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

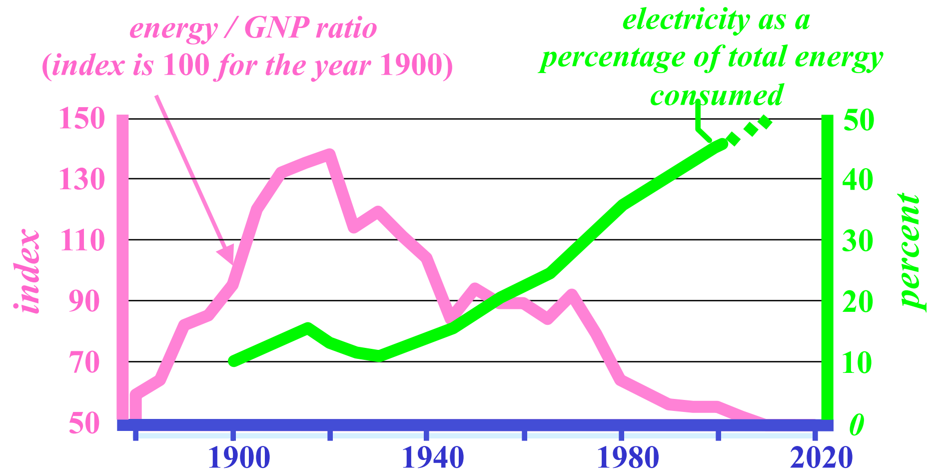
OUTLINE OF INTRODUCTION

- 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

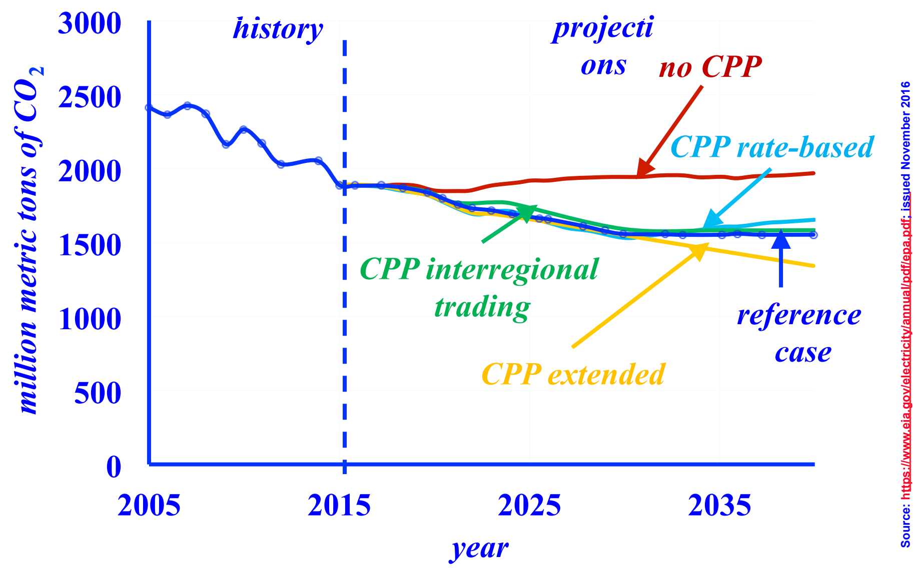
- Energy is the *lifeblood* of modern society
- The importance of electricity is on the rise
- Efficient and environmentally sensitive electricity services are key requirements for the nation's global competitiveness
- The electric power industry is one of the world's largest industrial sectors; the 2014 *US* revenues from retail sales were circa *$ 400 billion*

ENERGY CONSUMPTION AND ELECTRICITY USE



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

ELECTRIC POWER SECTOR CO_2 EMISSIONS



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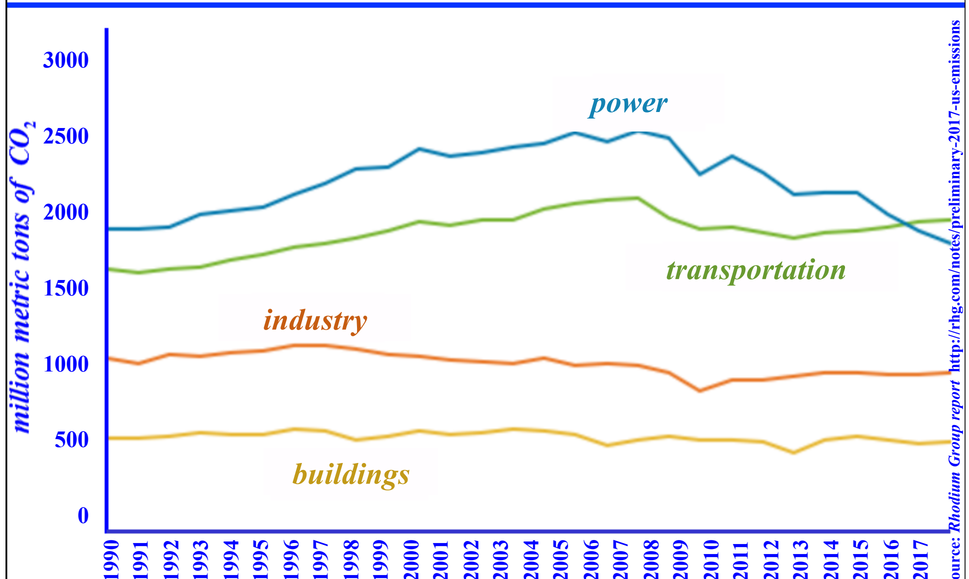
US CO_2 EMISSIONS: 1990 – 2017



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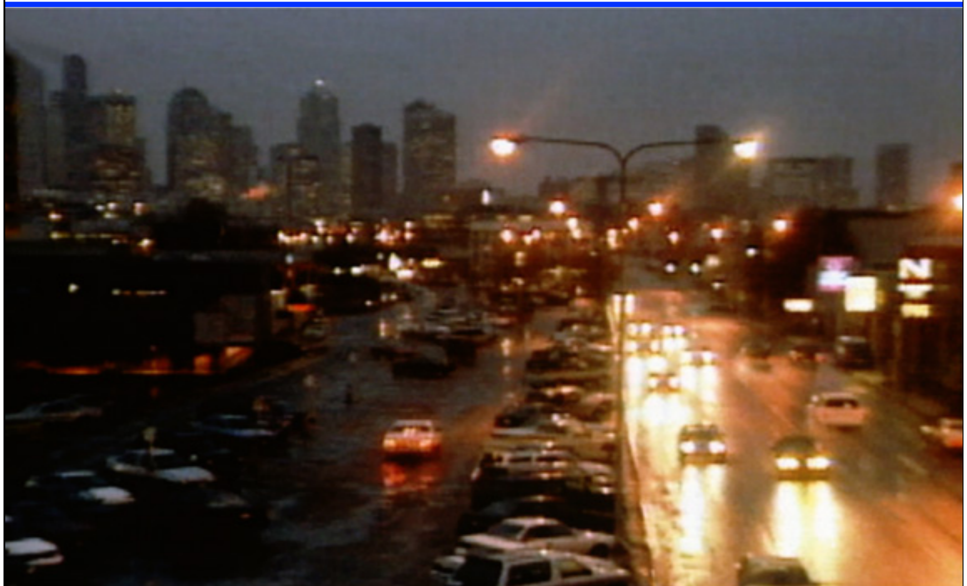
THE WORLD ECONOMIES RELY ON ABUNDANT AND AFFORDABLE ELECTRICITY



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

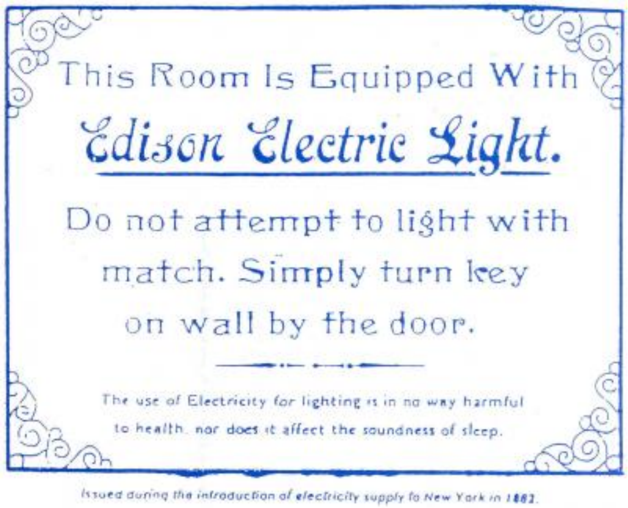
IMPACTS OF ELECTRICITY

- 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



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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

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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*)

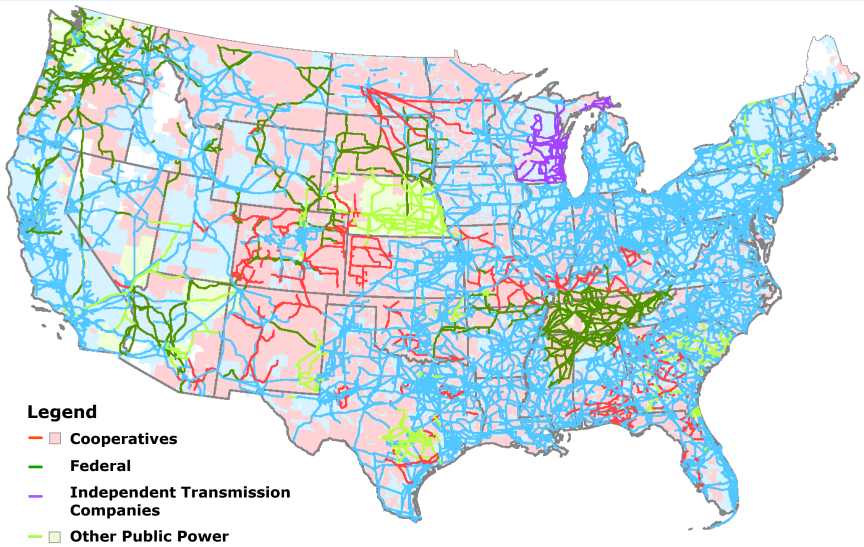
TECHNOLOGICAL DEVELOPMENTS

- 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

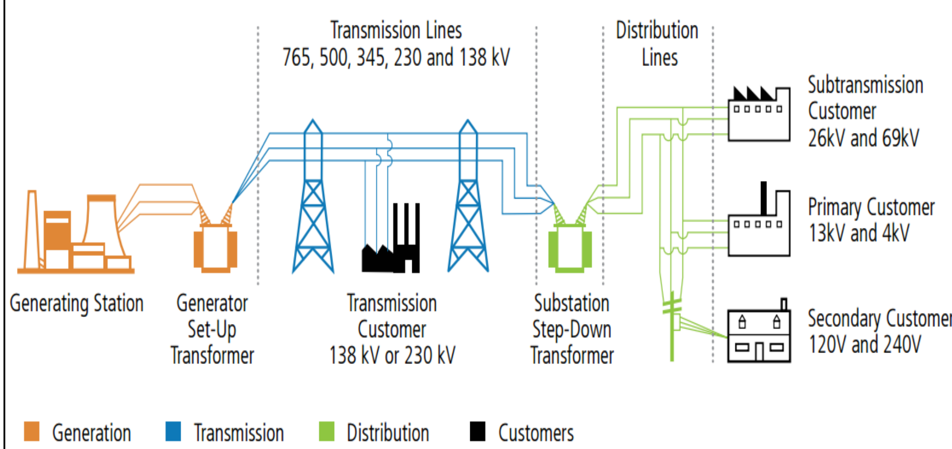
TECHNOLOGICAL DEVELOPMENTS

- 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

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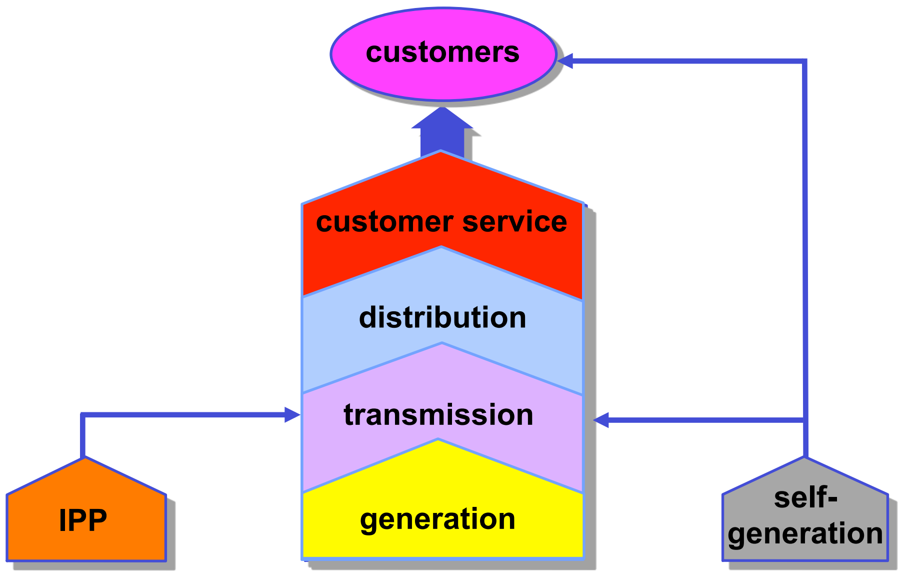
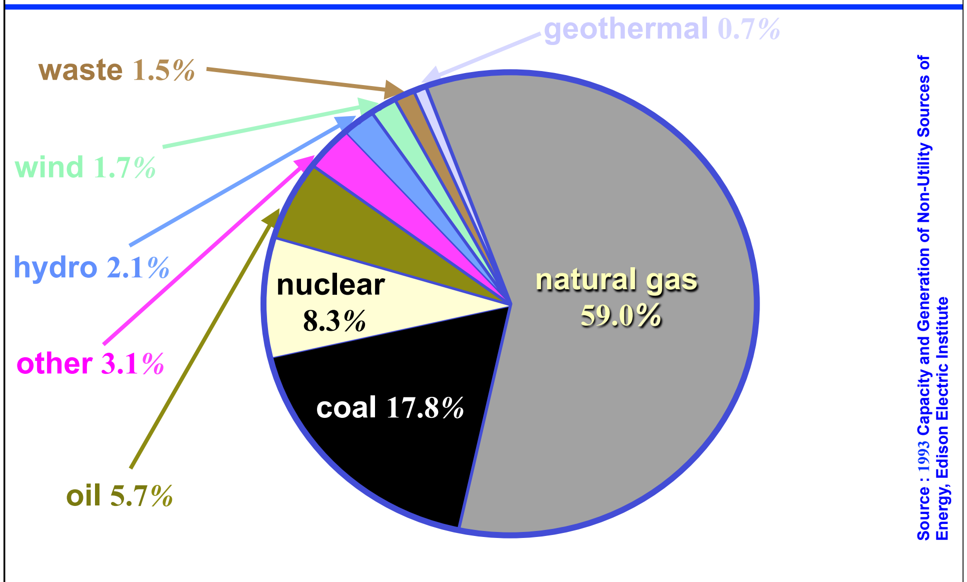
THE VERTICALLY INTEGRATED UTILITY INDUSTRY STRUCTURE



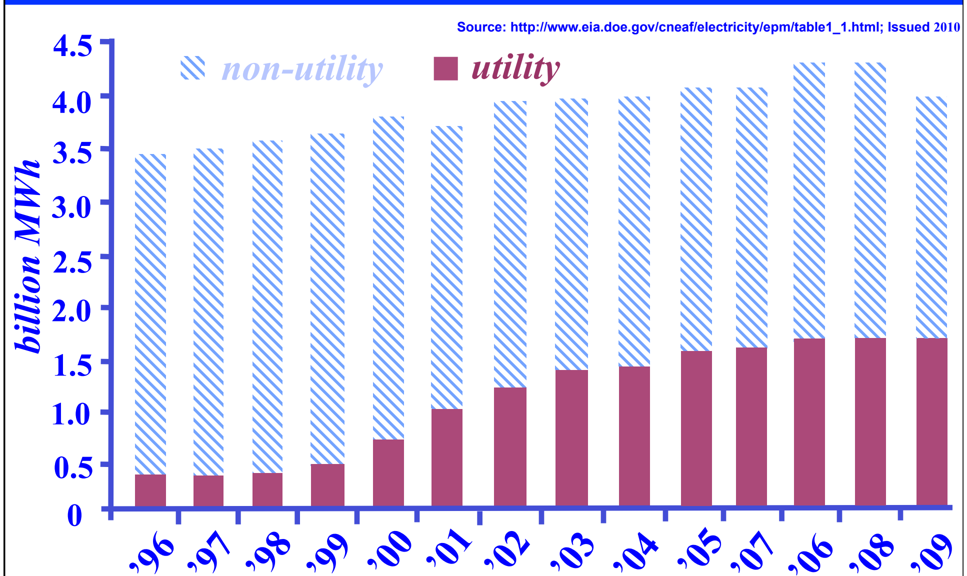
COMPETITION IN THE GENERATION MARKET

- 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

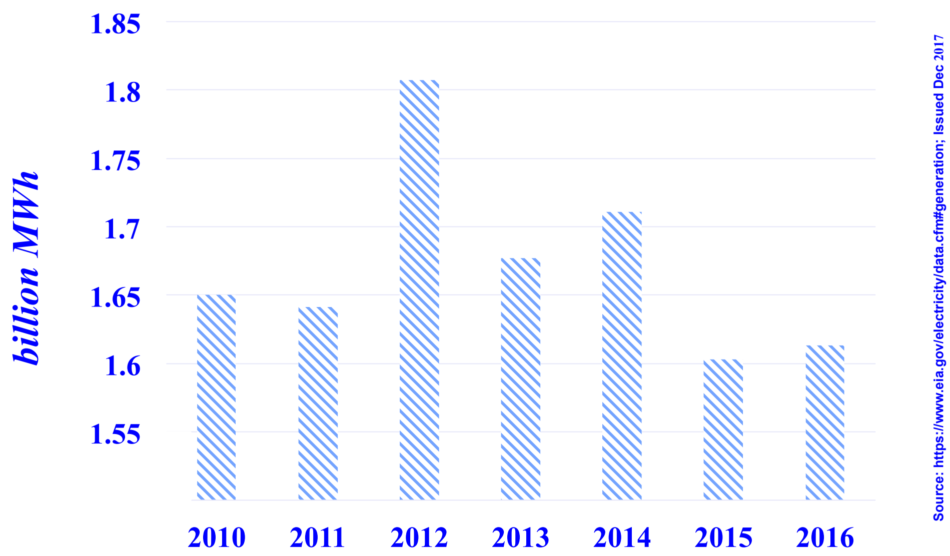
ENERGY SOURCES OF *NUG* CAPACITY



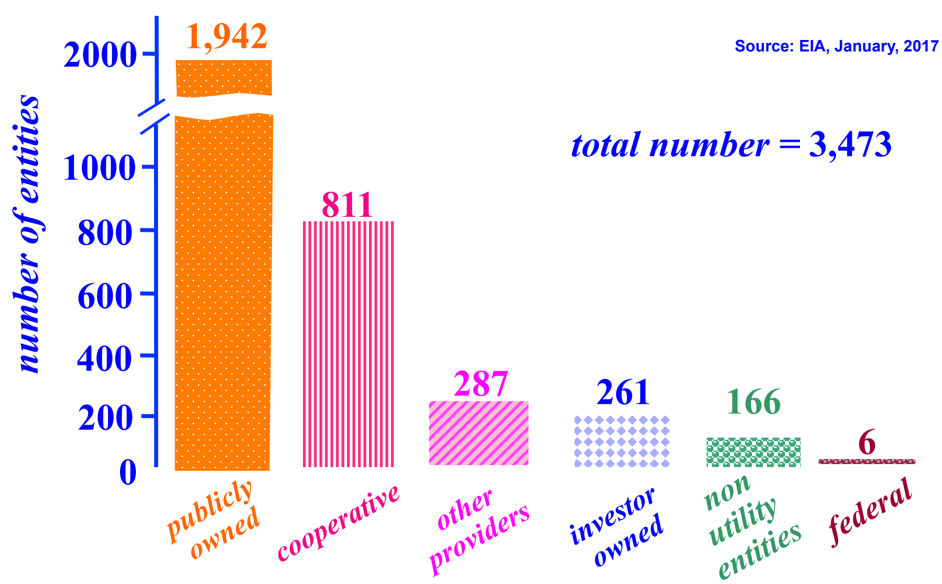
GROWING IMPACT OF *NUG* ENERGY



NUG ENERGY



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 6 federal power marketing agencies (*FPMA*s) include *Bonneville Power* and *TVA*

THE US ELECTRICITY INDUSTRY

- 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
- The 1,948 publicly owned electric utilities are the most numerous members of the industry: they represent non-profit, customer-owned government agencies at the local and state levels
- The 166 non–utility companies are, typically, not state–regulated entities

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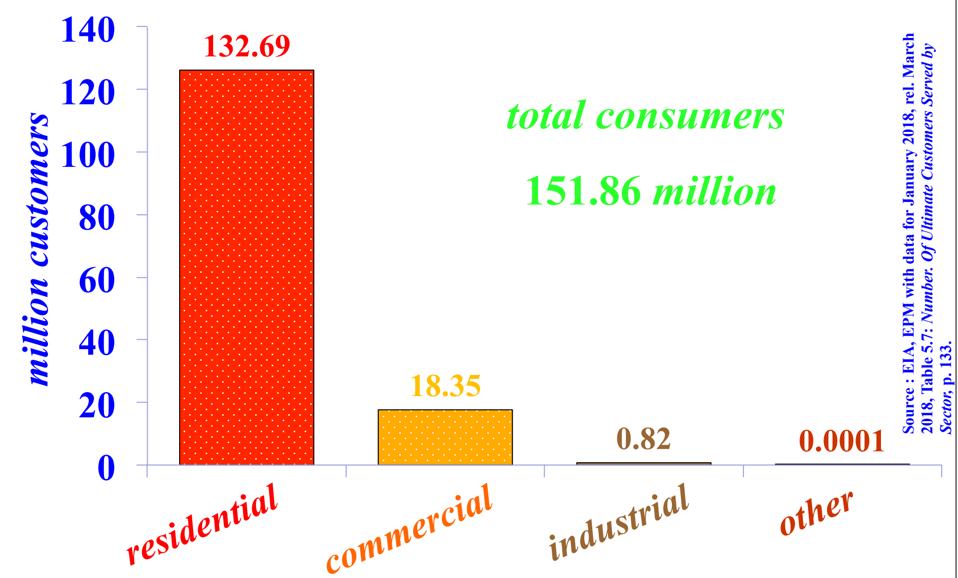
2017 *US* ELECTRICITY CUSTOMERS



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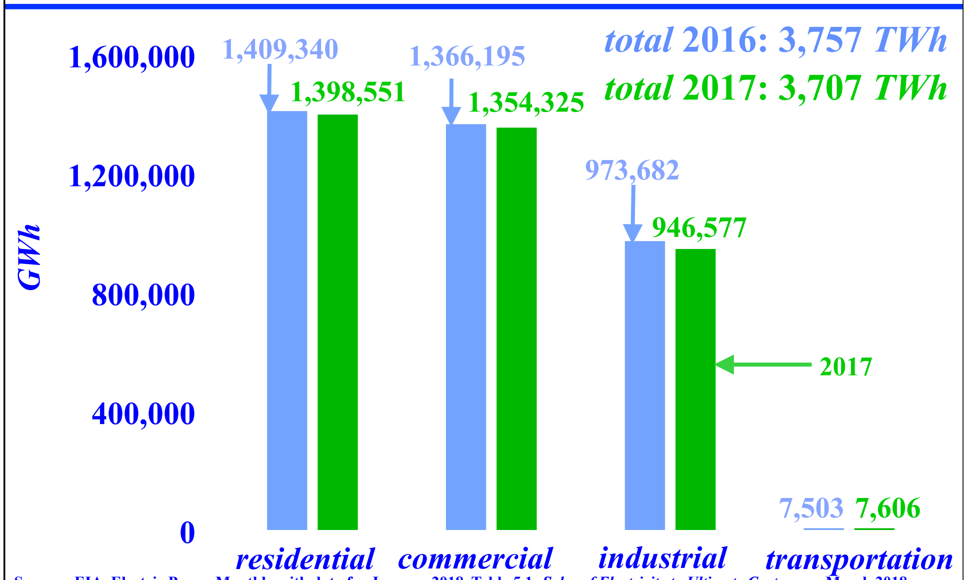
RETAIL SALES OF ELECTRICITY TO END–USE SECTOR CUSTOMERS



Source : EIA, Electric Power Monthly with data for January 2018, Table 5.1: *Sales of Electricity to Ultimate Customers,* March 2018.

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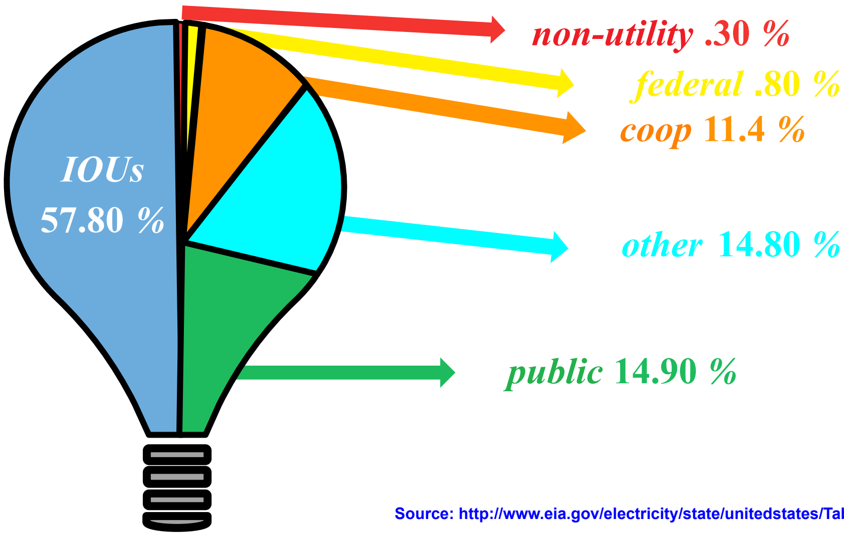
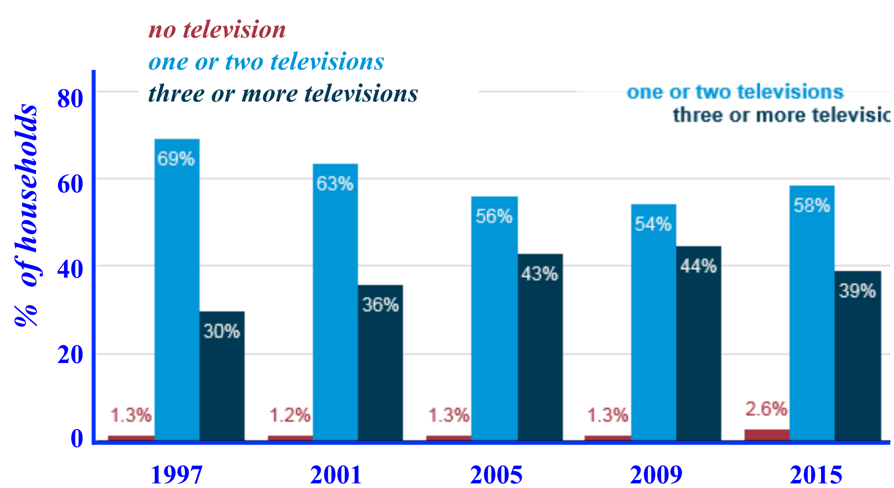
PERCENT CUSTOMERS SERVED BY ELECTRICITY PROVIDERS



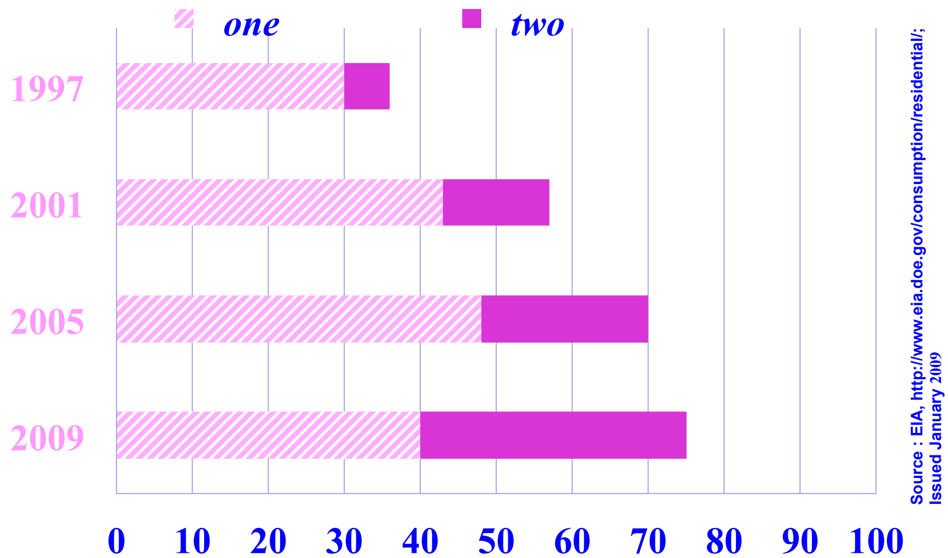
Source: http://www.eia.gov/electricity/state/unitedstates/Table 9

TV POPULATION IN *US* HOMES



Source: U.S. Energy Information Administration, Residential Energy Consumption Surveys, December 22, 2017, https://www.eia.gov/todayinenergy/detail.php?id=31692

RISING NUMBER OF COMPUTERS IN HOUSEHOLDS



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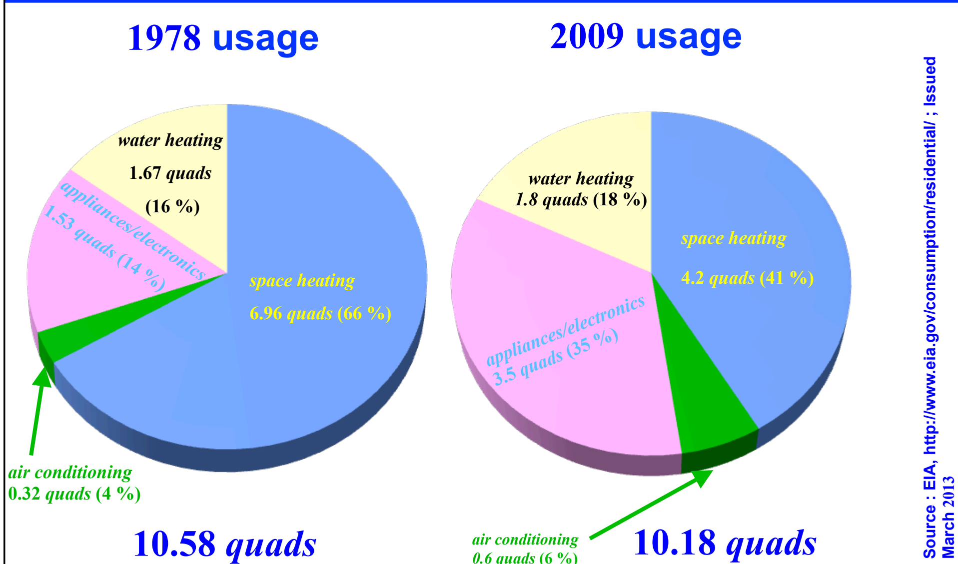
TOTAL RESIDENTIAL ENERGY USE



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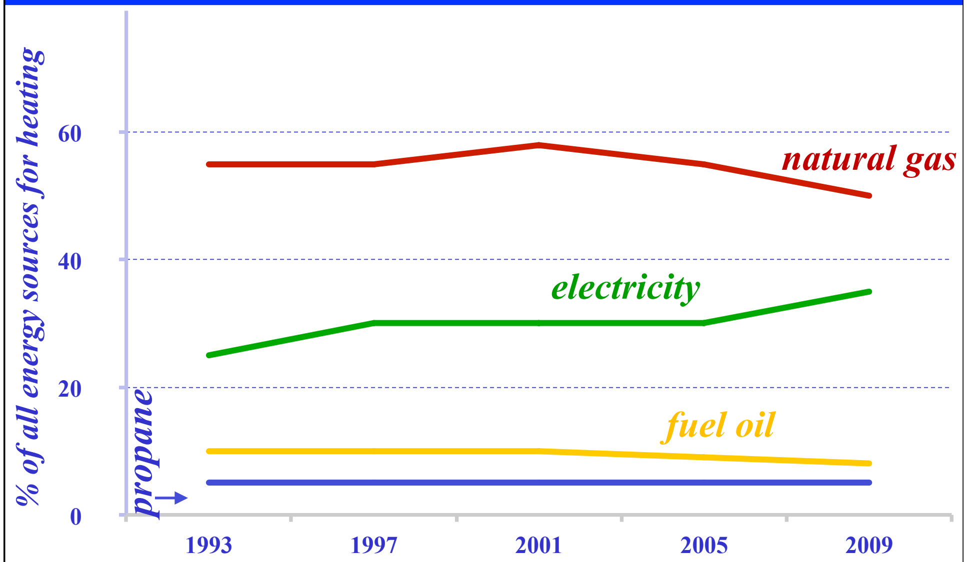
PREVALENT HEATING SOURCES IN *US* HOUSEHOLDS



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

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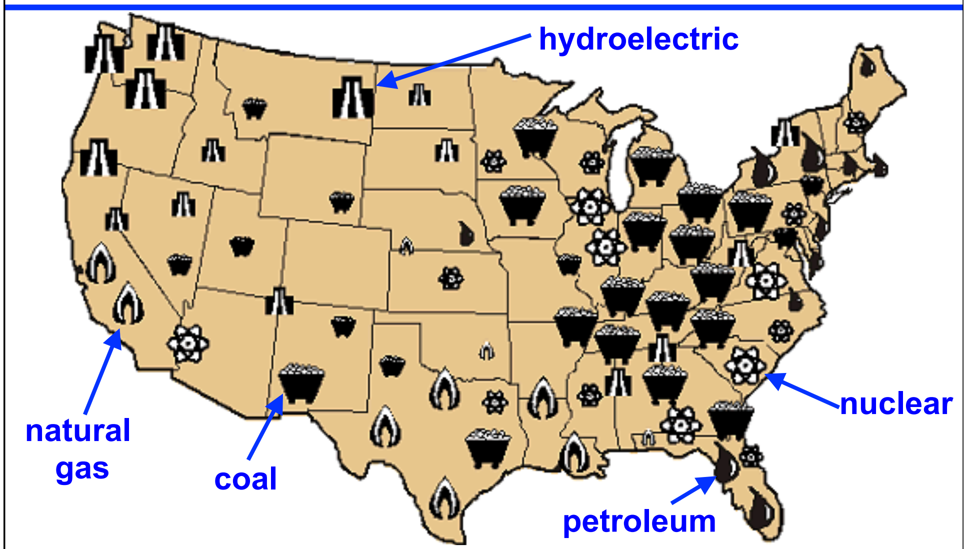
US CONVENTIONAL ELECTRICITY GENERATION SOURCES



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

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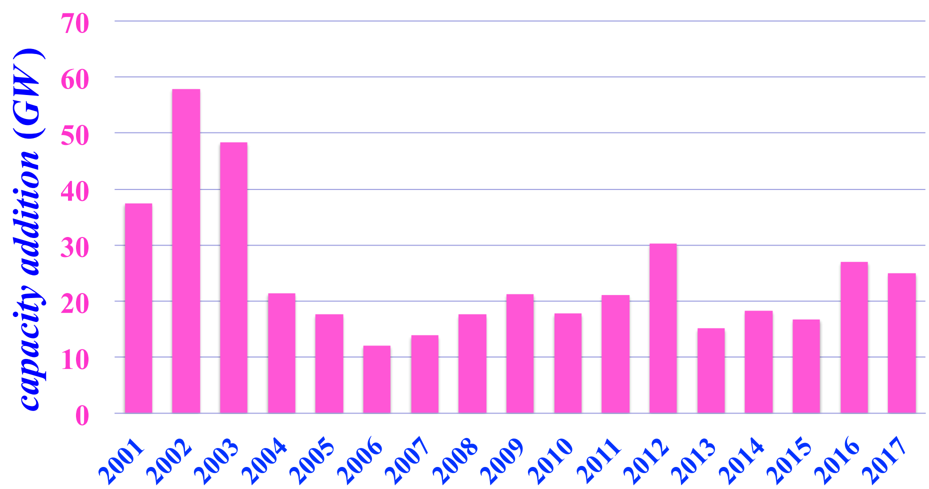
2001 – 2017 GENERATION CAPACITY ADDITIONS



Source: EIA, http://www.eia.gov/electricity/annual/html/epa_04_06.html; issued December 2017

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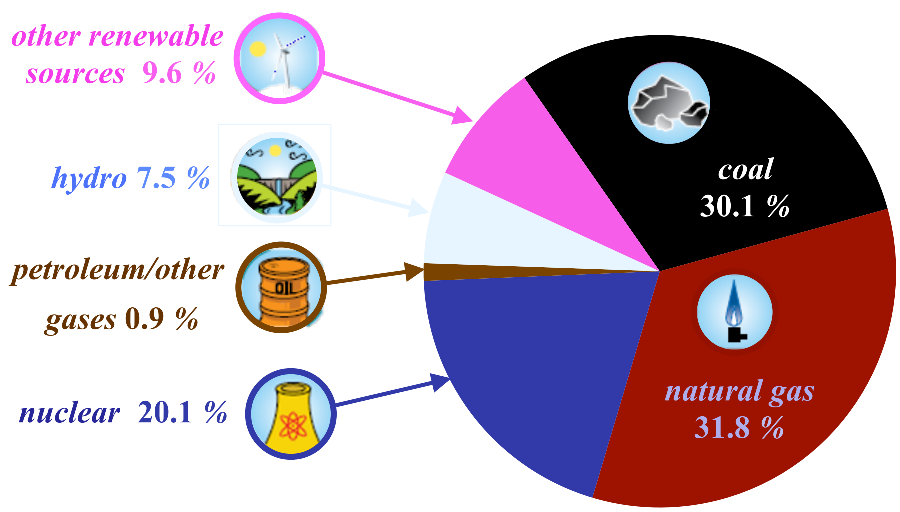
2017 GENERATION BY SOURCE



Source: EIA March 29,2018, https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf; issued March, 2018

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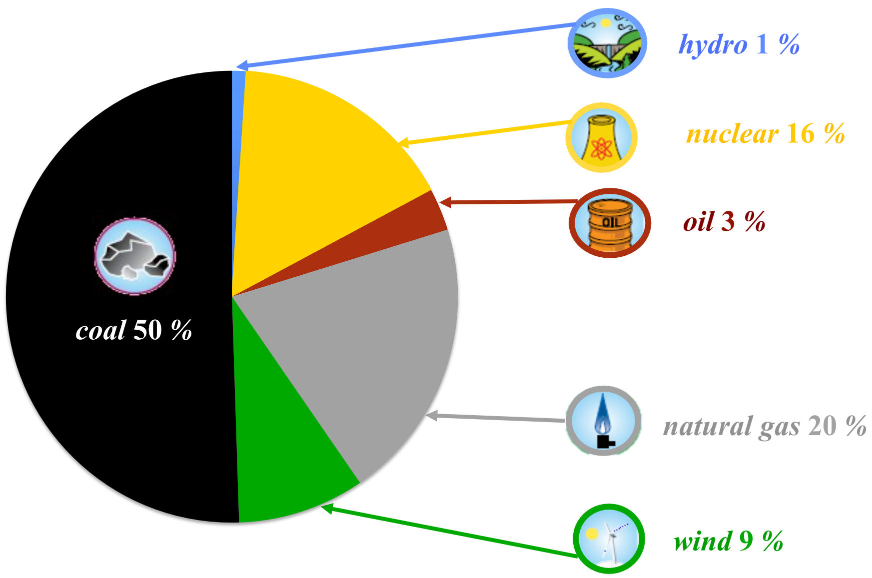
AMEREN ILLINOIS ENERGY SOURCES OF ELECTRICITY SUPPLIED IN 2017



Source: Ameren IP, April 2018

2017 *AMEREN ILLINOIS POWER* AVERAGE ELECTRICITY EMISSIONS / WASTE

output	*average amount per MWh*
carbon dioxide	1,373 *lb*
nitrogen oxides	0.72 *lb*
sulfur dioxide	1.38 *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 about
  - 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

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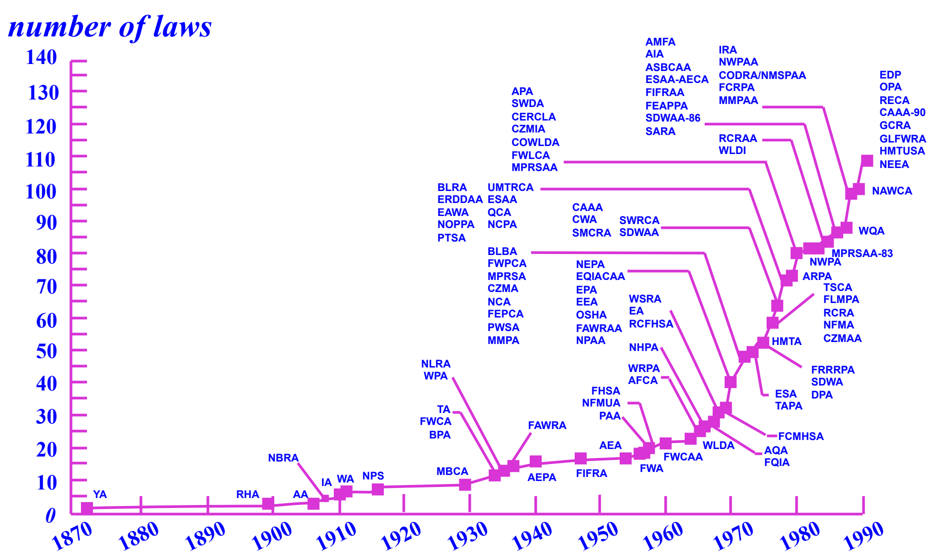
US LAWS ON ENVIRONMENTAL PROTECTION



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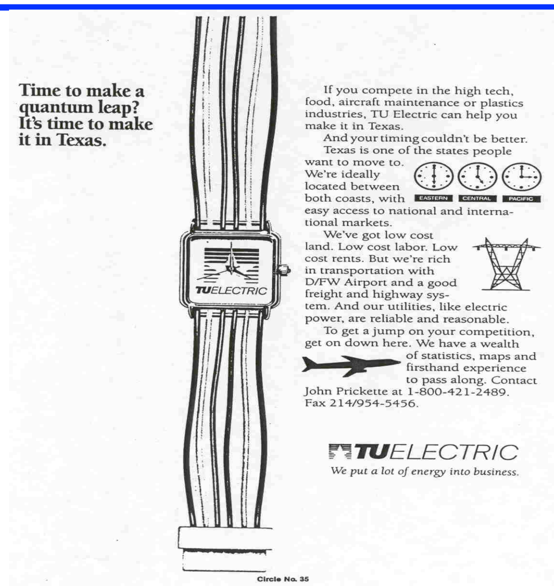
ACRONYM SOUP

- *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}

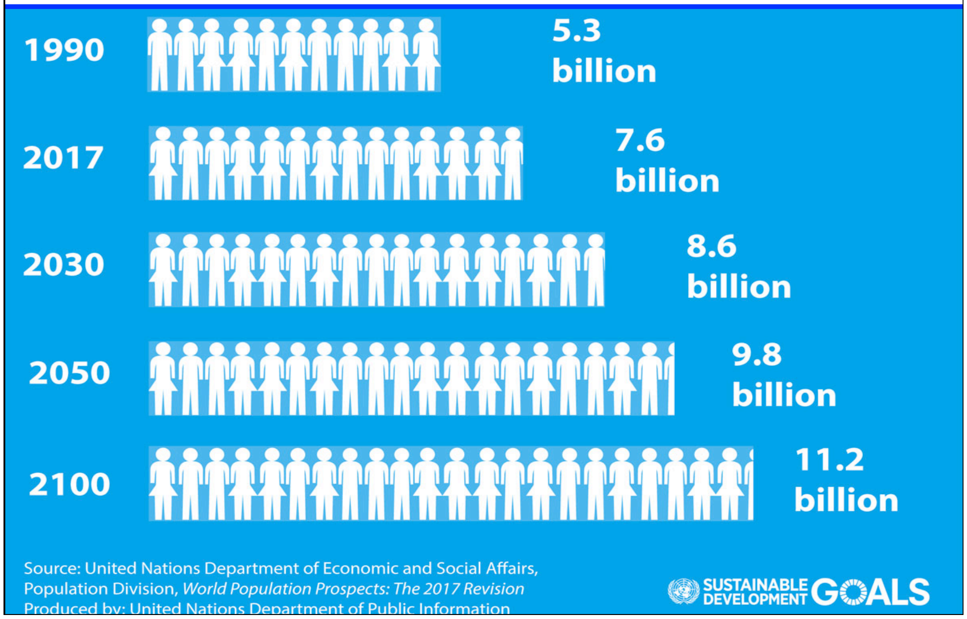
ENERGY AND POWER UNITS

- 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*

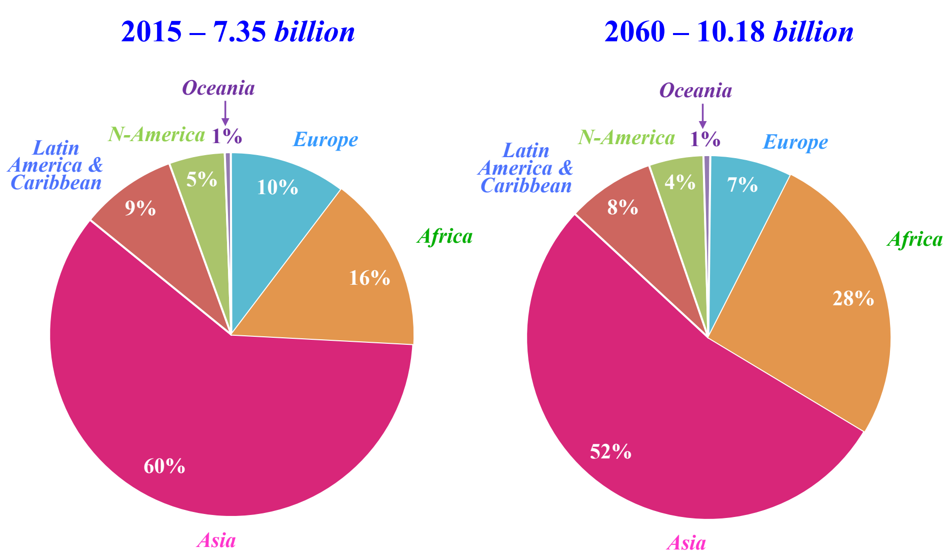
THE GLOBAL ENERGY DEMAND

- 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

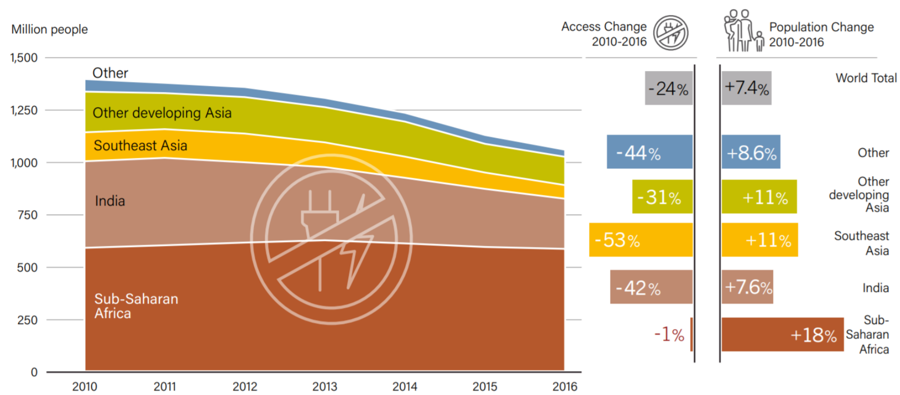


DEMOGRAPHIC TRANSFORMATIONS



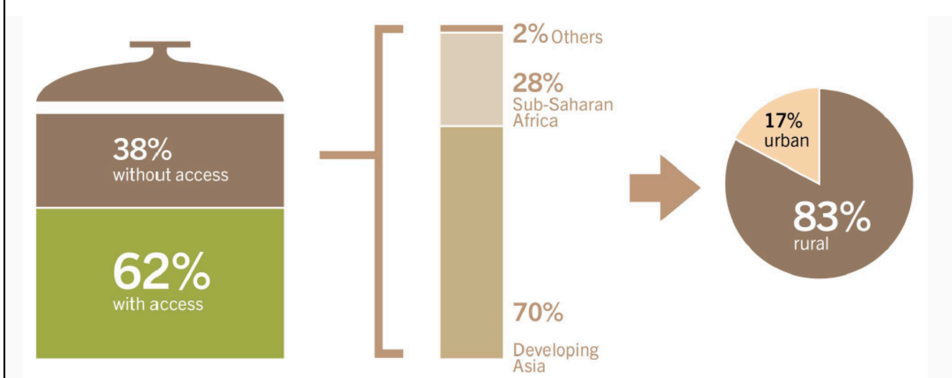
Source: UN, Population Division; http://esa.un.org/unpd/wpp/Excel-Data/population.htm

GLOBAL LACK OF ELECTRICITY ACCESS



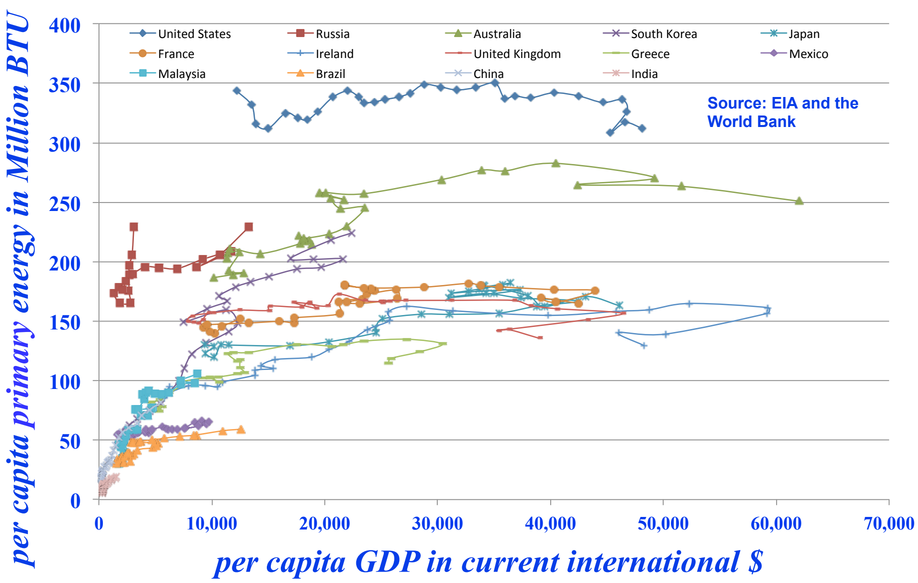
Source: REN 21 at http://www.ren21.net/wp-content/uploads/2018/06/17-8652_GSR2018_FullReport_web_-1.pdf

GLOBAL LACK OF CLEAN COOKING ACCESS

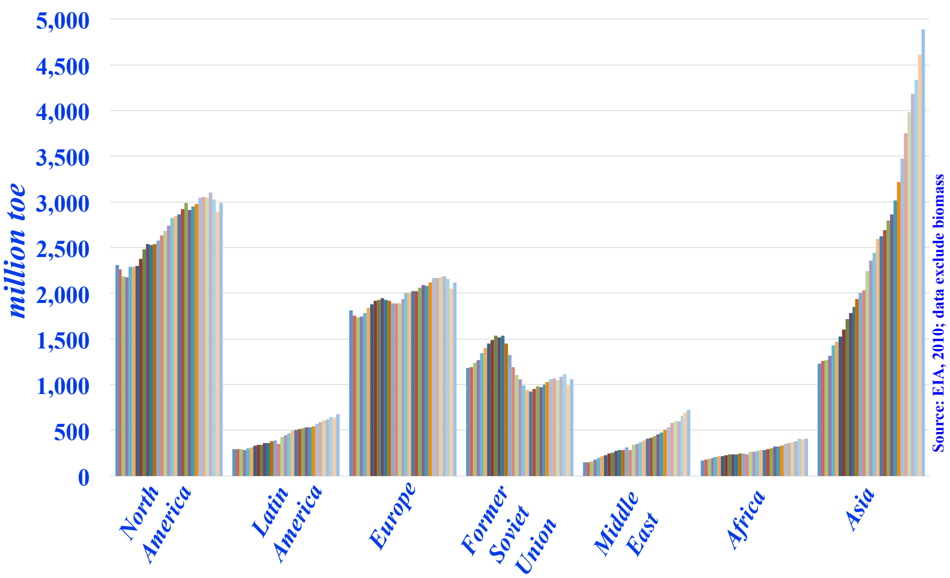


Source: REN 21

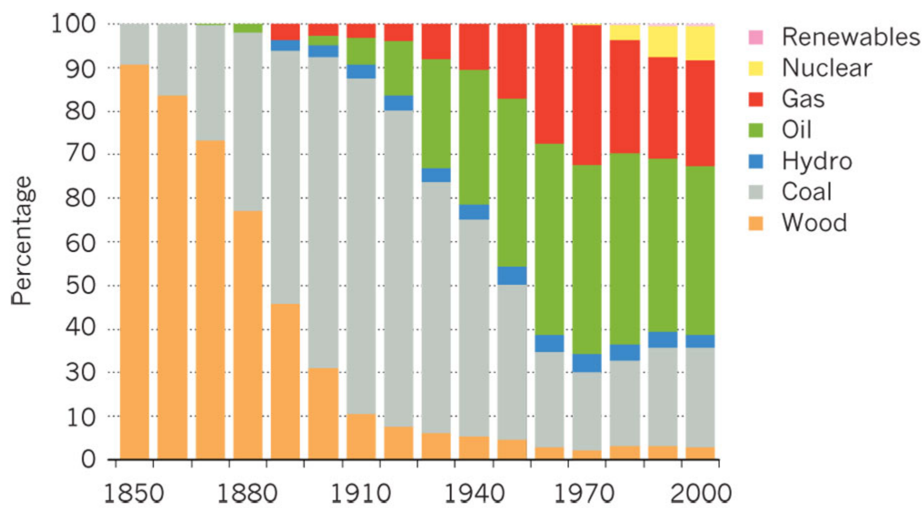
1980 – 2011 ENERGY DEMAND VS. *GDP PER CAPITA*



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

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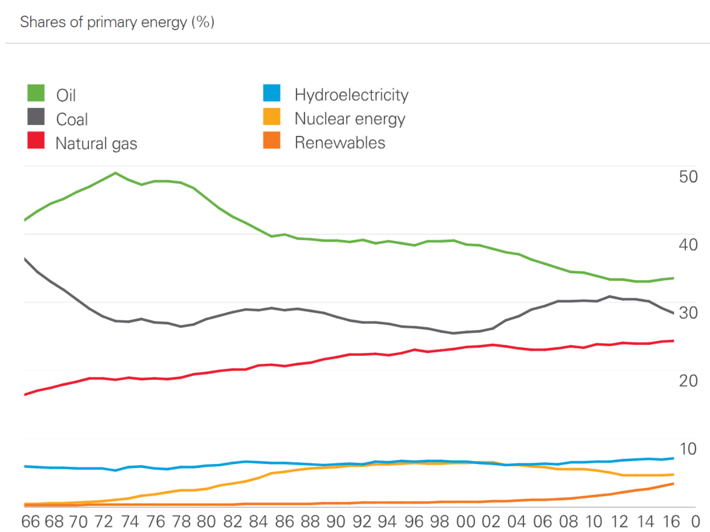
WORLDWIDE SHARES OF PRIMARY ENERGY: 1966 – 2016



Source: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/primary-energy.html

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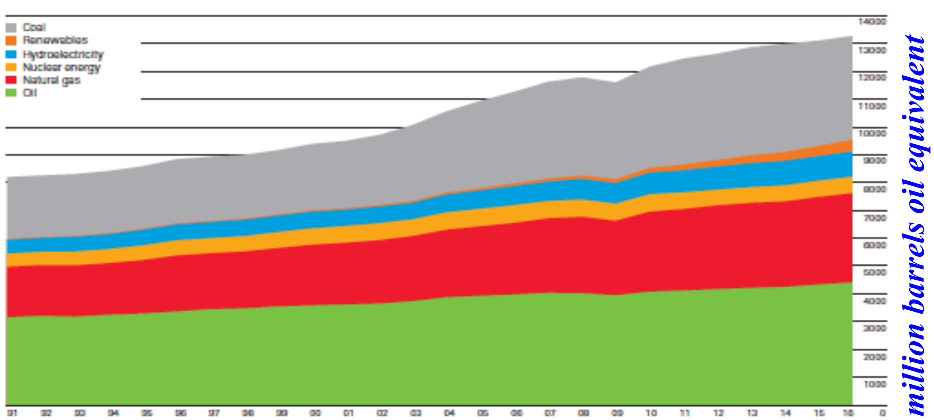
2012 WORLD PRIMARY ENERGY CONSUMPTION

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

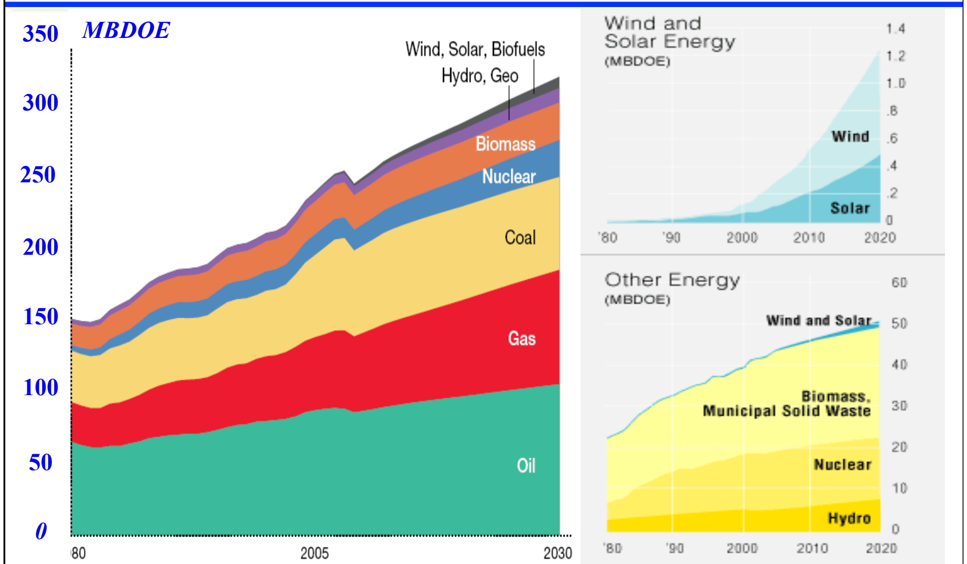
PREDOMINANCE OF OIL AND GAS



World primary energy consumption grew by 1.0% in 2016, well below the 10-year average of 1.8% 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

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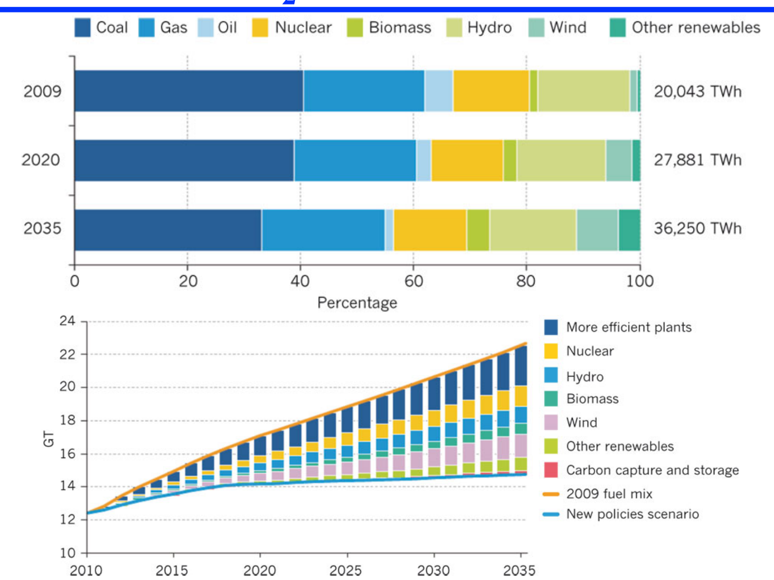
IEA ELECTRICITY GENERATION AND CO_2 FORECASTS



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

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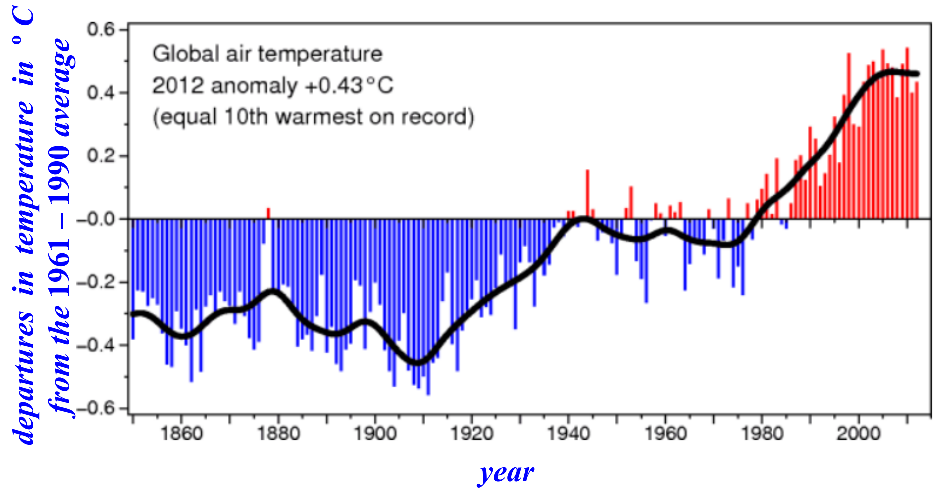
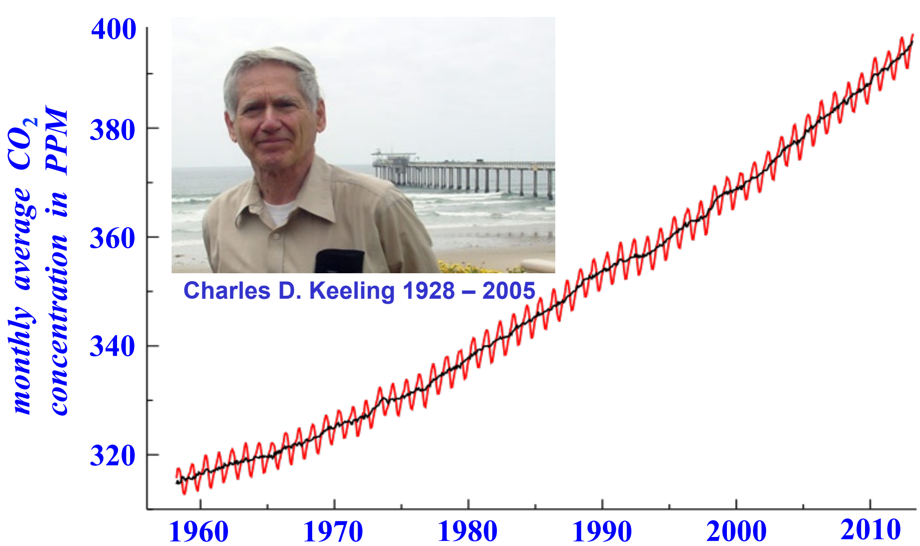
GLOBAL MEAN TEMPERATURE



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

Source: IPCC Fourth Assessment Report

KEELING CURVE



Source: Mauna Loa Observatory, Hawaii

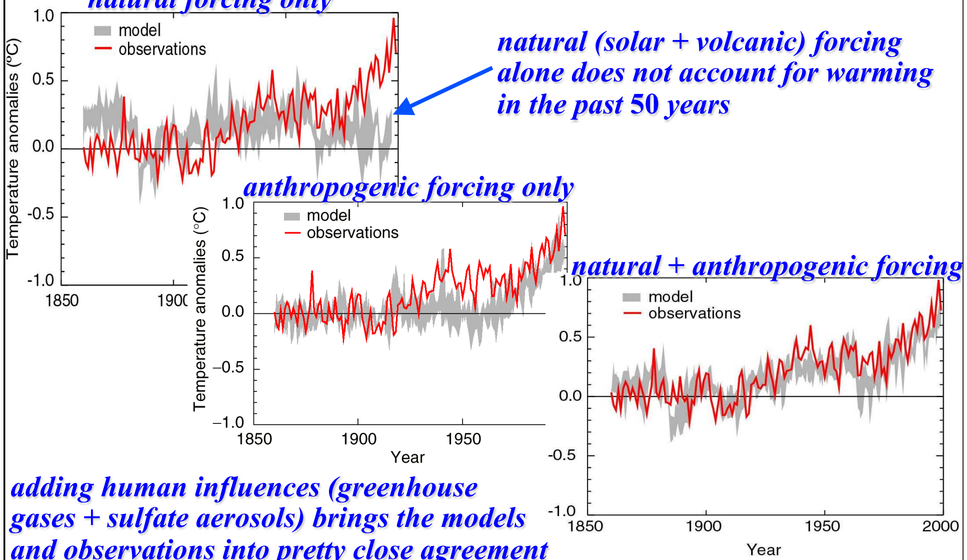
COMPELLING EVIDENCE

natural forcing only

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

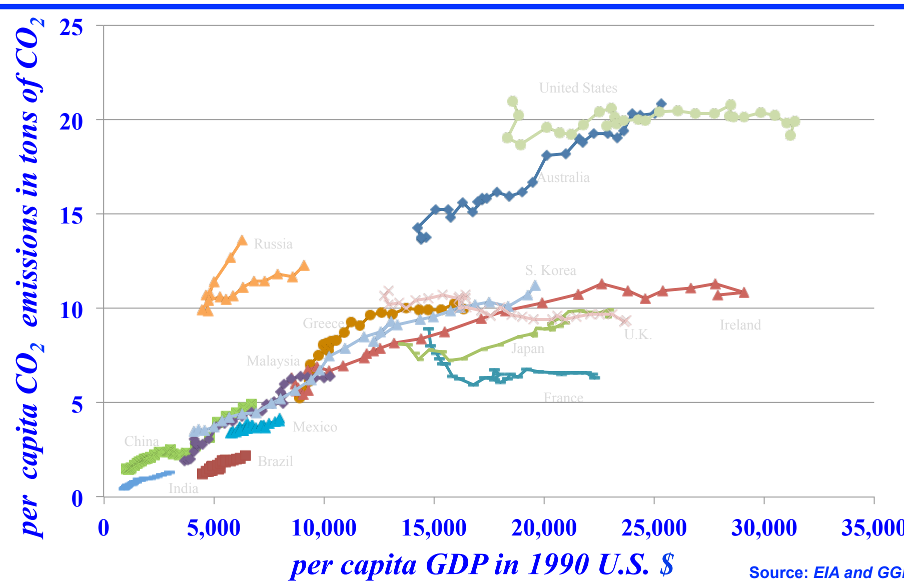
anthropogenic forcing only

natural + anthropogenic forcing



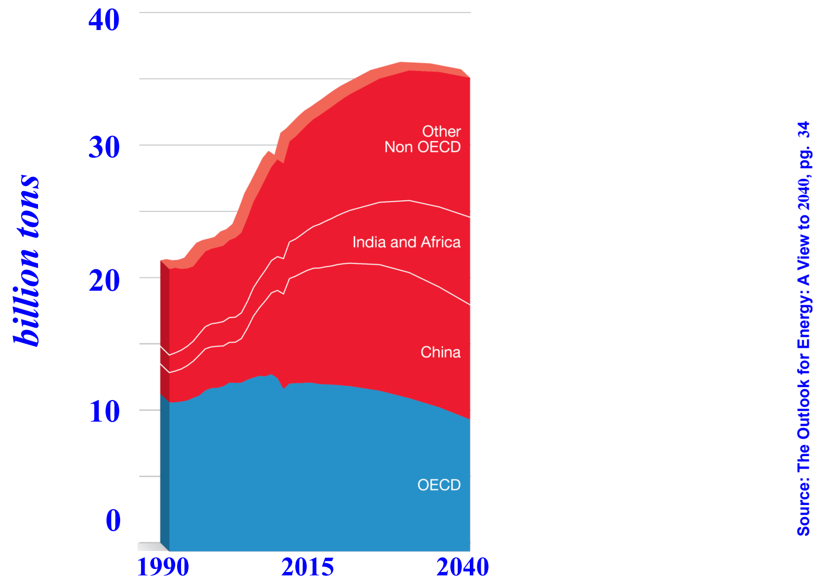
adding human influences (greenhouse gases + sulfate aerosols) brings the models and observations into pretty close agreement

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



Source: *EIA and GGDC*

CO_2 EMISSIONS FORECAST



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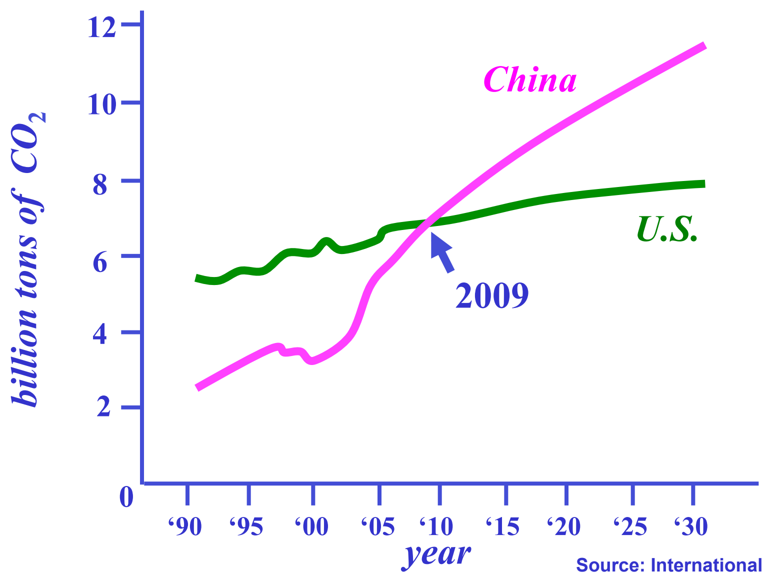
EMISSION HETEROGENEITIES



Source: International Energy Agency

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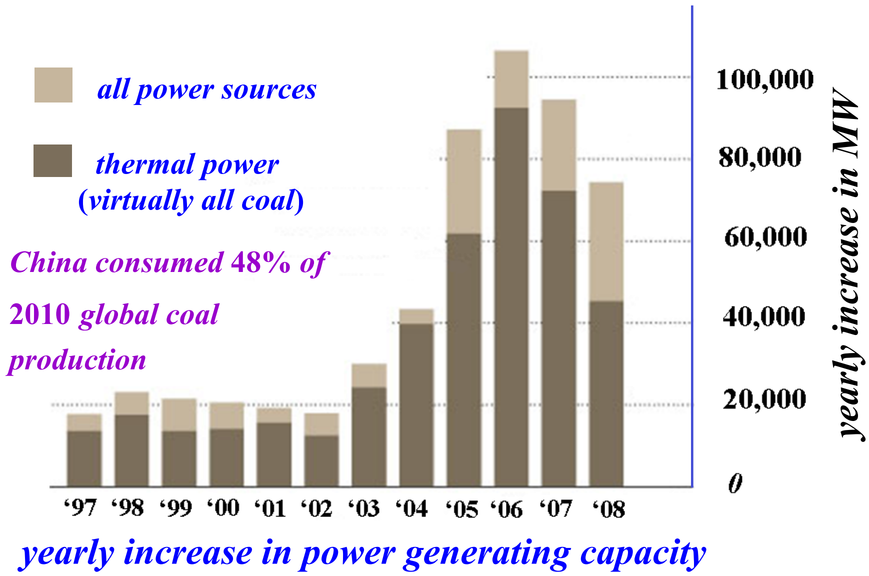
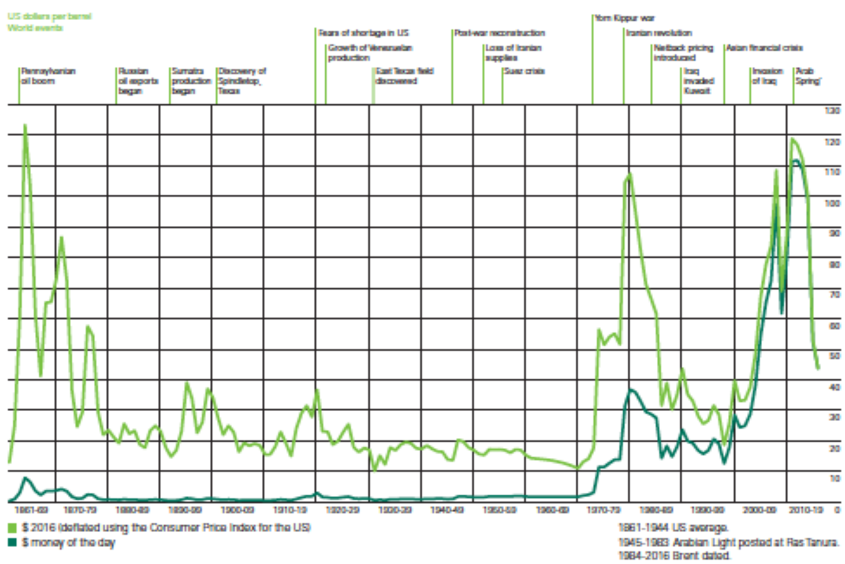
CHINA GENERATION CAPACITY



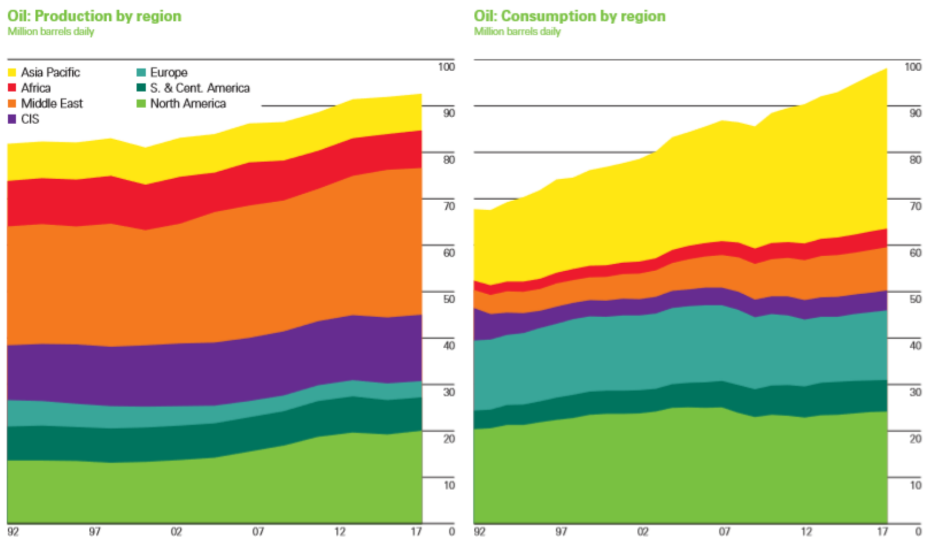
Sources: NYT article using China National Bureau of Statistics data; BP Statistical Review of World Energy 2011, pg. 5

CRUDE OIL PRICES 1861- 2016



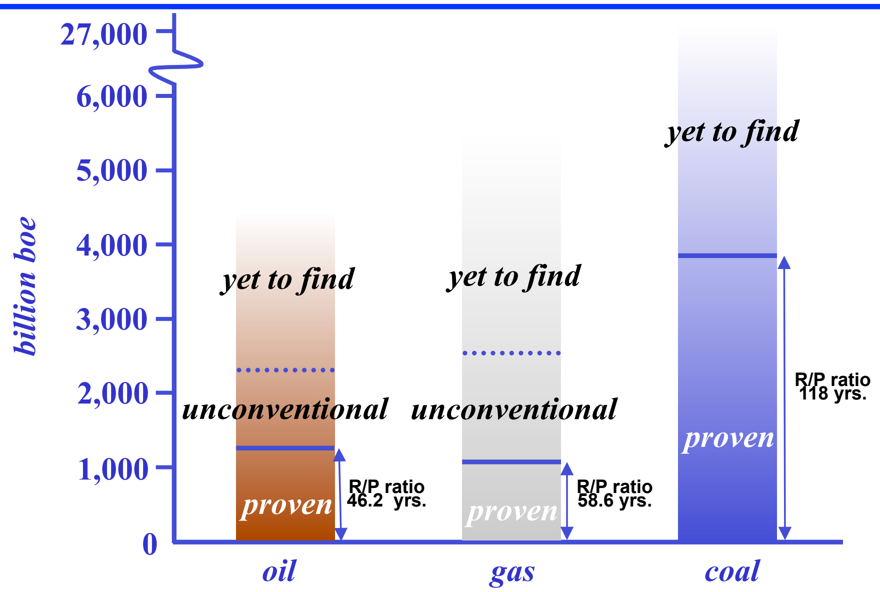
Source: BP Statistical Review of World Energy 2017

ANNUAL WORLD OIL PRODUCTION



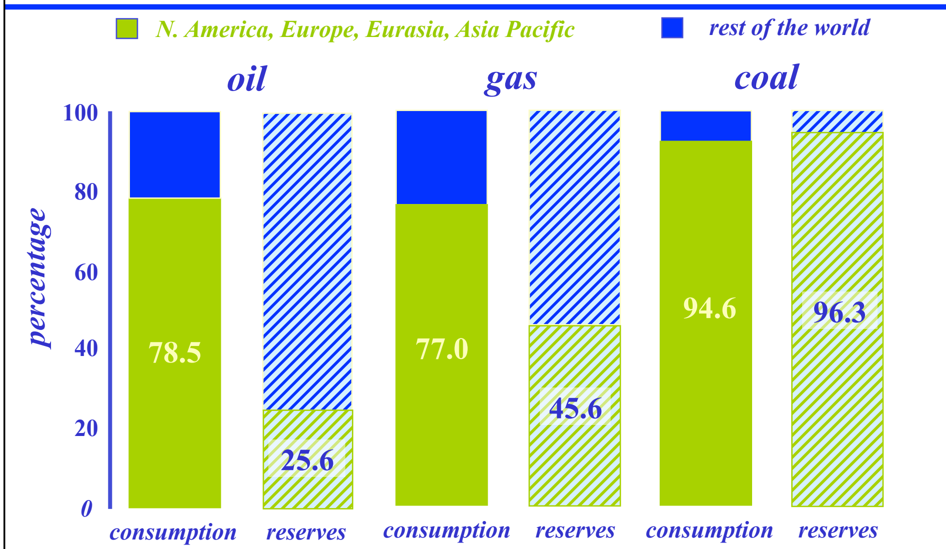
Source: BP Statistical Review of the World 2018

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

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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."*

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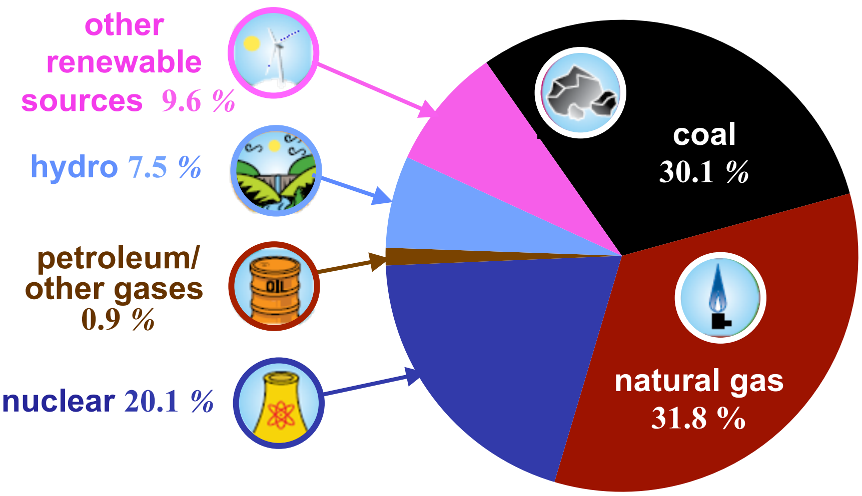
SUSTAINABILITY

- 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

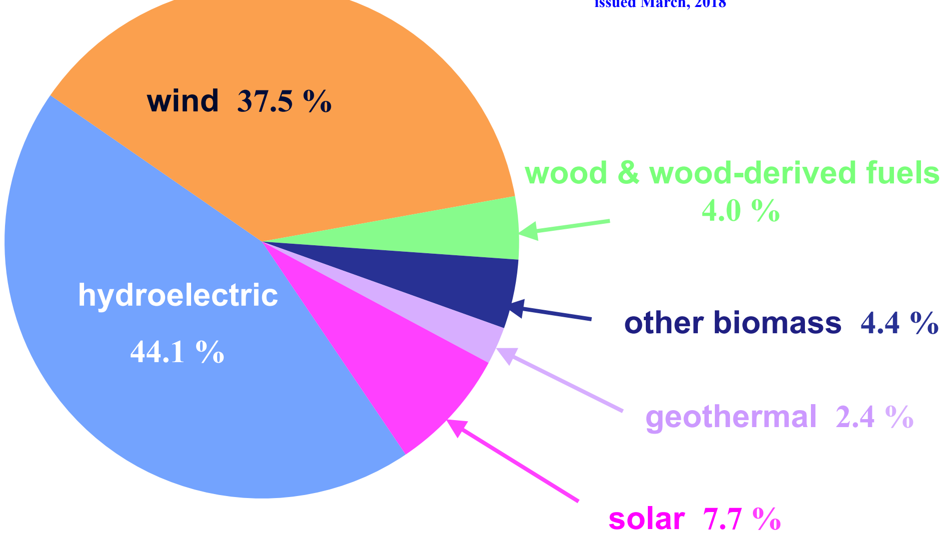
2017 GENERATION BY SOURCE



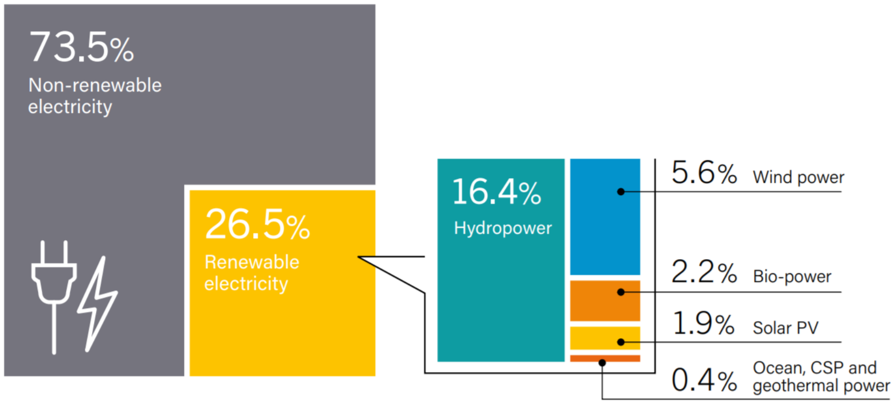
Source: EIA March 29,2018, https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf; issued March, 2018

2017 NET GENERATION OF RENEWABLE ENERGY SOURCES

Source: EIA March 29,2018 https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf; issued March, 2018

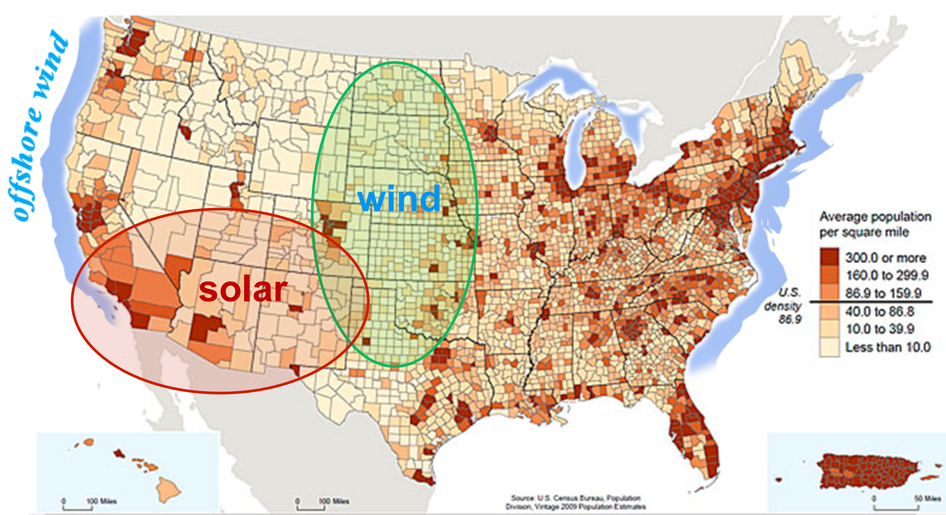


2017 RENEWABLE ENERGY SHARE OF GLOBAL ELECTRICITY GENERATION



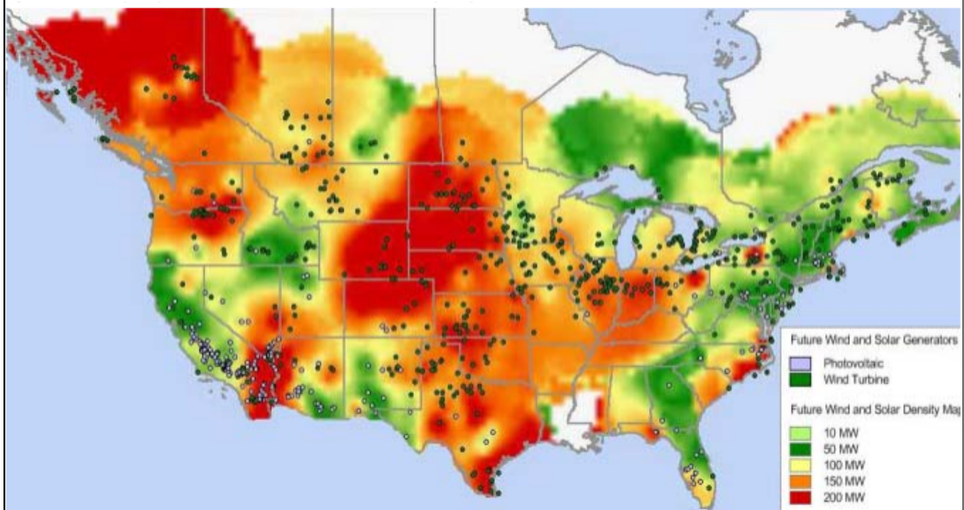
Source: REN 21, 2018 at http://www.ren21.net/wp-content/uploads/2018/06/17-8652_GSR2018_FullReport_web_-1.pdf

US POPULATION DENSITY AND RENEWABLE RESOURCE LOCATIONS



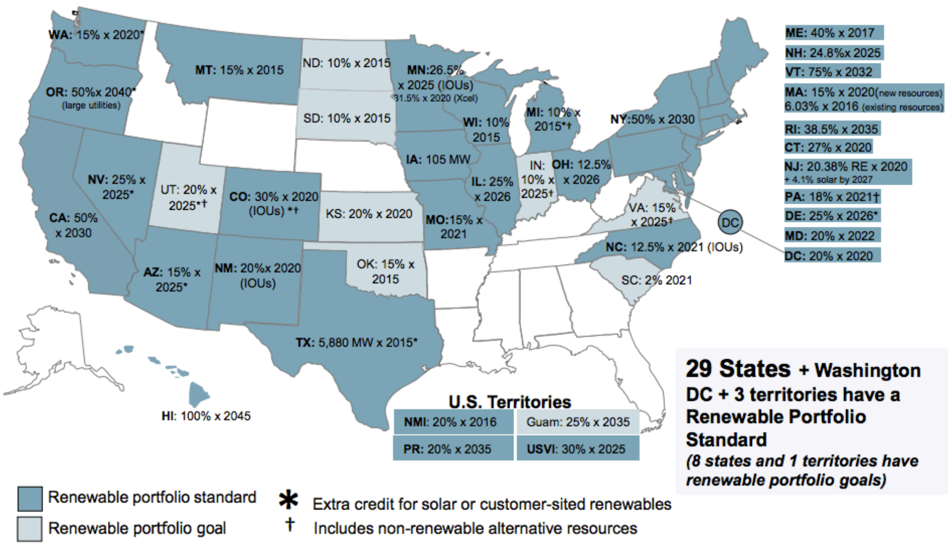
Source: http://www.census.gov/popest/data/maps/2009/PopDensity_09.jpg

DENSITY MAP OF FUTURE WIND AND SOLAR INSTALLED CAPACITY ADDITIONS



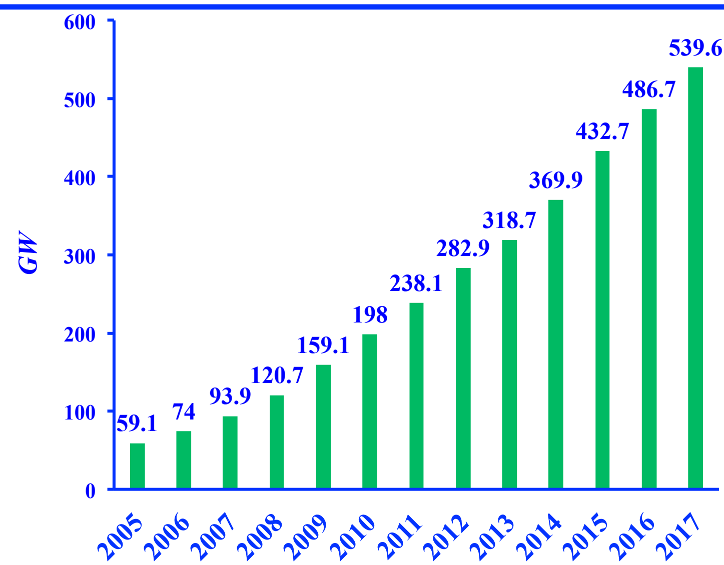
Source: NERC, LTRA 2012 http://www.nerc.com/files/2012_LTRA_FINAL.pdf; Issued November 2012

RENEWABLE PORTFOLIO STANDARDS (RPS)



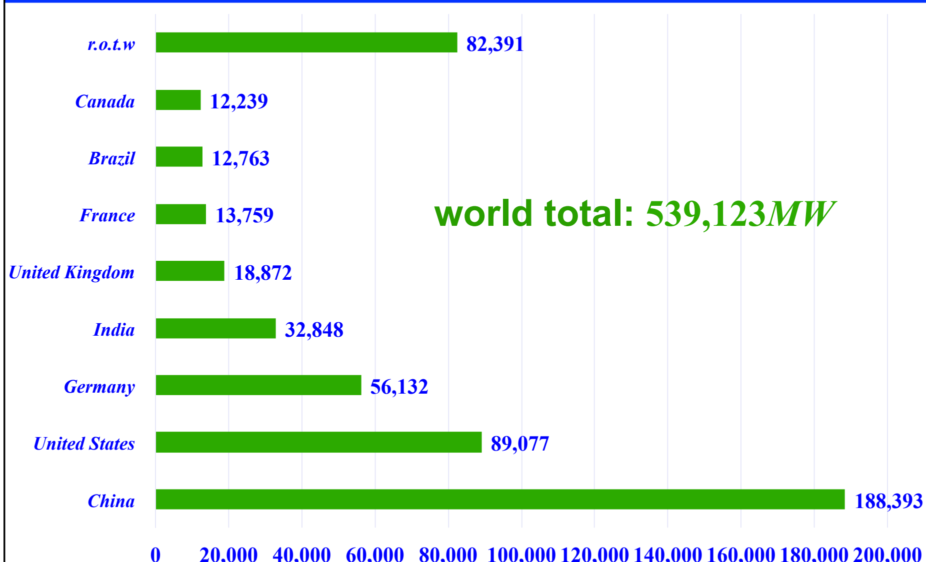
Source: http://www.dsireusa.org/resources/detailed-summary-maps/; February 2017

2005 – 2017 GLOBAL WIND CAPACITY



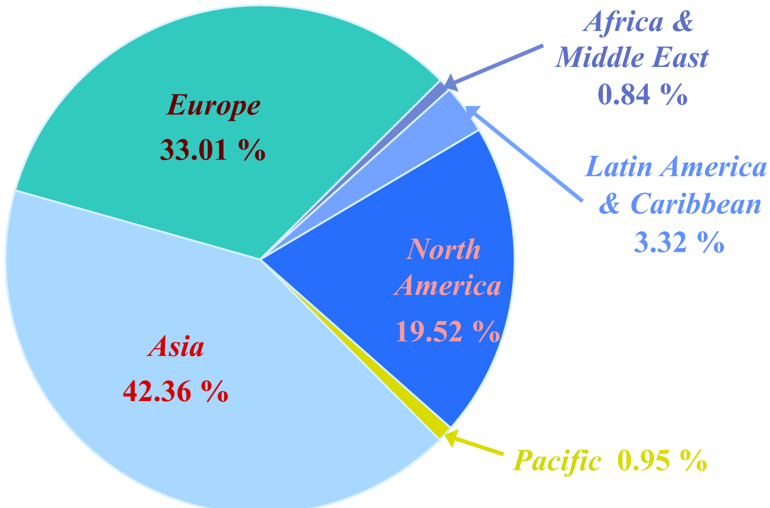
Source: GWEC Global Wind Statistics 2017, available at http://gwec.net/wp-content/uploads/vip/GWEC_PRstats2017_EN-003_FINAL.pdf

2017 TOP 10 COUNTRIES IN TOTAL INSTALLED WIND CAPACITY



Source: http://gwec.net/wp-content/uploads/2018/04/5_Top-10-cumulative-capacity-Dec-2017-1.jpg

2017 INSTALLED WIND CAPACITY

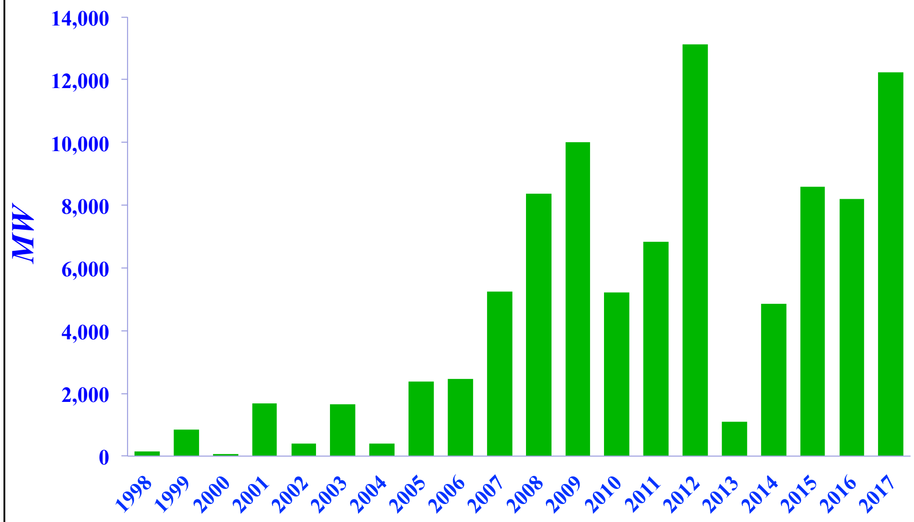


total installed capacity: 539,581 *MW*

Source: GWEC Global Wind Statistics 2017, available at http://gwec.net/wp-content/uploads/vip/GWEC_PRstats2017_EN-003_FINAL.pdf

WIND FARMS

1998 – 2017 INSTALLED *US* WIND CAPACITY ADDITIONS



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

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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*

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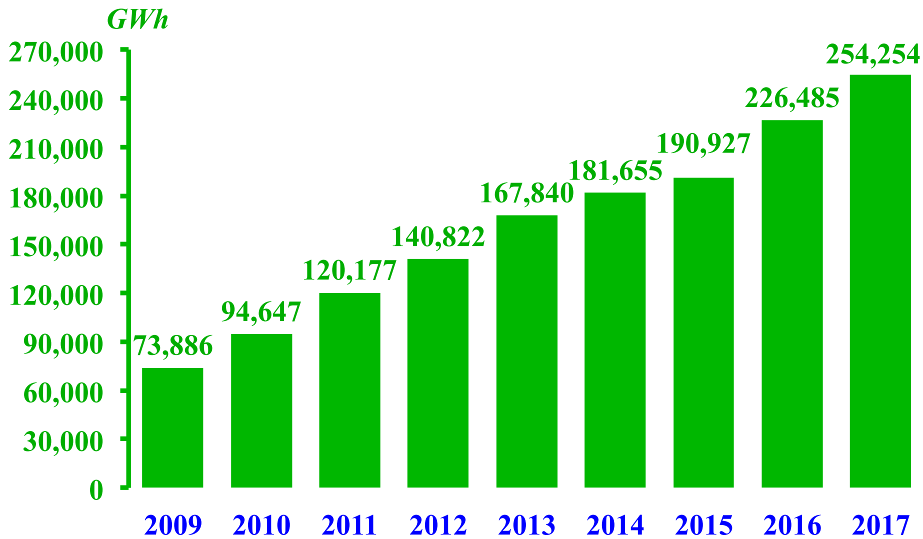
WIND DEVELOPMENTS IN 2016

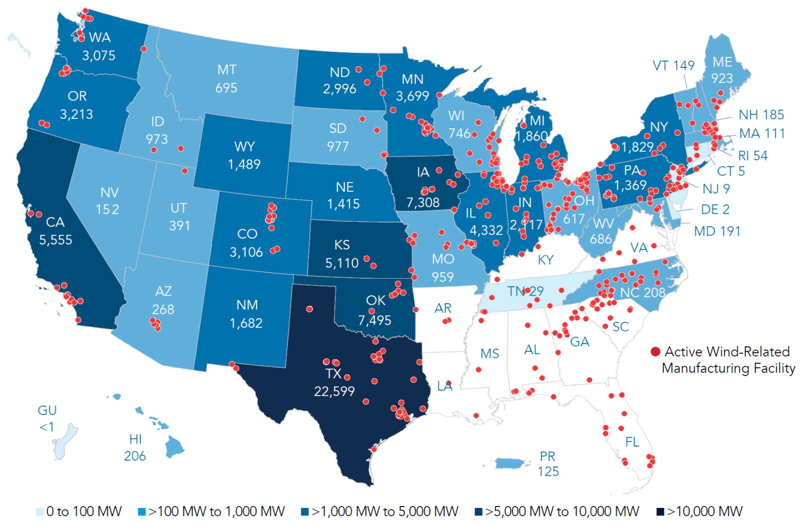
- In late 2016, *Block Island* – the first, offshore *US* wind farm with a 5–turbine 30–*MW* nameplate capacity –began operations off the *RI* coast
- Wind generated energy reduced 9 *%* of electric power energy CO_2 emissions – 159 *million mt* – and saved 87 *billion gallons* of water consumption
-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

2009 – 2017 *US* WIND POWER ENERGY PRODUCTION



Source: http://www.eia.gov/renewable/data.cfm#wind; December 2017

US WIND ENERGY INDUSTRY MANUFACTURING FACILITIES



Source: AWEA 2017 Annual Market Report Executive Summary

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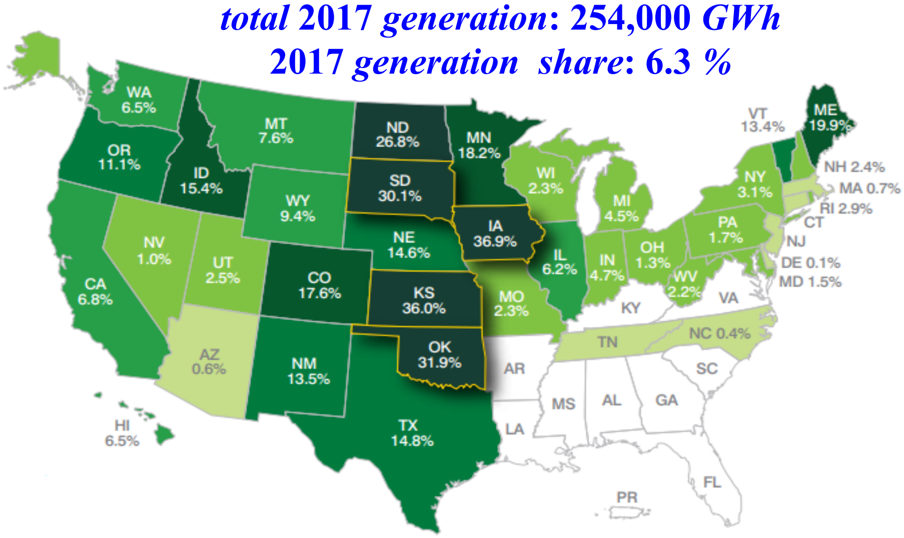
2017 *US* WIND GENERATION SHARE OF STATE CONSUMPTION

total* 2017 *generation*: 254,000 *GWh

2017 *generation share*: 6.3 %



Source: AWEA at https://www.awea.org/2017-market-reports

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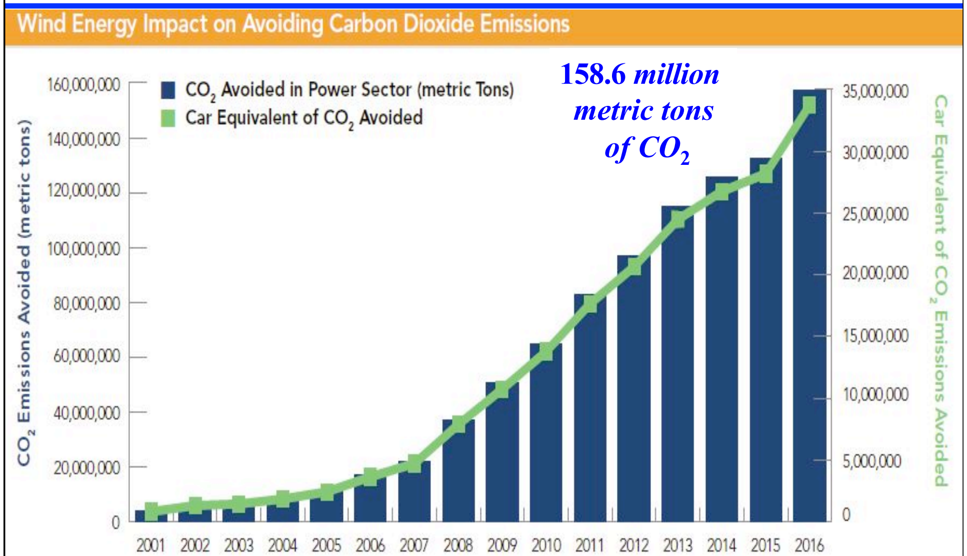
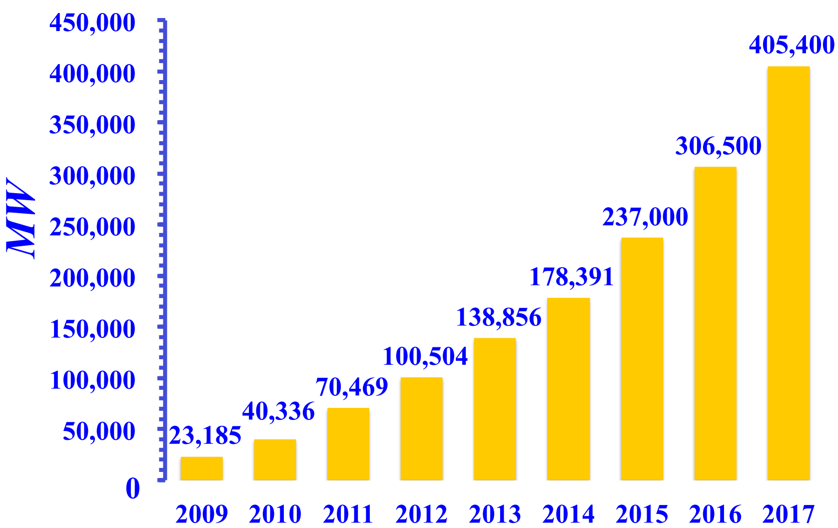
WIND ENERGY REDUCES *US GHG* EMISSIONS



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

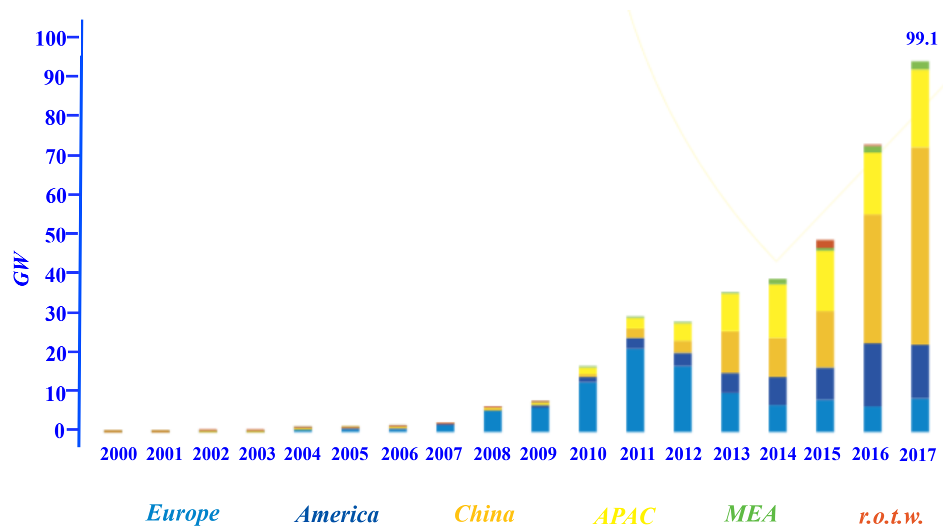
SOLAR ENERGY

2009 – 2017 GLOBAL CUMULATIVE *PV* CAPACITY



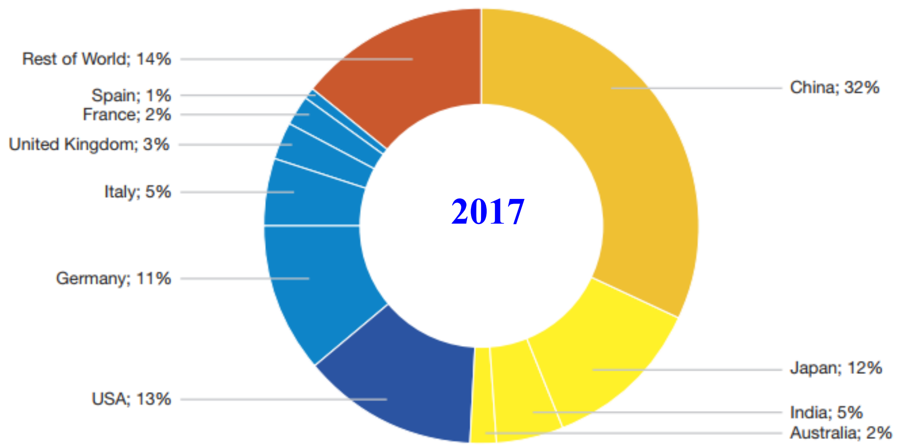
Source: http://www.rechargenews.com/transition/1452740/global-pv-build-booms-to-99gw-in-2017-solarpower-europe?utm_medium=email&utm_source=free_article_access&utm_content=222106020

GLOBAL ADDED *PV* CAPACITY: 2000 – 2018



Source: SolarPower Europe Global Market Outlook 2018-2022

2017 INSTALLED *PV* SOLAR TOP 10 COUNTRIES



Source: SolarPower Europe Global Market Outlook **2018-2022**

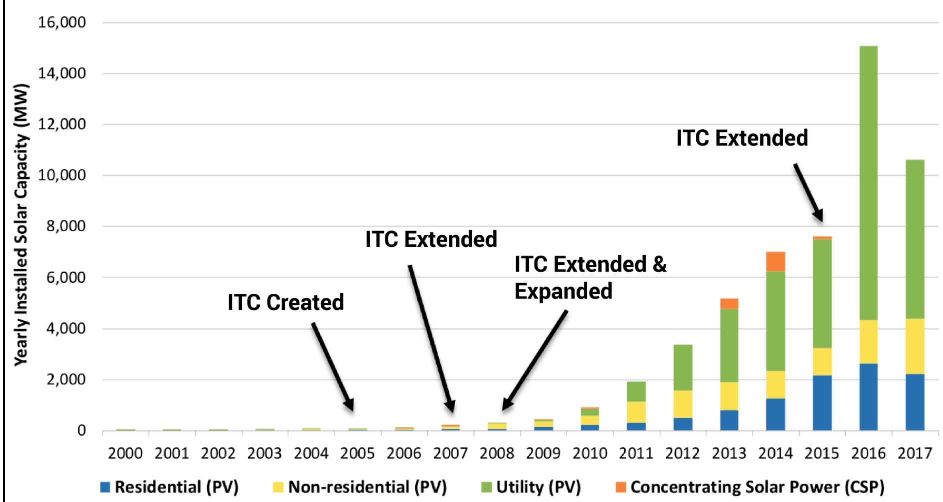
2017 SOLAR ENERGY STATUS

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

- The global *PV* cumulative capacity reached 405.4 *GW* in 2017
- The addition of 98.9 *GW* repre– sents a 30 % *year-on-year* growth over the 76.6 *GW* installed in 2016
- China installed 34.5 *GW* to continue as the dominant solar nation in the world
- Europe's share remained at 22 % of the global *PV* capacity with 8.6 *GW* added capacity

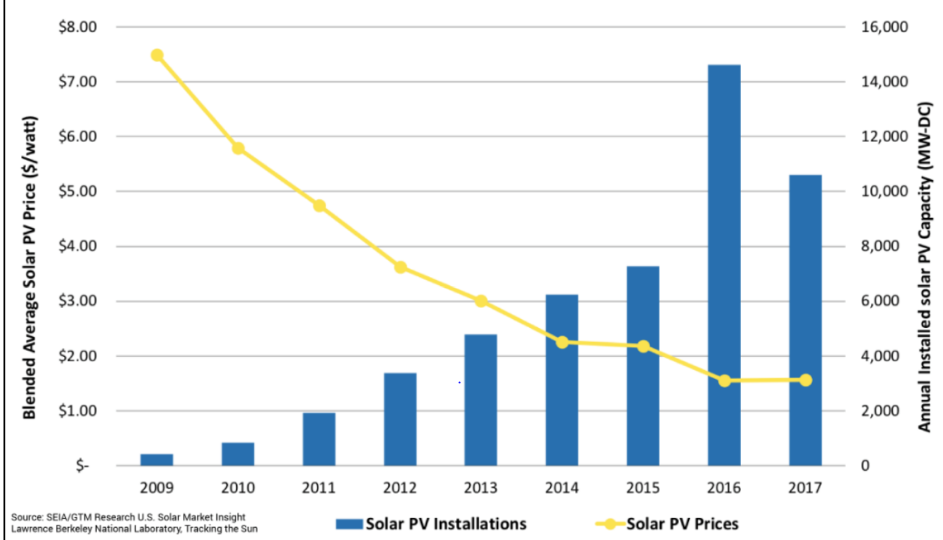
Source: http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_-__A_Snapshot_of_Global_PV_-_1992-2015_-_Final.pdf

US ANNUAL SOLAR CAPACITY ADDITIONS

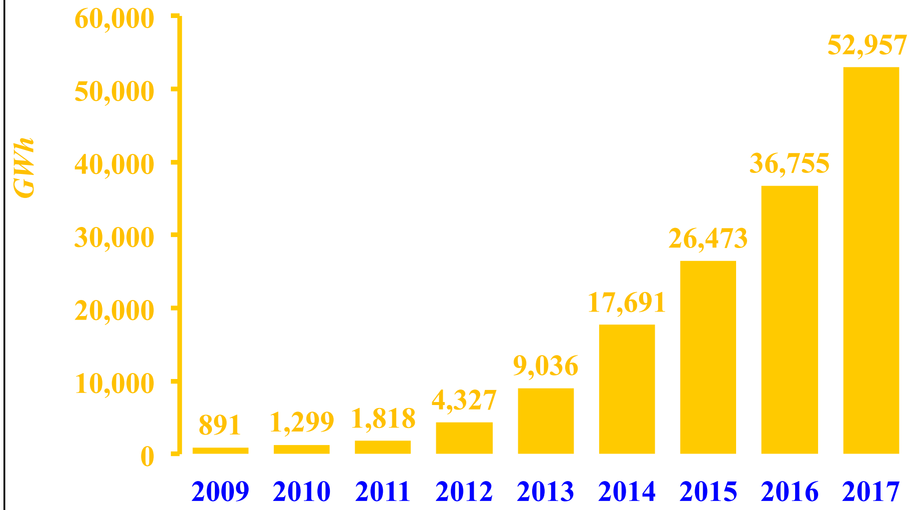


Source: https://www.seia.org/solar-industry-research-data

US ANNUAL *PV* SOLAR CAPACITY ADDITIONS AND PRICES

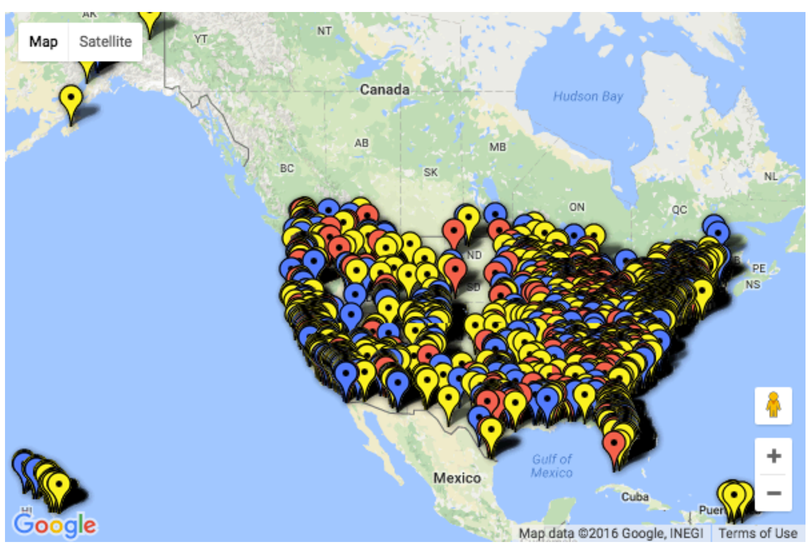


2009 – 2017 *US* SOLAR UTILITY – SCALE GENERATION



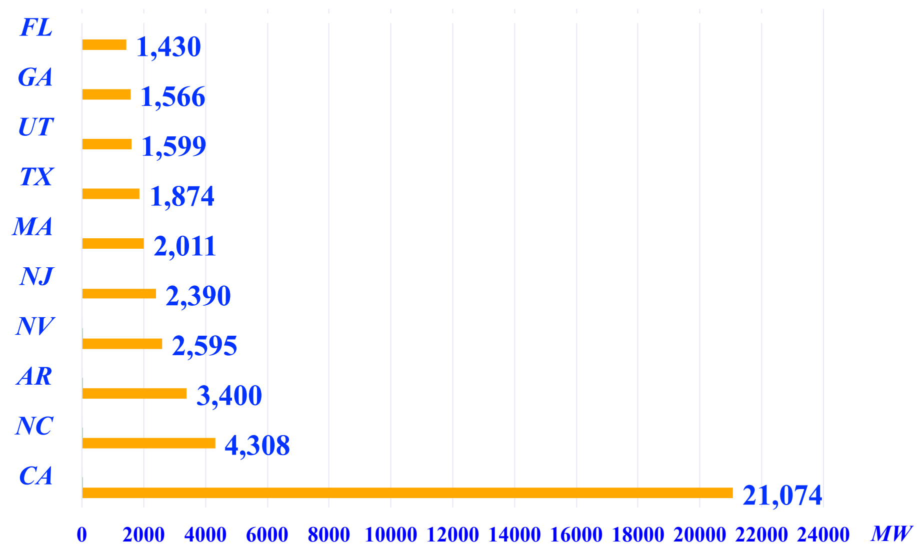
Source: http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01_a

NATIONAL SOLAR DATABASE



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

TOP 10 STATES WITH INSTALLED SOLAR *PV* CAPACITY IN 2017



Source: 2017 *data; available at https://www.seia.org/solar-industry-research-data*

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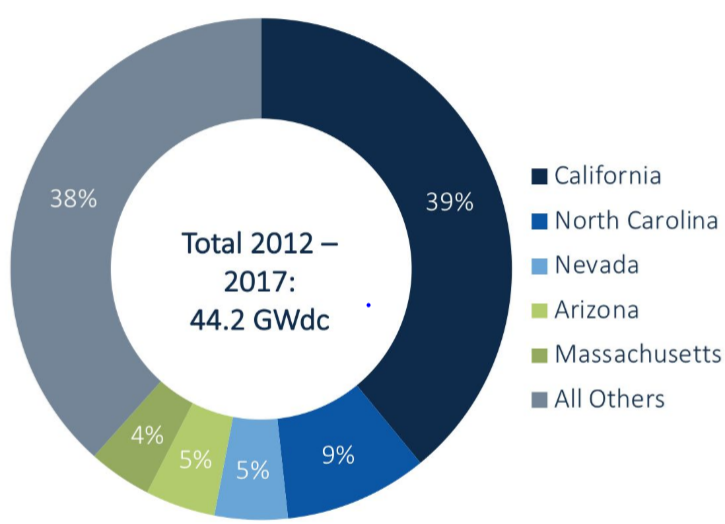
US SOLAR *PV* CAPACITY 2018 *Q*1



Source: *SEIA/GTM Research US Solar Market Insight Q*1 2018

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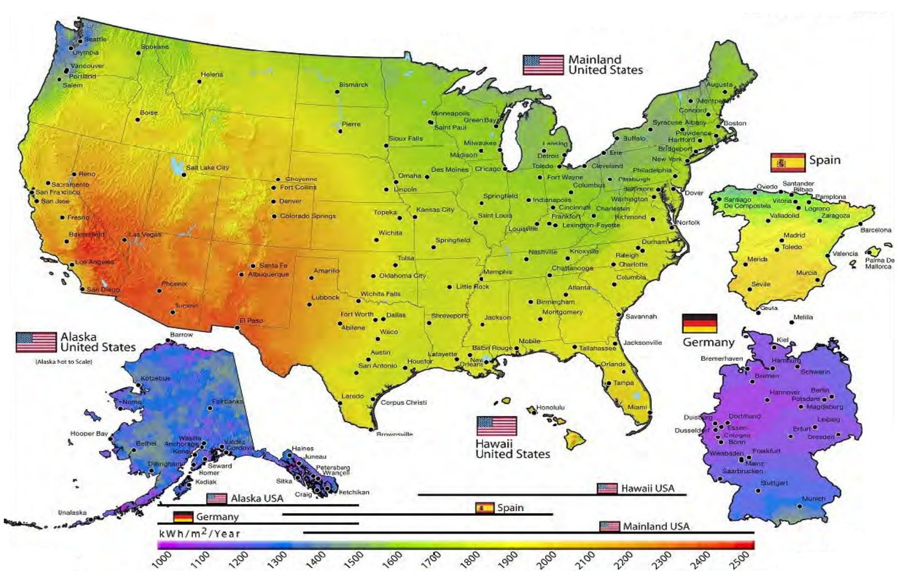
PV SOLAR RESOURCE MAP FOR THE *US*, SPAIN AND GERMANY



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

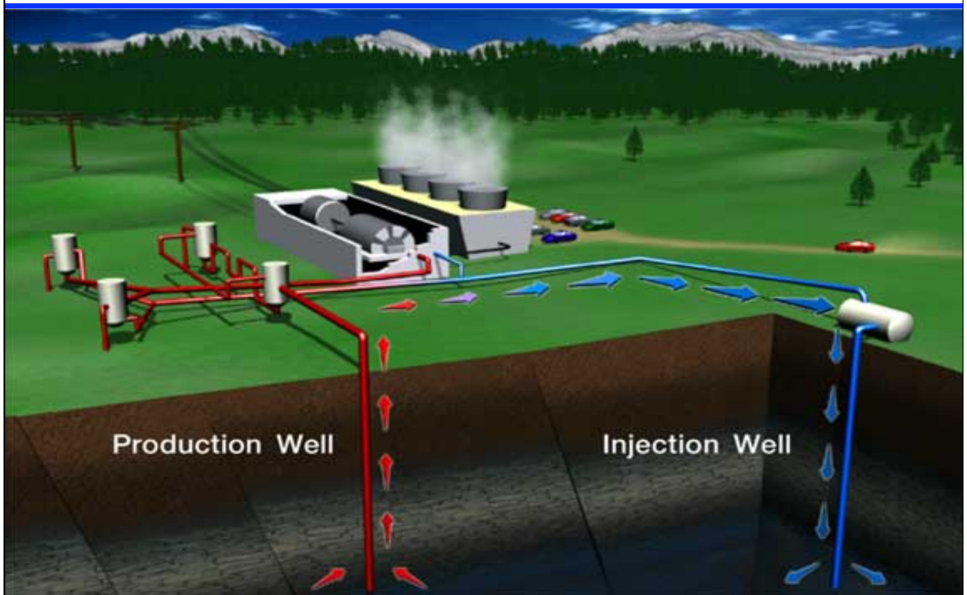
U.S.'s first geothermal power plant, Mayacama Mountains, California, turned 50 in 2009

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



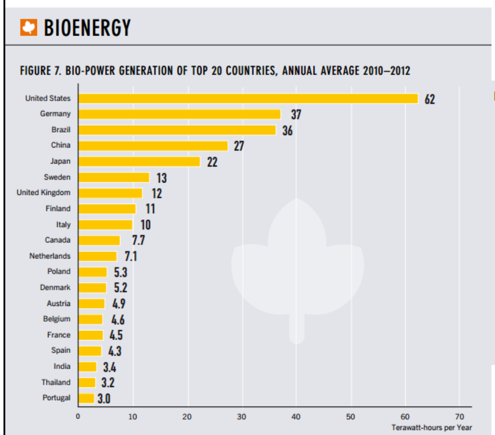
2016 BIOMASS / BIOFUELS STATUS

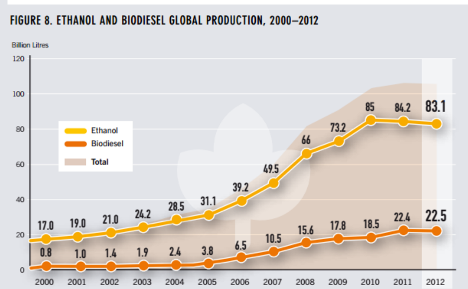
- World biomass installed electricity capacity is 112 *GW* with 504 *TWh* generation

21 *MW* Tracy Biomass Plant

- The *US* grid-connected installed capacity is 13.2 *GW*
- *US* and *Brazil* are the largest biofuel producers
- World biofuels production capacity is 135 *billion l/y*

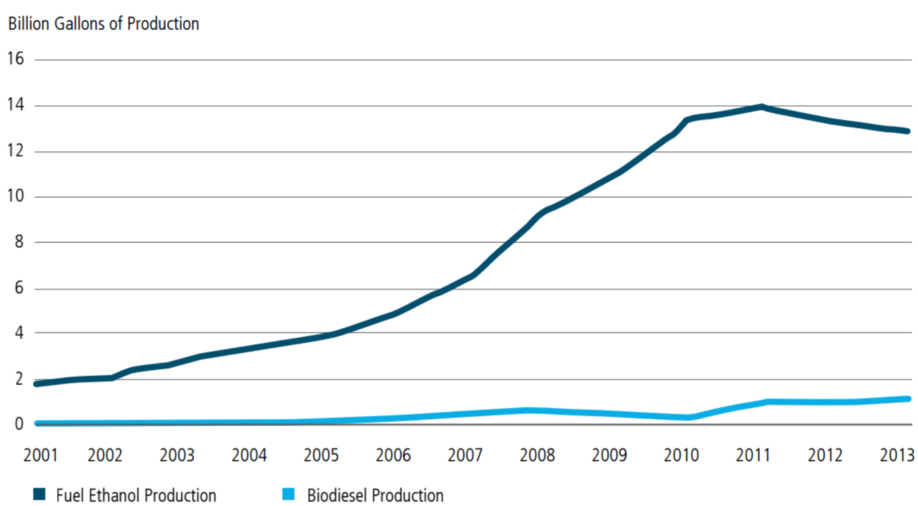
BIOENERGY AND BIOFUEL





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

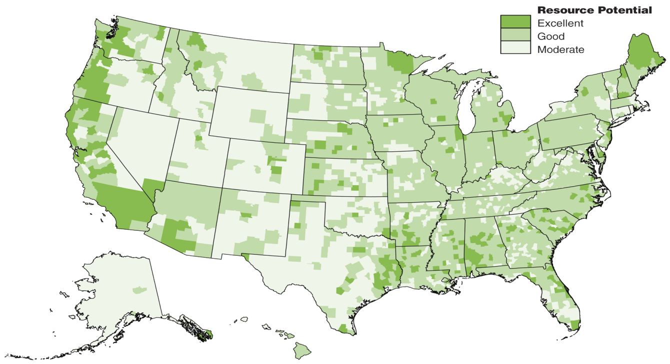
YEARLY ETHANOL AND BIODIESEL PRODUCTION



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

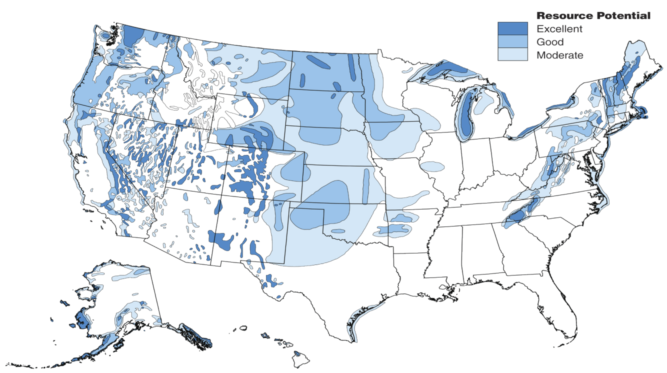
Source: EIA (2010-2013) http://www.eia.gov/electricity/monthly/current_year/february2014.pdf; pg 176; Issued April 2015

DOE BIOMASS/BIOFUELS GOALS



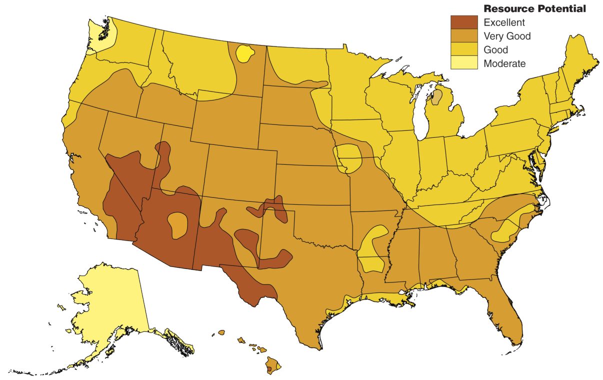
- Competitive electricity by 2020
- Ethanol production resources to be at the target of 1.07 $\$/g$ by 2020

DOE WIND PROGRAM GOALS



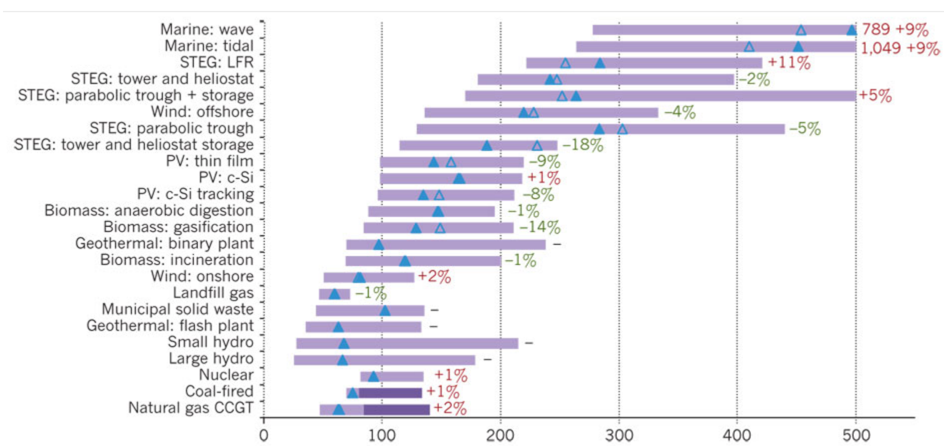
- 3 $¢/kWh$ in classes 4 and above onshore wind areas
- 5 $¢/kWh$ for off-shore regions

DOE SOLAR PROGRAM GOALS



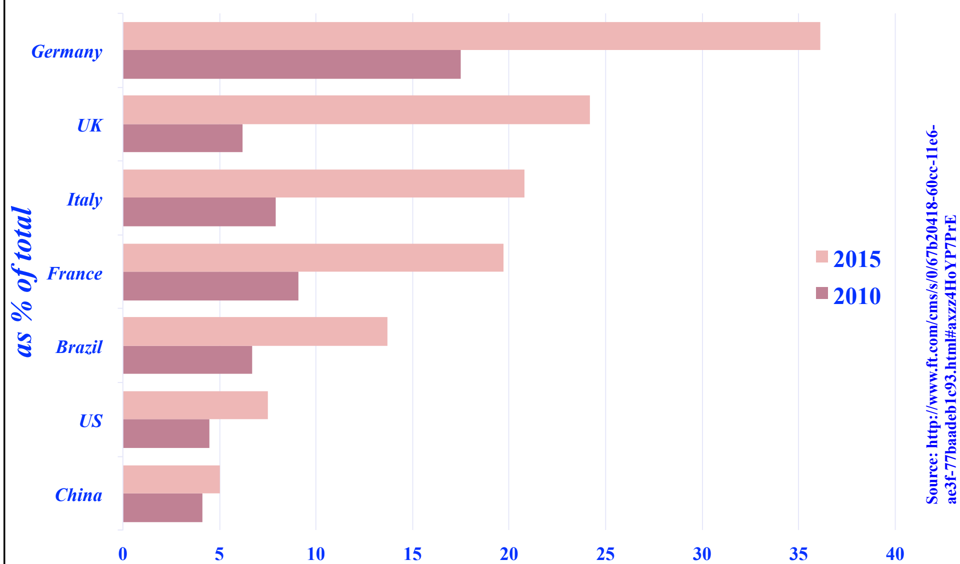
- Photovoltaics: 6 *¢/kWh* by 2020
- Concentrating solar power/troughs: 5 *¢/kWh* by 2012

*Q*3 2012 LEVELIZED COSTS OF ENERGY

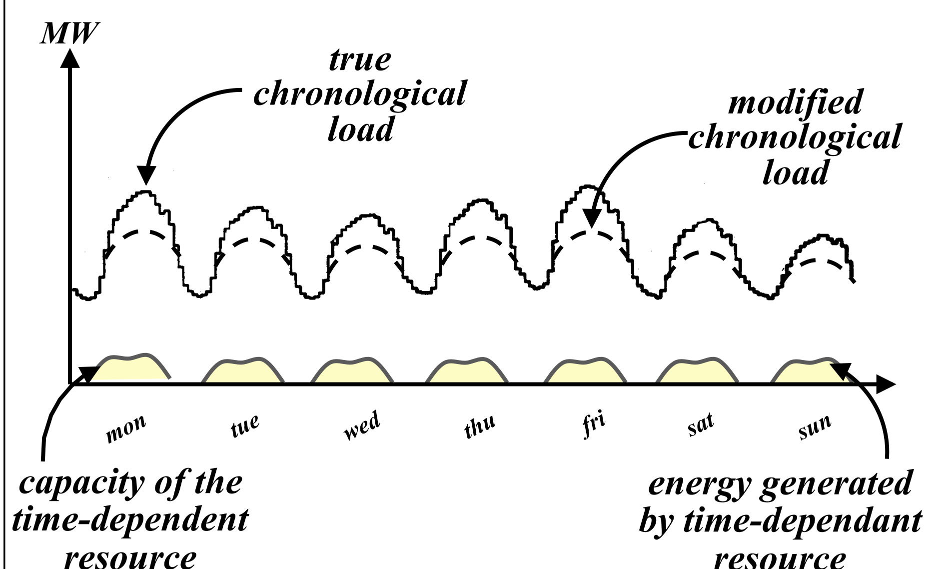


Source: Steve Chu and Arun Majumdar, "Opportunities and challenges for a sustainable energy future," Nature, August 2012

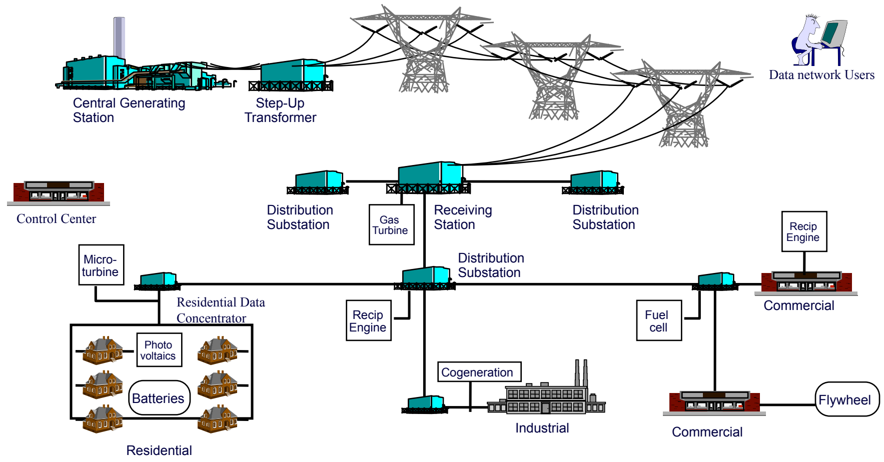
RENEWABLE ELECTRICITY GENERATION



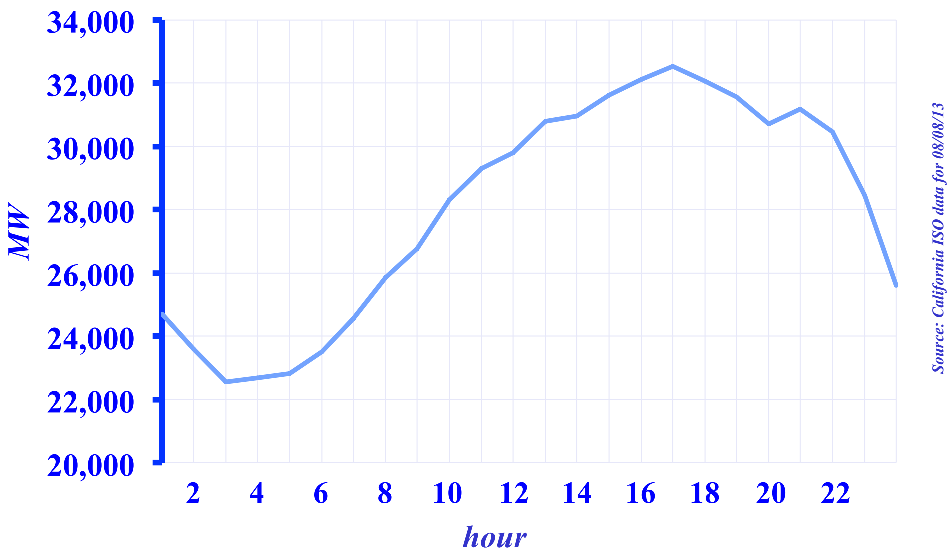
IMPACTS OF RENEWABLES



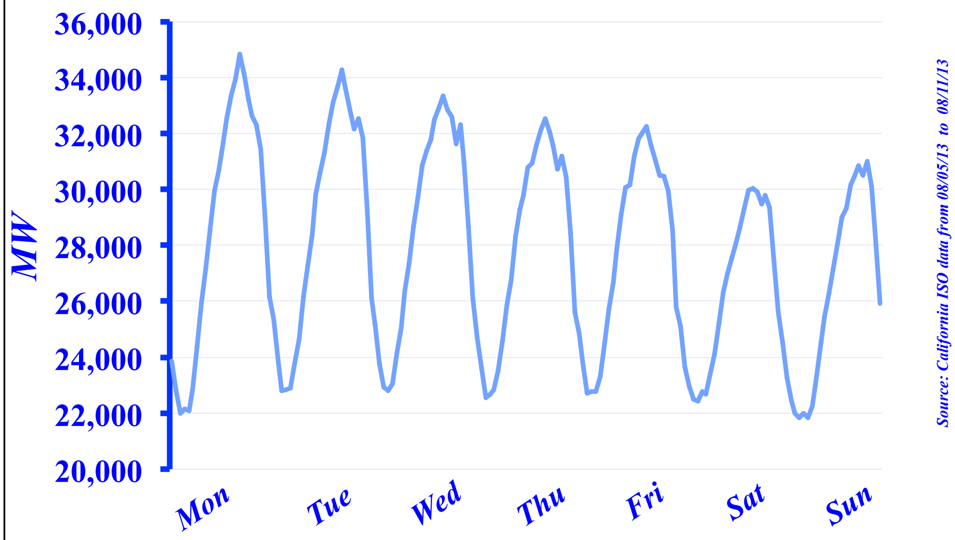
ELECTRIC SYSTEM INFRASTRUCTURE



TWENTY–FOUR HOUR PROFILE



WEEKLY LOAD CYCLE



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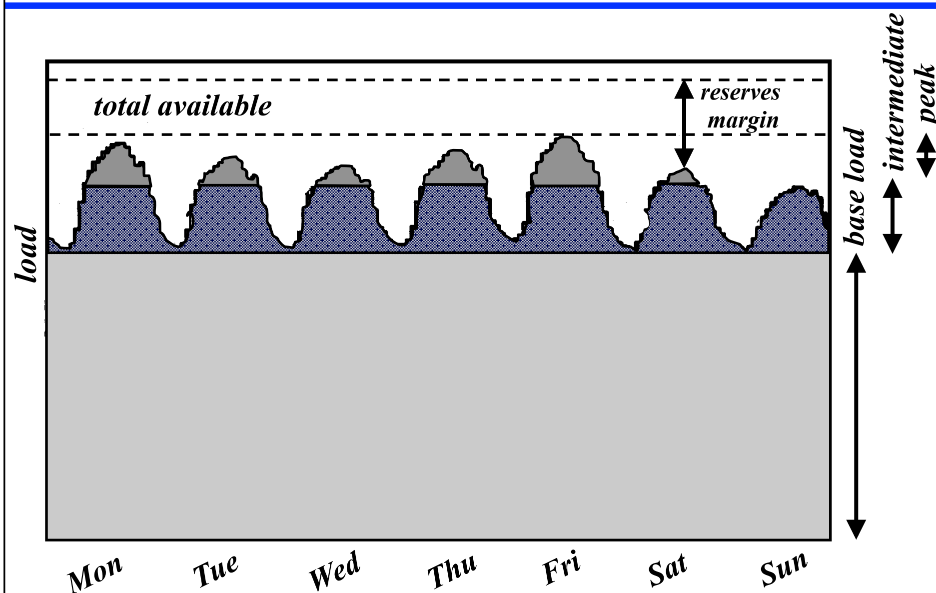
THE WEEKLY LOAD SHAPE



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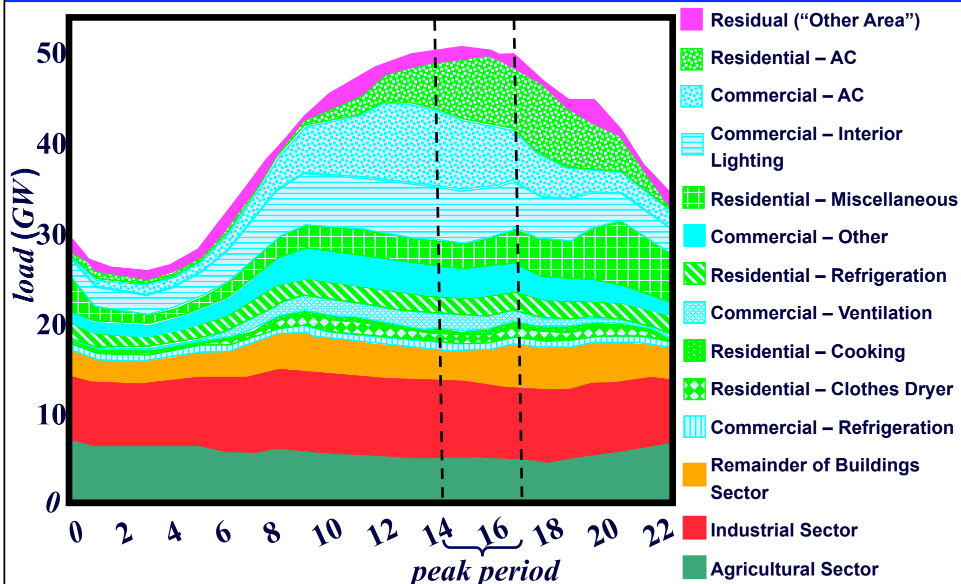
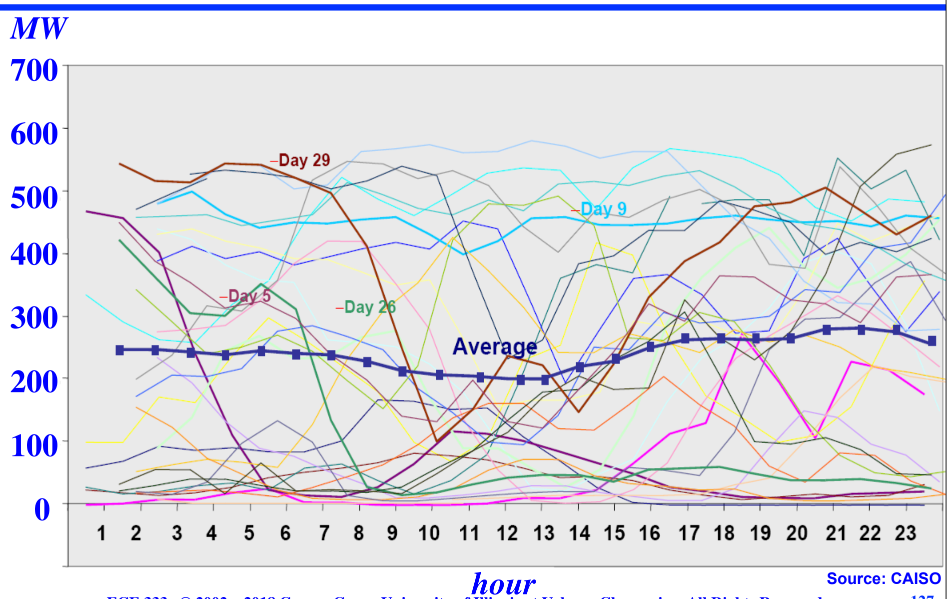
CALIFORNIA SUMMER LOAD: TYPICAL DAILY SHAPE



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

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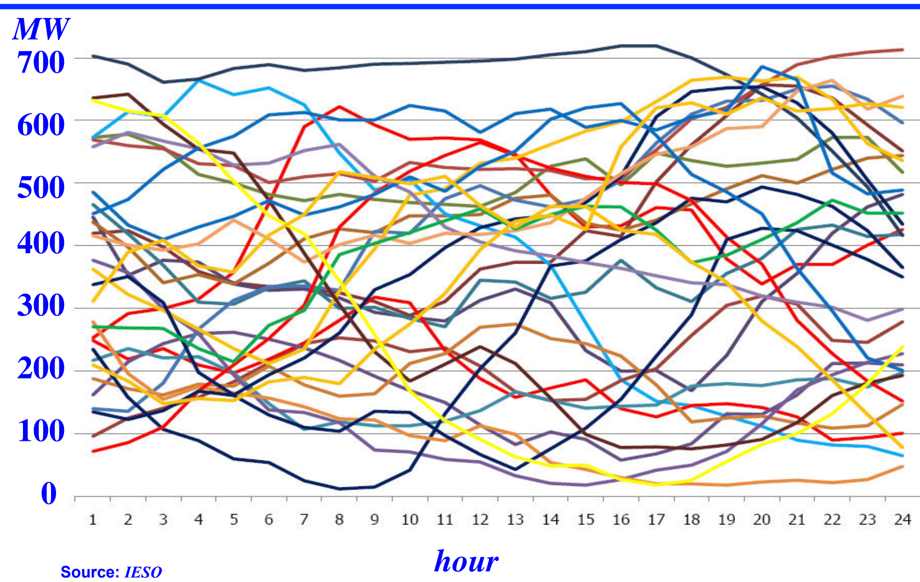
ONTARIO DAILY WIND POWER OUTPUT



Source: *IESO*

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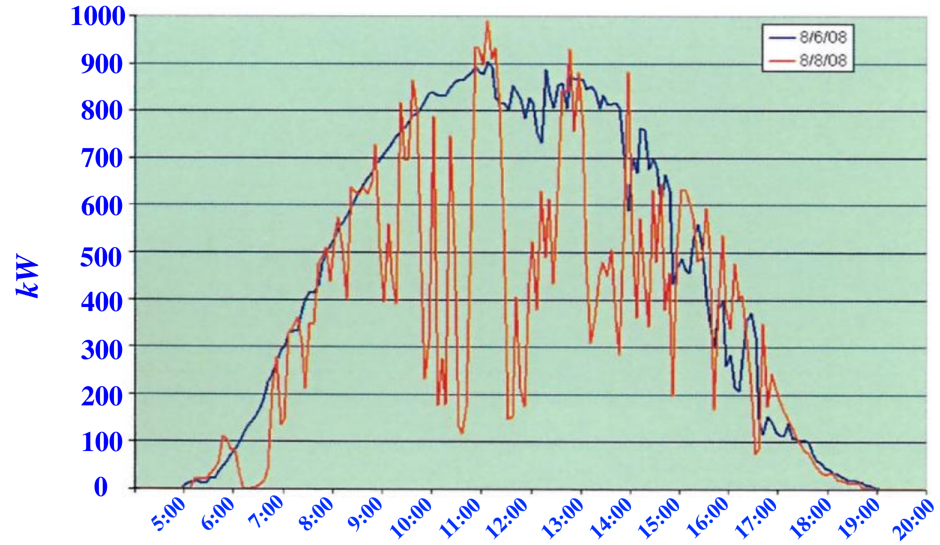
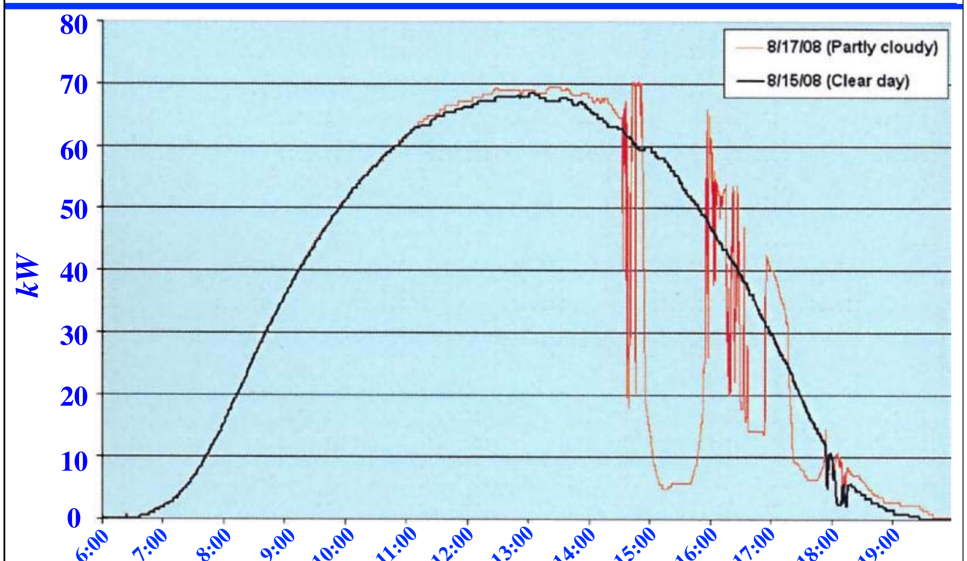
PV POWER OUTPUT OF 1 – *MW* *CdTe* ARRAY IN GERMANY



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

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

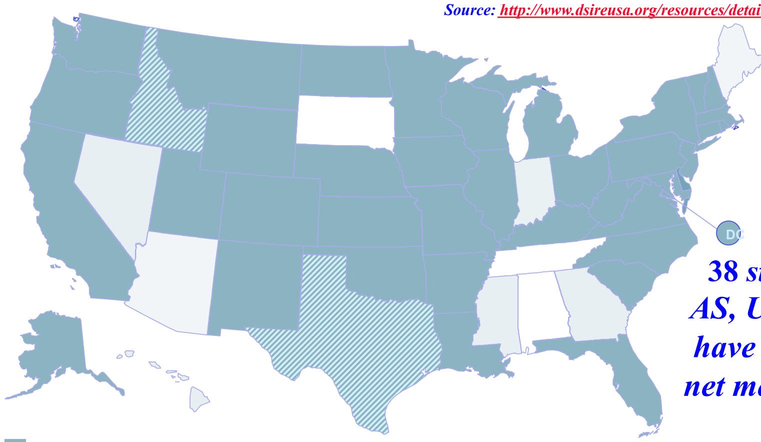
Source: http://www.seia.org/policy/distributed-solar/net-metering

grid – customers only pay for the electricity consumed in excess of what they feed into utility, the so – called *net energy*

- 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

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/role of each *renewable generation resource*
- Review of concepts in electric circuit analysis
- Engineering aspects of *renewable resource* generation technologies: wind energy conversion

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TOPICAL OUTLINE

systems; thermodynamics considerations; solar resource and solar array systems; economics of renewable 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

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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 electricity policy and regulatory dimensions

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	**20 x 2 = 40**
final	**45**
total	**100**

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