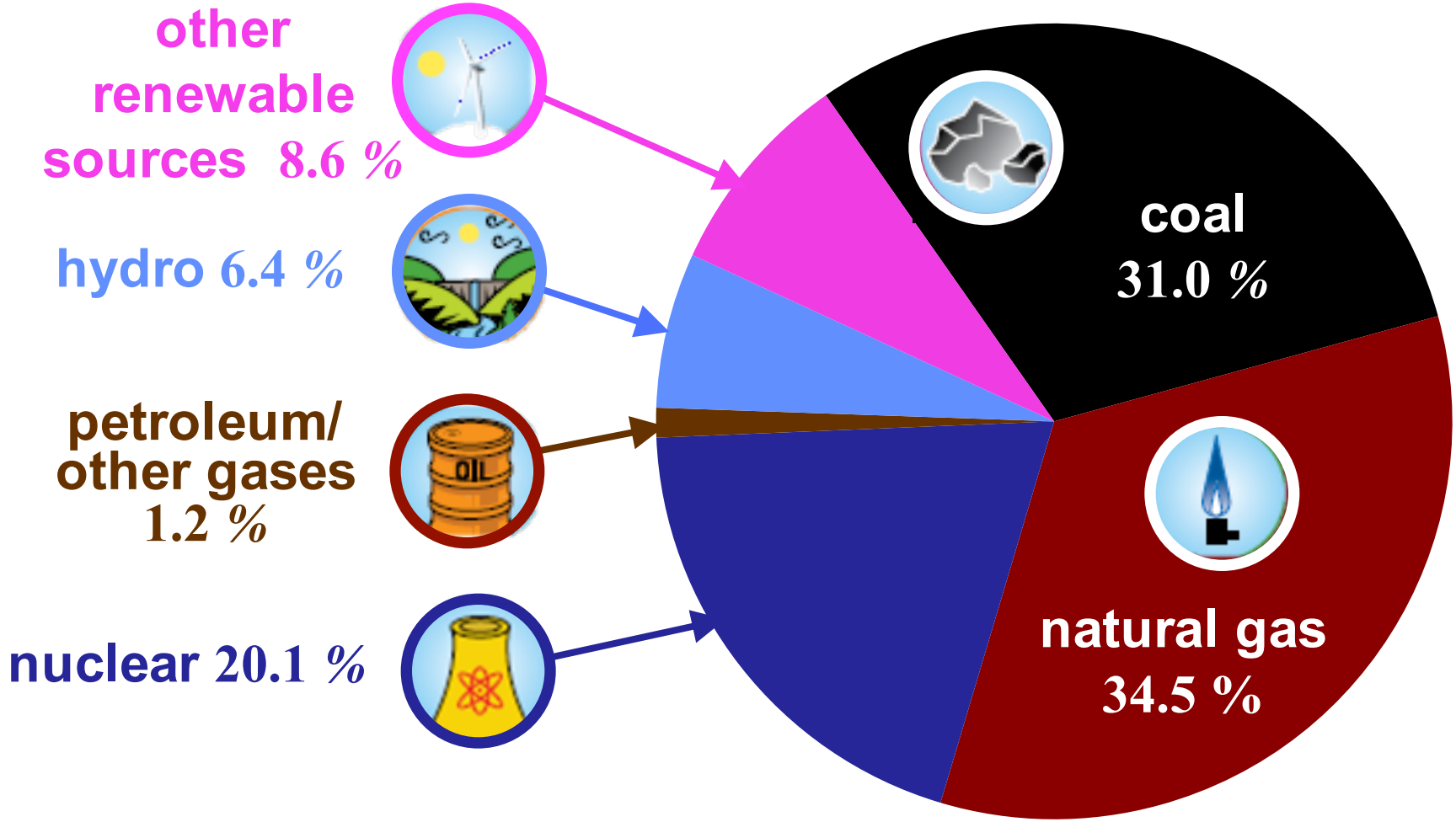
- The major thrust of the report was to explicitly recognize the scale and unevenness of economic development and population growth continue to place unprecedented pressures on the planet's land, water and other natural resources and without constraints are severe enough to wipe out regional populations and, over the long term, to lead to global catastrophes
- Sustainability is a key guiding principle in policy formulation in many nations, states and localities

ROLE OF RENEWABLES IS OF GROWING IMPORTANCE



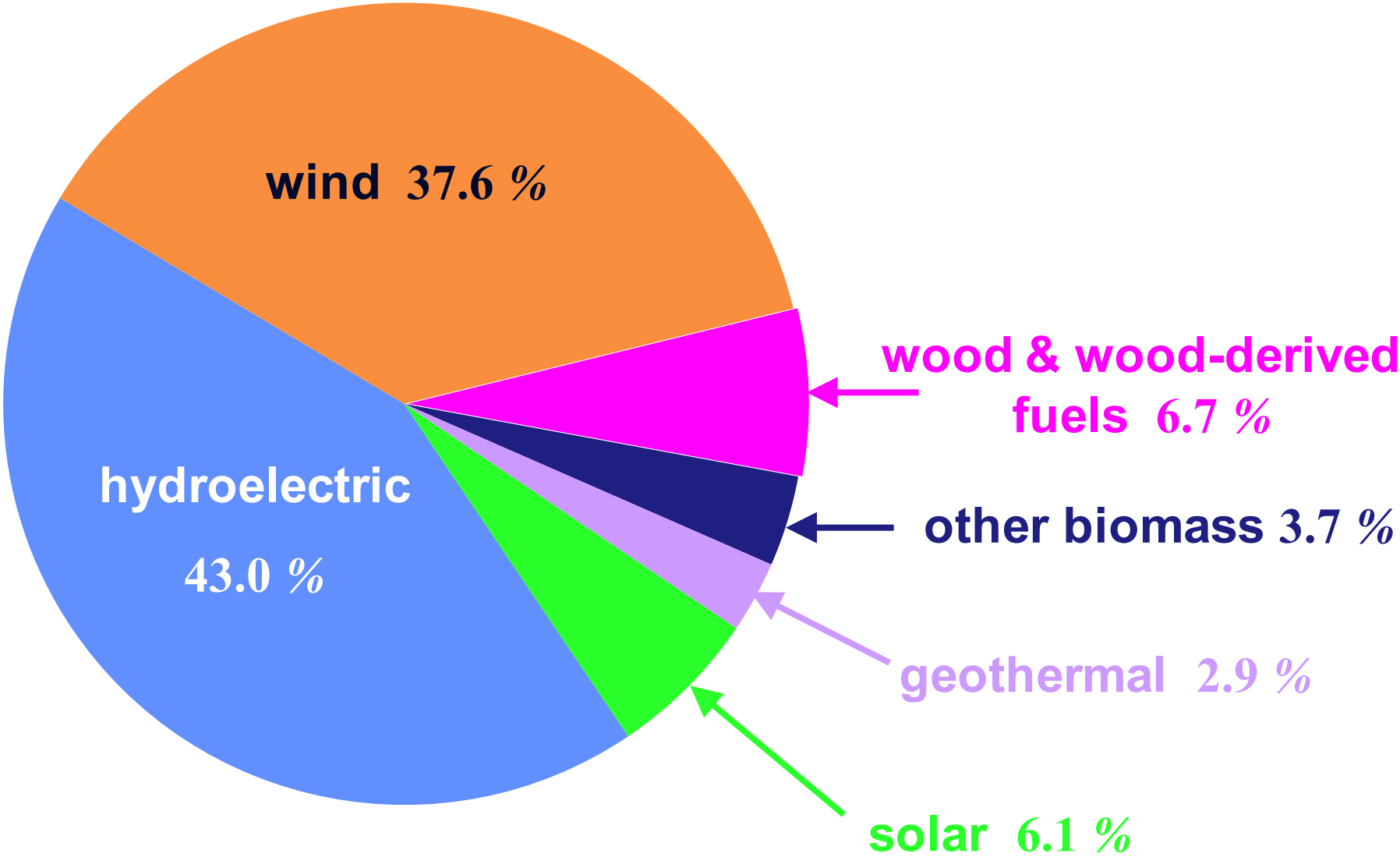


2016 GENERATION BY SOURCE



Source: http://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf; issued March, 2016

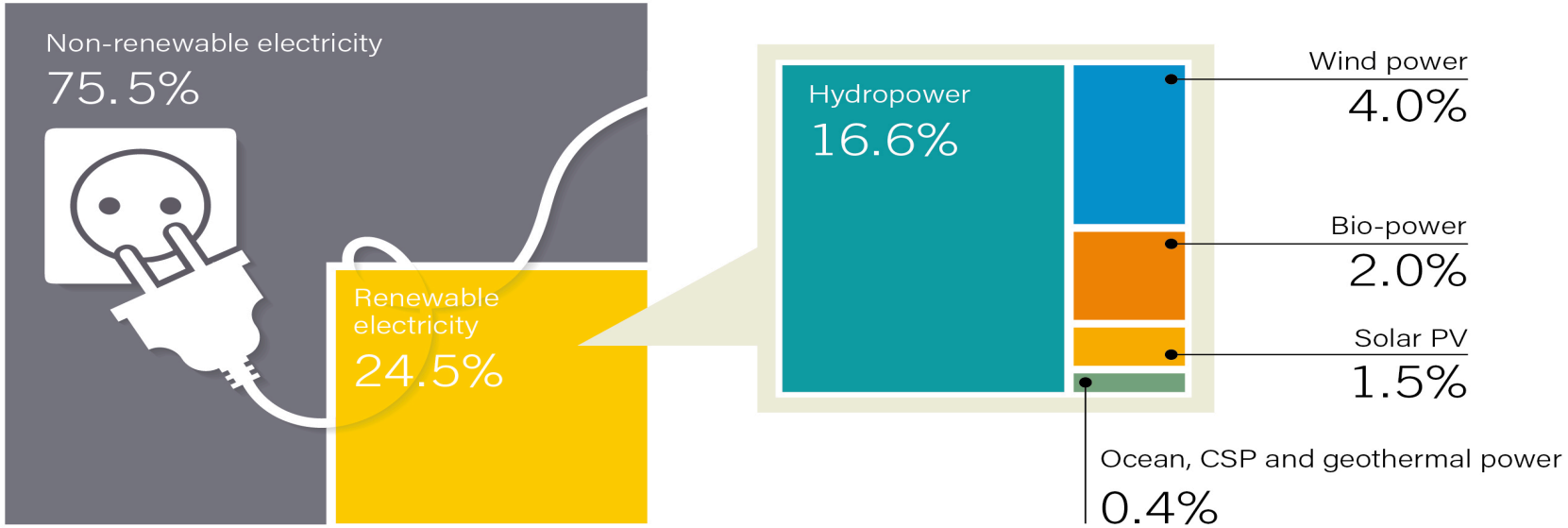
2016 NET GENERATION OF RENEWABLE ENERGY SOURCES



Source: http://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf; issued March, 2017

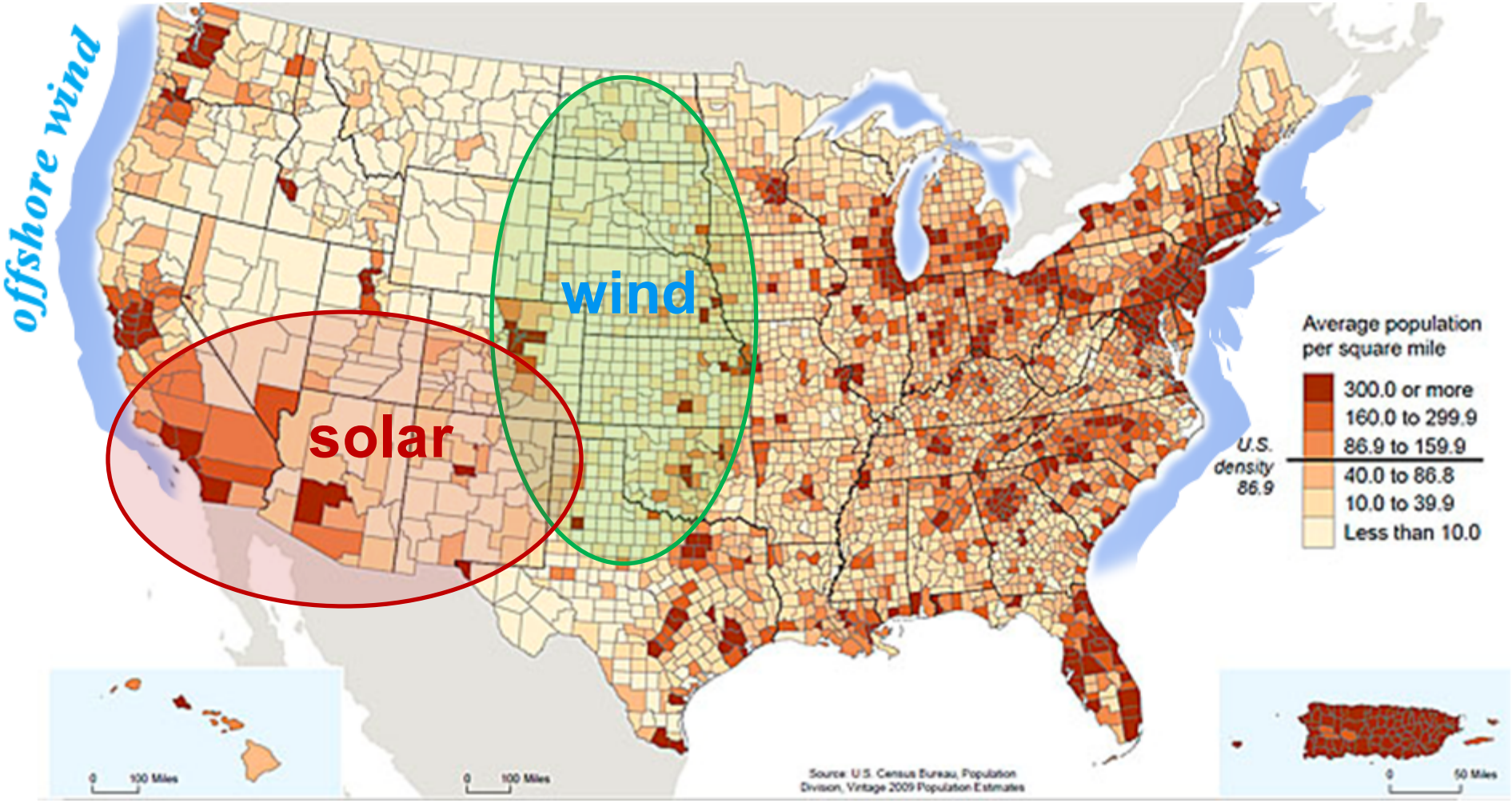
2016 RENEWABLE ENERGY SHARE OF GLOBAL ELECTRICITY GENERATION

Estimated Renewable Energy Share of Global Electricity Production, End-2016



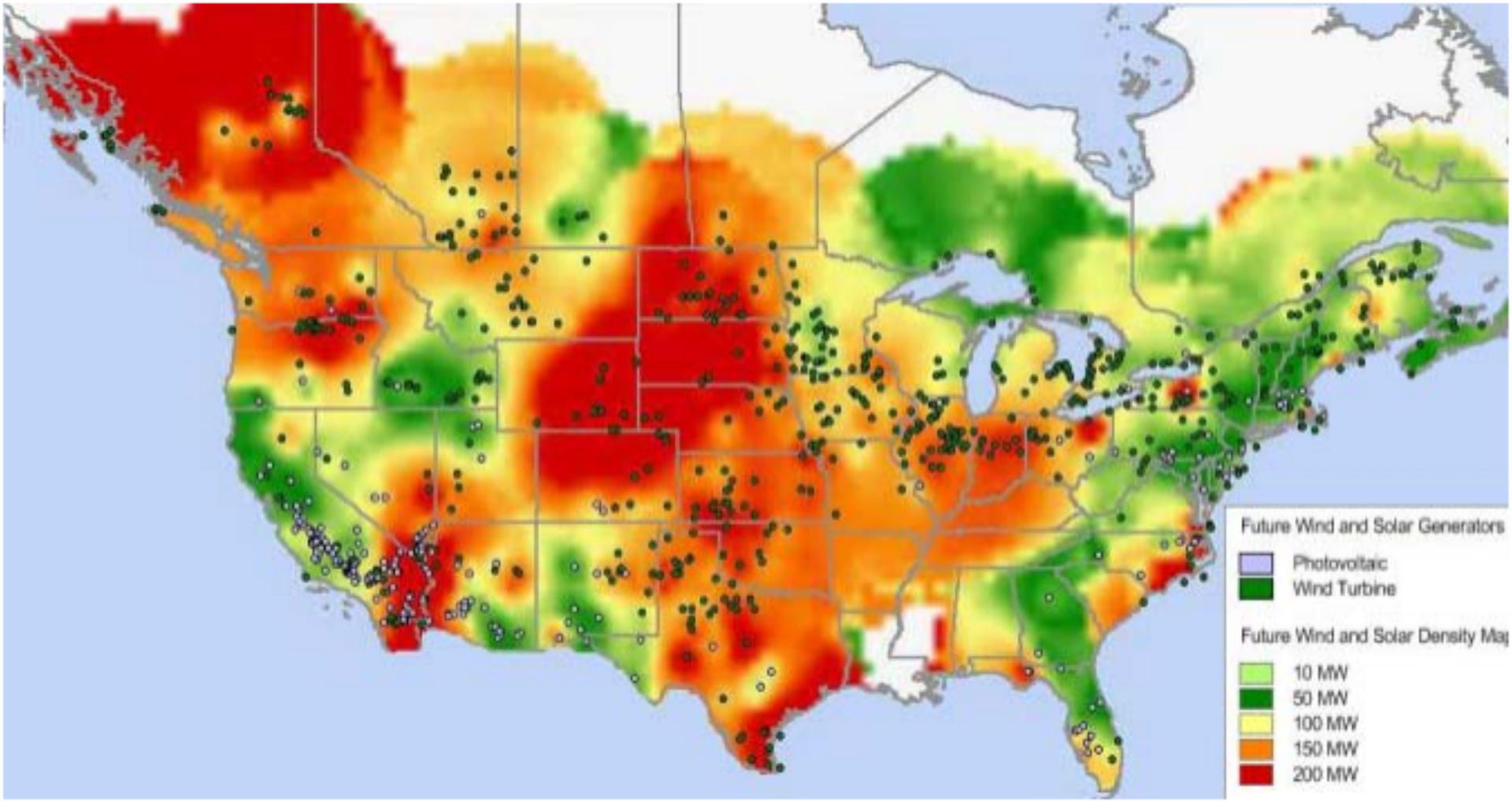
REN21 *Renewables 2017 Global Status Report*

US POPULATION DENSITY AND RENEWABLE RESOURCE LOCATIONS



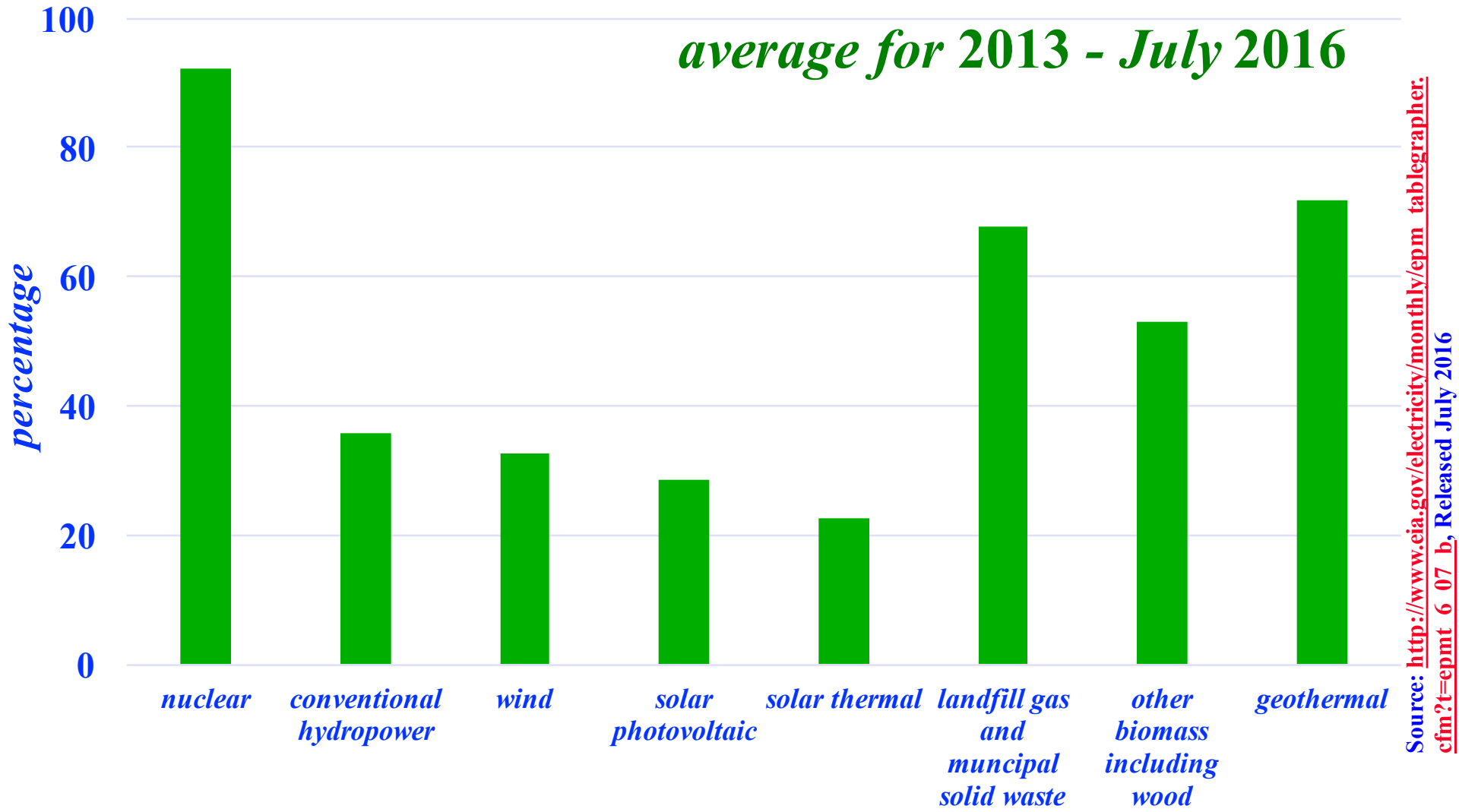
Source: http://www.census.gov/popest/data/maps/2009/PopDensity_09.jpg

DENSITY MAP OF FUTURE WIND AND SOLAR INSTALLED CAPACITY ADDITIONS

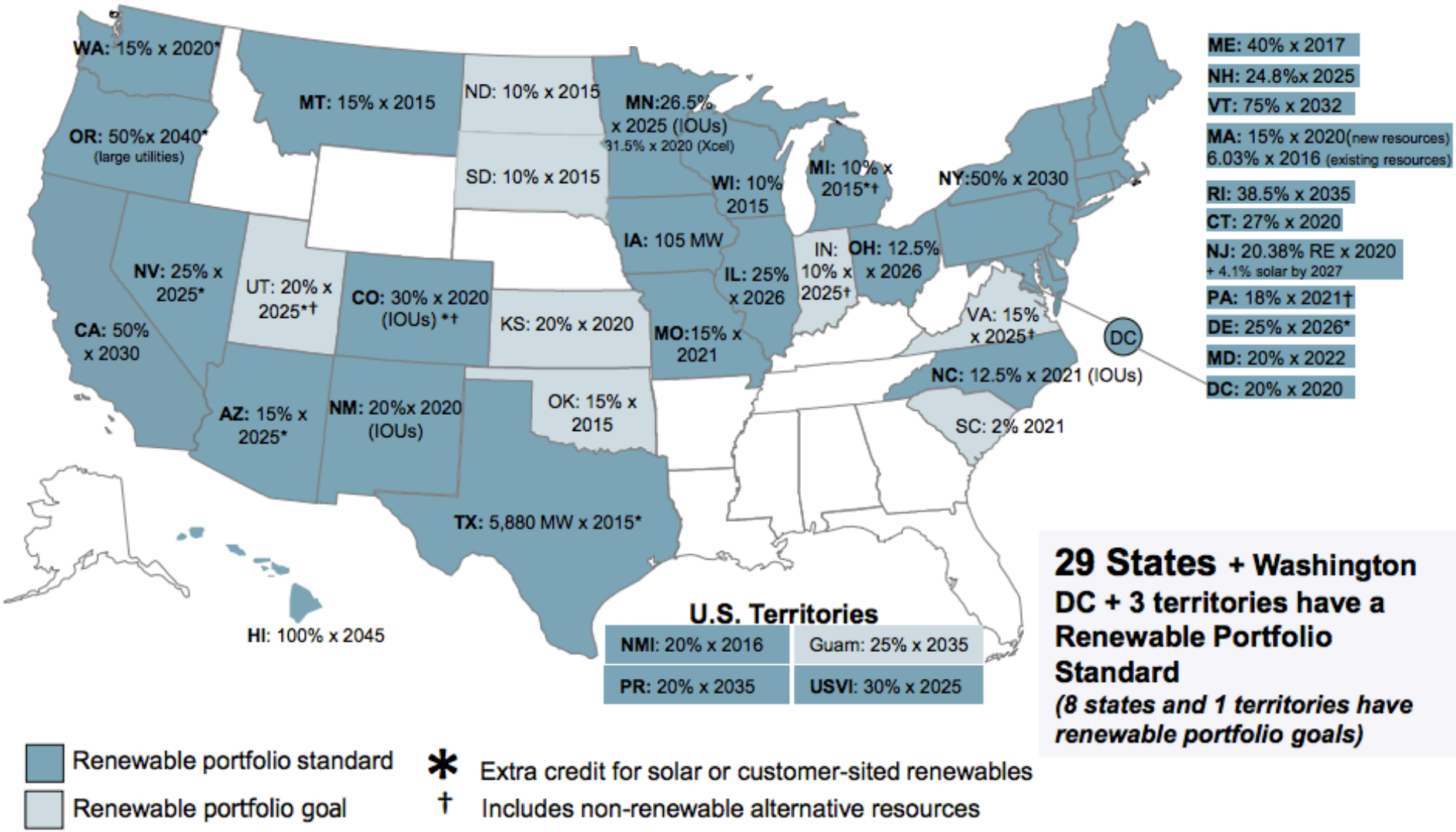


Source: NERC, LTRA 2012 http://www.nerc.com/files/2012_LTRA_FINAL.pdf; Issued November 2012

RENEWABLE ELECTRICITY CAPACITY FACTORS BY SOURCE

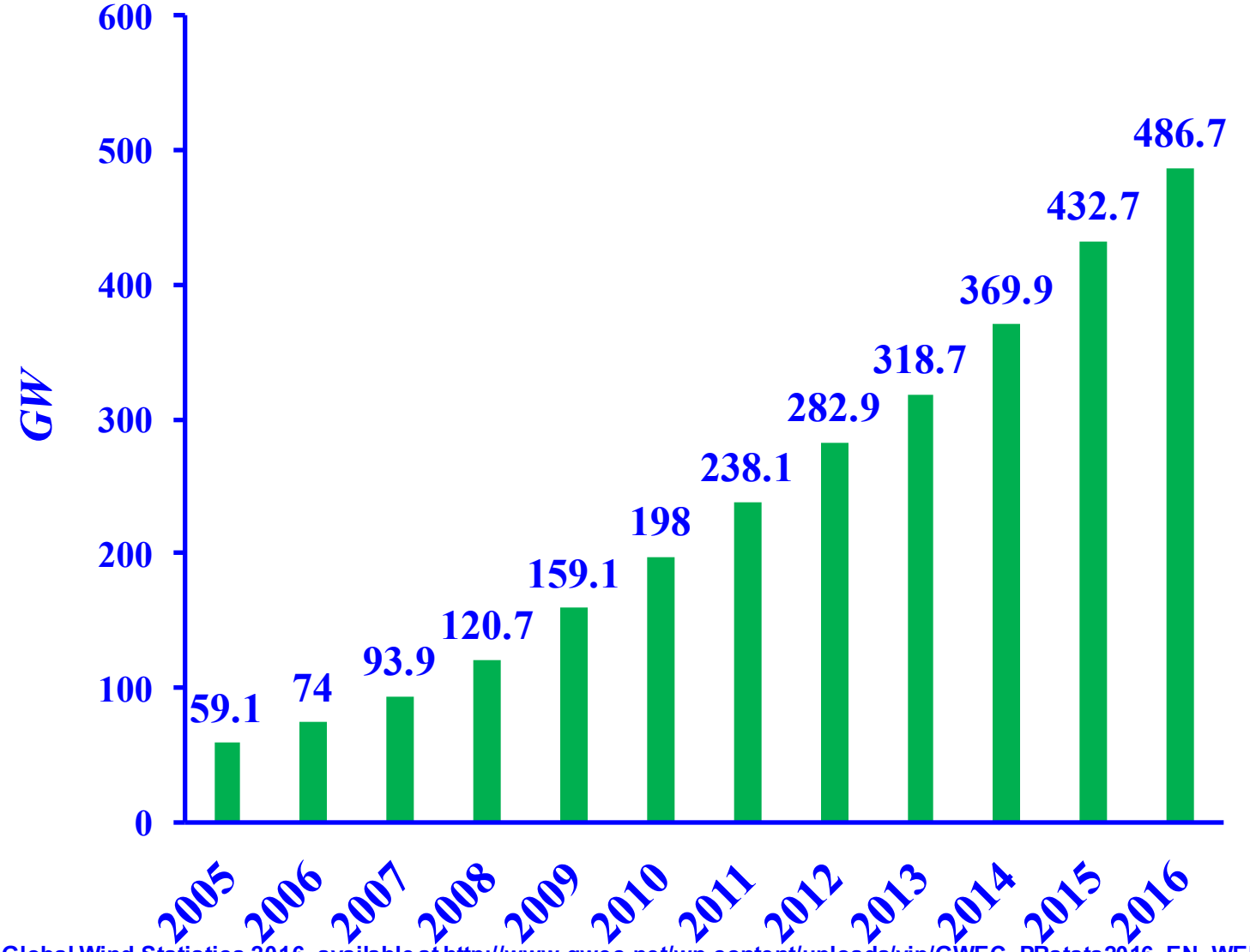


RENEWABLE PORTFOLIO STANDARDS (RPS)



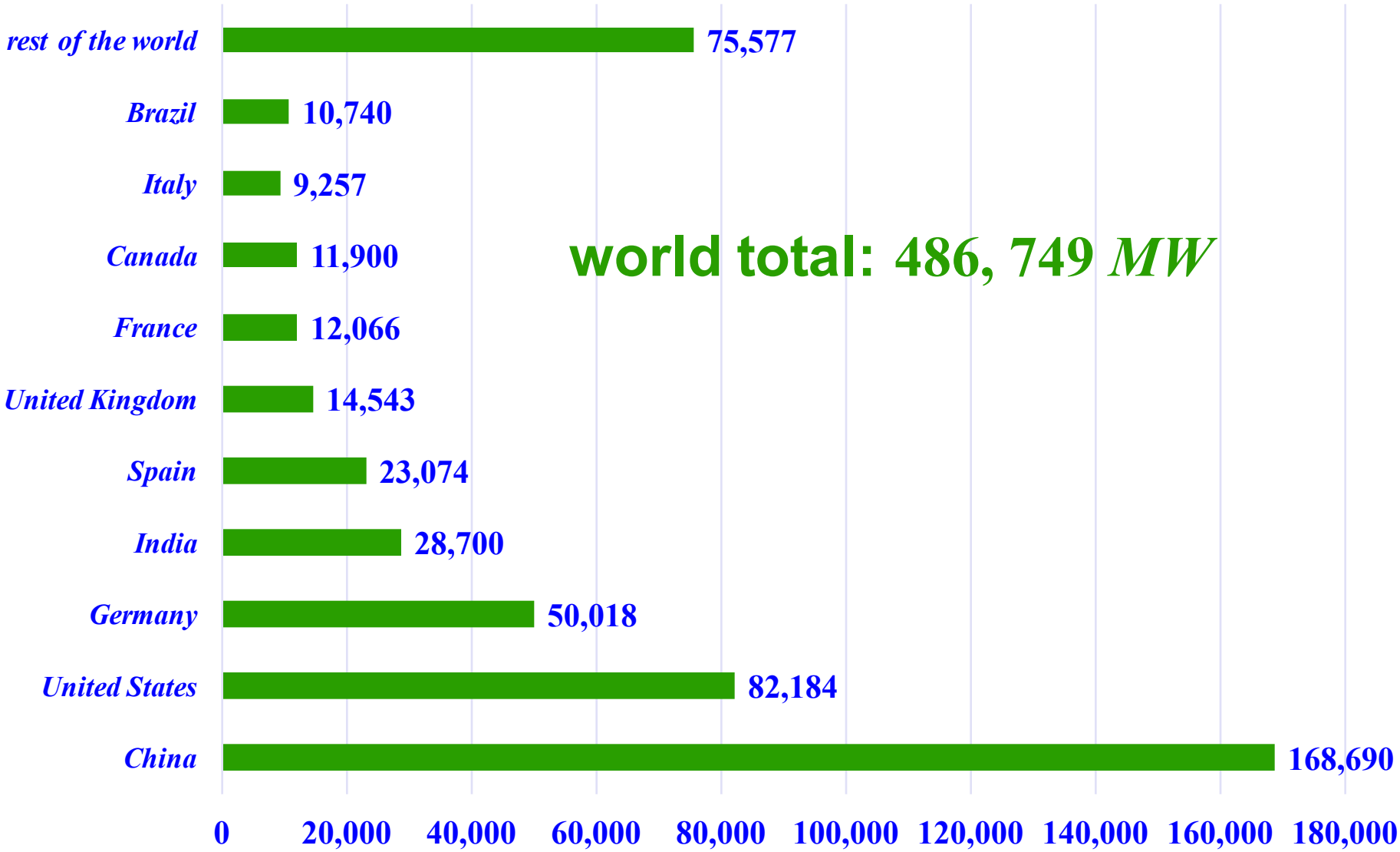
Source: http://www.dsireusa.org/resources/detailed-summary-maps/; February 2017

2005 – 2016 GLOBAL WIND CAPACITY



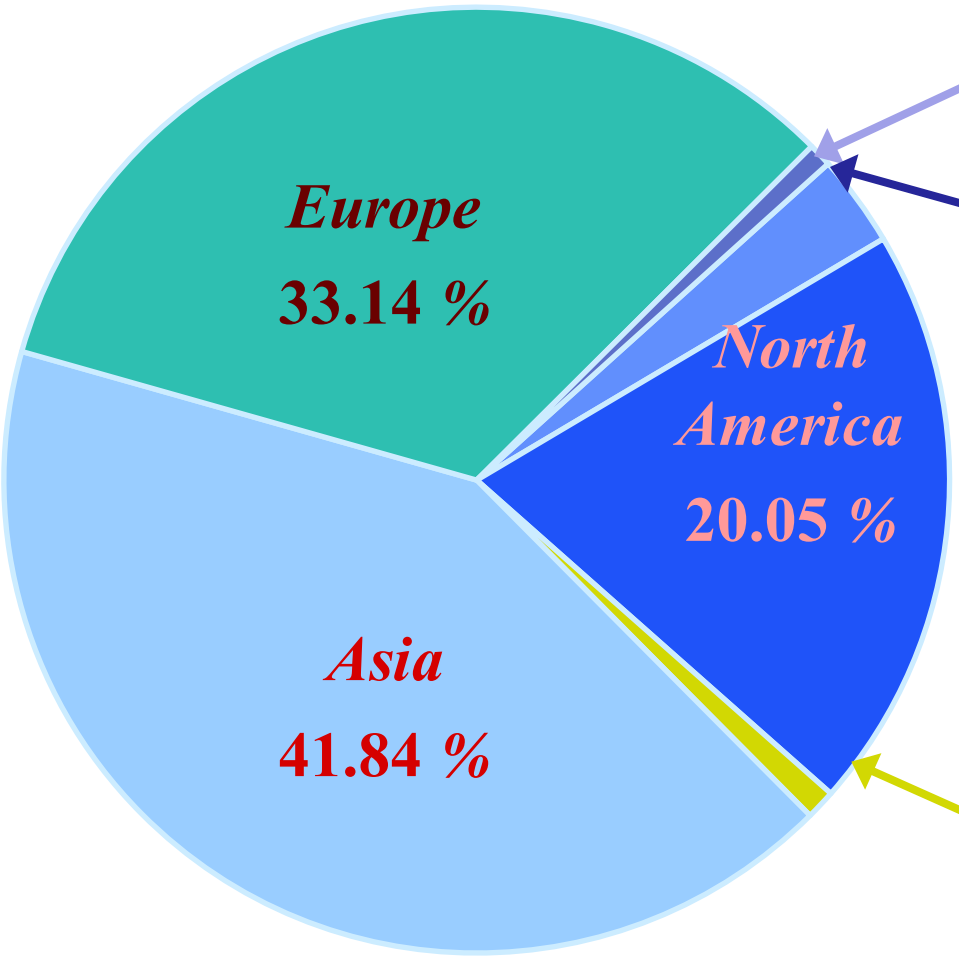
Source: GWEC Global Wind Statistics 2016, available at http://www.gwec.net/wp-content/uploads/vip/GWEC_PRstats2016_EN_WEB.pdf

2016 INSTALLED WIND CAPACITY: TOP 10 COUNTRIES



Source: GWEC Annual Report 2016, http://www.gwec.net/wp-content/uploads/vip/GWEC PRstats2016 EN WEB.pdf

2016 INSTALLED WIND CAPACITY

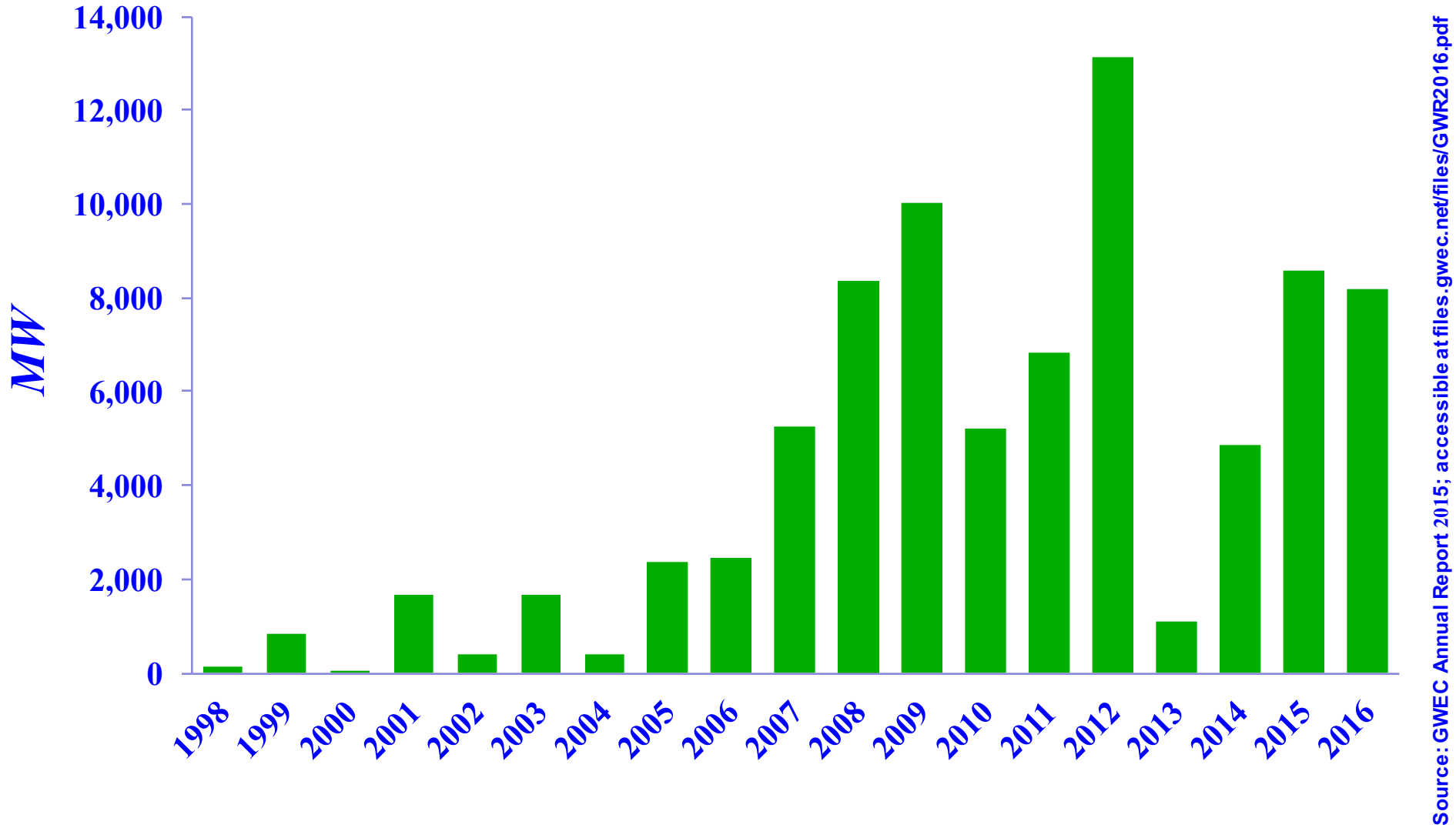


total installed capacity: 486, 749 *MW*

Source: GWEC Annual Report 2015; accessible at files.gwec.net/files/GWR2016.pdf

WIND FARMS

1998 –2016 INSTALLED *US* WIND CAPACITY ADDITIONS



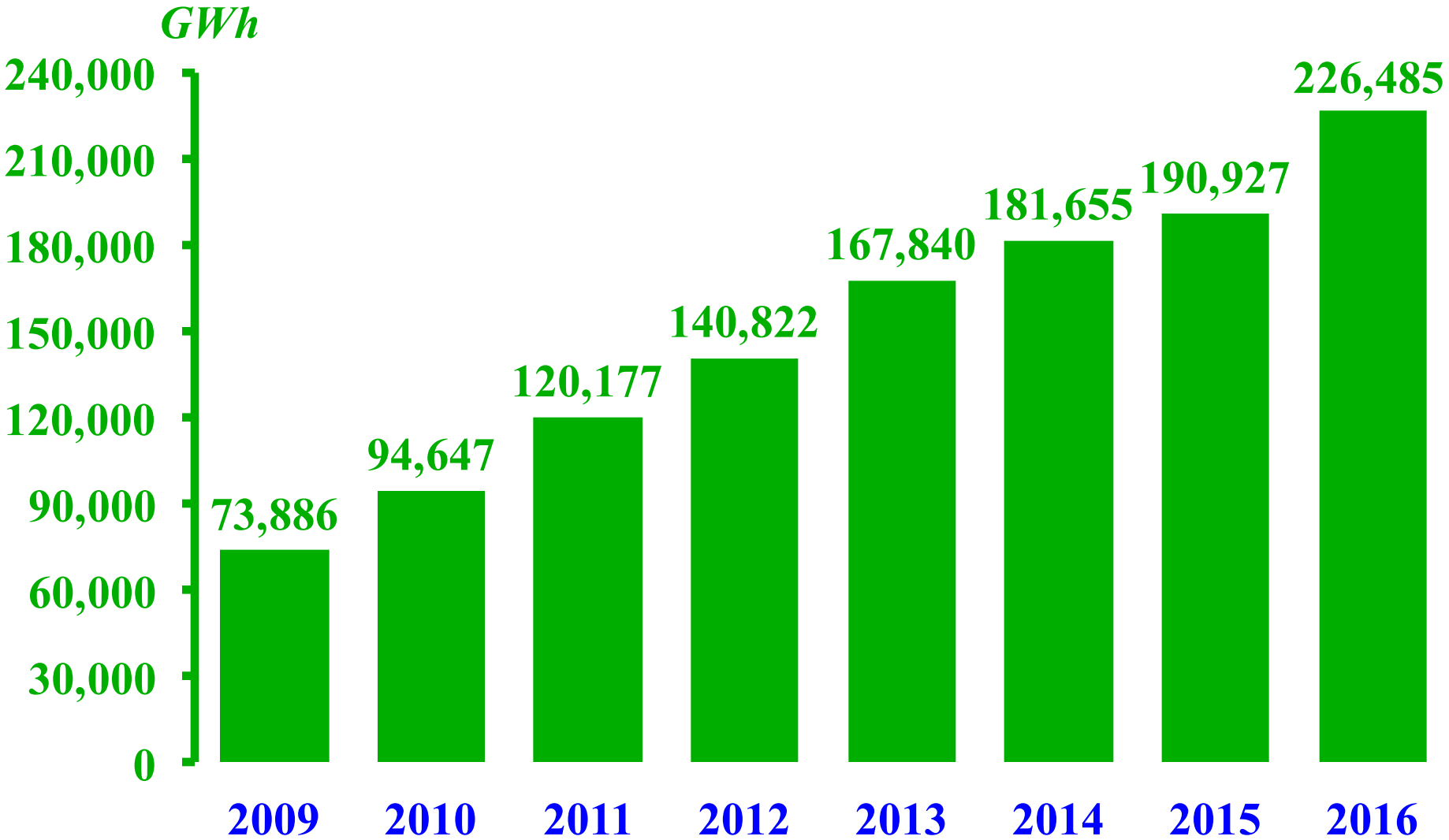
US WIND DEVELOPMENTS IN 2016

- Installed power capacity exceeded the *US* hydro capacity in 2016 so as to make wind the largest capacity *RER* with 52,000 turbines
- Added wind capacity in 2016 was 8,203 *MW*
- Total installed wind capacity in 2016 is 82,143 *MW*
- The *US* wind industry provides employment to 102,500 persons
- Wind turbine *technician* is the fastest growing job in the *US*

WIND DEVELOPMENTS IN 2016

- In late 2016, *Block Island* – the first offshore *US* wind farm with a 5–turbine 30–*MW* nameplate capacity – began operations off the Rhode Island coast
- Wind generated energy reduced 9 % of electric power energy CO_2 emissions – 159 *million mt* – and saved 87 *billion gallons* of water consumption
- Corporate interest in wind – not driven by *RPS* requirements – continued to remain high

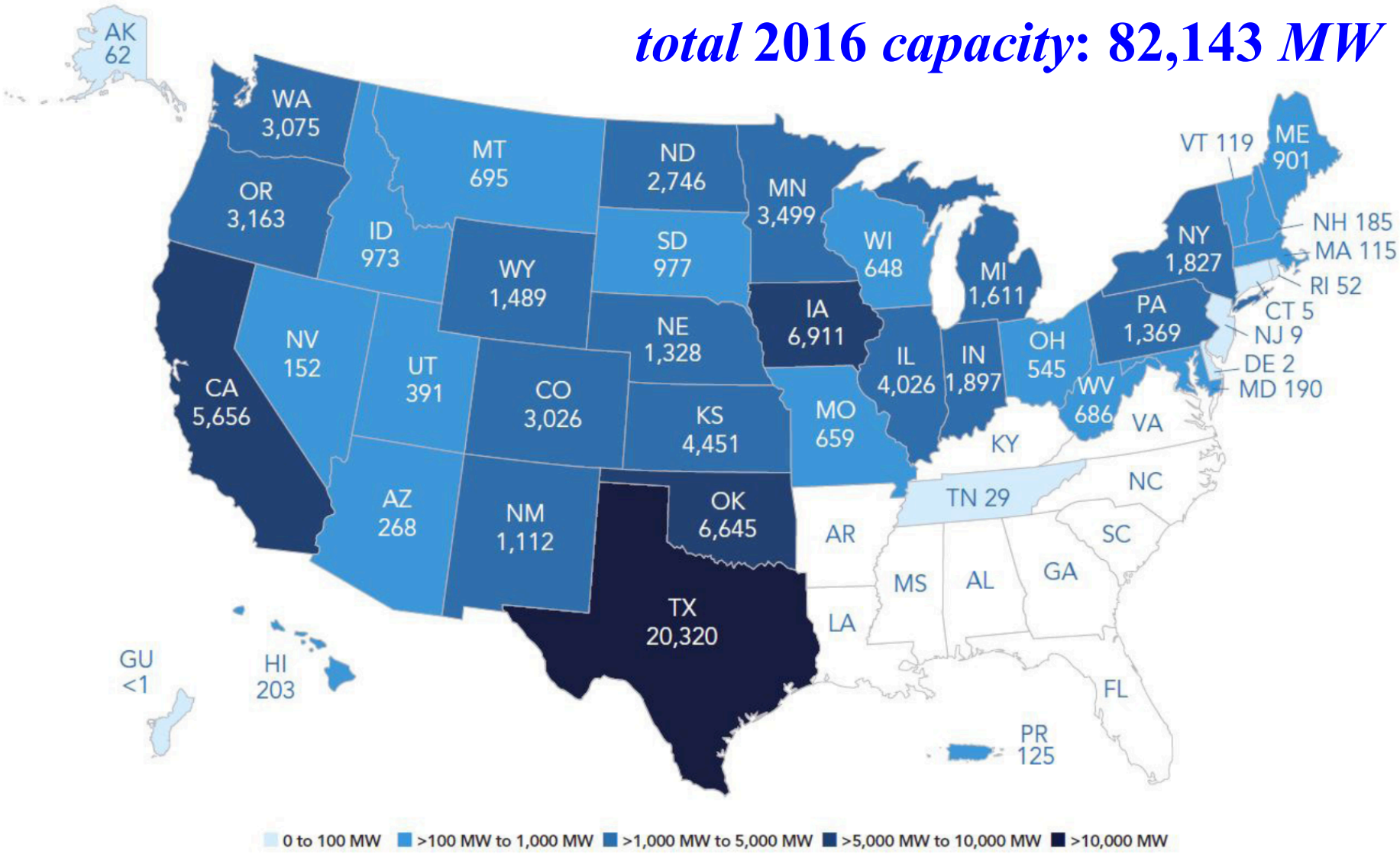
2009 – 2016 *US* WIND POWER ENERGY PRODUCTION



Source: http://www.eia.gov/renewable/data.cfm#wind; February 2016

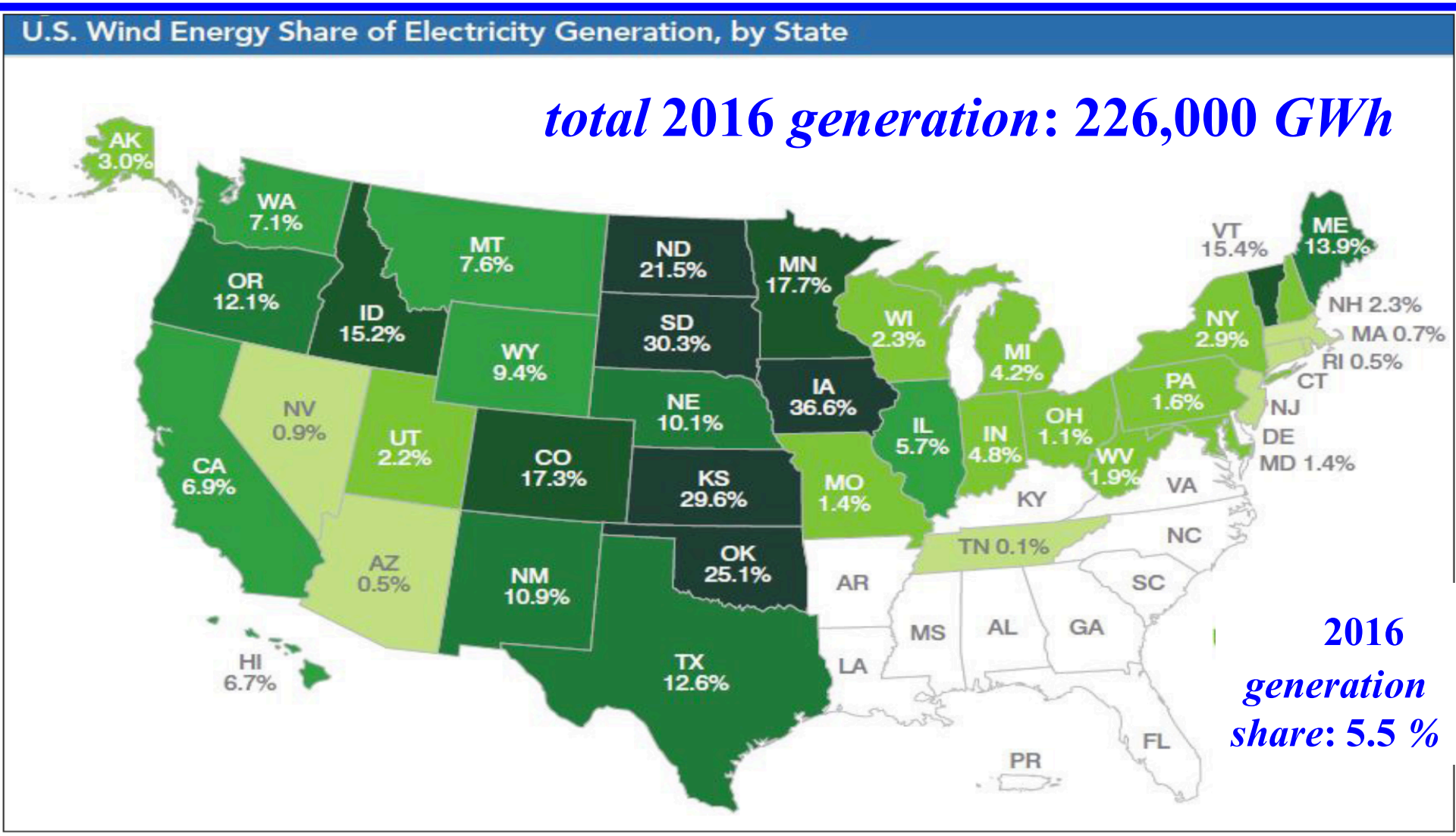
2016 *US* WIND CAPACITY BY STATE

total* 2016 *capacity*: 82,143 *MW



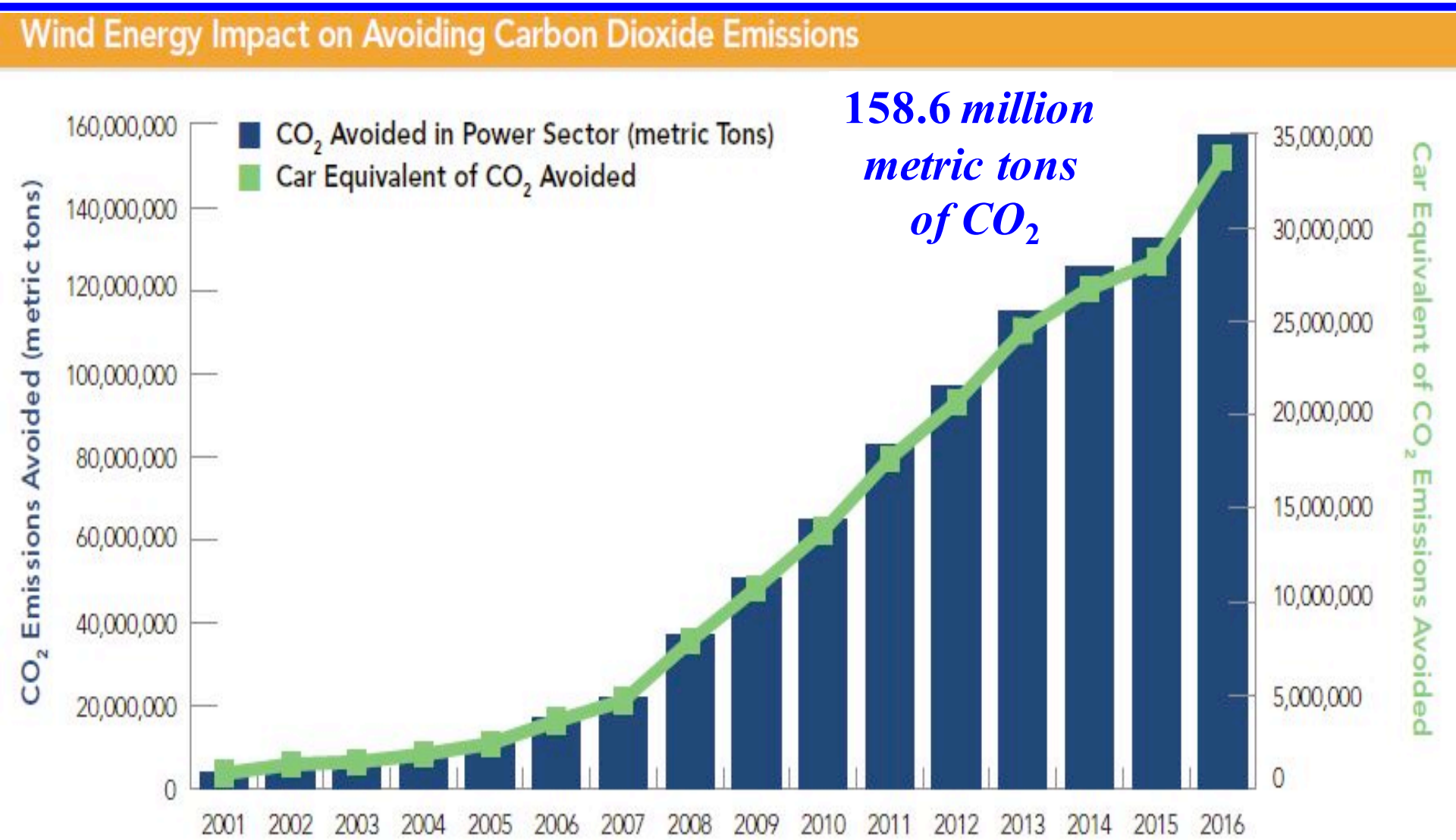
Source: AWEA at http://awea.files.cms-plus.com/Annual%20Capacity%20and%20Generation.pdf

2016 *US* WIND GENERATION SHARE OF STATE CONSUMPTION



Source: AWEA at http://awea.files.cms-plus.com/Annual%20Capacity%20and%20Generation.pdf

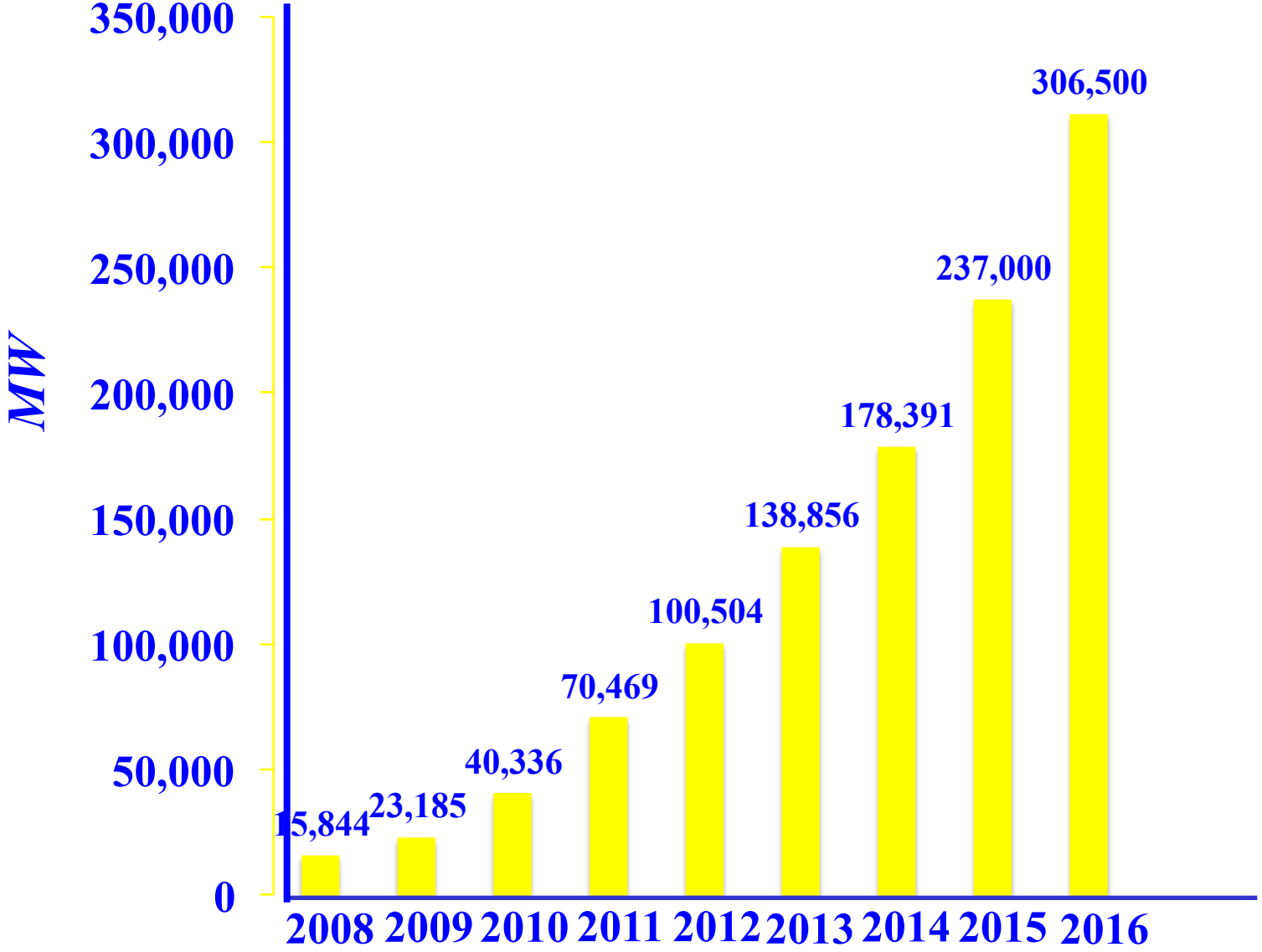
WIND ENERGY REDUCES *US GHG* EMISSIONS



Source: http://www.awea.org/Resources/Content.aspx?ItemNumber=8884

SOLAR ENERGY

2008 – 16 GLOBAL *PV* SOLAR CAPACITY



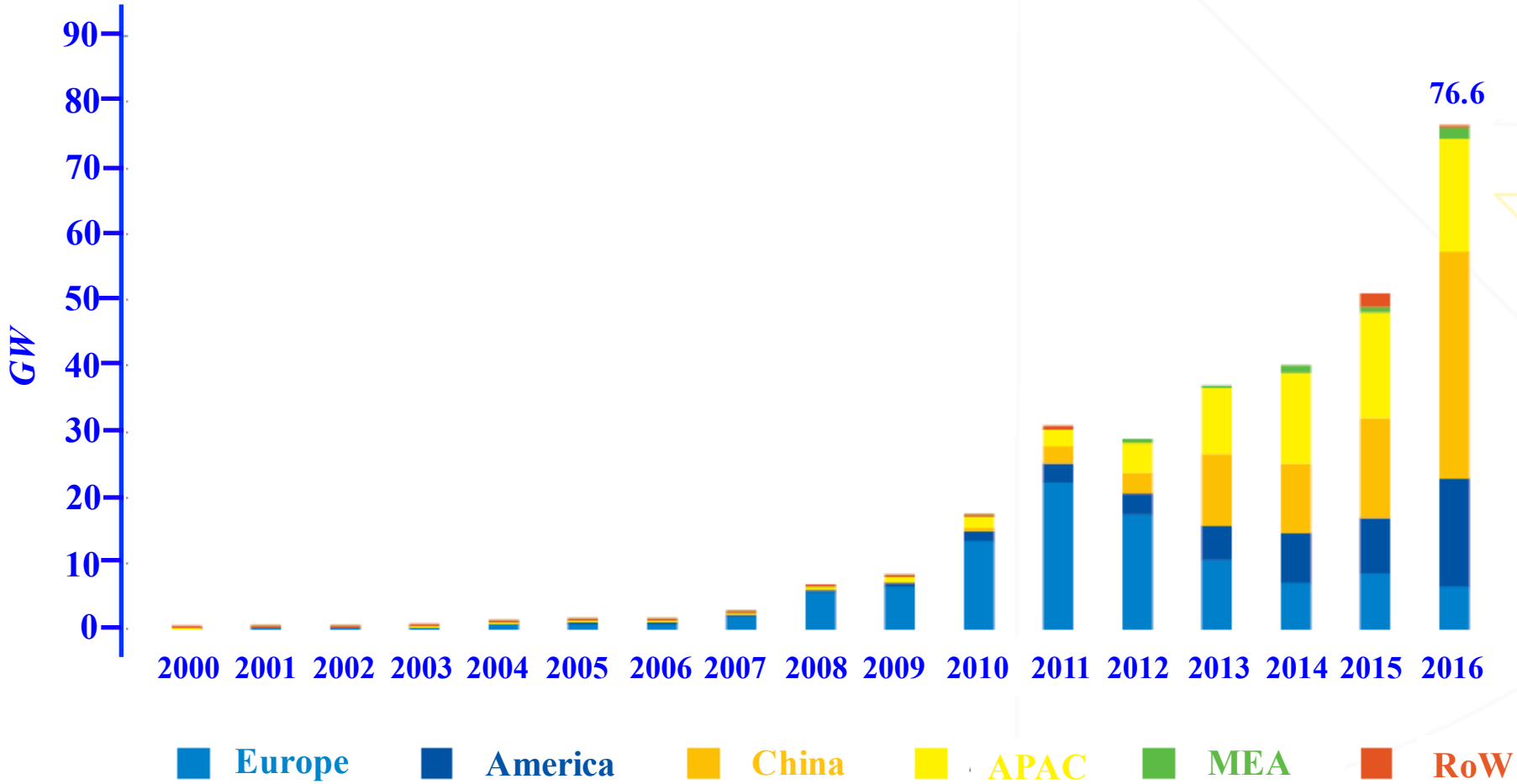
Source: https://www.greentechmedia.com

2016 SOLAR ENERGY STATUS

Lakelands Park Middle School, MD hosts a 111 kW rooftop system

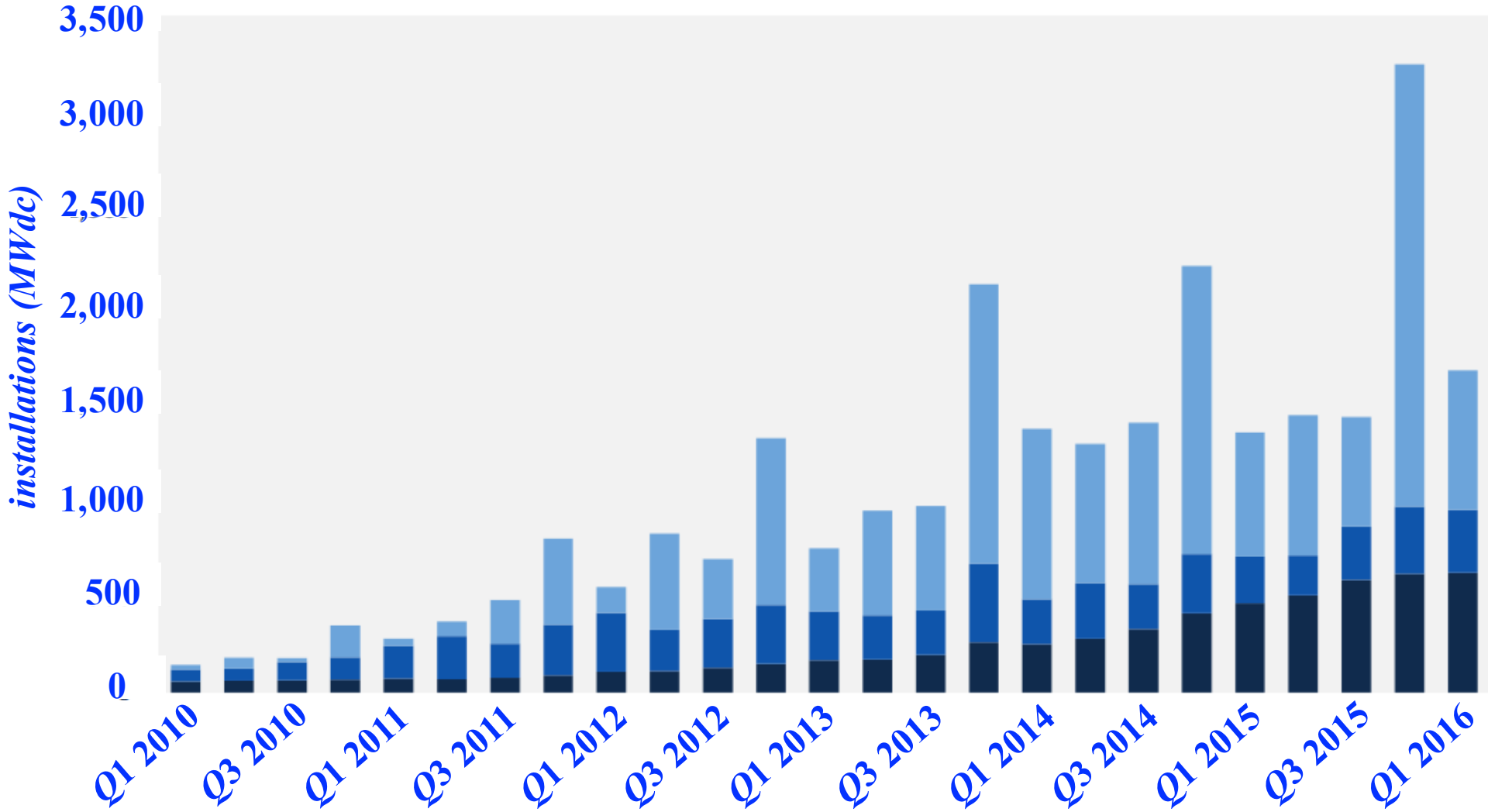
- The global *PV* cumulative capacity reached 306.5 *GW* in 2016
- The addition of 76.6 *GW* repre–sents a 50 % *year-on-year* growth over the 51.2 *GW* installed in 2015
- China installed 34.5 *GW* to continue as the dominant solar nation in the world
- The weak 6.7 *GW* added capacity shrank Europe's share to 22 % of the global *PV* capacity

GLOBAL ADDED *PV* CAPACITY: 2000 – 2016



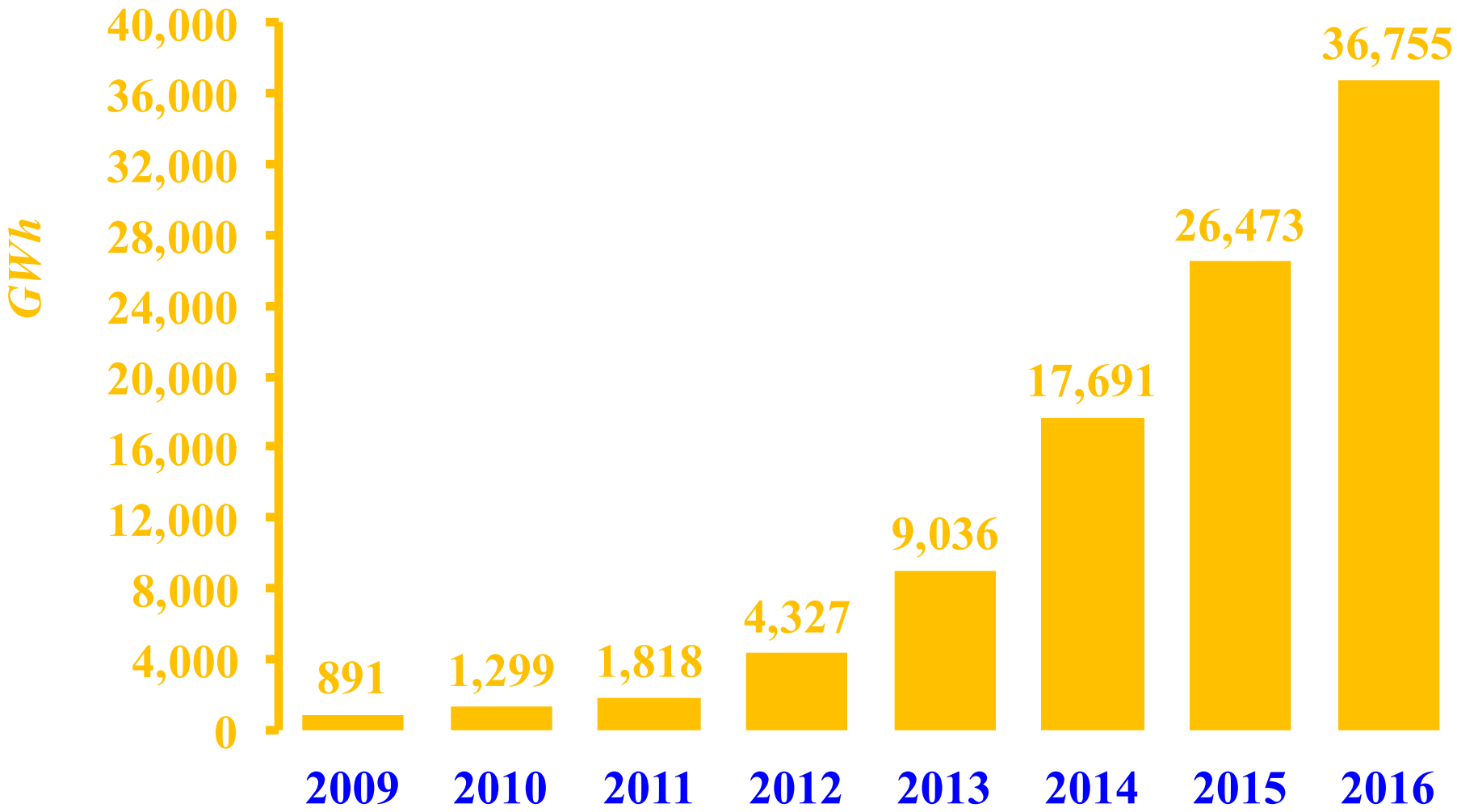
Source: SolarPower Europe Global Market Outlook 2017-2021

ANNUAL *US PV* INSTALLATIONS



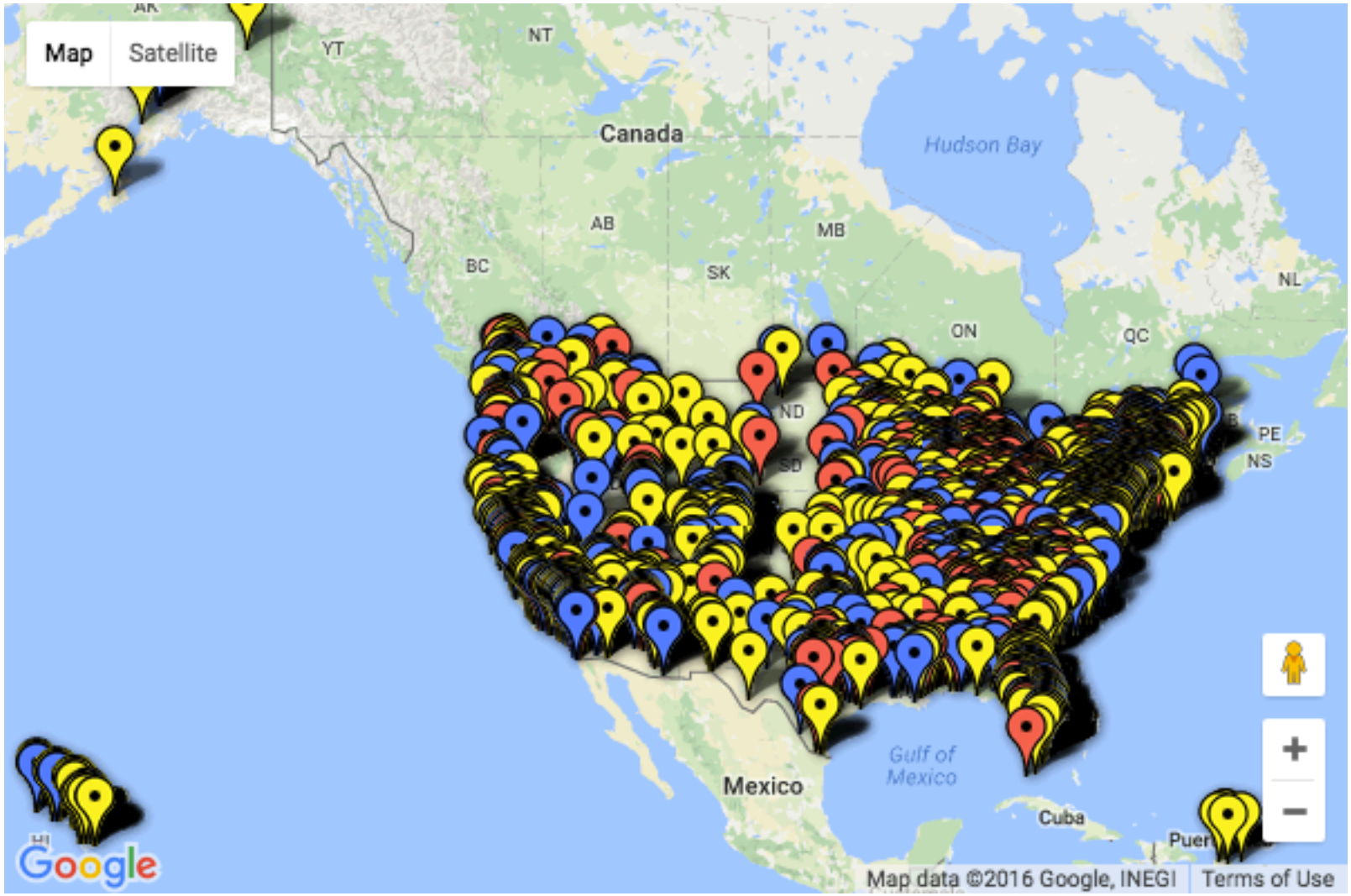
Source: http://www.greentechmedia.com/research/ussmi; Issued 2016

2009 – 2016 *US* SOLAR UTILITY – SCALE GENERATION



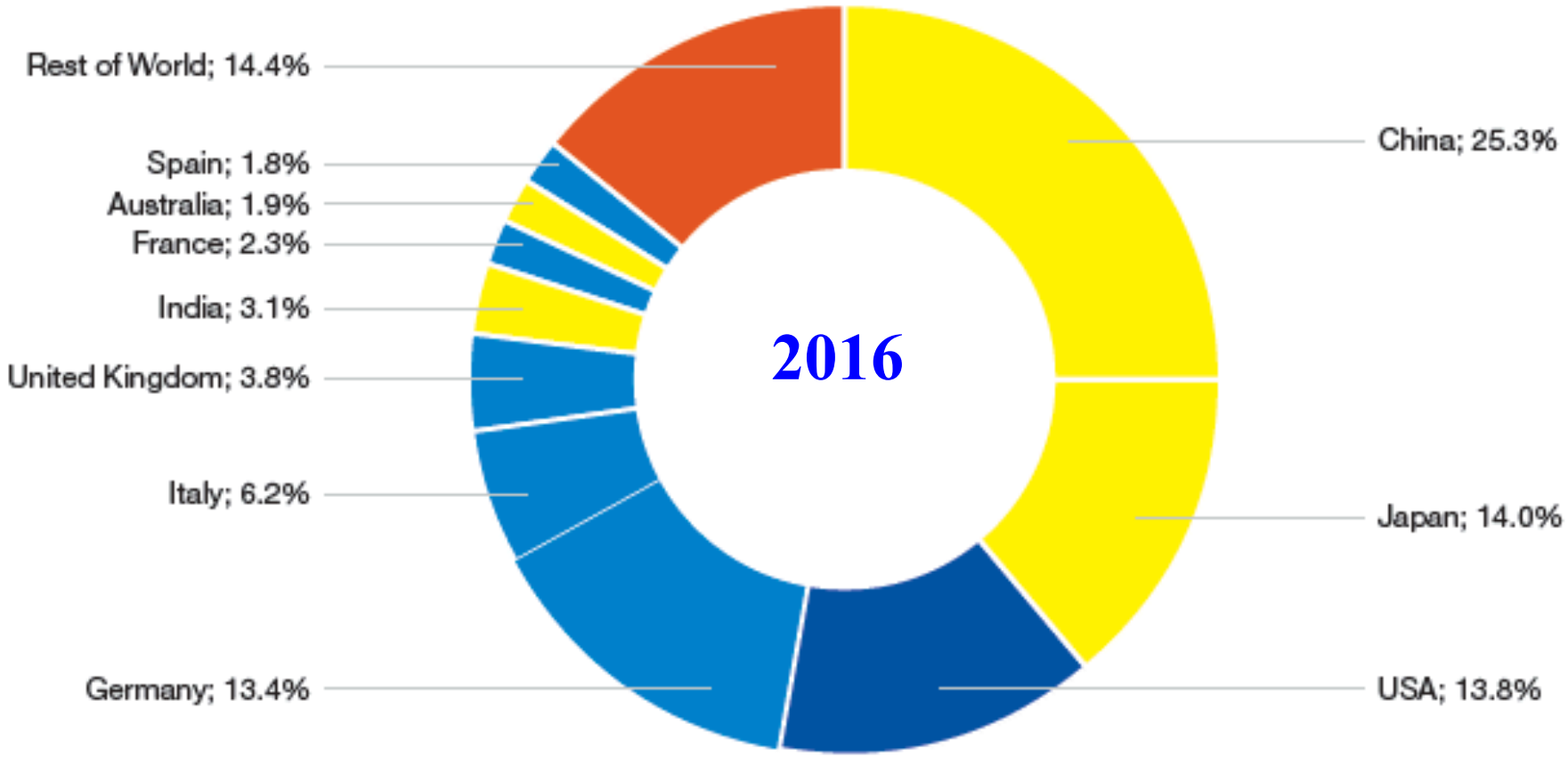
Source: http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01_a

NATIONAL SOLAR DATABASE



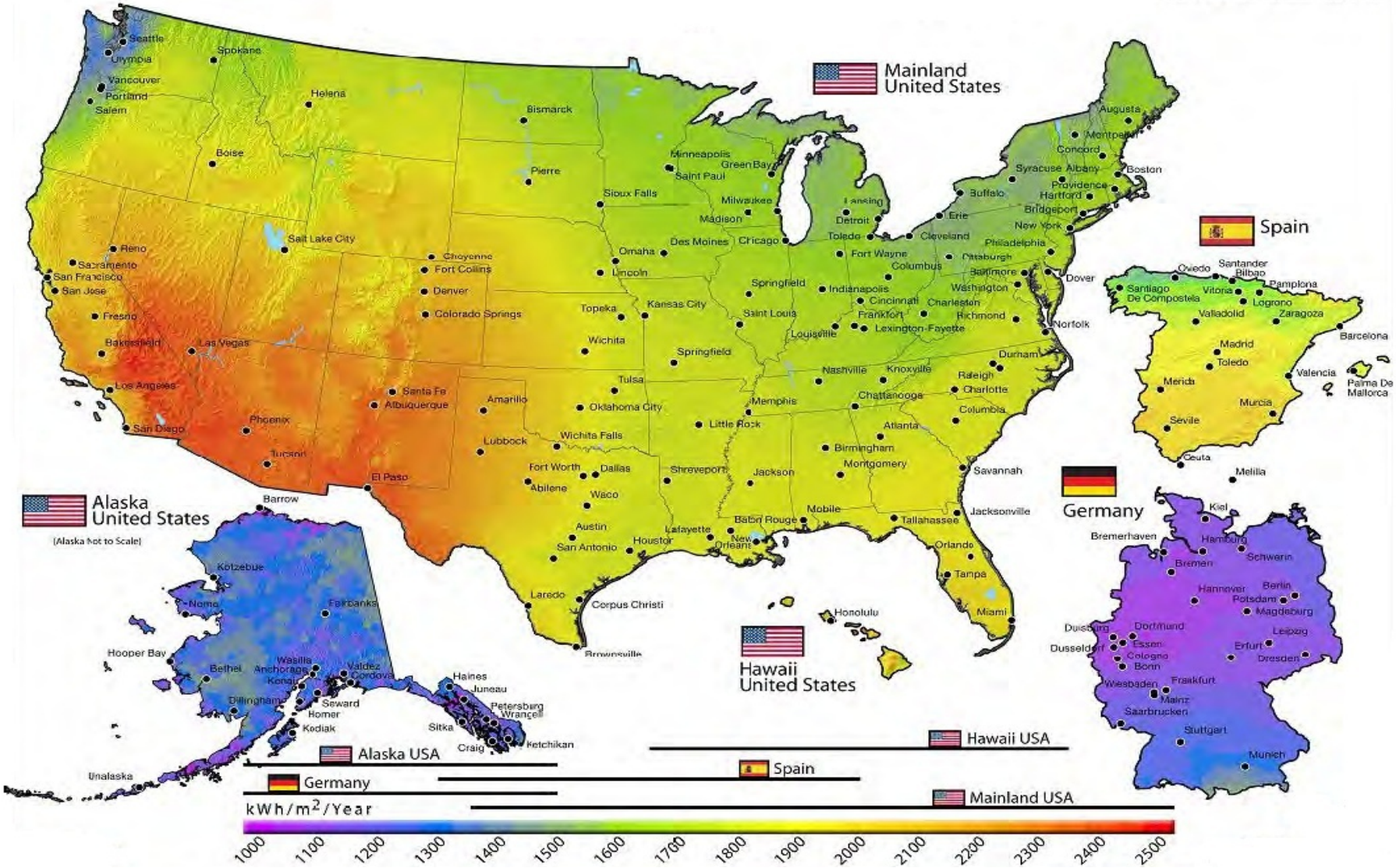
Source: http://www.seia.org/research-resources/national-solar-database; Issued 2016

2016 INSTALLED *PV* SOLAR TOP 10 COUNTRIES



Source: SolarPower Europe Global Market Outlook 2017-2021

PV SOLAR RESOURCE MAP FOR THE *US*, SPAIN AND GERMANY



Source: SEIA- US Solar Industry Year in Review, 2009

US – GERMANY COMPARISON

attribute	*US*	*Germany*	*ratio*
population (million)	321	82	3.9
area (mi^2)	3, 119, 884	137, 882	22.6
peak load (GW)	777	80	9.7
annual energy (billion kWh)	3, 963	544	7.3
installed wind capacity (MW)	65, 877	39,223	1.7

2011 *US* GEOTHERMAL ENERGY STATUS

- In 2011, *US* geothermal resources produced an estimated 16.7 *million MWh*

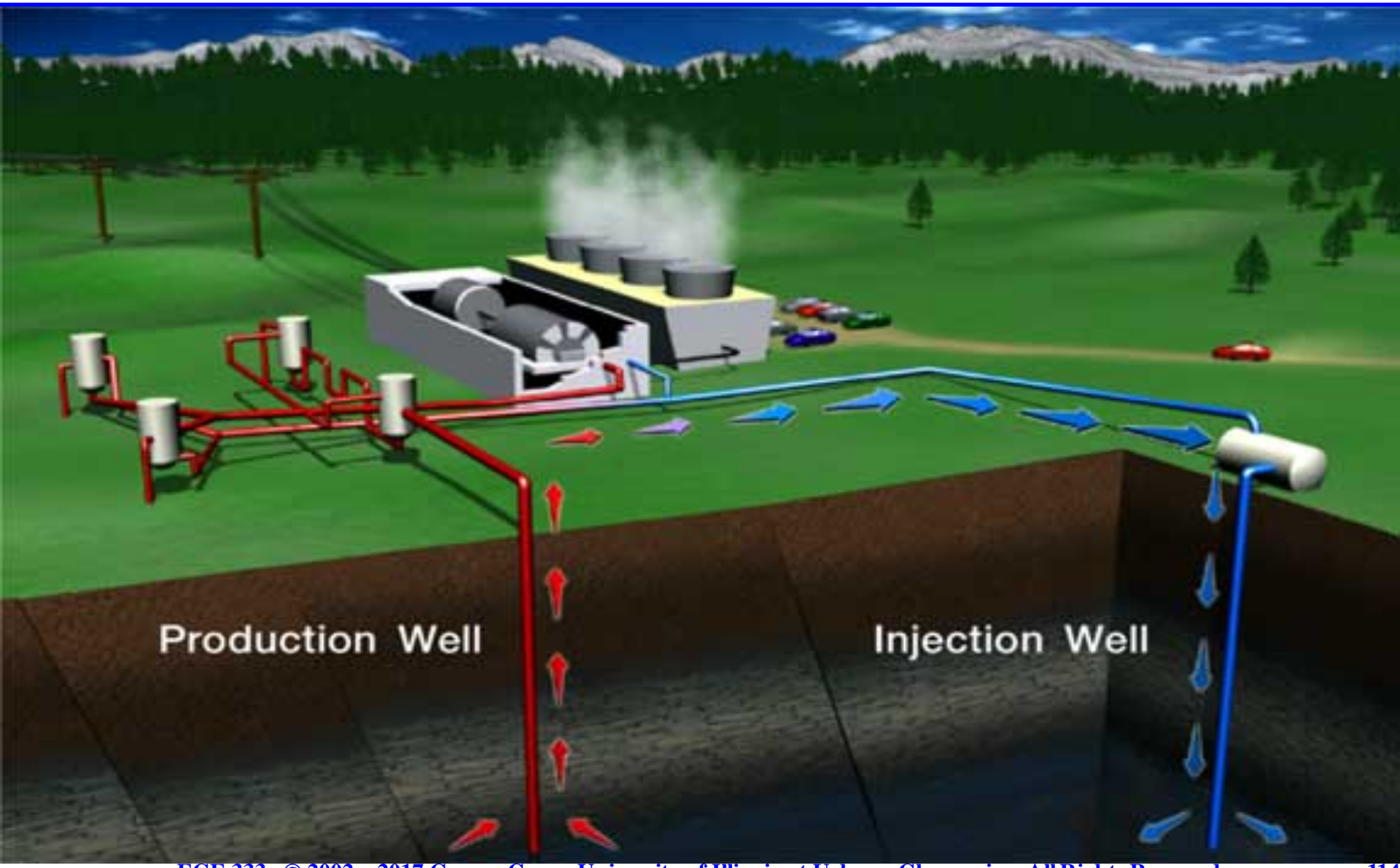
U.S.'s first geothermal power plant, Mayacama Mountains, California, turned 50 in 2009

- Total installed *US* geothermal capacity in 2011 reached 3,500 *MW*
- Geothermal generation has experienced slow growth over the last 10 years averaging 1.2 *%/y*
- Geothermal power prices are 4 - 6 *¢/kWh*

Source: NREL, http://www.nrel.gov/docs/fy10osti/48178.pdf

GEOTHERMAL PLANTS

GEOTHERMAL PRODUCTION



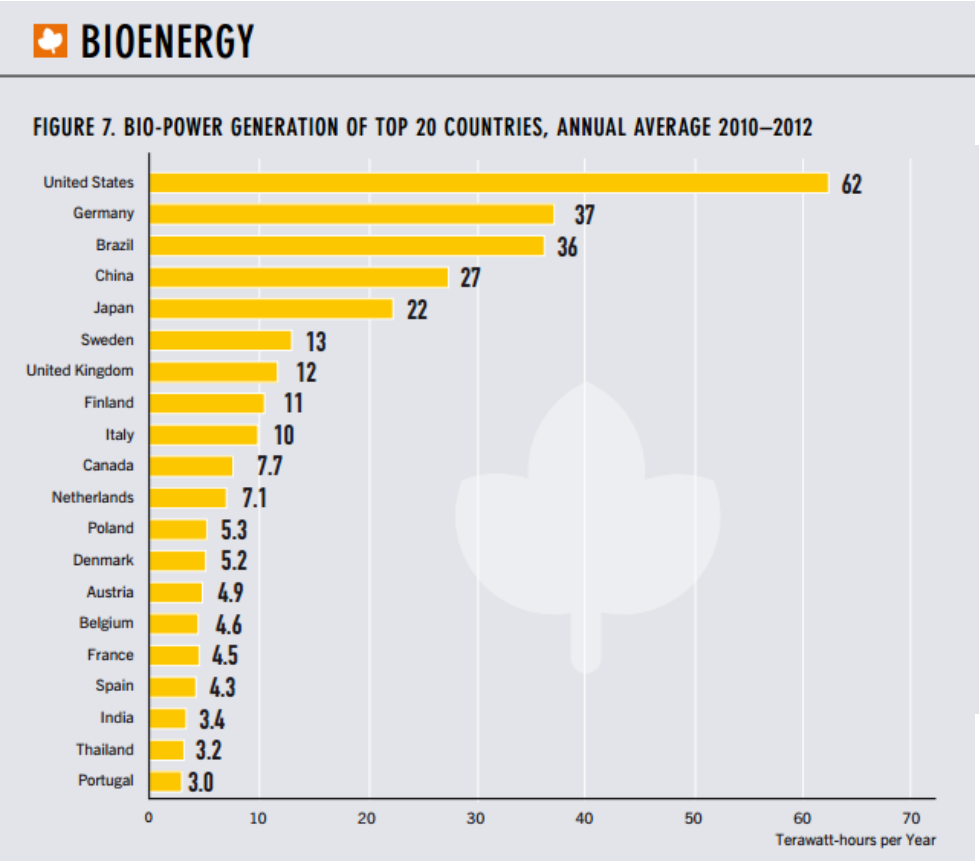
2016 BIOMASS / BIOFUELS STATUS

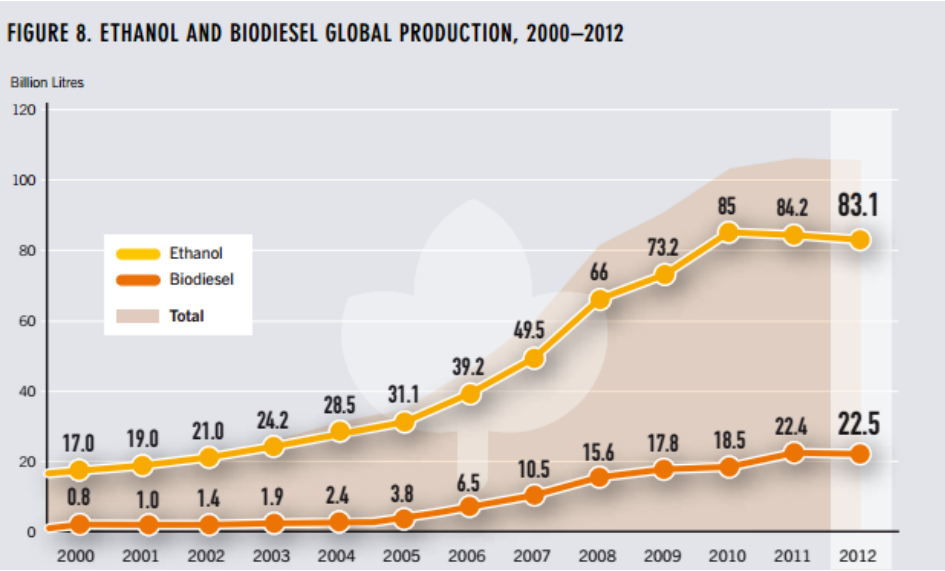
- World biomass installed electricity capacity is 112 *GW* with 504 *TWh* generation
- The *US* grid-connected installed capacity is 13.2 *GW*

21 *MW* Tracy Biomass Plant

- *US* and *Brazil* are the largest biofuel producers
- World biofuels production capacity is 135 *billion l/y*

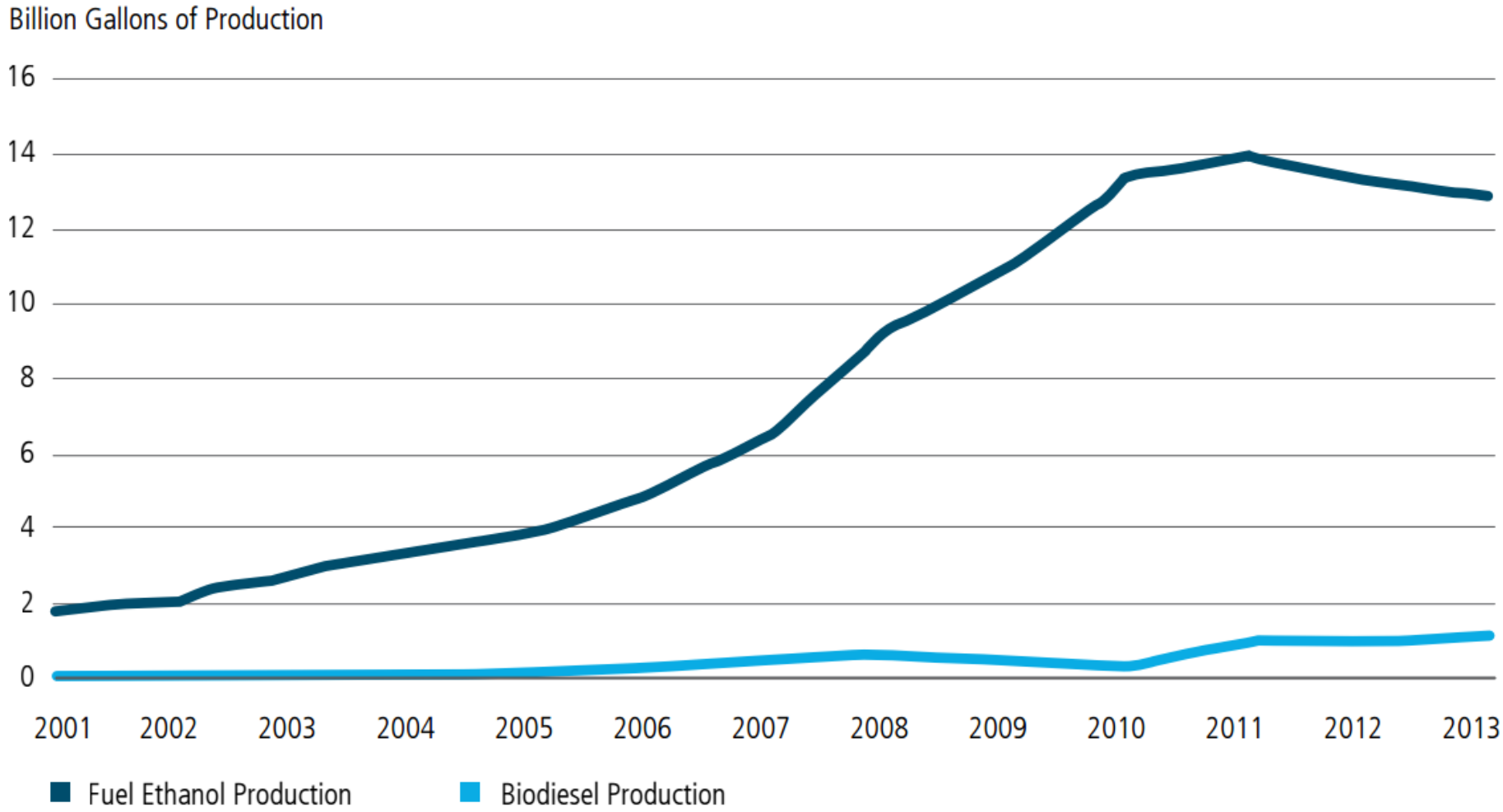
BIOENERGY AND BIOFUEL





Source: Renewables Global Status Report 2013, http://www.unep.org/pdf/GSR2013.pdf

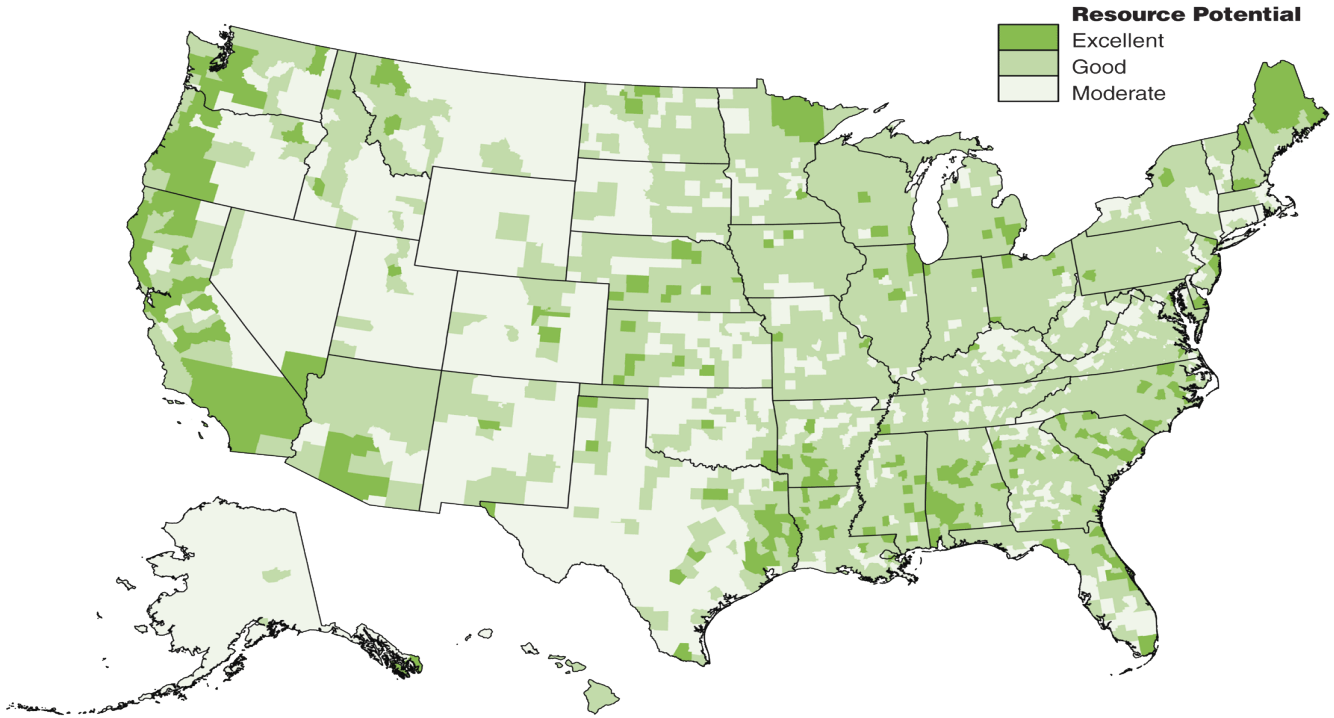
YEARLY ETHANOL AND BIODIESEL PRODUCTION



Yearly production of ethanol increased between 2001 and 2011 and has declined slightly through 2013.

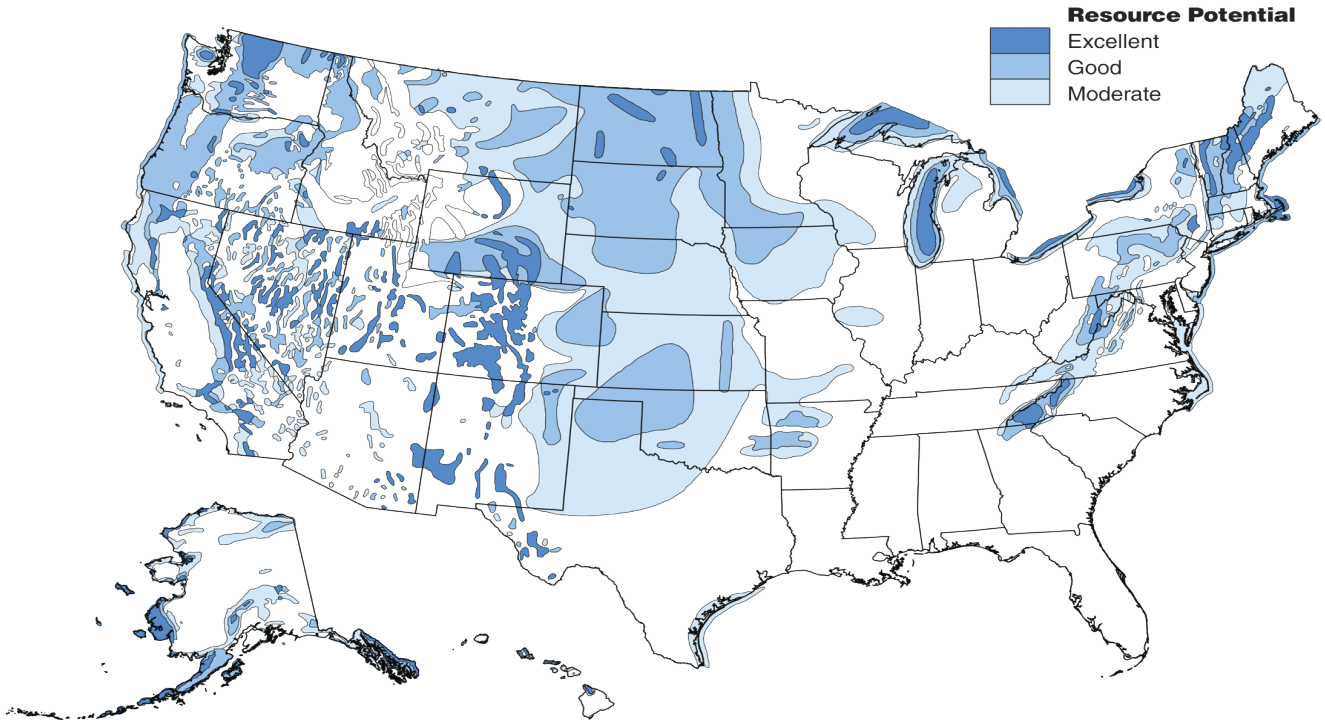
Source: EIA (2010-2013) http://www.eia.gov/electricity/monthly/current_year/february2014.pdf; pg 176; Issued April 2015

DOE BIOMASS/BIOFUELS GOALS



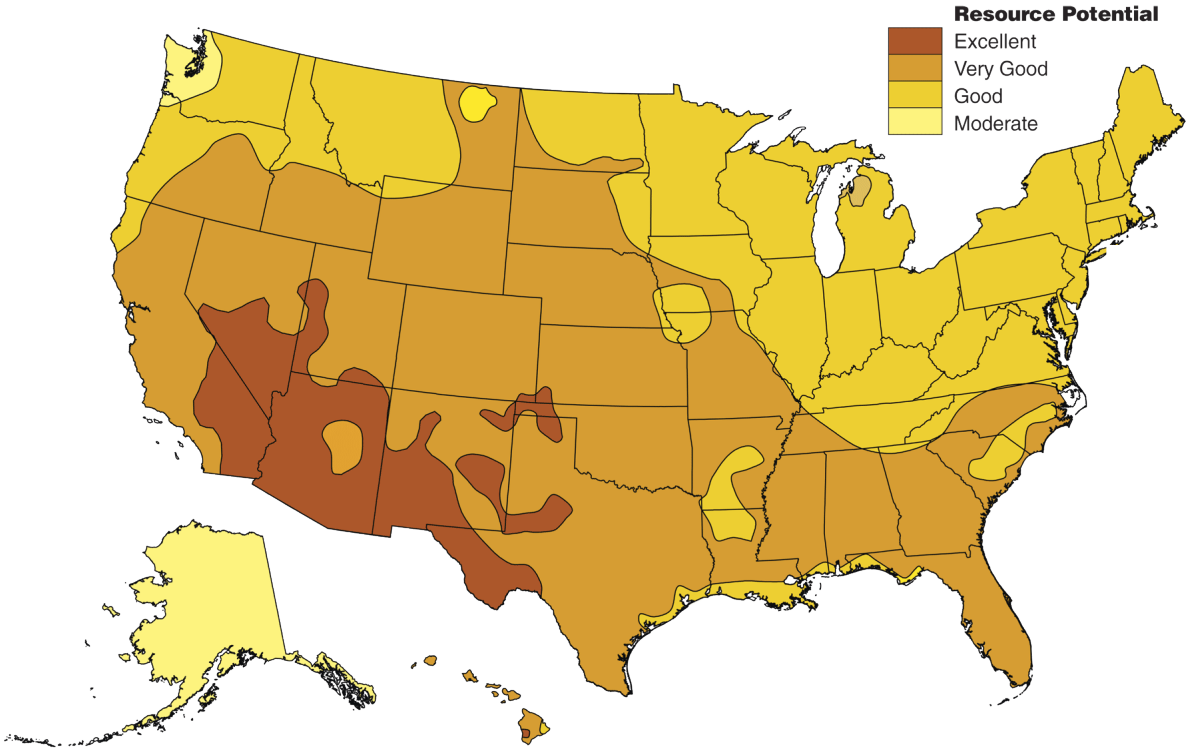
- Competitive electricity by 2020
- Ethanol production resources to be at the target of 1.07 $/g by 2020

DOE WIND PROGRAM GOALS



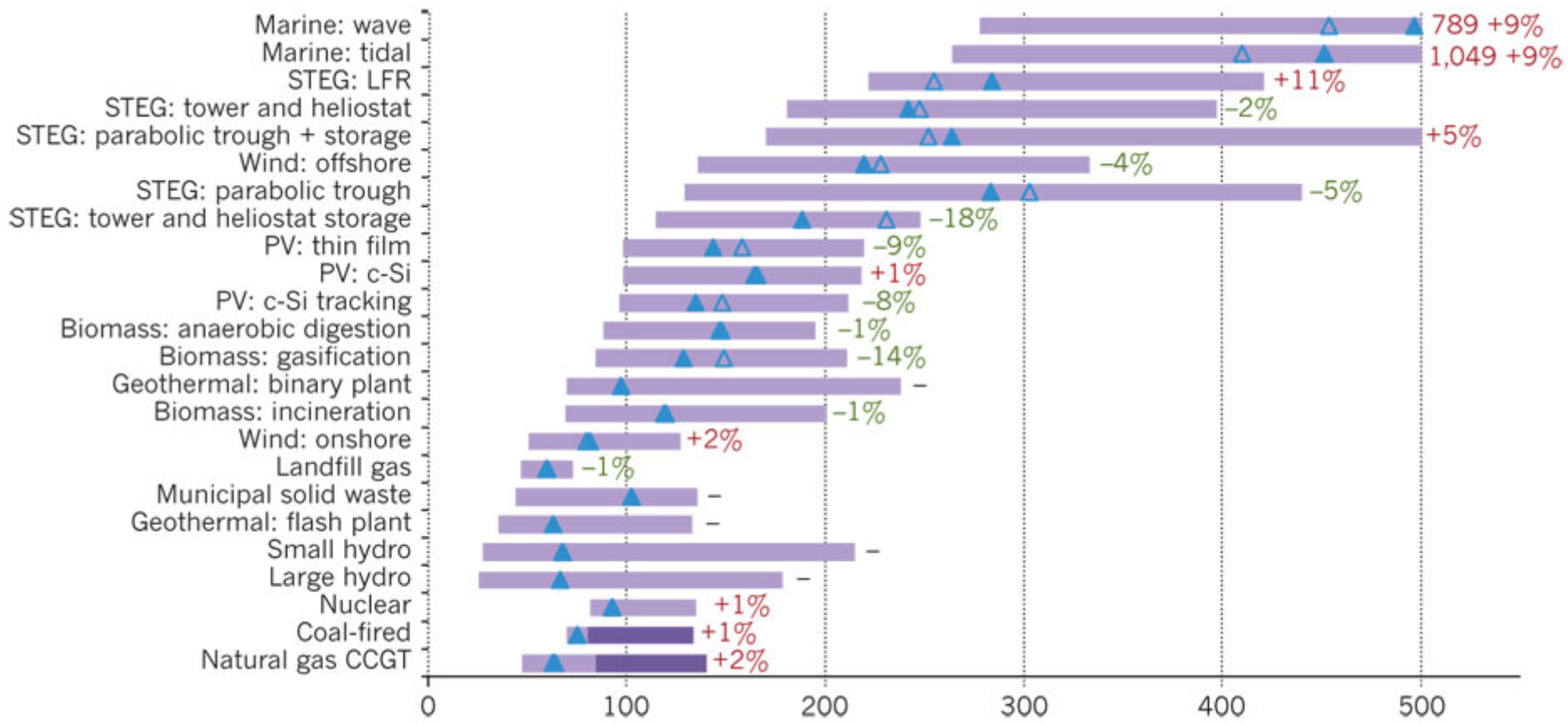
- 3 ¢/*kWh* in classes 4 and above onshore wind areas
- 5 ¢/*kWh* for off-shore regions

DOE SOLAR PROGRAM GOALS



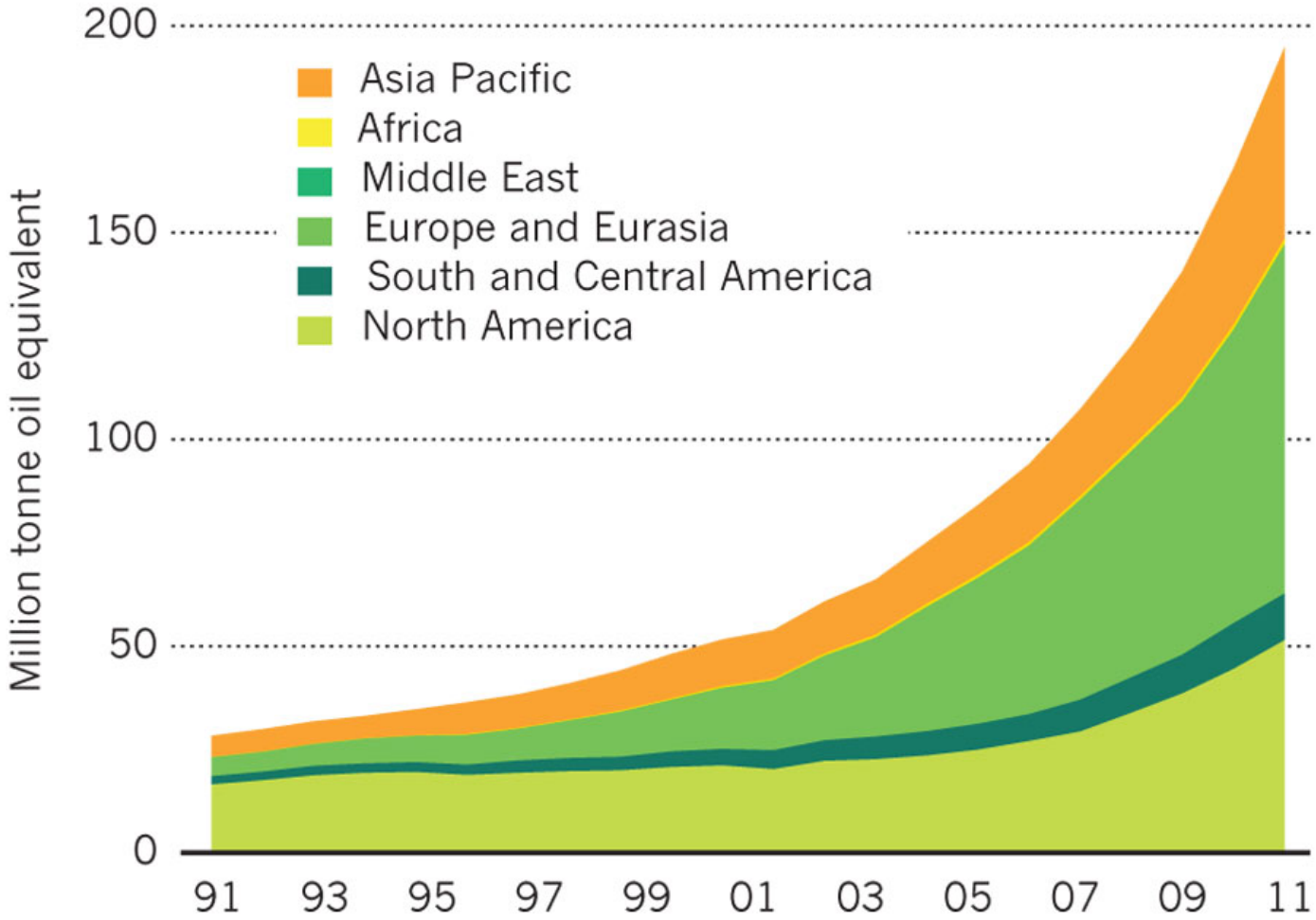
- Photovoltaics: 6 ¢/*kWh* by 2020
- Concentrating solar power/troughs: 5 ¢/*kWh* by 2012

*Q*3 2012 LEVELIZED COSTS OF ENERGY



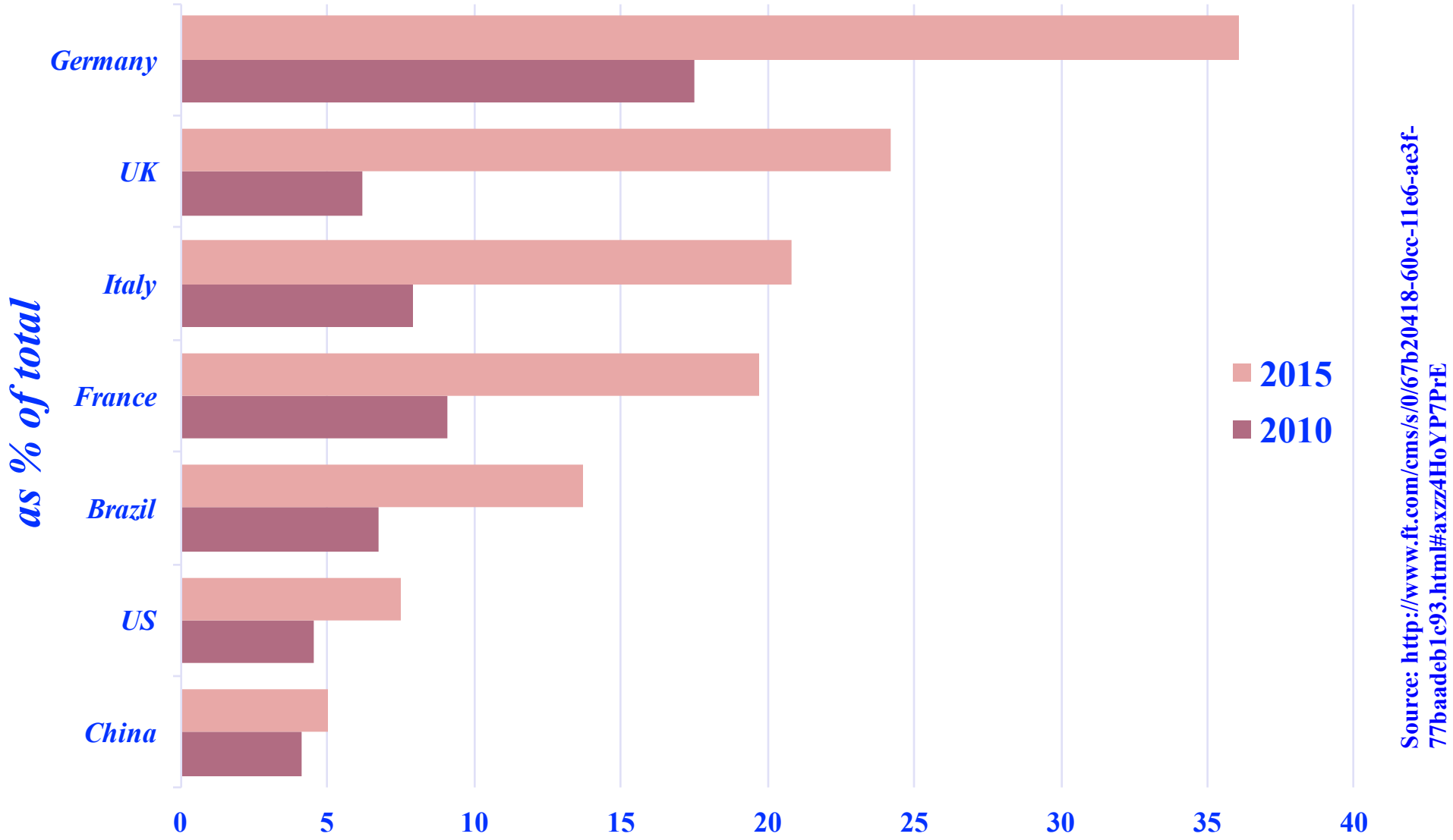
Source: Steve Chu and Arun Majumdar, "Opportunities and challenges for a sustainable energy future," Nature, August 2012

GLOBAL NON-HYDRO RENEWABLE ENERGY CONSUMPTION

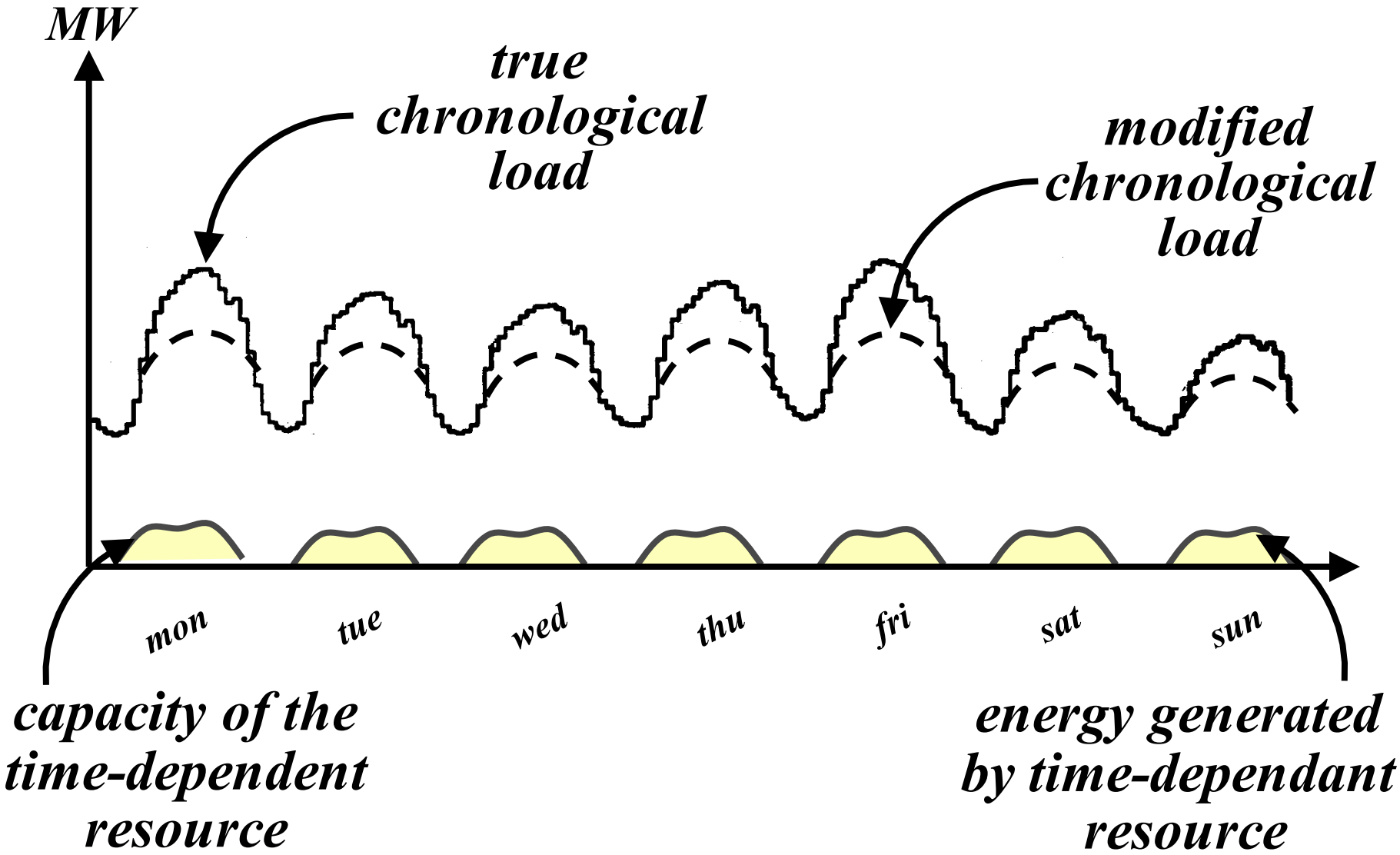


Source: Steve Chu and Arun Majumdar, "Opportunities and challenges for a sustainable energy future," Nature, August 2012

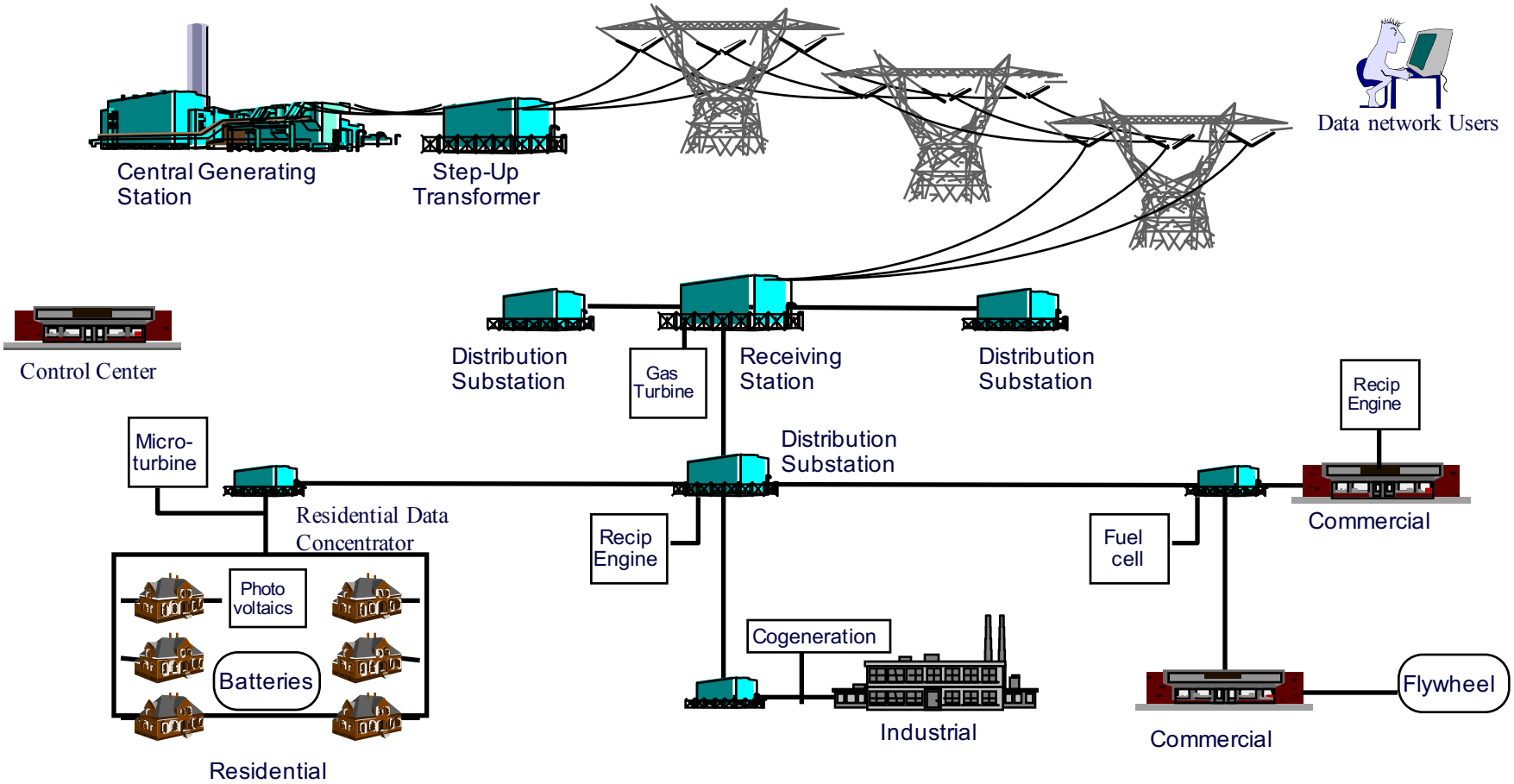
RENEWABLE ELECTRICITY GENERATION



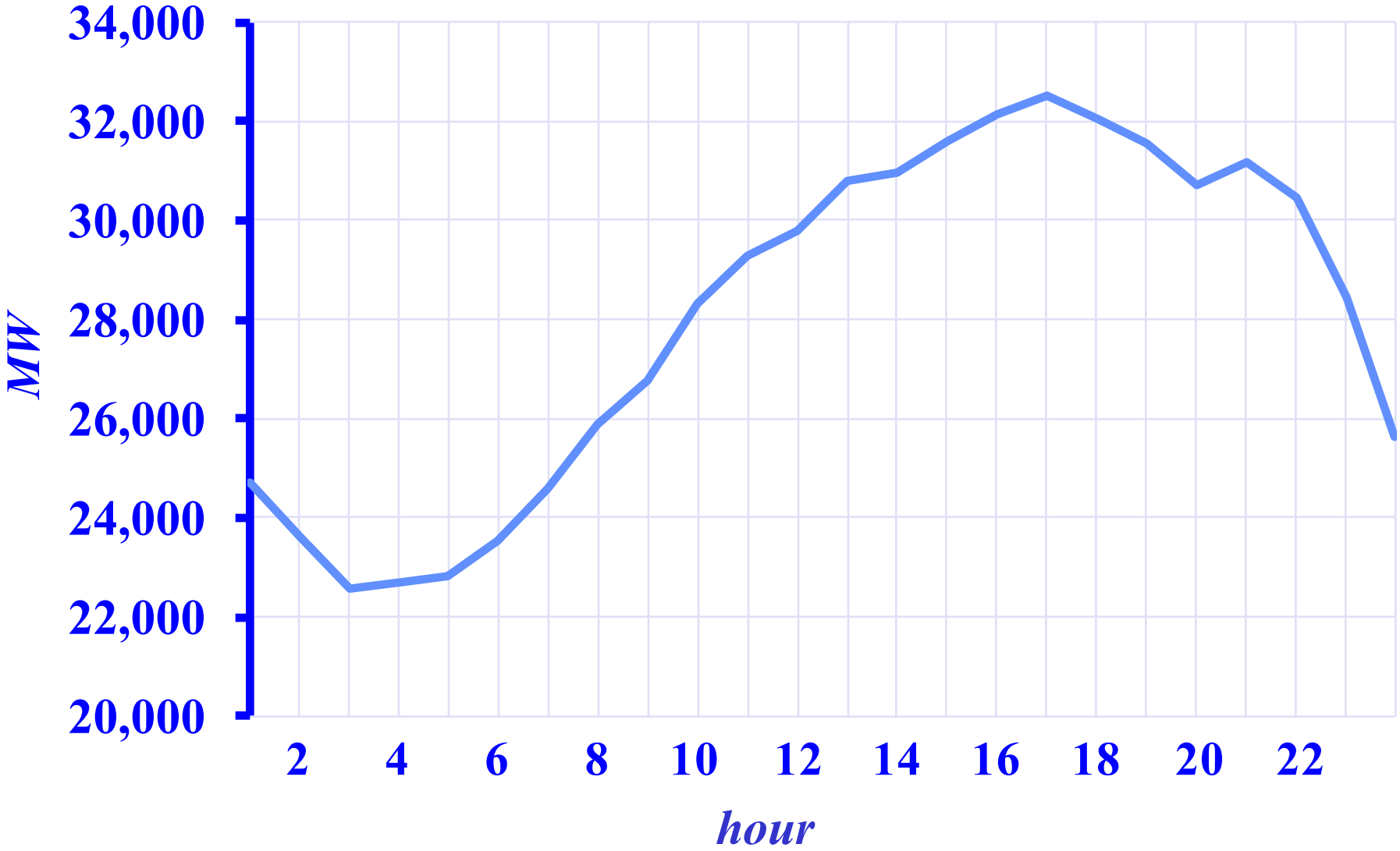
IMPACTS OF RENEWABLES



ELECTRIC SYSTEM INFRASTRUCTURE

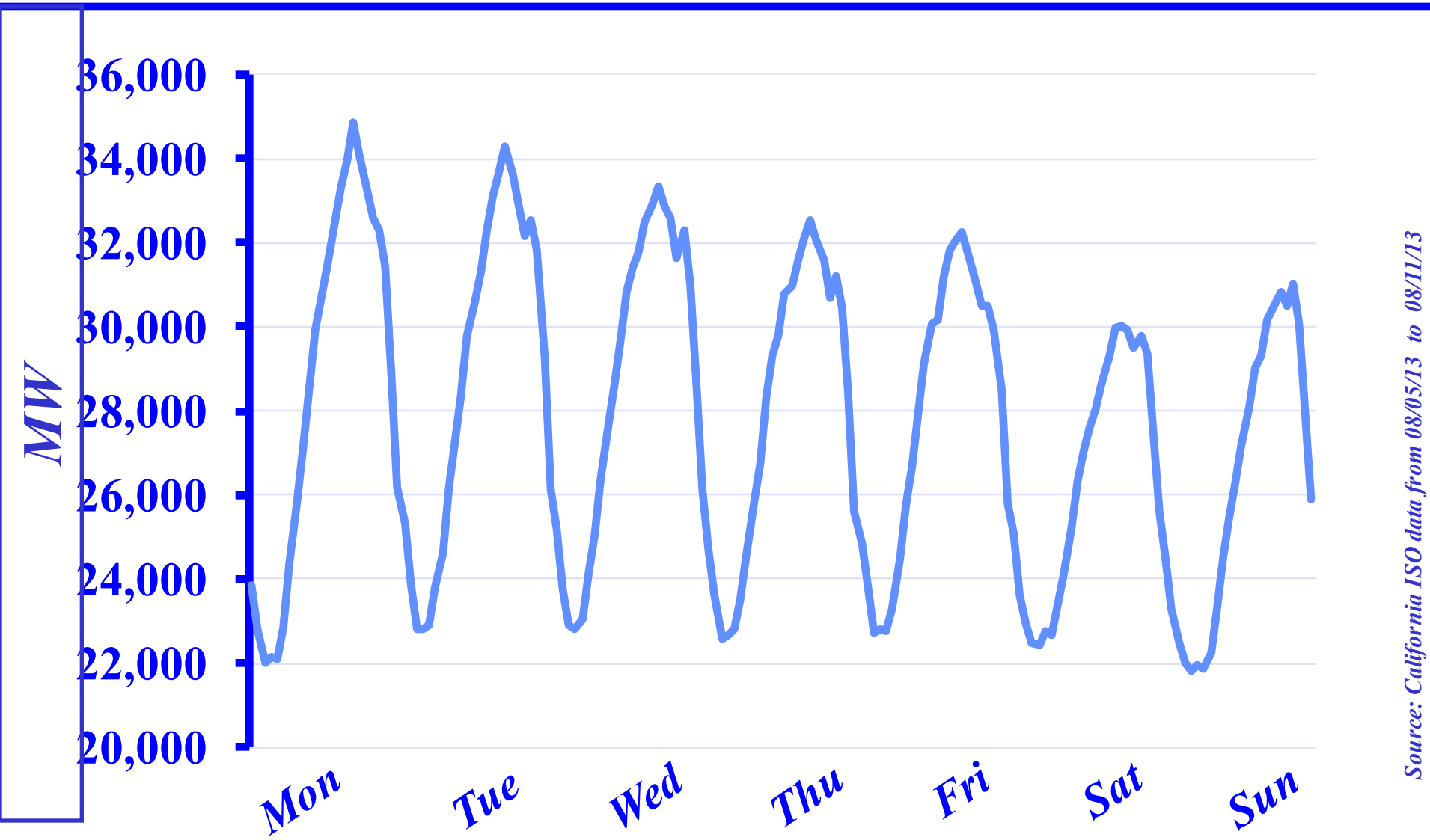


TWENTY–FOUR HOUR PROFILE

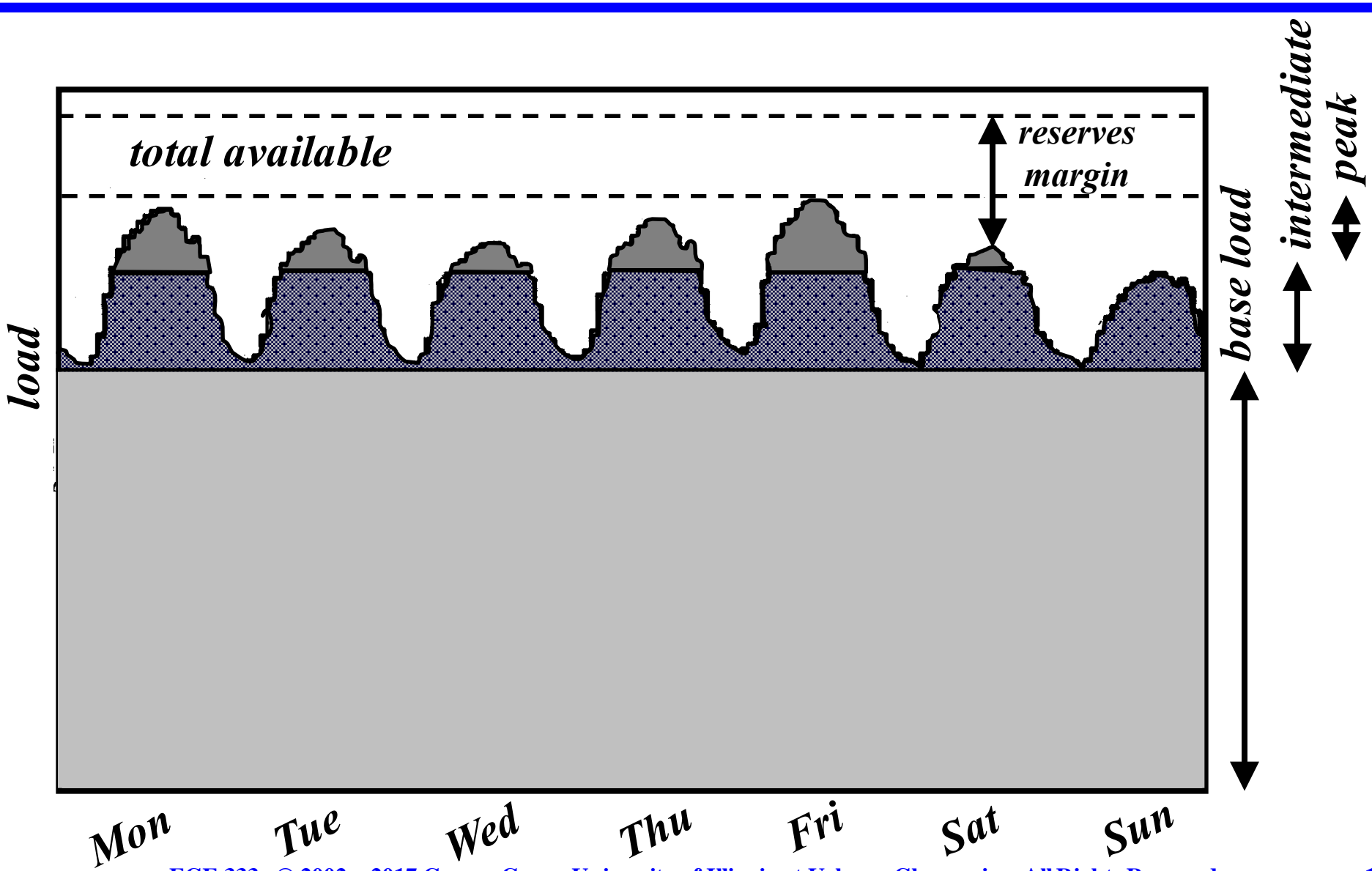


Source: California ISO data for 08/08/13

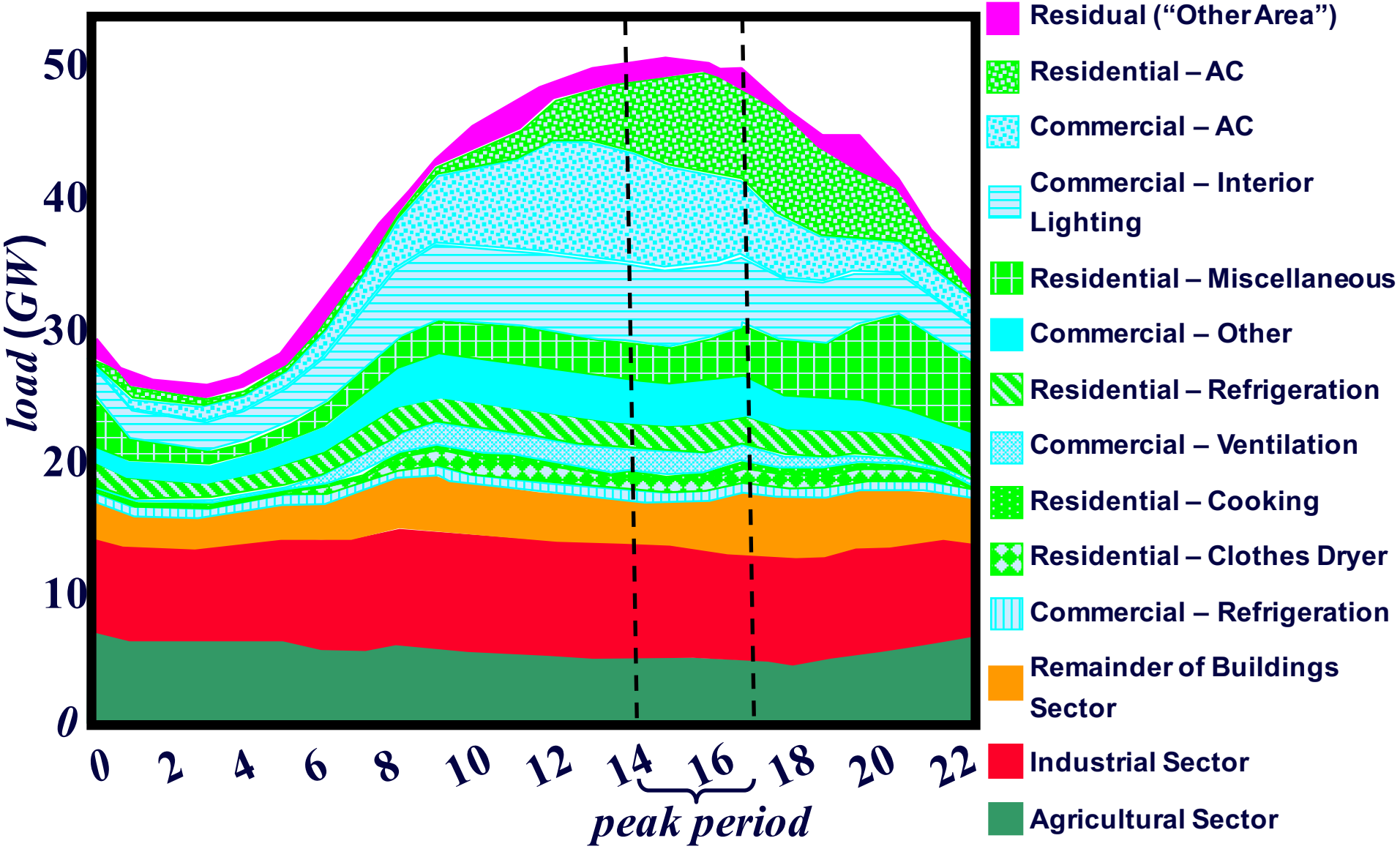
WEEKLY LOAD CYCLE



THE WEEKLY LOAD SHAPE



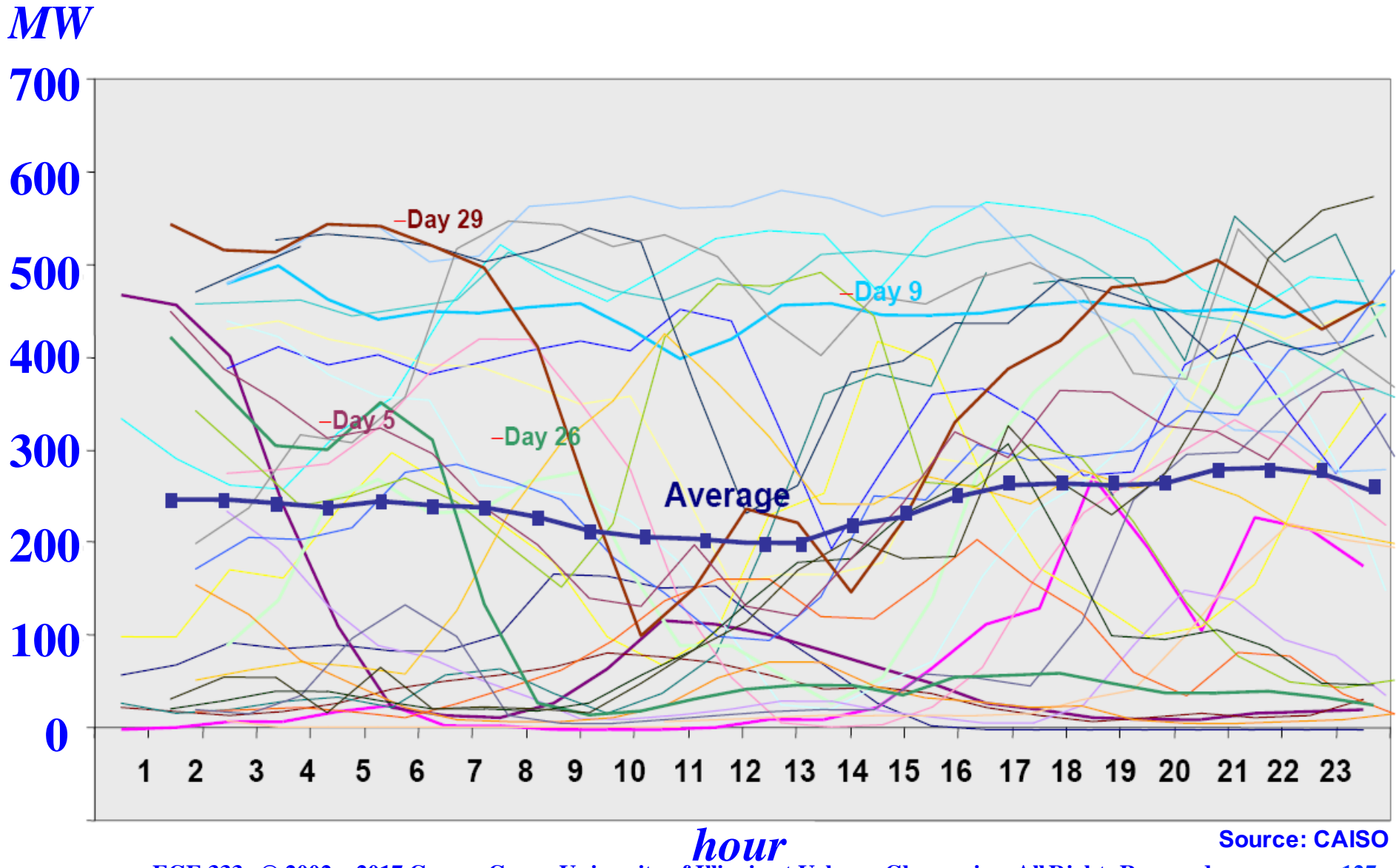
CALIFORNIA SUMMER LOAD: TYPICAL DAILY SHAPE



KEY CHALLENGES IN RENEWABLE EXPANSION

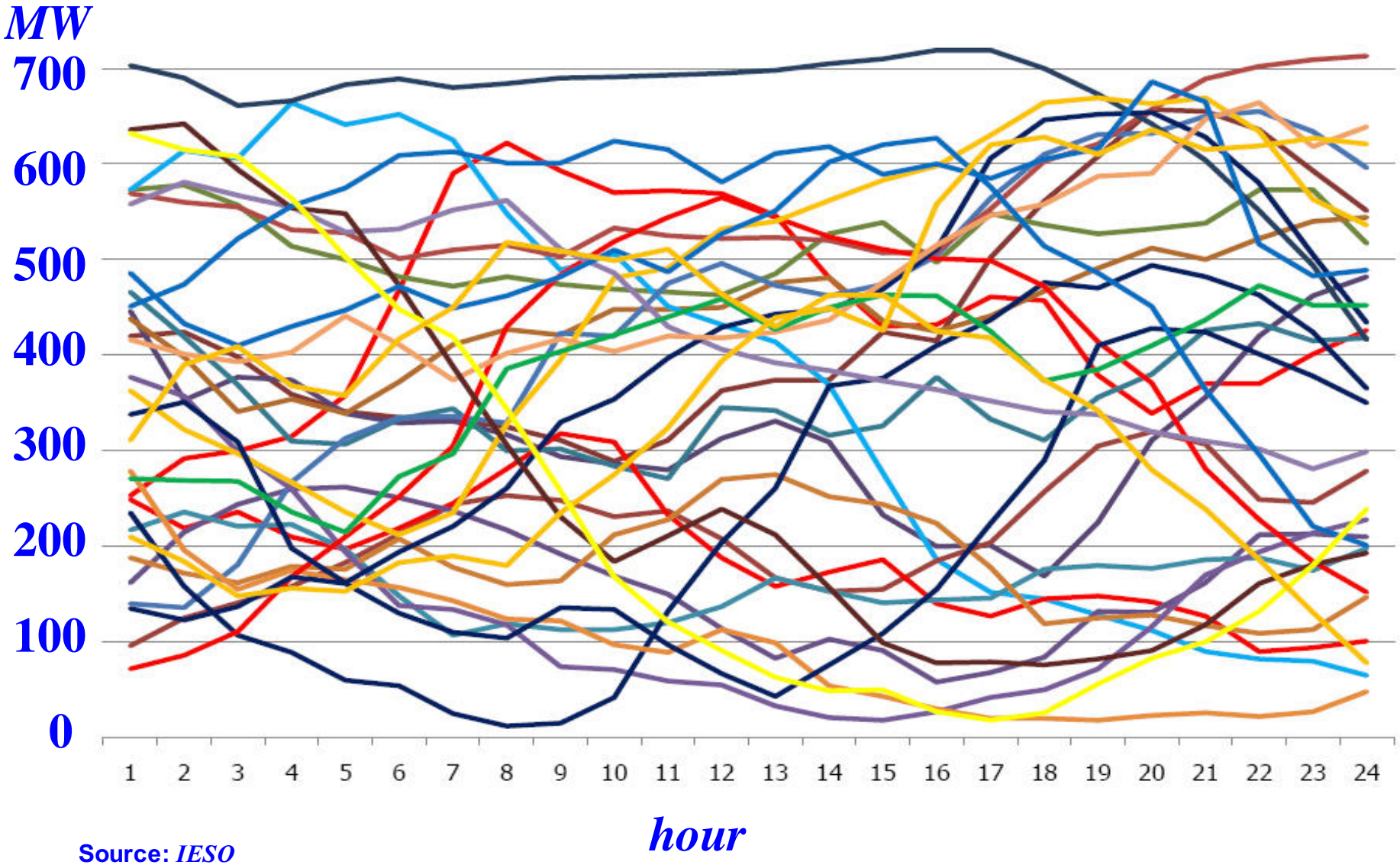
- Integration into the grid
  - interconnection
  - grid capability
  - reliability issues
  - power quality
- Competitiveness of technology costs
- Environmental problems
- Development of storage technology

CAISO APRIL 2005 DAILY WIND PATTERNS



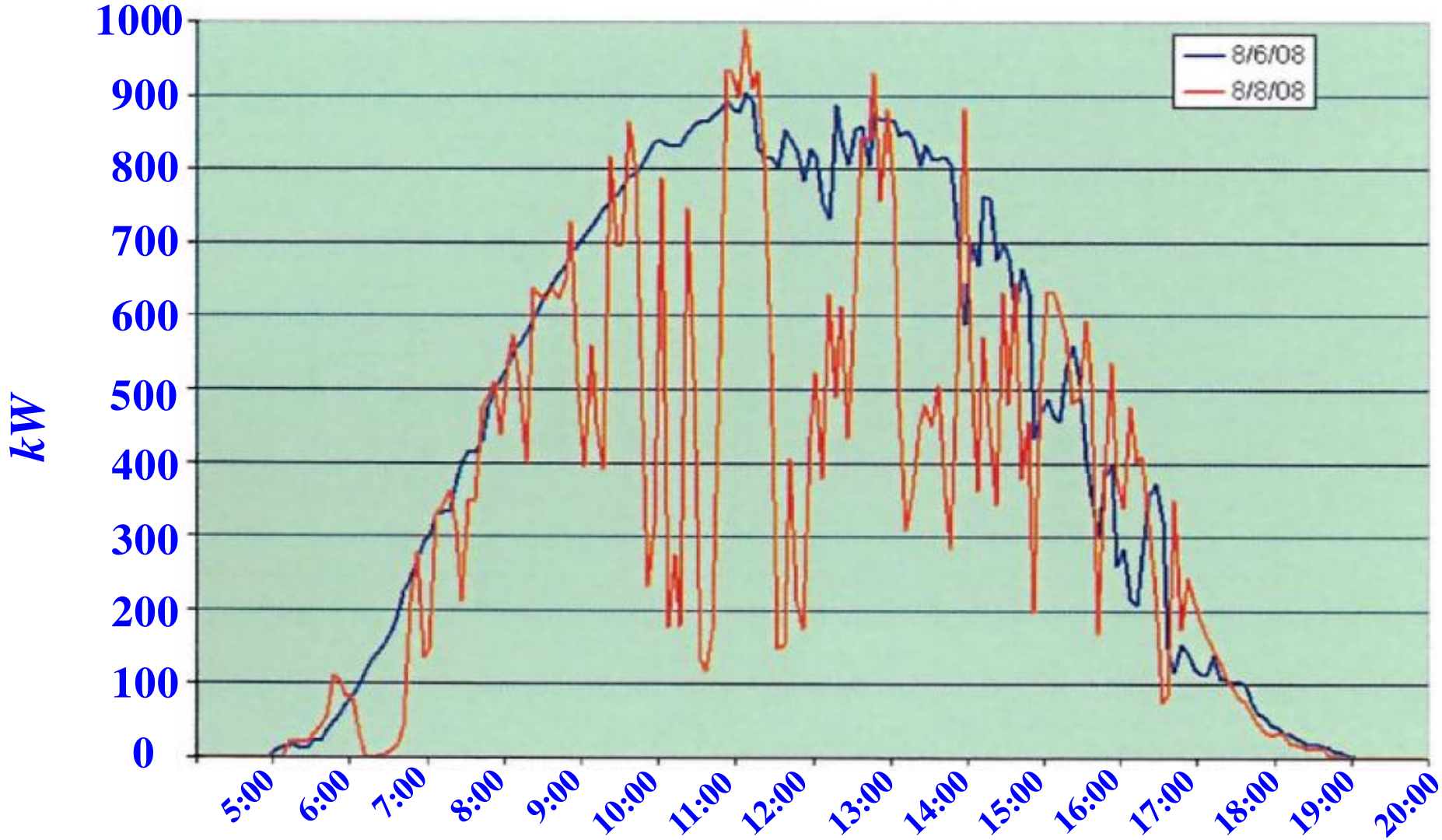
Source: CAISO

ONTARIO DAILY WIND POWER OUTPUT



Source: *IESO*

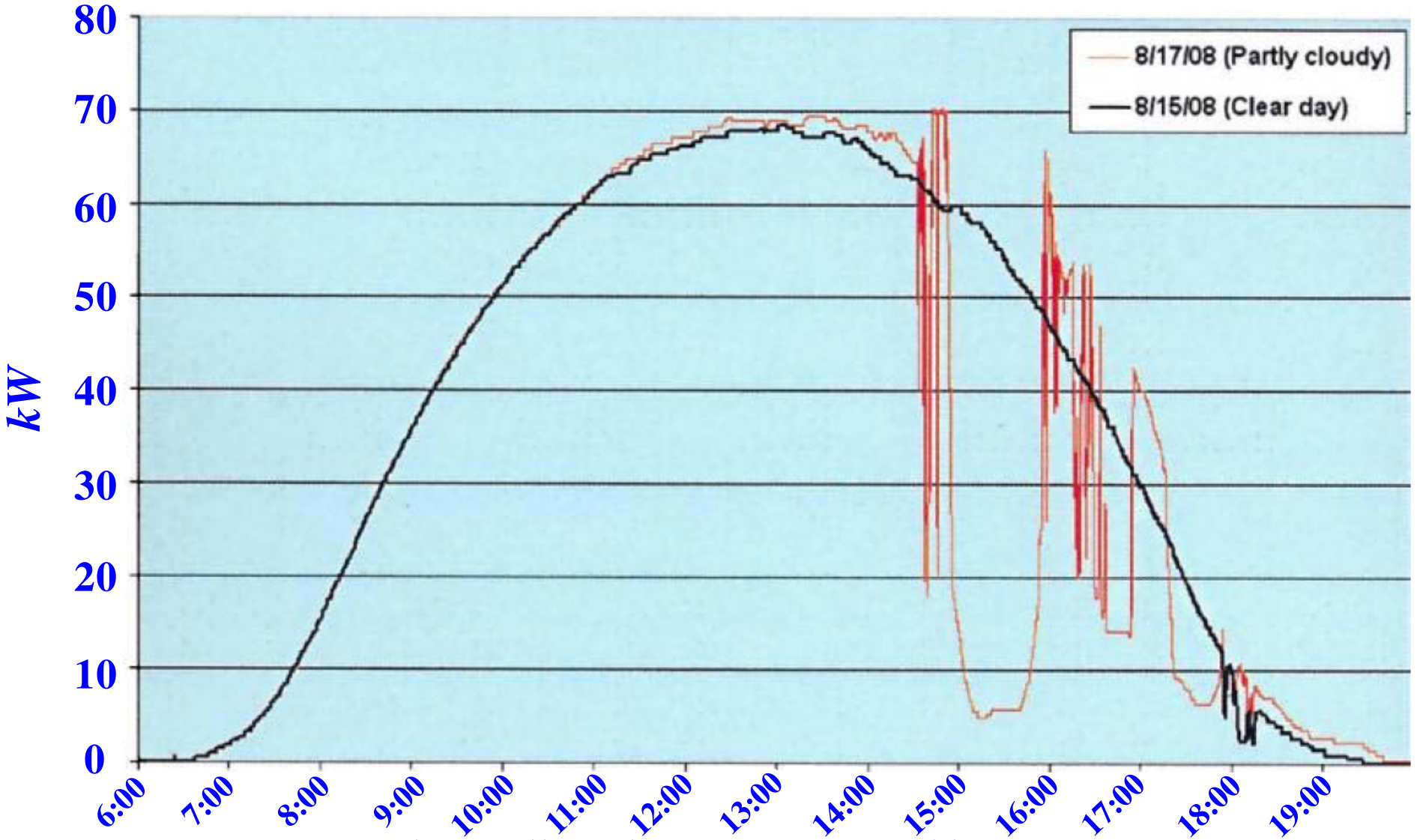
PV POWER OUTPUT OF 1 – *MW CdTe* ARRAY IN GERMANY



samples collected on a 5 – minute basis

Source: CAISO

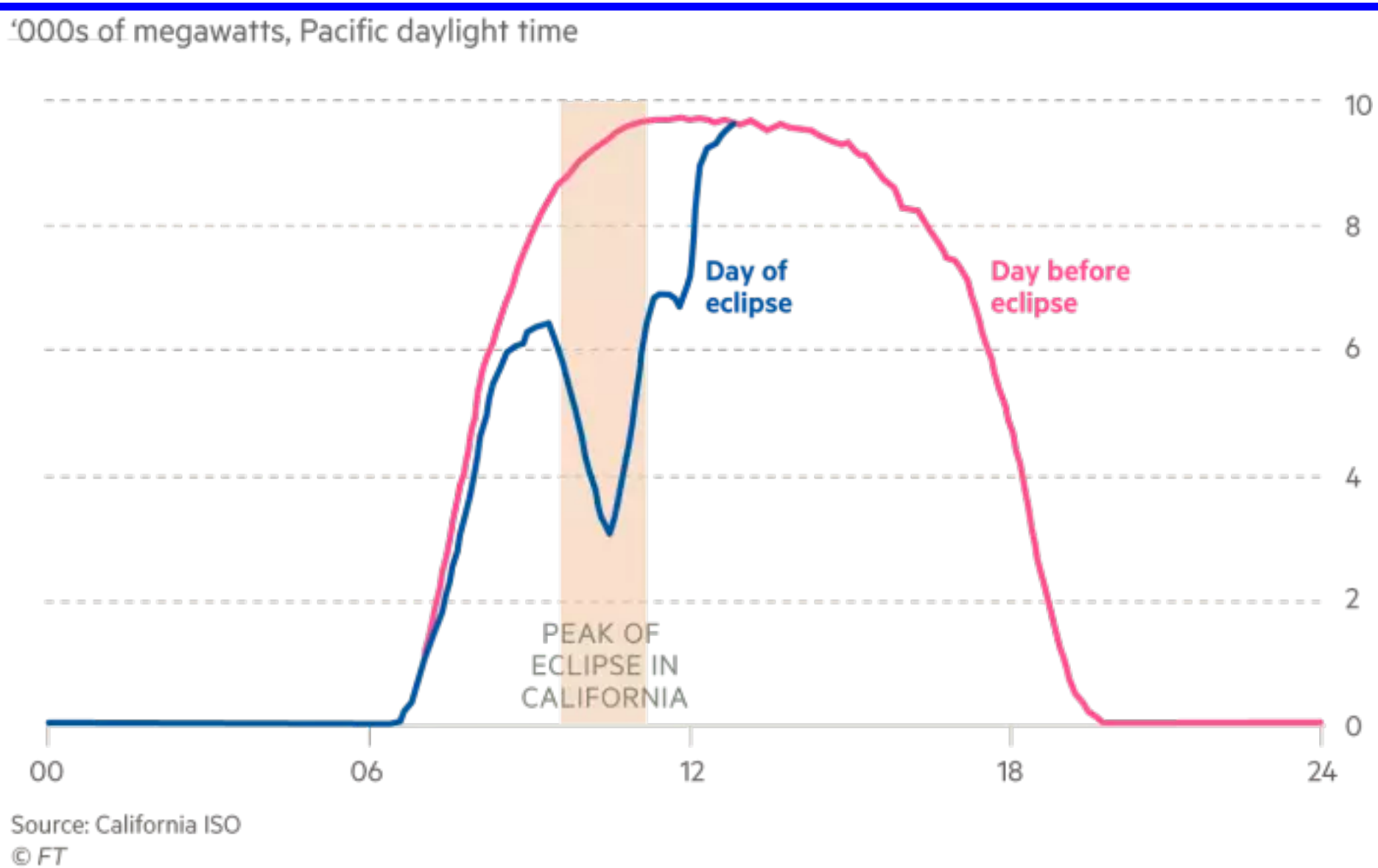
PV POWER OUTPUT AT THE NEVADA 70 – *kW* POLYCRYSTALLINE ARRAY



data collected on a 10 – second basis

Source: CAISO

AUGUST 21, 2017 SOLAR ECLIPSE



KEY CHALLENGES IN RENEWABLE EXPANSION

- Government policies at the
  - federal
  - state
  - local

  levels
- Regulatory accommodation
  - permitting processes
  - back up power
  - “green power” differential

ROOFTOP SOLAR IN THE *US*

Source: http://www.nytimes.com/2013/07/27/business/energy-environment/utilities-confront-fresh-threat-do-it-yourself-power.html?pagewanted=all

ROOFTOP SOLAR IN THE *US*

ROOFTOP SOLAR IN THE *US*

- *EIA* indicates that rooftop solar electricity represents less than 0.25 % of the *US electric generation*
- Government incentives aimed at promoting solar energy have made the installation of rooftop solar widespread in the Western states – *CA, AZ, CO, NV*
- Incentives include *tax credits*, *installment cost rebates* and *net metering* for customers with rooftop solar panels
- At present, 43 states, the District of Columbia and 4 territories offer net metering

ROOFTOP SOLAR IN THE *US*

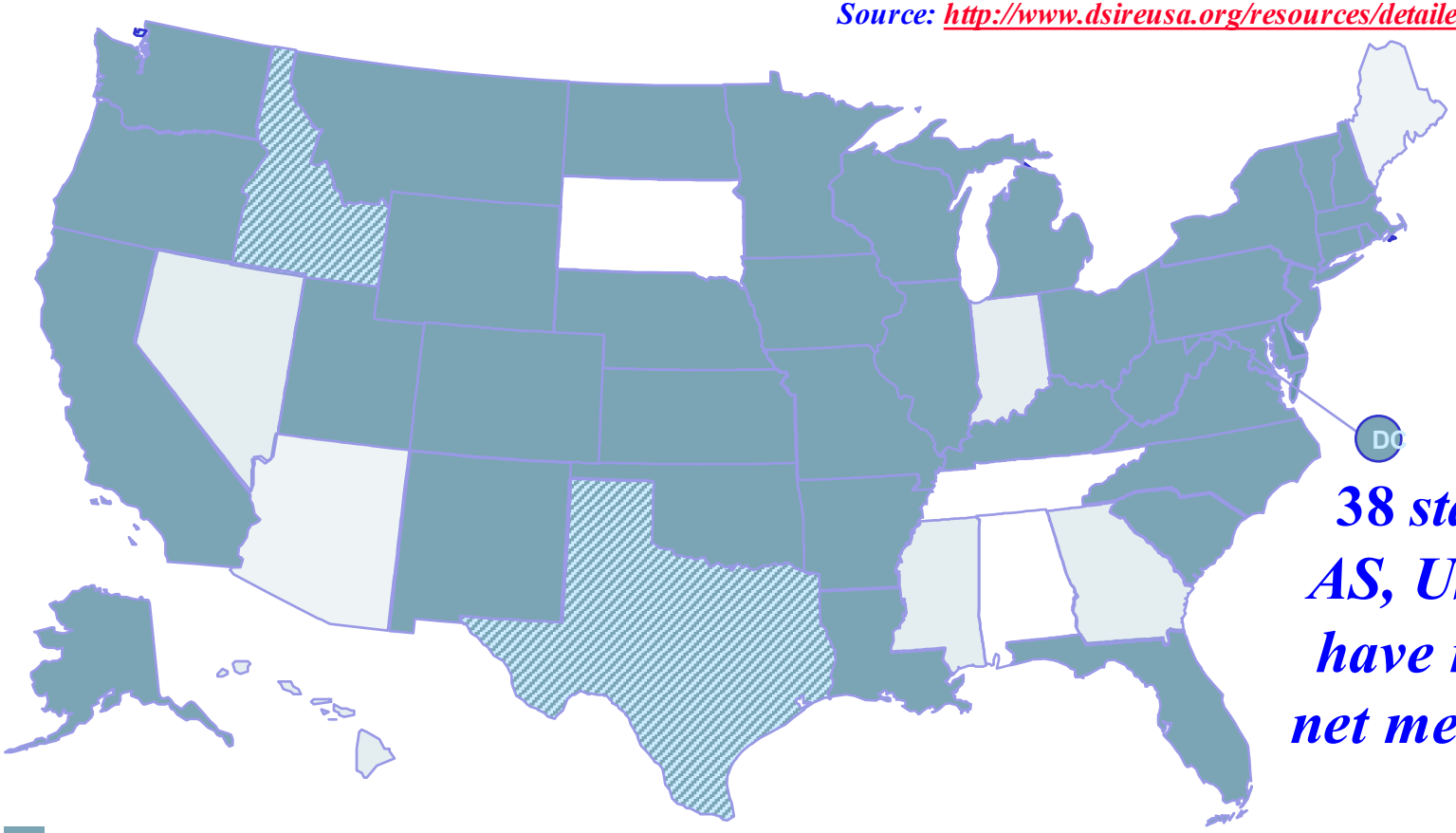
- Under net metering – a billing mechanism that credits solar energy system owners for excess energy injected into the grid – customers only pay for the electricity consumed in excess of what they feed into utility, the so – called *net energy*

Source: http://www.seia.org/policy/distributed-solar/net-metering

- The implementation of net metering varies from one jurisdiction to another

US NET METERING STATUS

Source: http://www.dsireusa.org/resources/detailed-summary-maps/; July 20



38 states + DC, AS, USVI, & PR have mandatory net metering rules

state-developed mandatory rules for certain utilities (38 states + DC+ 3 territories)

no statewide mandatory rules, but some utilities allow net metering (2 states)

state-wide distributed generation compensation rules other than net metering (7 states + 1 territory)

US Territories

AS	PR
VI	GU

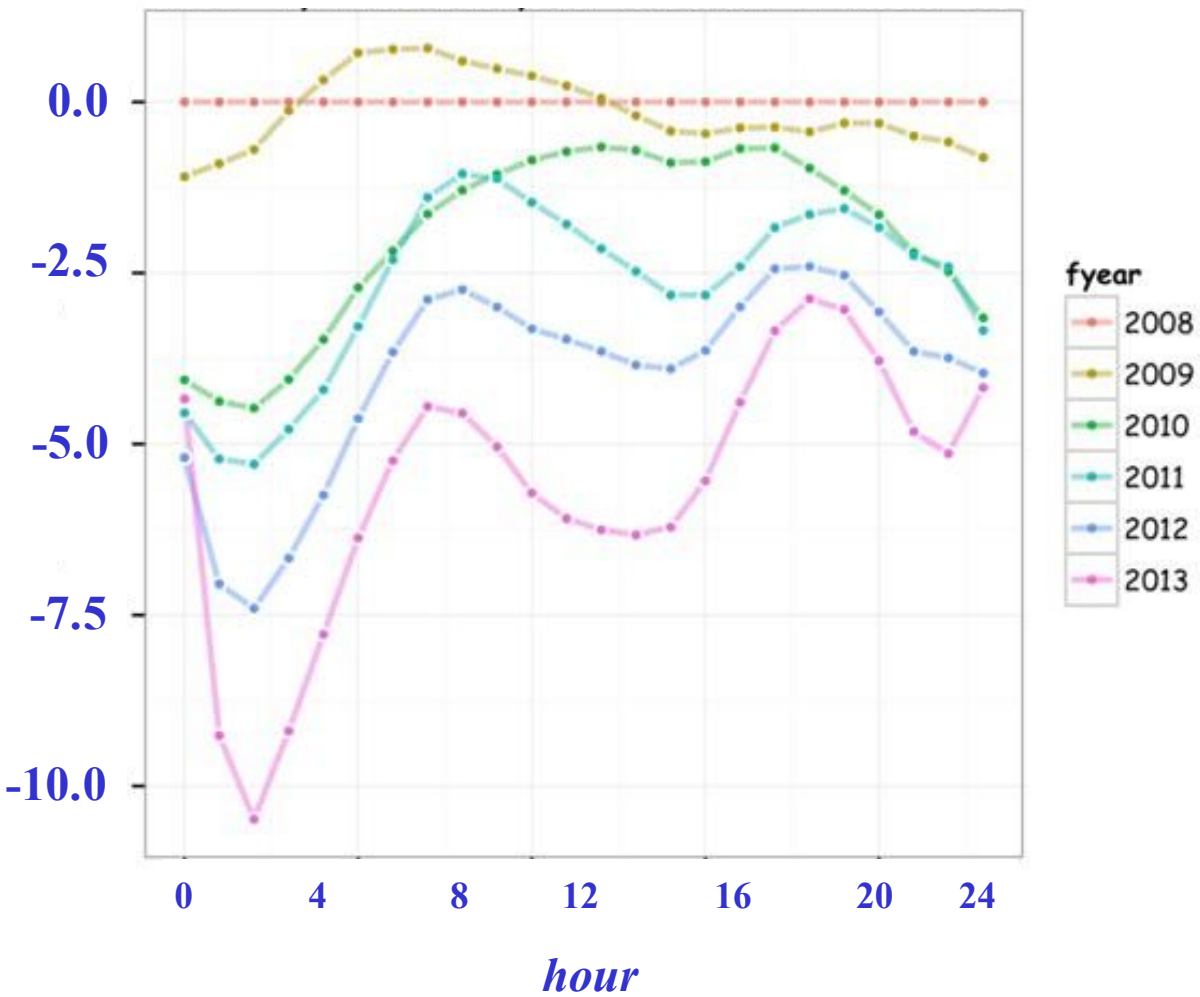
ROOFTOP SOLAR IN *CA*

- In *CA*, solar owners receive federal tax credits, rebates under the *CA Solar Initiative*, which is being phased out, and *net metering*; from 2010 to 2012, the installed *kW* amount increased 160 % annually
- The payments foregone by the net metered solar owners are pushing the distribution utilities to shift the collection of the electricity infrastructure to the non-solar-owner customers, that utilities fear results in a "*death spiral*"

ROOFTOP SOLAR IN AUSTRALIA

- Australia has installed over 1,000 *MW* of solar *PV*
- In South Australia, with the highest deployment of solar *PV* by households, the changes in electricity demand are noticeable since 2007
- The year-by-year drop in demand closely accompanies the sunrise-to-sunset time frame
- The plot shows the average percentage change in the hourly demand with respect to the 2007-2008 fiscal year

SOUTH AUSTRALIA DROP IN ELECTRICITY DEMAND



Source: Climate Spectator, http://www.businessspectator.com.au/article/2013/8/8/solar-energy/solars-bite-energy-demand

OPPOSITION TO GREEN POWER POLICIES

- Notwithstanding the growing importance of green energy, opponents of government policies that stimulated this growth are pushing to roll back those incentives and mandates
- Energy markets are strongly driven by policies and the various attempts to weaken or eliminate green energy mandates and incentives creates

OPPOSITION TO GREEN POWER POLICIES

new sources of uncertainty, whose effects are to chill markets and reduce investment momentum

- Ohio has enacted a bill – Senate Bill 310 – shelving requirements for utilities to ramp up the use of renewable energy and energy efficiency; in effect the bill provides a two-year freeze on the *RPS* requirements in Ohio to have 25 % of the consumption supplied by renewable resources

COURSE OBJECTIVES

- Acquaint students with key basic physical principles used in renewable energy
- Stress the importance of economics and environmental aspects in electricity developments
- Expose students to some major developments in renewable energy systems and their integration into the power grid
- Provide a good understanding of impacts of market forces on shaping the electricity business
- Expose students to the exciting developments in the energy sector

ECE 333 : KEY ASPECTS

- Understanding of the scientific principles underlying renewable resources is essential
- Awareness of the role that renewables can play is important
- Challenges in the integration of renewables are huge in nearly every aspect

TOPICAL OUTLINE

- General overview of electricity demand, supply, industry structure, interconnected system operations and state of technology
- Nature and role of alternative generation sources
- Review of concepts in electric circuit analysis
- Engineering aspects of alternative source generation technologies: wind resource/generation

TOPICAL OUTLINE

systems; thermodynamics considerations; solar resource and solar array systems; economics of various technologies; environmental aspects

- The roles of energy storage resources and their deployment in grids with integrated renewable
- The demand picture: the nature of electrical loads; time variation, periodicity and price dependence aspects

TOPICAL OUTLINE

- Demand management and energy conservation; efficiency improvements; price–responsive demand; load management; and, the role of new technologies
- Electricity market basics
- Integration of renewable generation into the grid
- The policy and regulatory dimensions in electricity

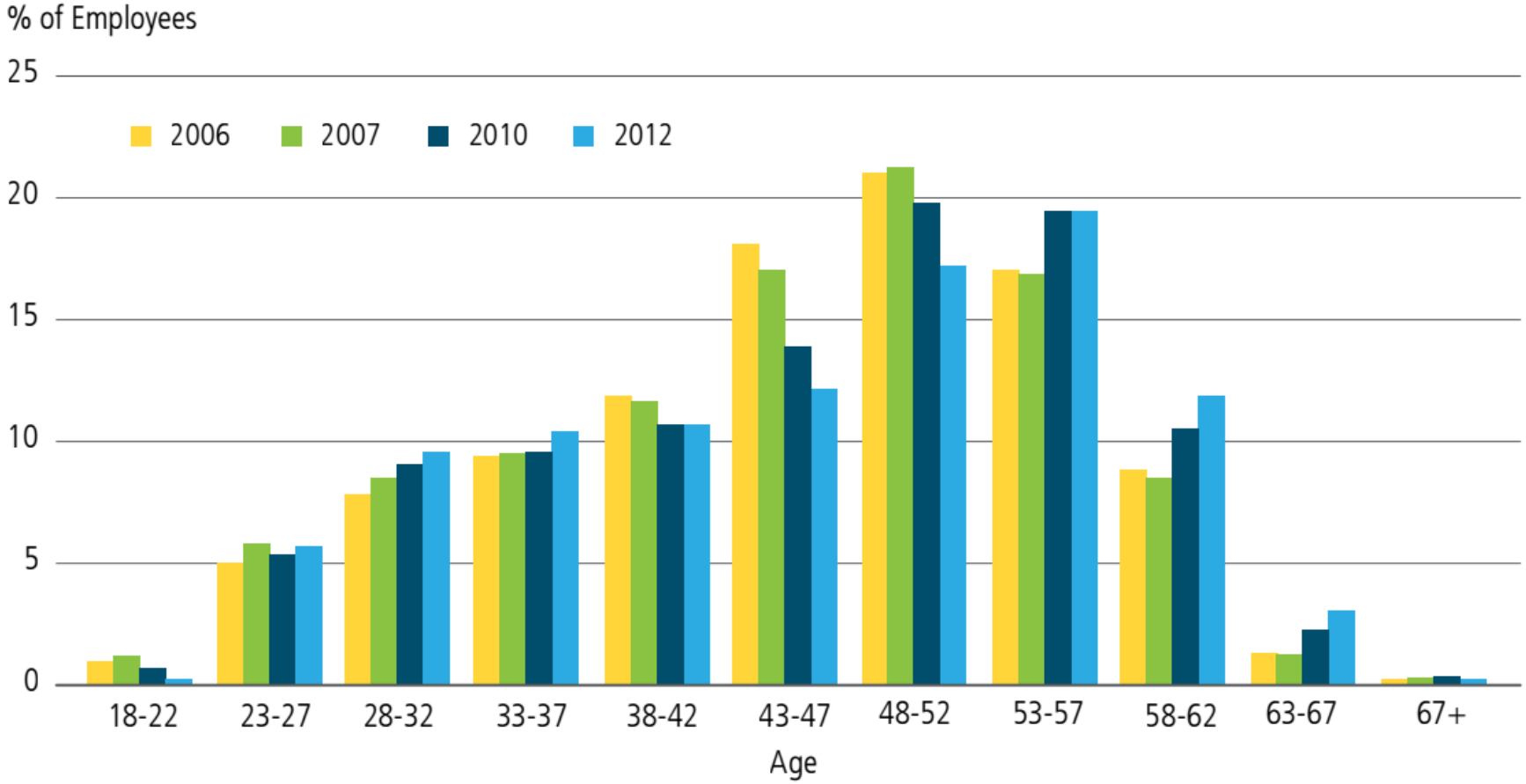
GRADING POLICY

- The course grade is based on the performance of the student in the quizzes, the two midterms and the final exam
- Students will be assigned homework but will not need to hand them in as they are not graded
- The problems in the short quizzes will be selected from the homework assignments

GRADING POLICY TABLE

component	*percentage*
homework	0
quizzes	15
midterm exams	25 x 2 = 50
final	35
total	100

WORKFORCE AGE DISTRIBUTION IN ELECTRIC & NATURAL GAS UTILITIES



The largest percentages of utility employees are in the 48–52 and 53–57 age groups; 38 percent of electric and natural gas employees will be eligible to retire in the next decade.

Source: EIA (2010-2013) http://www.eia.gov/electricity/monthly/current_year/february2014.pdf; pg 287; Issued April 2015

Suddenly, knowing a lot about the U.S. power grid became sexy at cocktail parties.