1. Introduction and Overview

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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
electricity will continue to substitute for less efficient and less productive energy forms
ELECTRIC POWER SECTOR
CARBON DIOXIDE EMISSIONS

history
projections

high economic growth

low economic growth

million metric tons


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
THE WORLD ECONOMIES RELY ON ABUNDANT AND AFFORDABLE ELECTRICITY
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 forms of energy, such as light, mechanical and sound.

- As more energy is consumed as electricity, the focus on its 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
This Room Is Equipped With Edison Electric Light.

Do not attempt to light with match. Simply turn key on wall by the door.

The use of Electricity for lighting is in no way harmful to health, nor does it affect the soundness of sleep.

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.
- 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 different voltage levels for generation/consumption and transmission
  - 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

Legend
- Cooperative
- Federal
- Independent Transmission Companies
- Other Public Power
- Shareholder-Owned

Copyright 2003 Edison Electric Institute. Source: POWERmap, © Platts, a Division of the McGraw Hill Companies.
THE ELECTRIC POWER GRID

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
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 commissions to regulate electricity
THE VERTICALLY INTEGRATED UTILITY INDUSTRY STRUCTURE

- Customers
- Customer Service
- Distribution
- Transmission
- Generation
- IPP
- Self-generation
COMPETITION IN THE GENERATION MARKET

- The 1978 Public Utility Regulatory Policies Act (PURPA) unleashes competition through the introduction of qualifying facilities (QFs).
- PURPA mandates each investor–owned utility to purchase power at avoided cost from QFs 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

- Oil: 5.7%
- Coal: 17.8%
- Natural gas: 59.0%
- Nuclear: 8.3%
- Hydro: 2.1%
- Other: 3.1%
- Wind: 1.7%
- Waste: 1.5%
- Geothermal: 0.7%

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

**Total number** = 3,307

- **Publicly owned**: 1,948
- **Cooperative**: 810
- **Investor owned**: 256
- **Entities**: 198
- **Facilities**: 89
- **Federal**: 6

The roughly 256 investor owned utility companies represent the predominant part of the industry because more than 60% of all electricity sales come from these entities.

The 810 rural electric coops are the remnants of the New Deal years and were a result of the push to provide electricity to everyone and everywhere.

The 89 “facilities” includes co-generators and other industrial generators while the “other” 198 entities are made up of marketers selling delivery or energy services, but not both.
US ELECTRICITY CUSTOMERS

- Total consumers: 147.37 million
- Residential: 128.68 million
- Commercial: 17.85 million
- Industrial: 0.84 million
- Other: 0.0001 million

US ELECTRICITY SALES IN 2015

**Total sales:** 3,724 million MWh

- Residential: 1,400 TWh
- Industrial: 959 TWh
- Commercial: 1,358 TWh
- Other: 7.7 TWh

**Total revenues:** $389 billion

- Residential: $177 billion
- Industrial: $66 billion
- Commercial: $144 billion
- Other: $0.8 billion

PERCENT CUSTOMERS SERVED BY THE ELECTRICITY PROVIDERS

- IOUs: 63.40%
- coops: 12.97%
- public: 14.49%
- other: 9.1%
- federal: 0.03%
- facilities: 0.0003%

RISING NUMBER OF TELEVISIONS IN HOUSEHOLDS


The chart shows the rising number of televisions in households from 1997 to 2009. The data indicates a gradual increase in the number of televisions per household over the years, with more households having more than one television. The chart is sourced from the EIA and was issued in January 2009. 

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RISING NUMBER OF COMPUTERS IN HOUSEHOLDS

TOTAL RESIDENTIAL ENERGY USE

1978 usage

- **space heating**: 6.96 quads (66 %)
- **water heating**: 1.67 quads (16 %)
- **appliances/electronics**: 1.53 quads (14 %)
- **air conditioning**: 0.32 quads (4 %)

10.58 quads

2009 usage

- **space heating**: 4.2 quads (41 %)
- **water heating**: 1.8 quads (18 %)
- **appliances/electronics**: 3.5 quads (35 %)
- **air conditioning**: 0.6 quads (6 %)

10.18 quads

PREVALENT HEATING SOURCES IN US HOUSEHOLDS

% of all energy sources for heating

- **natural gas**
- **electricity**
- **fuel oil**
- **propane**

US CONVENTIONAL ELECTRICITY GENERATION SOURCES

2001 – 2014 GENERATION CAPACITY ADDITIONS

2015 NET GENERATION BY SOURCE

- Coal: 33.2%
- Natural gas: 32.7%
- Nuclear: 19.5%
- Petroleum: 1.0%
- Hydro: 6.1%
- Other renewable sources: 7.5%

Source: http://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf; issued March 2016
AMEREN ILLINOIS POWER SOURCES OF ELECTRICITY SUPPLIED IN 2015

Coal 52%

nuclear 16%
natural gas 21%
wind 7%
hydro 1%
oil 3%

Source: Ameren IP, data for the 12 months ending March 31, 2016
## 2015 AMEREN ILLINOIS POWER AVERAGE ELECTRICITY EMISSIONS / WASTE

<table>
<thead>
<tr>
<th>output</th>
<th>average amount per MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbon dioxide</td>
<td>1,382 lbs</td>
</tr>
<tr>
<td>nitrogen oxides</td>
<td>0.79 lbs</td>
</tr>
<tr>
<td>sulfur dioxide</td>
<td>1.54 lbs</td>
</tr>
<tr>
<td>high–level nuclear waste</td>
<td>0.0009 lbs</td>
</tr>
<tr>
<td>low–level nuclear waste</td>
<td>0.0002 ft³</td>
</tr>
</tbody>
</table>

*Source: Ameren IP, data for the 12 months ending March 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:
  - $\frac{3}{4}$ of $SO_X$ emissions
  - $\frac{1}{3}$ of $CO_2$ and $NO_X$ emissions
  - $\frac{1}{4}$ of particulate matter and toxic heavy metals emissions
US LAWS ON ENVIRONMENTAL PROTECTION

number of laws

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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

WE’LL PAY YOU IF WE CAN DO THIS TO YOUR SPARE REFRIGERATOR.

* You’d flatten your spare refrigerator yourself, if you realized how wasteful it is. An average one devours a whopping $150 a year in energy costs. * If you let us recycle it, not only will you get rid of an old energy guzzler, you’ll get a $50 savings bond from Edison or DWP. * To qualify, it must be in working order and used as a second refrigerator for the last six months. * So for your $50 savings bond, call Edison or DWP at 1-800-234-9722. Or use our TDD accessible number 1-800-234-9710. It pays to recycle your spare refrigerator.

Southern California Edison

Los Angeles Department of Water and Power
Time to make a quantum leap? It's time to make it in Texas.

If you compete in the high tech, food, aircraft maintenance or plastics industries, TU Electric can help you make it in Texas.

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To get a jump on your competition, get on down here. We have a wealth of statistics, maps and firsthand experience to pass along. Contact John Prickette at 1-800-421-2489, Fax 214/954-5456.

We put a lot of energy into business.
## THE ENERGY UNIT PREFIX

<table>
<thead>
<tr>
<th>prefix</th>
<th>symbol</th>
<th>value</th>
<th>exponent value</th>
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<tr>
<td>kilo</td>
<td>$k$</td>
<td>thousand</td>
<td>$10^3$</td>
</tr>
<tr>
<td>Mega</td>
<td>$M$</td>
<td>million</td>
<td>$10^6$</td>
</tr>
<tr>
<td>Giga</td>
<td>$G$</td>
<td>billion</td>
<td>$10^9$</td>
</tr>
<tr>
<td>Tera</td>
<td>$T$</td>
<td>trillion</td>
<td>$10^{12}$</td>
</tr>
<tr>
<td>Peta</td>
<td>$P$</td>
<td>quadrillion</td>
<td>$10^{15}$</td>
</tr>
<tr>
<td>Exa</td>
<td>$E$</td>
<td>quintillion</td>
<td>$10^{18}$</td>
</tr>
</tbody>
</table>
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), BTUs, calories or cubic feet for gas and acre feet for water

- In round numbers
  - the US annually consumes 100 quads of energy
  - the US installed electric generation capacity is about 1000 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


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DEMOGRAPHIC TRANSFORMATIONS

2015 – 7.35 billion

- Asia: 60%
- Latin America & Caribbean: 9%
- N-America: 1%
- Europe: 16%
- Oceania: 5%
- Africa: 10%

2060 – 10.18 billion

- Asia: 52%
- Latin America & Caribbean: 8%
- N-America: 1%
- Europe: 7%
- Oceania: 4%
- Africa: 28%

Source: UN, Population Division; http://esa.un.org/unpd/wpp/Excel-Data/population.htm
1980 – 2011 ENERGY DEMAND VS. GDP PER CAPITA

![Graph showing energy demand vs. GDP per capita over the years. The graph displays data for several countries, including the United States, Russia, Australia, South Korea, Japan, France, Ireland, United Kingdom, Greece, Mexico, Malaysia, Brazil, China, and India. The x-axis represents per capita GDP in current international $, while the y-axis represents per capita energy in Million BTU. The source of the data is noted as EIA and the World Bank.]
1980 – 2011 ENERGY DEMAND TRENDS

Source: EIA, 2010; data exclude biomass
WORLDWIDE SHARES OF PRIMARY ENERGY: 1966 – 2011

## 2012 WORLD PRIMARY ENERGY CONSUMPTION

<table>
<thead>
<tr>
<th>source</th>
<th>generation (PJ)</th>
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<tbody>
<tr>
<td>solid fuels</td>
<td>156,171</td>
</tr>
<tr>
<td>liquid fuels</td>
<td>172,935</td>
</tr>
<tr>
<td>natural gas</td>
<td>125,063</td>
</tr>
<tr>
<td>hydroelectric power</td>
<td>34,796</td>
</tr>
<tr>
<td>nuclear power</td>
<td>23,462</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td><strong>522,370</strong></td>
</tr>
</tbody>
</table>

*Source: BP Statistical Review of the World 2013*
EVOLUTION OF THE MAIN SOURCES OF US ENERGY CONSUMPTION

INCREASE IN WORLD ENERGY PRODUCTION AND CONSUMPTION

* 1 tonne of oil equivalent (toe) = 42 GJ (net calorific value) = 10034 Mcal

Source: IEA 2006
WORLD CAPACITY ADDITIONS AND INVESTMENT REQUIREMENTS

Source: IEA 2002
IEA ELECTRICITY GENERATION AND $CO_2$ FORECASTS

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

Charles D. Keeling 1928 – 2005
COMPELLING EVIDENCE

**natural forcing only**

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

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

**anthropogenic forcing only**
CO$_2$ EMISSIONS FORECAST

Source: The Outlook for Energy: A View to 2040, pg. 34
China consumed 48% of 2010 global coal production.
CRUDE OIL PRICES 1861-2015

Source: BP Statistical Review of World Energy 2016, pg. 15
ANNUAL WORLD OIL PRODUCTION

Oil: Production by region
Million barrels daily


Oil: Consumption by region
Million barrels daily

GLOBAL FOSSIL RESOURCE RESERVES


- **Oil**
  - Proven: 27,000 billion boe, R/P ratio 46.2 yrs.
  - Unconventional: yet to find

- **Gas**
  - Proven: yet to find
  - Unconventional: yet to find

- **Coal**
  - Proven: yet to find
  - R/P ratio 118 yrs.
GLOBAL OIL AND GAS RESERVES

oil reserves

gas reserves

Trillion bbls

0 0.4 0.8 1.2 1.6 2.0


Trillion cm

0 50 100 150 200 250


Other
North America
FSU
OPEC
MISALIGNMENT OF SUPPLY AND DEMAND

# 2015 RESERVES

<table>
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<tr>
<th>source</th>
<th>reserves</th>
<th>annual consumption</th>
<th>period (years)</th>
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<tr>
<td>oil</td>
<td>1.698 T barrels</td>
<td>32.7 G barrels</td>
<td>40.6</td>
</tr>
<tr>
<td>gas (US)</td>
<td>10.4 T m³</td>
<td>654.0 G m³</td>
<td>10.4</td>
</tr>
<tr>
<td>gas (world)</td>
<td>0.187 P m³</td>
<td>2.98 T m³</td>
<td>65</td>
</tr>
<tr>
<td>coal (US)</td>
<td>237 T tons</td>
<td></td>
<td>240</td>
</tr>
<tr>
<td>coal (world)</td>
<td>892 T tons</td>
<td></td>
<td>155</td>
</tr>
<tr>
<td>uranium</td>
<td>2.7 M tons @ 40 $/kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11.8 M tons @ 130 $/kg</td>
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</tr>
</tbody>
</table>

Source: *BP 2013, 2016 Statistical Review of World Energy*
OUT OF GAS

DAVID GOODSTEIN

Out of Gas

The End of the Age of Oil
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
RENEWABLES’ ROLE IN THE 2015 US ENERGY SUPPLY

97.5 quadrillion BTU

- petroleum 36.3%
- natural gas 29.0%
- coal 16.0%
- renewables 9.8%
- nuclear 8.5%

9.68 quadrillion BTU

- hydroelectric 25.0%
- wind 18.8%
- biomass 48.5%
- solar PV 5.7%
- geothermal 2.3%

DENSITY MAP OF FUTURE WIND AND SOLAR INSTALLED CAPACITY ADDITIONS

RENEWABLE ELECTRICITY CAPACITY FACTORS BY SOURCE

average for 2013 - July 2016

Source: http://www.eia.gov/electricity/monthly/epm_tablegrapher.cfm?t=epmt_6_07_b, Released July 2016

<table>
<thead>
<tr>
<th>Source</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Nuclear</td>
<td>100</td>
</tr>
<tr>
<td>Conventional</td>
<td>30</td>
</tr>
<tr>
<td>Wind</td>
<td>20</td>
</tr>
<tr>
<td>Solar</td>
<td>15</td>
</tr>
<tr>
<td>Solar Thermal</td>
<td>10</td>
</tr>
<tr>
<td>Landfill Gas</td>
<td>80</td>
</tr>
<tr>
<td>Other</td>
<td>50</td>
</tr>
<tr>
<td>Geothermal</td>
<td>70</td>
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RENEWABLE PORTFOLIO STANDARDS (RPS)

Source: http://www.dsireusa.org/resources/detailed-summary-maps/; August 2016
2016 Q2 WIND ENERGY STATUS

Source: AWEA, Second Quarter 2016 Market Report, p. 6
WIND FARMS
1998 –2015 INSTALLED US WIND CAPACITY ADDITIONS

The **US** installed over **8,598 MW** of wind power capacity in 2015.

The total installed wind power capacity in the **US** has approached **74,471 MW** by the end of 2015.

Wind power represented 41% of **US** electric-generating capacity additions in 2015.

*Source: U.S. Department of Energy 2015 Wind Technologies Market Report*
2009 – 2015 US WIND POWER ENERGY PRODUCTION

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

GWh

<table>
<thead>
<tr>
<th>Year</th>
<th>Production (GWh)</th>
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<tbody>
<tr>
<td>2009</td>
<td>73,886</td>
</tr>
<tr>
<td>2010</td>
<td>94,647</td>
</tr>
<tr>
<td>2011</td>
<td>120,177</td>
</tr>
<tr>
<td>2012</td>
<td>140,822</td>
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<tr>
<td>2013</td>
<td>167,840</td>
</tr>
<tr>
<td>2014</td>
<td>181,655</td>
</tr>
<tr>
<td>2015</td>
<td>190,927</td>
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</table>
2015 INSTALLED WIND CAPACITY: TOP 10 COUNTRIES

rest of the world: 67,151 MW
Brazil: 8,715 MW
Italy: 8,958 MW
France: 10,358 MW
Canada: 11,205 MW
United Kingdom: 13,603 MW
Spain: 23,025 MW
India: 25,088 MW
Germany: 44,947 MW
United States: 74,471 MW
China: 145,362 MW

world total: 432,883 MW

Source: GWEC Global Wind Statistics 2015
2015 INSTALLED WIND CAPACITY

Europe 34.14 %
North America 20.50 %
Asia 40.62 %
Pacific 1.11 %
Africa & Middle East 0.81 %
Latin America & Caribbean 0.28 %

total installed capacity: 432,883 MW

2015 SOLAR ENERGY STATUS

- The global $PV$ cumulative capacity reached 227 $GW$ in 2015 with ability to produce 275 $TWh$ of electricity every year.

- 42% of the world’s total $PV$ cumulative capacity is installed in Europe.

- In 2015, the annual growth rate of $PV$ has reached almost 25%, and is currently the third largest renewable energy source in terms of global, installed capacity.


Lakelands Park Middle School, MD hosts a 111 kW rooftop system.
EVOLUTION OF GLOBAL PV INSTALLATIONS 2000 - 2013

<table>
<thead>
<tr>
<th>Year</th>
<th>ROW</th>
<th>MEA</th>
<th>China</th>
<th>Americas</th>
<th>APAC</th>
<th>Europe</th>
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<tbody>
<tr>
<td>2000</td>
<td>88</td>
<td>1</td>
<td>19</td>
<td>2</td>
<td>126</td>
<td>58</td>
</tr>
<tr>
<td>2001</td>
<td>56</td>
<td>0</td>
<td>5</td>
<td>3</td>
<td>128</td>
<td>133</td>
</tr>
<tr>
<td>2002</td>
<td>80</td>
<td>0</td>
<td>19</td>
<td>30</td>
<td>190</td>
<td>134</td>
</tr>
<tr>
<td>2003</td>
<td>77</td>
<td>0</td>
<td>10</td>
<td>48</td>
<td>230</td>
<td>202</td>
</tr>
<tr>
<td>2004</td>
<td>29</td>
<td>0</td>
<td>10</td>
<td>61</td>
<td>282</td>
<td>705</td>
</tr>
<tr>
<td>2005</td>
<td>10</td>
<td>0</td>
<td>8</td>
<td>82</td>
<td>304</td>
<td>985</td>
</tr>
<tr>
<td>2006</td>
<td>105</td>
<td>1</td>
<td>10</td>
<td>110</td>
<td>325</td>
<td>997</td>
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<tr>
<td>2007</td>
<td>42</td>
<td>1</td>
<td>20</td>
<td>166</td>
<td>271</td>
<td>2023</td>
</tr>
<tr>
<td>2008</td>
<td>76</td>
<td>1</td>
<td>40</td>
<td>306</td>
<td>530</td>
<td>5708</td>
</tr>
<tr>
<td>2009</td>
<td>80</td>
<td>22</td>
<td>160</td>
<td>500</td>
<td>745</td>
<td>5833</td>
</tr>
<tr>
<td>2010</td>
<td>284</td>
<td>46</td>
<td>500</td>
<td>1,082</td>
<td>1,578</td>
<td>13,616</td>
</tr>
<tr>
<td>2011</td>
<td>508</td>
<td>125</td>
<td>2,500</td>
<td>2,181</td>
<td>2,562</td>
<td>22,407</td>
</tr>
<tr>
<td>2012</td>
<td>365</td>
<td>385</td>
<td>3,500</td>
<td>3,774</td>
<td>4,646</td>
<td>17,580</td>
</tr>
<tr>
<td>2013</td>
<td>85</td>
<td>385</td>
<td>11,300</td>
<td>5,153</td>
<td>9,833</td>
<td>10,253</td>
</tr>
</tbody>
</table>

ANNUAL US PV INSTALLATIONS

Source: http://www.greentechmedia.com/research/ussmi; Issued 2016
2009 – 2015 US SOLAR POWER GENERATION

Source: http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?
NATIONAL SOLAR DATABASE

2015 WORLD CUMULATIVE PV CAPACITY

Germany: 43.5 GW
China: 39.7 GW
Japan: 34.4 GW
US: 25.6 GW
Italy: 18.9 GW
UK: 9.1 GW
France: 6.6 GW
Spain: 5.4 GW
India: 5.2 GW
Australia: 5.1 GW

cumulative capacity in GW

PV SOLAR RESOURCE MAP FOR THE US, SPAIN AND GERMANY

### US – GERMANY COMPARISON

<table>
<thead>
<tr>
<th>attribute</th>
<th>US</th>
<th>Germany</th>
<th>ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>population (million)</td>
<td>321</td>
<td>82</td>
<td>3.9</td>
</tr>
<tr>
<td>area (mi²)</td>
<td>3,119,884</td>
<td>137,882</td>
<td>22.6</td>
</tr>
<tr>
<td>peak load (GW)</td>
<td>777</td>
<td>80</td>
<td>9.7</td>
</tr>
<tr>
<td>annual energy (billion kWh)</td>
<td>3,963</td>
<td>544</td>
<td>7.3</td>
</tr>
<tr>
<td>installed wind capacity (MW)</td>
<td>65,877</td>
<td>39,223</td>
<td>1.7</td>
</tr>
</tbody>
</table>
2011 **US GEOTHERMAL ENERGY STATUS**

- 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: National Geographic

U.S.’s first geothermal power plant, Mayacama Mountains, California, turned 50 in 2009
GEOTHERMAL PLANTS
GEOTHERMAL PRODUCTION
2011 **US** BIOMASS / BIOFUELS STATUS

- World biomass installed electricity capacity is **74 GW**

- The **US** grid-connected installed capacity is **13.2 GW**

- Biopower electricity prices are **8-12 ¢/kWh**

- World biofuels production capacity is **55 billion l/y** of ethanol and **9.09 billion l/y** of biodiesel
BIOENERGY AND BIOFUEL

YEARLY ETHANOL AND BIODIESEL PRODUCTION

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

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 \( \epsilon/kWh \) in classes 4 and above onshore wind areas
- 5 \( \epsilon/kWh \) for off-shore regions
DOE SOLAR PROGRAM GOALS

- Photovoltaics: 6¢/kWh by 2020
- Concentrating solar power/troughs: 5¢/kWh by 2012
Q3 2012 LEVELIZED COSTS OF ENERGY

GLOBAL NON-HYDRO RENEWABLE ENERGY CONSUMPTION

TOTAL MONTHLY HYDRO AND NON-HYDRO RENEWABLE GENERATION

Source: http://www.eia.gov/todayinenergy/detail.cfm?id=17351; Issued July 31, 2014
CHANGES IN ANNUAL HYDRO & NON-HYDRO RENEWABLE GENERATION

Source: http://www.eia.gov/todayinenergy/detail.cfm?id=17351; Issued July 31, 2014
RENEWABLE ELECTRICITY GENERATION

as % of total

- Germany
- UK
- Italy
- France
- Brazil
- US
- China

Source: http://www.ft.com/cms/s/0/67b20418-60cc-11e6-ae3f-77baadeb1c93.html#axzz4HoYP7PrE
IMPACTS OF RENEWABLES

$MW$

true chronological load

modified chronological load

capacity of the time-dependent resource

energy generated by time-dependant resource
ELECTRIC SYSTEM INFRASTRUCTURE

Central Generating Station

Step-Up Transformer

Data network Users

Control Center

Micro-turbine

Residential Data Concentrator

Photo voltaics

Batteries

Residential

Distribution Substation

Gas Turbine

Receiving Station

Distribution Substation

Commercial

Recip Engine

Cogeneration

Industrial

Fuel cell

Commercial

Flywheel
TWENTY-FOUR HOUR PROFILE

Source: California ISO data for 08/08/13
WEEKLY LOAD CYCLE

MW

Source: California ISO data from 08/05/13 to 08/11/13
THE WEEKLY LOAD SHAPE

- **load**
- **total available**
- **reserves margin**
- **base load**
- **intermediate peak**

Days of the week:
- Mon
- Tue
- Wed
- Thu
- Fri
- Sat
- Sun
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

MW

1234567891011121314151617181920212223

Source: CAISO
ONTARIO DAILY WIND POWER OUTPUT

MW

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
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

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

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

Source: http://www.seia.org/policy/distributed-solar/net-metering
US NET METERING STATUS

Source: http://www.dsireusa.org/resources/detailed-summary-maps/; July 2016

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US NET METERING STATUS

44 States + DC, AS, Guam, USVI, & PR have mandatory net metering rules

Note: Numbers indicate individual system capacity limit in kW. Percentages refer to customer demand. Some limits vary by customer type, technology and/or application. Other limits might also apply. This map generally does not address statutory changes until administrative rules have been adopted to implement such changes.
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

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
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 some 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 basic 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 and wind generation systems; thermodynamics considerations
TOPICAL OUTLINE

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

- The role of electrical storage technologies
- The demand picture: the nature of electrical loads; time variation, periodicity and price dependence aspects
TOPICAL OUTLINE

- Demand management and energy conservation; efficiency improvements; load management; price-responsive demand; and, the role of new technologies
- Electricity market basics
- Integration of renewable generation into the grid
- Regulatory policy issues
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

<table>
<thead>
<tr>
<th>component</th>
<th>percentage</th>
</tr>
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<td>0</td>
</tr>
<tr>
<td>quizzes</td>
<td>15</td>
</tr>
<tr>
<td>midterm exams</td>
<td>25 x 2 = 50</td>
</tr>
<tr>
<td>final</td>
<td>35</td>
</tr>
<tr>
<td>total</td>
<td>100</td>
</tr>
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</table>
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.


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