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 energy.
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

Source: [http://www.eia.gov/todayinenergy/detail.cfm?id=21252; issued May 15, 2015](http://www.eia.gov/todayinenergy/detail.cfm?id=21252)

[https://www3.epa.gov/climatechange/ghgemissions/sources/electricity.html; issued April 2016](https://www3.epa.gov/climatechange/ghgemissions/sources/electricity.html)
## ELECTRIC POWER SECTOR $CO_2$ EMISSIONS

**History**

- **History**
- **Projectons**
  - **no CPP**
  - **CPP rate-based**
  - **CPP interregional trading**
  - **CPP extended**

**Source:** [https://www.eia.gov/electricity/annual/pdf/epa.pdf](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.
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.
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 different voltage levels for generation/transmission 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.
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
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 ELECTRIC POWER GRID


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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 regulatory commissions to regulate electricity
THE VERTICALLY INTEGRATED UTILITY INDUSTRY STRUCTURE

customers

customer service

distribution

transmission

generation

IPP

self-generation
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

- **Natural Gas**: 59.0%
- **Coal**: 17.8%
- **Oil**: 5.7%
- **Nuclear**: 8.3%
- **Wind**: 1.7%
- **Hydro**: 2.1%
- **Waste**: 1.5%
- **Other**: 3.1%
- **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
Source: https://www.eia.gov/electricity/data.cfm#generation; Issued April 2016
DIVERSITY OF THE US ELECTRICITY INDUSTRY

Source: EIA, January, 2017

total number = 3,473

number of entities

publicly owned 1,942
cooperative 811
other providers 287
investor owned 261
non utility entities 166
federal 6

total number = 3,473
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 (*IOUs*) represent the predominant part of the industry because nearly three fifths of all electricity sales come from these entities.
US ELECTRICITY CUSTOMERS

147.37 million total consumers

- Residential: 128.68 million
- Commercial: 17.85 million
- Industrial: 0.84 million
- Other: 0.0001 million

RETAIL SALES OF ELECTRICITY TO END-USE SECTOR CUSTOMERS

<table>
<thead>
<tr>
<th>Sector</th>
<th>2015 (TWh)</th>
<th>2016 (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>1,407,394</td>
<td>1,404,096</td>
</tr>
<tr>
<td>Industrial</td>
<td>1,359,617</td>
<td>1,360,752</td>
</tr>
<tr>
<td>Commercial</td>
<td>936,269</td>
<td>986,508</td>
</tr>
<tr>
<td>Transportation</td>
<td>7,499</td>
<td>7,637</td>
</tr>
</tbody>
</table>

Total 2015: 3,759 TWh  
Total 2016: 3,711 TWh

PERCENT CUSTOMERS SERVED BY THE ELECTRICITY PROVIDERS

Source: http://www.eia.gov/electricity/state/unitedstates/Table 9
RISING NUMBER OF TELEVISIONS IN HOUSEHOLDS

Source: EIA, http://www.eia.doe.gov/consumption/residential;
Issued 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%)

Total: 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%)

Total: 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

2016 GENERATION BY SOURCE

- coal 31.0%
- natural gas 34.5%
- nuclear 20.1%
- petroleum/other gases 1.2%
- hydro 6.4%
- other renewable sources 8.6%

AMEREN ILLINOIS ENERGY SOURCES OF ELECTRICITY SUPPLIED IN 2016

- Coal 49%
- Nuclear 16%
- Wind 8%
- Hydro 1%
- Oil 3%
- Other resources 1%

Source: Ameren IP, December 2017
<table>
<thead>
<tr>
<th>output</th>
<th>average amount per MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbon dioxide</td>
<td>1,370 lb</td>
</tr>
<tr>
<td>nitrogen oxides</td>
<td>0.78 lb</td>
</tr>
<tr>
<td>sulfur dioxide</td>
<td>1.54 lb</td>
</tr>
<tr>
<td>high–level nuclear waste</td>
<td>0.0009 lb</td>
</tr>
<tr>
<td>low–level nuclear waste</td>
<td>0.0002 ft $^3$</td>
</tr>
</tbody>
</table>

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
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.
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.

And your timing couldn't be better. Texas is one of the states people want to move to. We're ideally located between both coasts, with easy access to national and international markets.

We've got low cost land. Low cost labor. Low cost rents. But we're rich in transportation with DFW Airport and a good freight and highway system. And our utilities, like electric power, are reliable and reasonable.

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>
</tr>
</thead>
<tbody>
<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 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
<table>
<thead>
<tr>
<th>Year</th>
<th>World Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>5.3 billion</td>
</tr>
<tr>
<td>2017</td>
<td>7.6 billion</td>
</tr>
<tr>
<td>2030</td>
<td>8.6 billion</td>
</tr>
<tr>
<td>2050</td>
<td>9.8 billion</td>
</tr>
<tr>
<td>2100</td>
<td>11.2 billion</td>
</tr>
</tbody>
</table>

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
DEMOGRAPHIC TRANSFORMATIONS

2015 – 7.35 billion

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

2060 – 10.18 billion

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

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

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GLOBAL LACK OF ELECTRICITY ACCESS

Source: REN 21
GLOBAL LACK OF CLEAN COOKING ACCESS

38% without access
62% with access

2% Others
28% Sub-Saharan Africa
70% Developing Asia

83% rural
17% urban

Source: REN 21
1980 – 2011 ENERGY DEMAND VS. GDP PER CAPITA

Source: EIA and the World Bank
1980 – 2011 ENERGY DEMAND TRENDS

Source: EIA, 2010; data exclude biomass
EVOLUTION OF THE MAIN SOURCES OF US ENERGY CONSUMPTION

WORLDWIDE SHARES OF PRIMARY ENERGY: 1966 – 2011

## 2012 WORLD PRIMARY ENERGY CONSUMPTION

<table>
<thead>
<tr>
<th>source</th>
<th>generation (PJ)</th>
</tr>
</thead>
<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*
PREDOMINANCE OF OIL AND GAS

Source: BP Statistical Review of World Energy, 2017

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).
PREDOMINANCE OF OIL AND GAS

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

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

![Graph showing per capita CO\(_2\) emissions vs. per capita GDP over time for various countries.](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 consumed 48% of 2010 global coal production

yearly increase in power generating capacity

CRUDE OIL PRICES 1861-2015

Source: BP Statistical Review of World Energy 2016, pg. 15
GLOBAL FOSSIL RESOURCES RESERVES


- **Oil**:
  - Proven: 1,000 billion boe (R/P ratio 46.2 yrs.)
  - Unconventional: yet to find

- **Gas**:
  - Proven: 2,000 billion boe (R/P ratio 58.6 yrs.)
  - Unconventional: yet to find

- **Coal**: yet to find

- **Total**: 27,000 billion boe

- R/P ratio for coal: 118 yrs.
MISALIGNMENT OF SUPPLY AND DEMAND

- **Oil**
  - Consumption: 78.5%
  - Reserves: 25.6%

- **Gas**
  - Consumption: 77.0%
  - Reserves: 45.6%

- **Coal**
  - Consumption: 94.6%
  - Reserves: 96.3%

*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."
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

- **Coal**: 31.0%
- **Natural gas**: 34.5%
- **Nuclear**: 20.1%
- **Other renewable sources**: 8.6%
- **Hydro**: 6.4%
- **Petroleum/other gases**: 1.2%

2016 NET GENERATION OF RENEWABLE ENERGY SOURCES

- **Hydroelectric**: 43.0%
- **Wind**: 37.6%
- **Solar**: 6.1%
- **Wood & Wood-Derived Fuels**: 6.7%
- **Other Biomass**: 3.7%
- **Geothermal**: 2.9%

Source: [http://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf](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

Non-renewable electricity 75.5%
Renewable electricity 24.5%

- Wind power 4.0%
- Bio-power 2.0%
- Solar PV 1.5%
- Ocean, CSP and geothermal power 0.4%

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

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
RENEWABLE PORTFOLIO STANDARDS (RPS)

Source: http://www.dsireusa.org/resources/detailed-summary-maps/; February 2017
2005 – 2016 GLOBAL WIND CAPACITY

2016 INSTALLED WIND CAPACITY: TOP 10 COUNTRIES

world total: 486,749 MW

rest of the world 75,577
Brazil 10,740
Italy 9,257
Canada 11,900
France 12,066
United Kingdom 14,543
Spain 23,074
India 28,700
Germany 50,018
United States 82,184
China 168,690

2016 INSTALLED WIND CAPACITY

Europe 33.14 %
North America 20.05 %
Asia 41.84 %
Africa & Middle East 0.80 %
Latin America & Caribbean 0.28 %
Pacific 1.01 %

Total installed capacity: 486,749 MW

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.
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 CO₂ 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

GWh

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

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2016 US WIND CAPACITY BY STATE

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

2016 US WIND GENERATION SHARE OF STATE CONSUMPTION

U.S. Wind Energy Share of Electricity Generation, by State

Total 2016 generation: 226,000 GWh

WIND ENERGY REDUCES US GHG EMISSIONS

158.6 million metric tons of CO₂

SOLAR ENERGY

Images From: http://www.scientificamerican.com/article.cfm?id=how-to-use-solar-energy-at-night
2008–16 GLOBAL PV SOLAR CAPACITY

Source: https://www.greentechmedia.com
The global PV cumulative capacity reached 306.5 GW in 2016. The addition of 76.6 GW represents 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 shrunk 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

GWh

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

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NATIONAL SOLAR DATABASE

2016 INSTALLED PV SOLAR TOP 10 COUNTRIES

- China; 25.3%
- USA; 13.8%
- Germany; 13.4%
- United Kingdom; 3.8%
- Italy; 6.2%
- India; 3.1%
- France; 2.3%
- Australia; 1.9%
- Spain; 1.8%
- Rest of World; 14.4%

Source: SolarPower Europe Global Market Outlook 2017-2021
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 (mi^2)</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>
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.


U.S.’s first geothermal power plant, Mayacama Mountains, California, turned 50 in 2009.
GEOTHERMAL PLANTS
GEOTHERMAL PRODUCTION
World biomass installed electricity capacity is 112 \textit{GW}

with 504 \textit{TWh} generation

The \textit{US} grid-connected installed capacity is 13.2 \textit{GW}

\textit{US} and \textit{Brazil} are the largest biofuel producers

World biofuels production capacity is 135 \textit{billion l/y}
BIOENERGY AND BIOFUEL

YEARNLY 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

- $3/\text{kWh}$ in classes 4 and above onshore wind areas
- $5/\text{kWh}$ 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

RENEWABLE ELECTRICITY GENERATION

as % of total

Source: http://www.ft.com/cms/s/0/67b20418-60cc-11e6-ae3f-77baedb1e939.html#axzz4HoYP7PrE

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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
Distribution Substation
Receiving Station
Distribution Substation
Commercial
Recip Engine
Fuel cell
Flywheel
Residential Data Concentrator
Photo voltaics
Batteries
Micro-turbine
Gas Turbine
Cogeneration
Industrial
Commercial
Data network Users
TWENTY-FOUR HOUR PROFILE

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

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

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

**load**

- Mon
- Tue
- Wed
- Thu
- Fri
- Sat
- Sun
CALIFORNIA SUMMER LOAD: TYPICAL DAILY SHAPE

- Residual ("Other Area")
- Residential – AC
- Commercial – AC
- Commercial – Interior Lighting
- Residential – Miscellaneous
- Commercial – Other
- Residential – Refrigeration
- Commercial – Ventilation
- Residential – Cooking
- Residential – Clothes Dryer
- Commercial – Refrigeration
- Remainder of Buildings Sector
- Industrial Sector
- Agricultural Sector
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
ONTARIO DAILY WIND POWER OUTPUT

Source: IESO
PV POWER OUTPUT OF 1–MW CdTe ARRAY IN GERMANY

Source: CAISO

samples collected on a 5–minute basis
PV POWER OUTPUT AT THE NEVADA 70 – kW POLYCRYSTALLINE ARRAY

Data collected on a 10 - second basis

Source: CAISO
AUGUST 21, 2017 SOLAR ECLIPSE

Graph showing '000s of megawatts, Pacific daylight time. The graph indicates a peak of eclipse in California during daylight hours. The graph is labeled "Day of eclipse" and "Day before eclipse." Source: California ISO © FT
KEY CHALLENGES IN RENEWABLE EXPANSION

- Government policies at the
  - federal
  - state
  - local

- 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


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

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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

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

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