Unit 2: Energy Resources

Econ 3535

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Lecture 13

- Energy Overview

Energy vs Electricity

Important distinction: electricity is a subset of the energy sector

Some energy uses have electric and non-electric versions:

- Road vehicles, heaters, cooking stoves, lighting

Some energy uses are essentially always one or the other:

- Electric: Computers, air conditioning
- Non-electric: Airplanes, heat-intensive industrial processes

US primary energy use

Primary energy is measured in British thermal units (Btu), which allows us to compare physical units of different types and qualities of fuel. (BTU is amount of heat required to raise one pound of water by one degree F)

From eia.gov

- Electric power - 39%
- Transportation - 29%
- Industrial - 22%
- Residential - 6%
- Commercial - 4%

The electric power sector generates most of the electricity, which is mostly used by the other sectors

US energy resource mix

What are we using for energy? (EIA 2016)

Natural gas (NG)- 33%

- Biggest single source for electricity generation, also common in residential/commercial heating and some industrial processes

Petroleum- 28%

- 92% of the transportation sector, only about 1% of the electricity generating sector

Coal- 17%

- Second most common source for electricity generation

Renewable energy- 12%

- Mostly just for electricity, though other applications are emerging

Nuclear- 10%

- Just for electricity

Greenhouse gas emissions

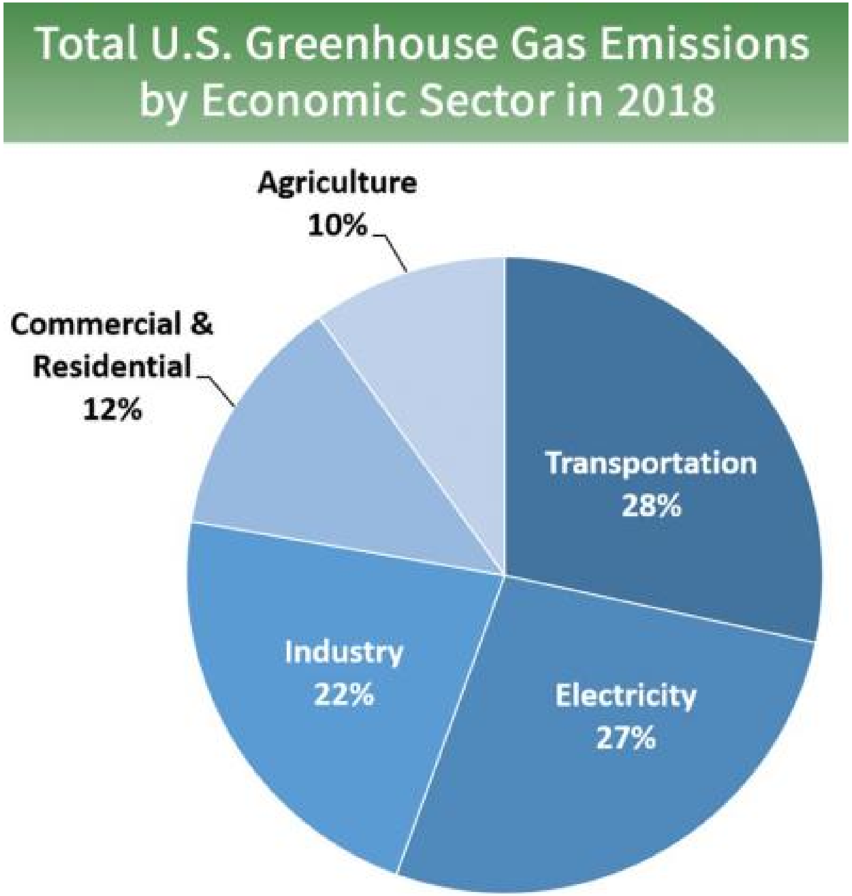
Energy use is responsible for the vast majority of greenhouse gas that the US produces, within each of these sectors

- Within energy use, fossil fuel consumption creates the vast majority of GHGs

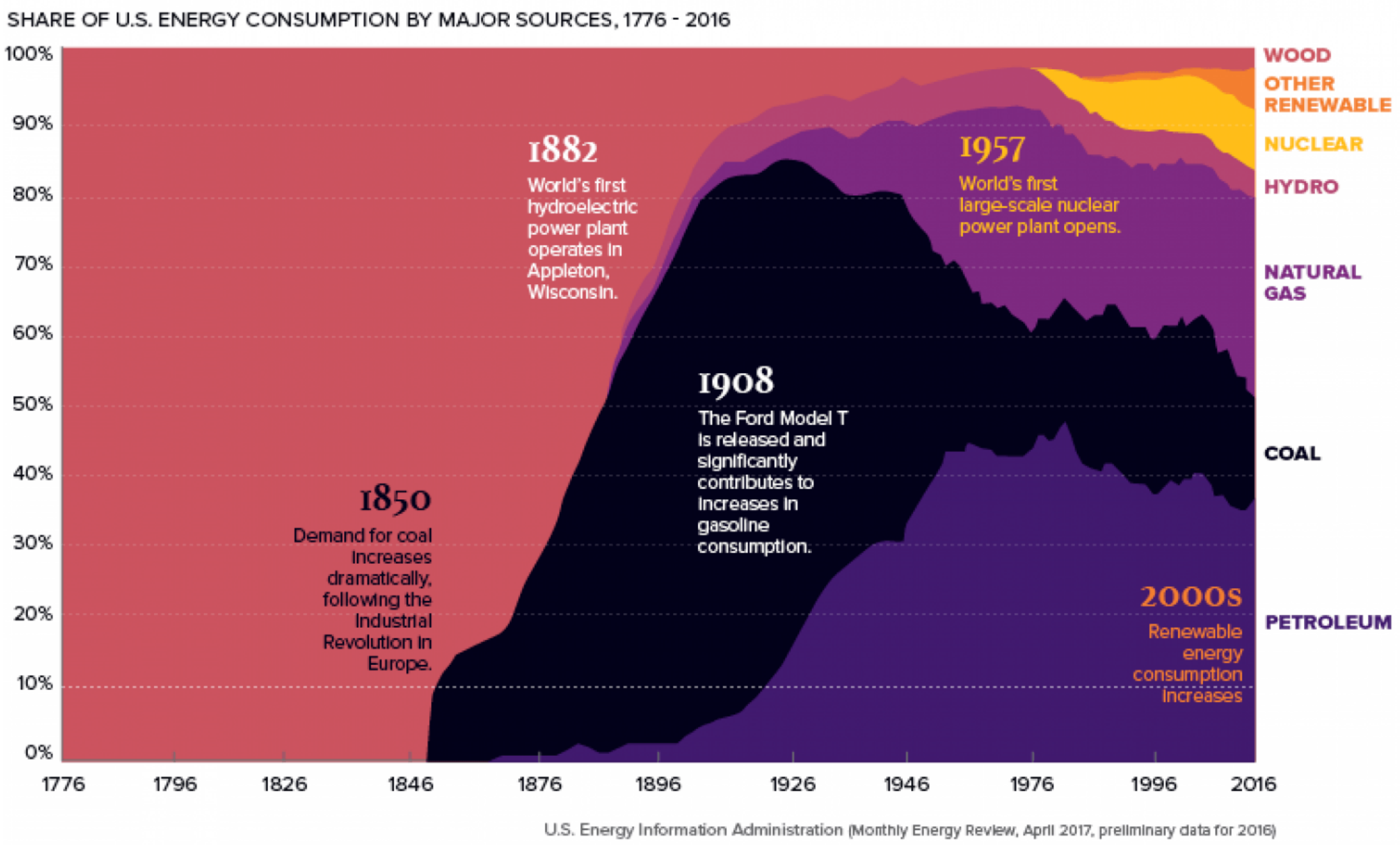
Generally argued that decarbonizing the electricity sector is a huge part of the most efficient path forward

- Recall efficiency $\implies$ abatement from "least cost sources first"
- Aviation, marine, freight, and agricultural fertilizers have no good low-carbon alternatives yet

The next unit will cover climate change policy, and most of the action is in energy and electricity


Total U.S. Greenhouse Gas Emissions by Economic Sector in 2018
Agriculture 10%
Commercial & Residential 12%
Transportation 28%
Industry 22%
Electricity 27%

From epa.gov


SHARE OF U.S. ENERGY CONSUMPTION BY MAJOR SOURCES, 1776 - 2016
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1776
1796
1826
1846
1876
1896
1926
1946
1976
1996
2016
WOOD
OTHER RENEWABLE
NUCLEAR
HYDRO
NATURAL GAS
COAL
PETROLEUM
1850
Demand for coal increases dramatically, following the Industrial Revolution in Europe.
1882
World's first hydroelectric power plant operates in Appleton, Wisconsin.
1908
The Ford Model T is released and significantly contributes to increases in gasoline consumption.
1957
World's first large-scale nuclear power plant opens.
2000s
Renewable energy consumption increases
U.S. Energy Information Administration (Monthly Energy Review, April 2017, preliminary data for 2016)

Energy mix over time

The energy we use changes dramatically over time

- So far, almost all of the changes can be explained by evolving economic costs and benefits

Regulations on safety, energy security, environmental effects are more recently impactful -How important? Good question.

Energy demand

Household and commercial energy demand is usually very inelastic in the short run

- *Inelastic*: change in price leads to relatively small change in quantity demanded
- *Short run*: sooner than it takes to make big changes (abstract, not specific)

For instance, if gasoline, electricity, or NG heating prices increase, most people don't change their behavior, or even notice

- In the long run, you can move to a more energy efficient house, install expensive upgrades, or buy a more fuel efficient car

Industrial energy demand is somewhat more elastic in the short run, mostly because energy is a more significant cost there

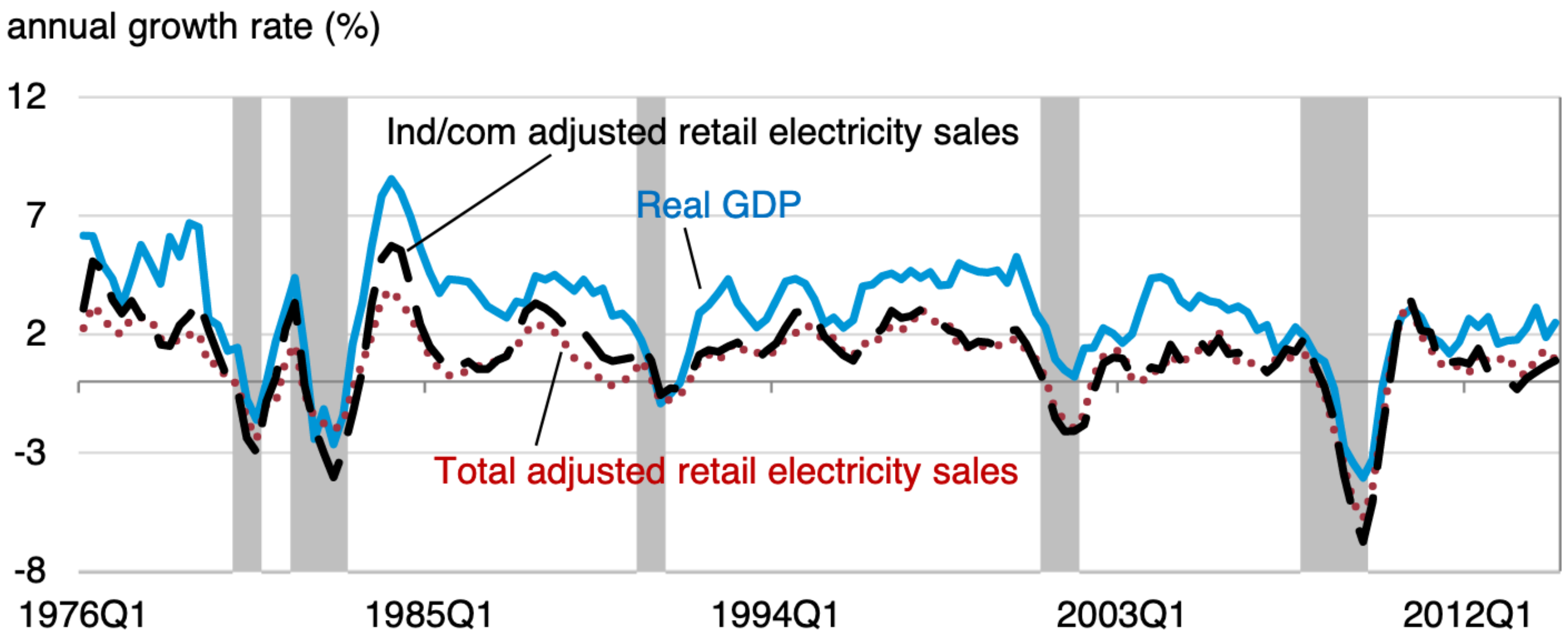
- Sometimes they even coordinate their energy demand with their electric utility
- Very cool idea, more in the "Demand Response" section later

Energy demand and macroeconomics

Energy demand (especially electricity) is closely tied to the health of the overall economy

- During recessions, producers cut back on energy-intensive processes
    - In this sense, recessions can be good for the environment

Figure 5. U.S. electricity use and economic growth, 1976Q1-2014Q2, recessions shaded



Source: EIA, BEA

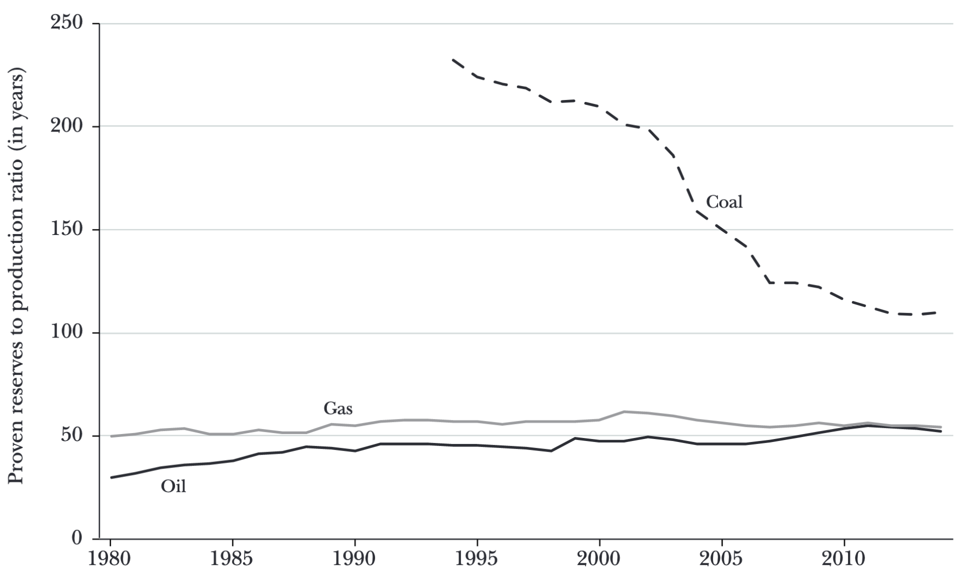
Energy supply- fossil fuel reserves

Proven fossil fuel reserves = "current reserves" from the first unit

Over time, we extract and process more of our endowment. However, we also discover more endowment and economic factors evolve so that it is easier to get For natural gas and oil, we have maintained around 50 years of reserves (at current usage rates) for a long time

Figure 1

Ratio of Proven Fossil Fuel Reserves to Production



Source: BP Statistical Review of World Energy, 2015.

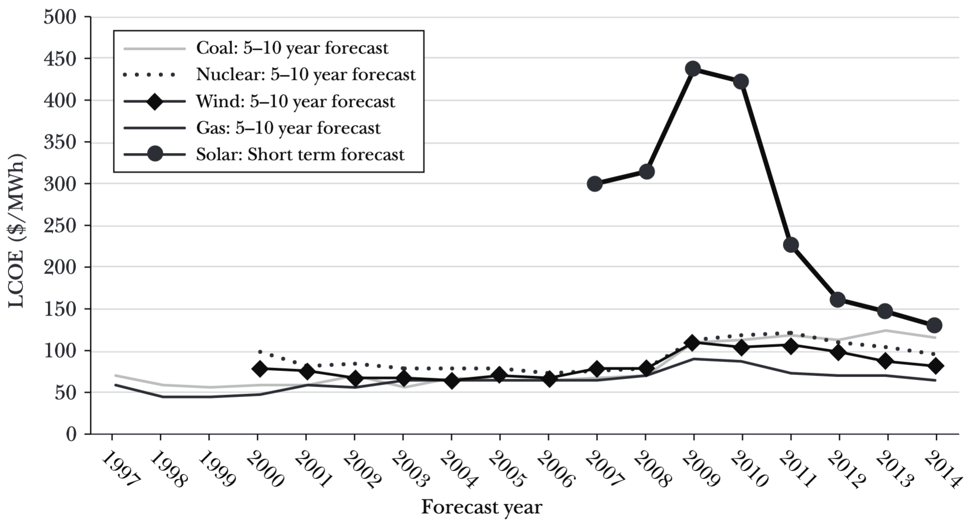
Levelized cost of energy (LCOE)

The LCOE represents the average revenue per unit of electricity generated that would be required to recover the costs of building and operating a generating plant during an assumed financial life and duty cycle

- Measured in $ / MWh

Figure 4

Levelized Cost of Energy (LCOE) Forecasts from the US Energy Information Administration



Source: EIA Annual Energy Outlook reports from 1997 to 2014.

Energy supply- LCOE

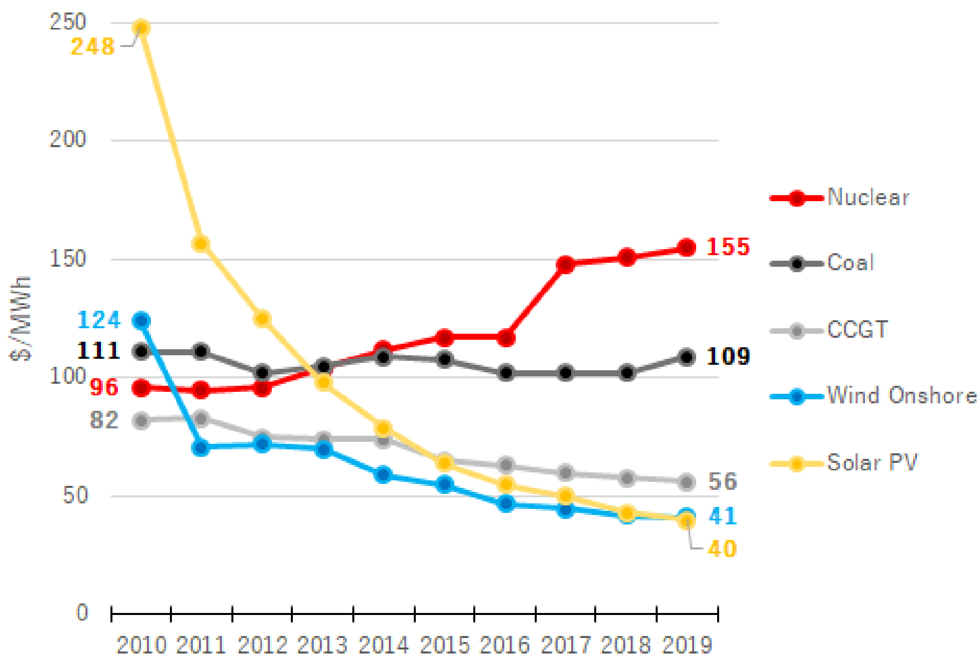
In the US, energy supply is primarily driven by costs and benefits, not by government decree. Best value options usually win out.

Other countries have more government control. Even then, incentives for elected officials still mostly come down to user satisfaction with prices and the cost of energy provision.

Future of Renewables

LCOE and related measures are the best predictors of energy resource mix

- Generally agreed upon that renewables and emerging technologies must be able to beat other sources in the market if they are to become dominant
- Luckily, things may be moving in that direction fairly quickly



Reading for next time

- "Will we ever stop using fossil fuels?", pages 117-120
- "Electricity" and Examples 7.5 and 7.6, pages 163-168

Lecture 14

Electricity Industry

- How the price and quantity of electricity is determined in the short run
- How the market for electricity is structured
    - Who are the producers of electricity?

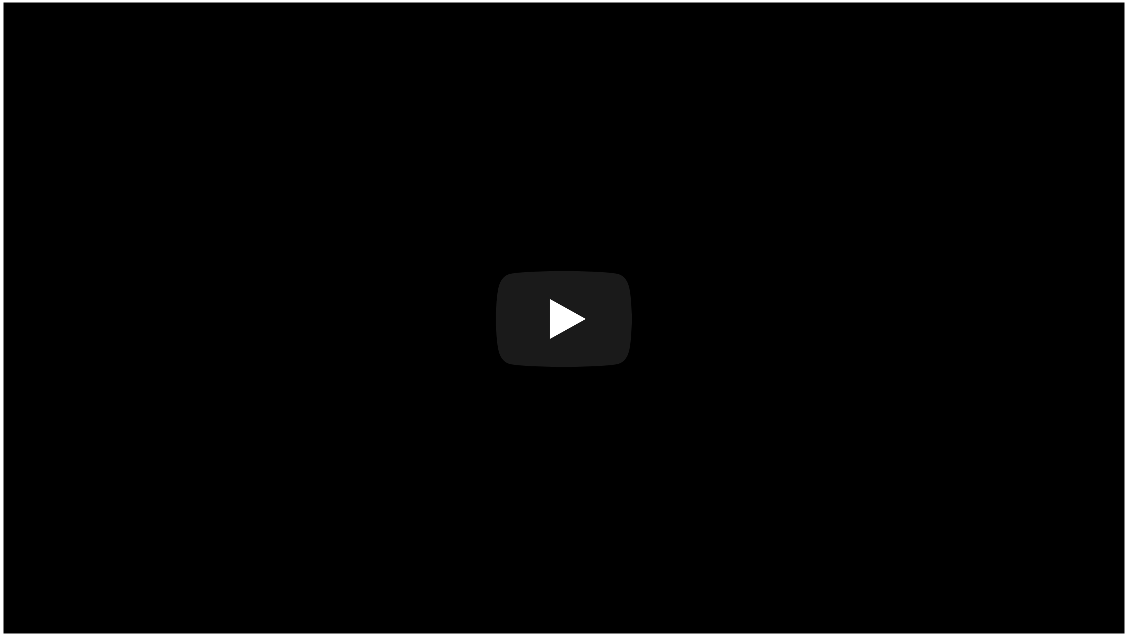
Electricity Market Features - (1) Distinct Features of Electricity

Electricity can not be (economically) stored

- For now this is true, although battery technology is changing this

Supply = Demand at all times

- Costly blackouts occur if demand and supply are not equal.
- Since demand varies a lot, so too does the price of electricity



Electricity Market Features - (1) Distinct Features of Electricity

It is a homogenous good to consumers

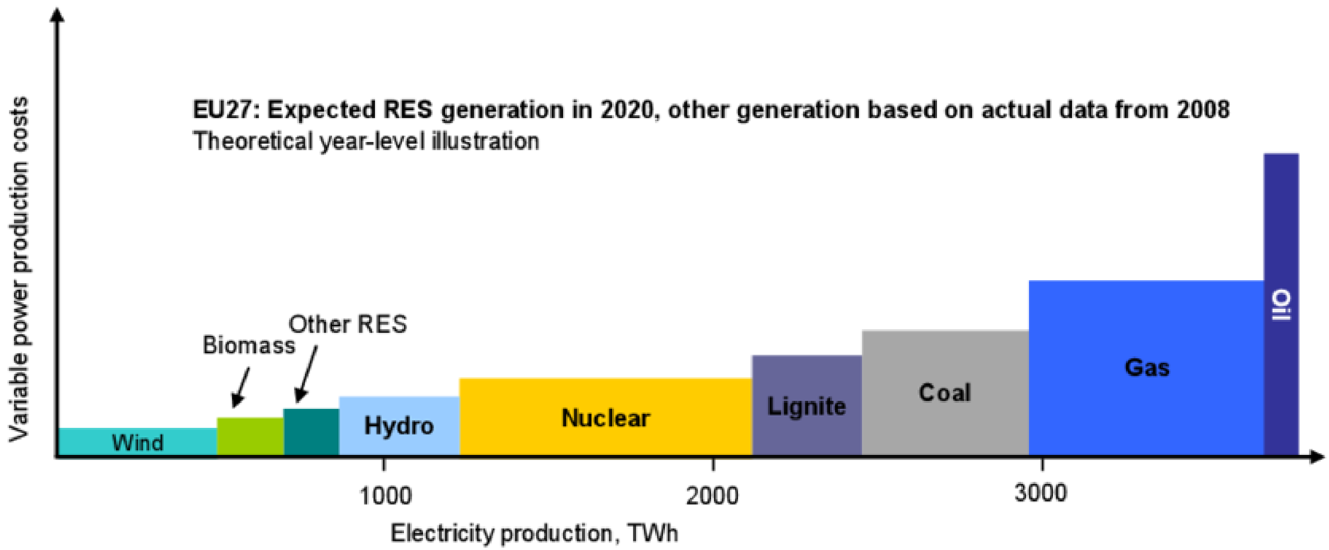
- To me an electron is an electron, I can not tell where it comes from once it is on the grid

It is not homogenous to the grid regulators

- Regulators value flexibility, resiliency, and anything that helps balance supply and demand
- In the previous video how did Simon increase the Hz so quickly? Solar panels, for instance, can't just increase the sun they absorb in an instant

Merit Order

Inputs with the lowest marginal cost are dispatched first, and when demand increases, sources with higher marginal cost are dispatched



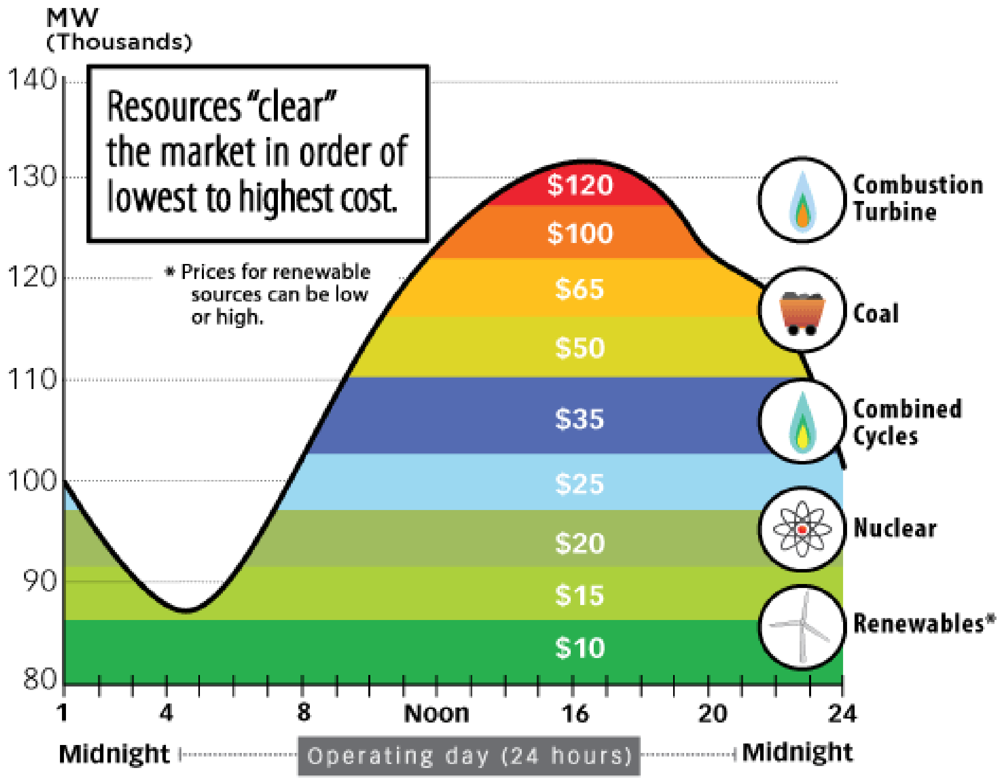
Source

Electricity Market Features - (2) Economic dispatch

Electricity supply must keep up with electricity demand. This is tricky because demand is hard to forecast perfectly

A lot of Demand Shifters

- Demand goes through daily cycles (shown next page) and seasonal cycles
- A wide variety of inputs are used to generate a standardized output good

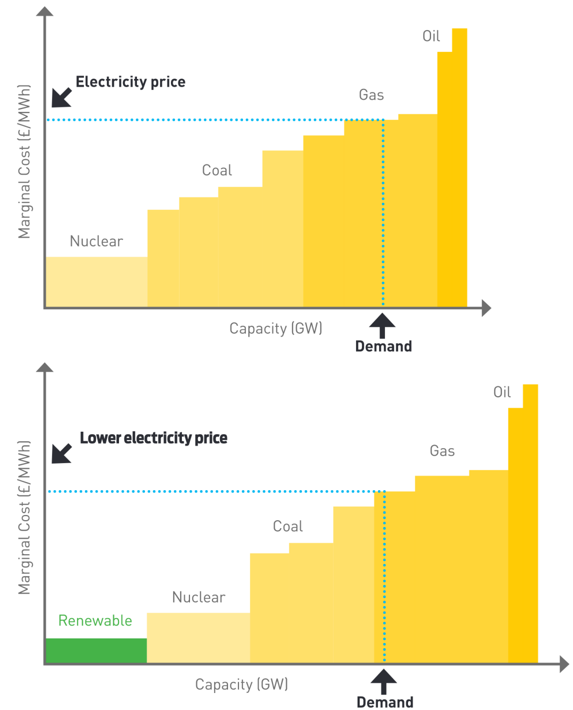

MW
(Thousands)
140
130
120
110
100
90
80
Resources "clear" the market in order of lowest to highest cost.
* Prices for renewable sources can be low or high.
$120
$100
$65
$50
$35
$25
$20
$15
$10
Combustion Turbine
Coal
Combined Cycles
Nuclear
Renewables*
1
4
8
Noon
16
20
24
Midnight
Operating day (24 hours)
Midnight

Source

The Merit Order Effect of Renewable Generation (supply shift)

"The power price is determined by the "merit order" – the sequence in which power stations contribute power to the market, with the cheapest offer made by the power station with the smallest running costs setting the starting point." Source

This report argues that you should count for the Merit Order savings on consumers when calculating net costs and benefits.



Source

Electricity Market Features – (3) Natural Monopoly

Monopoly: only one seller is present in the market

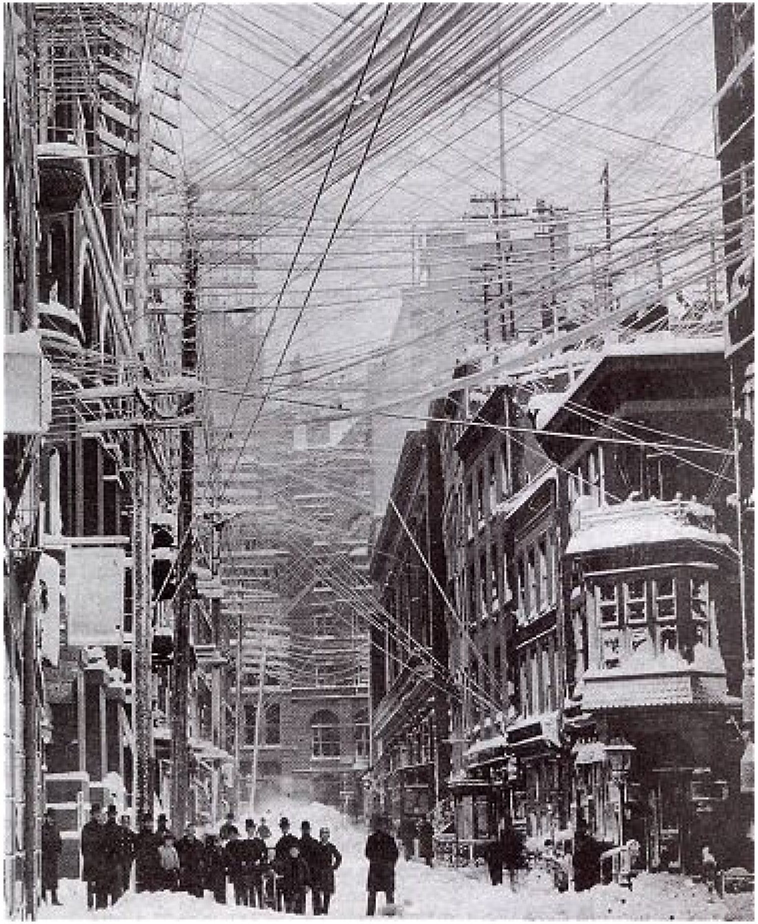
Natural monopoly: it makes sense, from a social perspective, to only have one seller in the market

- High fixed costs, low marginal costs $\implies$ declining average total costs
- Double the number of customers $\implies$ less than double costs
- Natural monopolies usually involve big infrastructure spending (e.g. cable, internet, phones, other utilities)

Natural Monopoly Problem

- More efficient to avoid wasteful duplication of infrastructure
- However then we are subject to monopoly prices and quantities

Before Natural Monopoly

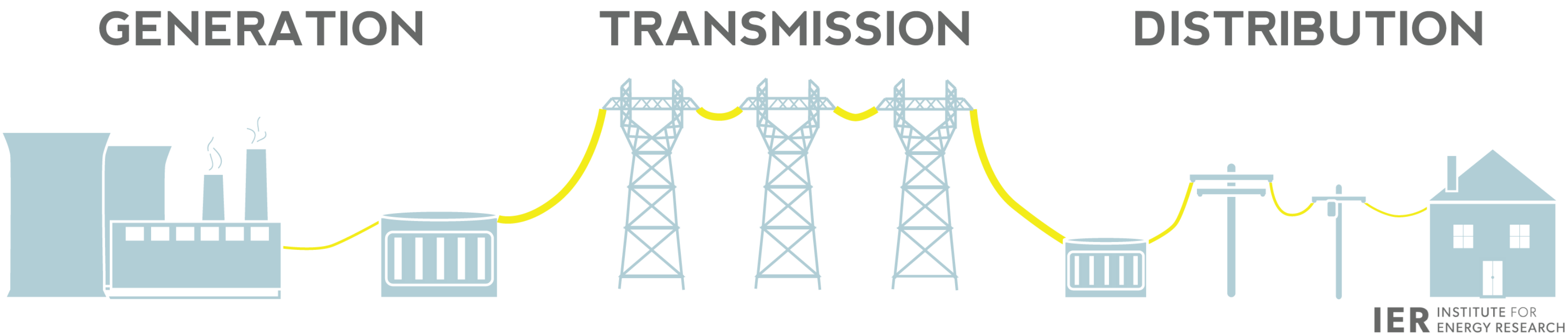


Regulated markets

The original solution to the natural monopoly problem was to allow monopolies to exist, but restrict the prices they can charge

Rate of Return regulation grants monopoly to a single generator of electricity owned by either investors or municipalities.

- The generator is allowed total cost recovery and a profit on all *capital* investments
- Prices charged to consumers are required around the competitive price
- These single firms (like Xcel Energy) are vertically integrated and own the generation, transmission, and retail portions of the business



The Age of Deregulation

People began to wonder if we could do better by promoting competition:

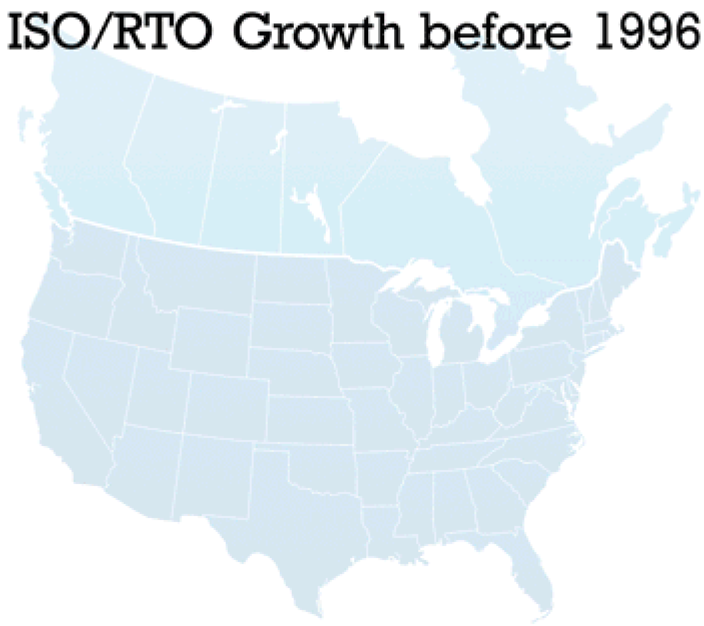
- *"Averch Johnson effect"*: the tendency of regulated companies to engage in excessive amounts of capital accumulation in order to expand the volume of their profits.
- *"gold plating"*: the phenomenon of working on a project or task past the point of diminishing returns.
- No attempt to find lowest cost fuel

Wholesale Markets

By the 1990s, computers became able to support a more complicated market structure. Federal Energy Regulatory Committee (FERC) promoted wholesale markets

- Competition will bring down costs, stop "gold plating", integrate markets
- *Regional Transmission Organizations* or *Independent Supply Operators* manage the grid (Transmission)
- Utilities and Independent Power Producers compete in a a wholesale market.

Wholesale Market Expansion



The Age of Deregulation

States passed policies to break up vertically integrated monopolies.

- Idea: only the transmission grid is a natural monopoly
- Forced divestiture of assets
- Sometimes wholesale competition
- Sometimes retail competition

Some success (costs do go down!) and some failures (Enron in California)

Reading for next time

- "Coal", page 159
- "Uranium", pages 159-163

Lecture 15

- Coal
- Carbon capture and storage
- Nuclear

Coal use

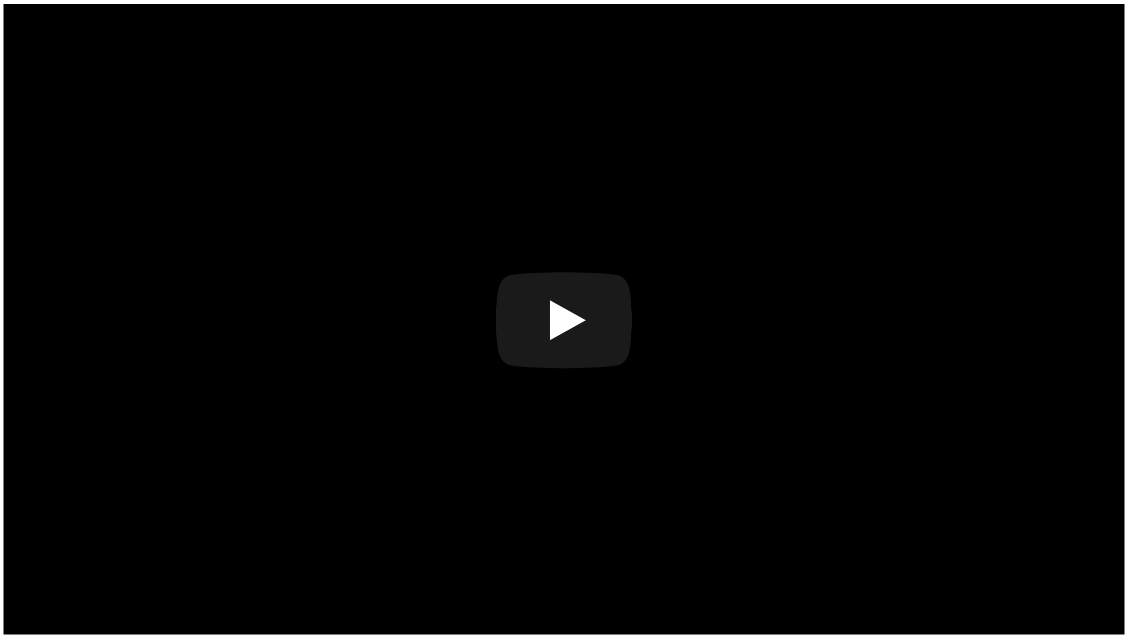
Globally, coal provides 41% of the electricity we use

- 33% in OECD countries and 49% in non-OECD countries
- Global coal use peaked in 2013 and has begun to decline
- Coal use in the US began to decline in the 1980s, and its share of generation has declined from about 52% $\rightarrow$ 32% since 2000

Biggest factor driving the decline of coal has been competition from natural gas (NG)

- Recall, deregulation started in the late 1990s, and competitive markets incentivized people to build a lot of Natural Gas plants
- Additionally, shale gas extraction technologies led to lower NG prices

Coal in China



Coal- advantages

Easily storable as solid fuel

- Possibly more resilient source than NG in very cold weather

Relatively abundant and inexpensive

- About 100 years of current reserves at today's use rate
- Cost-competitive especially in developing countries

Well-established domestic supply chain

- Vast majority of US supply is from the US, transported by existing railroads

Coal plants already exist

- This is the main advantage
- US has basically stopped building coal plants, but existing ones compete with yet-unbuilt renewables

Coal- disadvantages

Produces a relatively large amount of CO2

- Generally better than petroleum but worse than most other sources

Also produces a relatively large amount of local pollutants

- Big disadvantage
- US regulates local emissions from coal but not from NG

Non-renewable

- For aforementioned reasons, not as important as you would think

Economically significant marginal cost

- Obviously higher MC than renewables and nuclear, but the big one is cheap NG

Slower response than natural gas

- NG can be dispatched more quickly than coal, so coal is less useful for grid services

Can coal make a comeback?

Probably not as the LCOE is too high for new development.

Carbon capture and storage

Coal plants with CCS are sometimes called "clean coal"

Idea: alter the production process so that CO2 never reaches the atmosphere

- Filter emissions, store the pollution

Currently an experimental technology, not yet widely deployed

Important debate in climate change economics- how much can we count on CCS?

- CCS complements fossil fuels, just like battery storage complements renewables

Big upside- a huge breakthrough in CCS technology could make climate policy much simpler and cheaper

Major downside- requires strong, long-term commitment to carbon pricing; there is virtually no incentive to invest in CCS otherwise

Nuclear- advantages

Very low marginal cost of operation

- Fuel costs and ongoing maintenance are generally lower than in fossil fuel plants

Very low emissions compared to fossil fuels

- Electricity production process is very clean
- Uranium mining has environmental issues, but so does all mining

Relies on an essentially non-scarce resource

- Long-run endowment of fissile material is very large
- Nuclear fusion technology improvements could make it even larger

Nuclear- disadvantages

Very high up-front costs

- Expensive to build, takes a long time from start to finish (often 10+ years)
- Big financial risk given that it takes so long to recover fixed costs
- Many projects are abandoned before completion ($9 billion loss in SC)

Consistency issues

- Typically spend ~40 days per year undergoing maintenance and refueling
- Plants are very large, so outages require redundant capacity

Low-risk, high-cost scenarios

- Chernobyl, Three-mile island, Fukushima, terrorism (?)

Nuclear waste is costly

- Must be treated in a special facility for ~50 years before safe to dispose

Role of nuclear

Nuclear power is another very controversial technology

Some, such as Bill Gates' Breakthrough Institute, have been investing heavily in nuclear research

- Mass production of miniature reactors, lower cost, risk, and construction time
- Nuclear fusion technology

Others believe this is a foolish idea, and we should decarbonize without gambling on technologies that don't exist yet

- Most concern seems to be about cost/benefit rather than safety
- Time is running out, and nuclear takes a long time to build

Reading for next time

- "Natural Gas", pages 142-146
- Renewable energy - the global transition, explained in 12 charts (online version)

Lecture 16

- Natural Gas

Natural gas use

Natural gas (NG) is the single largest source of electricity in the US (34%), and it is the second biggest source of energy overall (29%) next to petroleum

- Used for electricity generation and many heating-related applications

NG became much more common starting around the year 2000

- Shale Revolution
- Industry deregulation and replacement of coal

Natural Gas History

NG industry started in the same way that the electricity industry did, with regulated natural monopoly firms

Unregulated monopolies charge artificially high prices

- Government forced NG producers to set lower prices

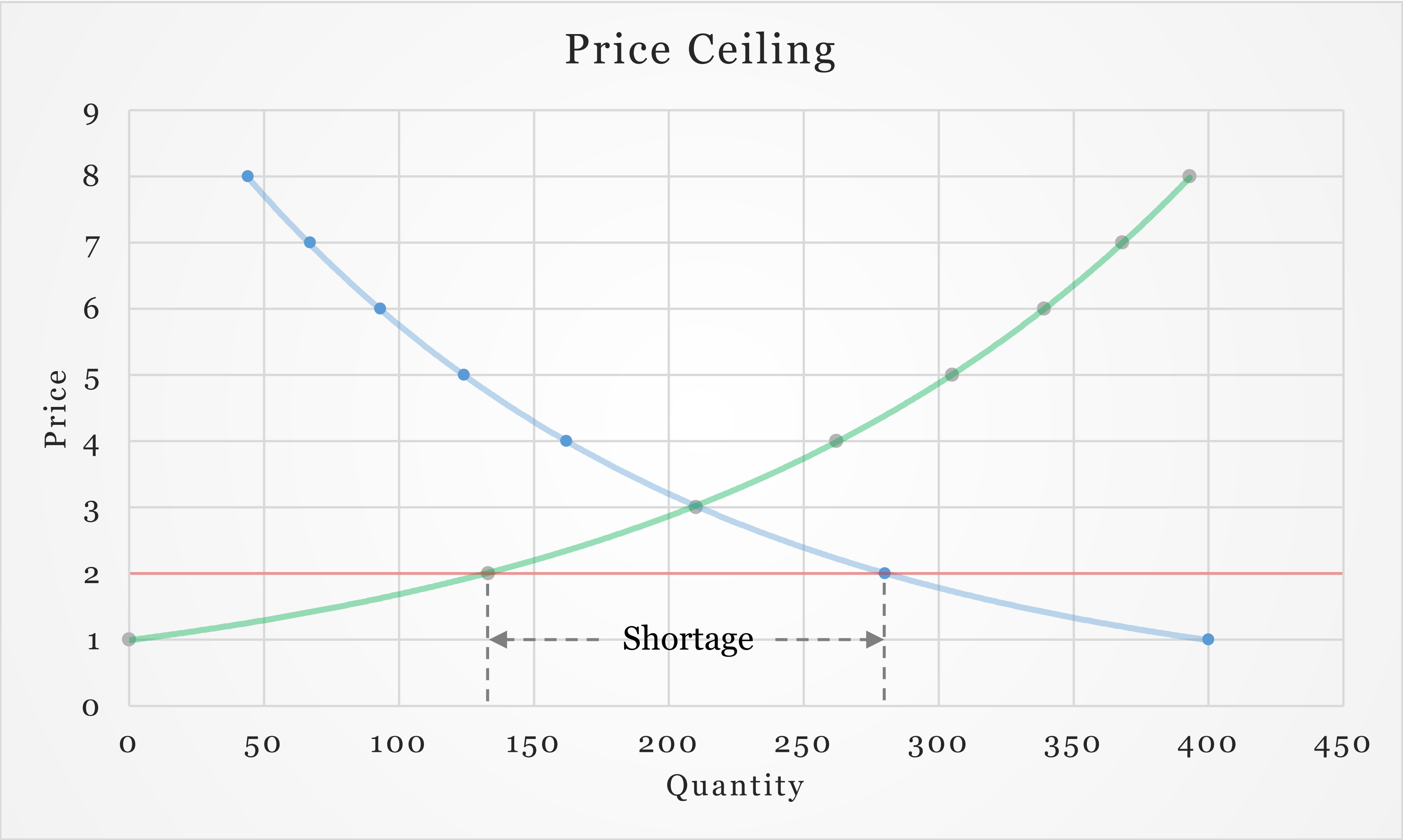
1970’s - price ceiling led to shortages (diagram)

- Allocate the resource according to high vs low priority customers?
- Didn’t work out very well

All price controls were removed by 1993

- NG prices rose, so companies were willing to increase quantity supplied

Price Ceiling



Shale revolution

Technology improvements in hydraulic fracturing (fracking) and horizontal drilling expanded the current reserves of NG

- Supply curve shifts to the right (increases), so price of NG falls while quantity produced increases

Primary reason behind the decline of coal

Property Rights in the US were very advantageous to the Shale Revolution:

1. Private land rights in the US extend to underground resources

2. Transferability - rights to the land and rights to the underground resources can be owned separately, bought and sold

Measuring environmental effects of these technologies is controversial

Natural gas- advantages

Relatively clean among fossil fuels

- Life cycle GHG emissions are about half those of coal

Responsive, dispatchable resource

- As renewables and nuclear (essentially non-dispatchable) become more common, value of NG increases

- Very important for responding to the daily cycle of electricity demand

Very cost effective in a wide range of roles

- Competitive with renewables for low-MC "baseload" generation
- Competitive with petroleum, battery storage, etc. for "peaking" generation

Well-established domestic supply chain

- US has good NG infrastructure and promising shale gas formations

Natural gas- disadvantages

Harder to store emergency reserves of NG on-site

- Coal and nuclear can do this, renewables do it by default

Still emits plenty of CO_2

- Most long-run forecasts suggest that we must eventually stop using fossil fuels entirely to meet even moderate climate change goals

Reading for next time

- "Transitioning to Renewables", pages 170-176

Good news

Renewables to Account for a Third of Global Power Generation in 2022 (online version).

Bad news

Renewables Are Expanding at an Astounding Pace. But It’s Still Not Enough to Meet Climate Goals (online version).

Lecture 17

- Renewables overview
- Wind

Renewables overview

IEA projects that renewables will reach 33% of global electricity production by 2022

- Around 23% currently

Hydroelectric and geothermal power

- Very cost effective and reliable
- Inherently limited by geographic availability

Solar and wind power

- Rapidly improving LCOE projections
- Big potential for expansion

Biofuels

- Currently we mostly use bio-waste
- Uncertain future for intentionally produced biomass

Policy

Renewable Portfolio Standards (RPS)

- States (29 states, DC and PR) set a target for renewable generation percentage by a future date
- For instance, Colorado- 30% renewable by 2020

Renewable Energy Credits (RECs)

- One REC is given to anyone who builds 1 MW of active renewable generating capacity.
- These can be bought or sold to comply with RPS

Think of RPS as a reverse cap-and-trade system, and RECs as reverse permits

Policy

Federal Production Tax Credit

- Federal subsidy of about $23 per MWh for renewable generation

- Applies for first 10 years

Recall the LCOE forecasts from last time

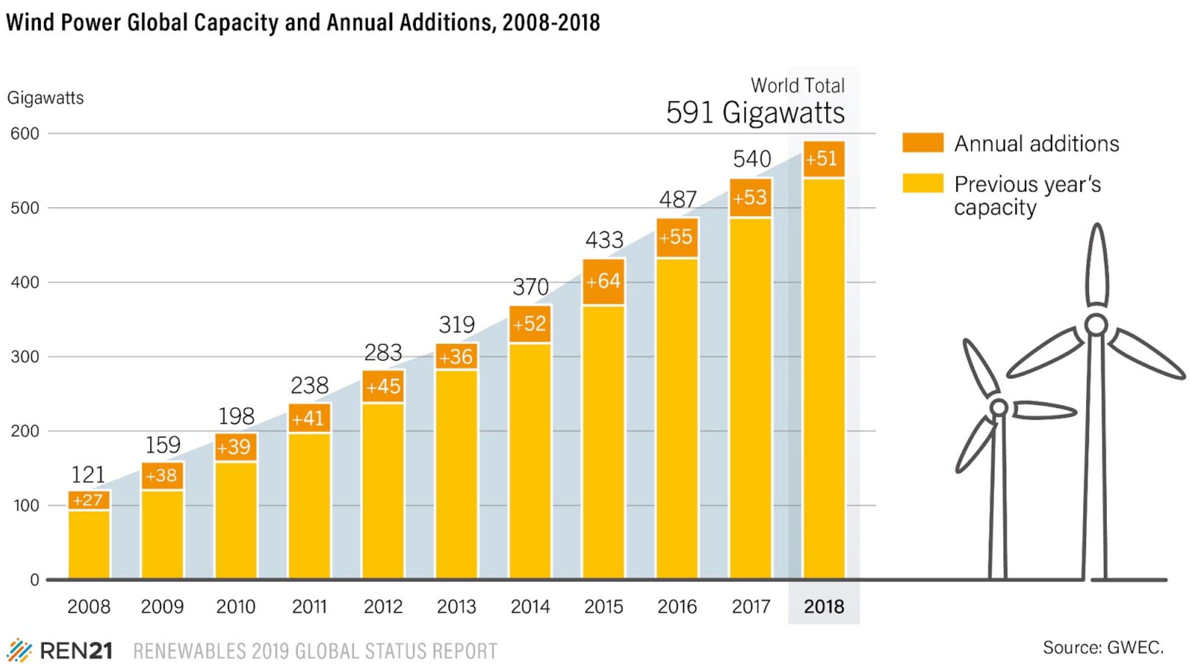
- Wind: ~$80 per MWh over next 5-10 years
- Natural Gas: ~$60 per MWh over next 5-10 years

When firms decide to build more energy capacity, the PTC pushes wind to be competitive with natural gas for many places

Other decision factors include

- Regional wind averages, natural gas prices, labor costs, availability of land, etc.

Wind power overview



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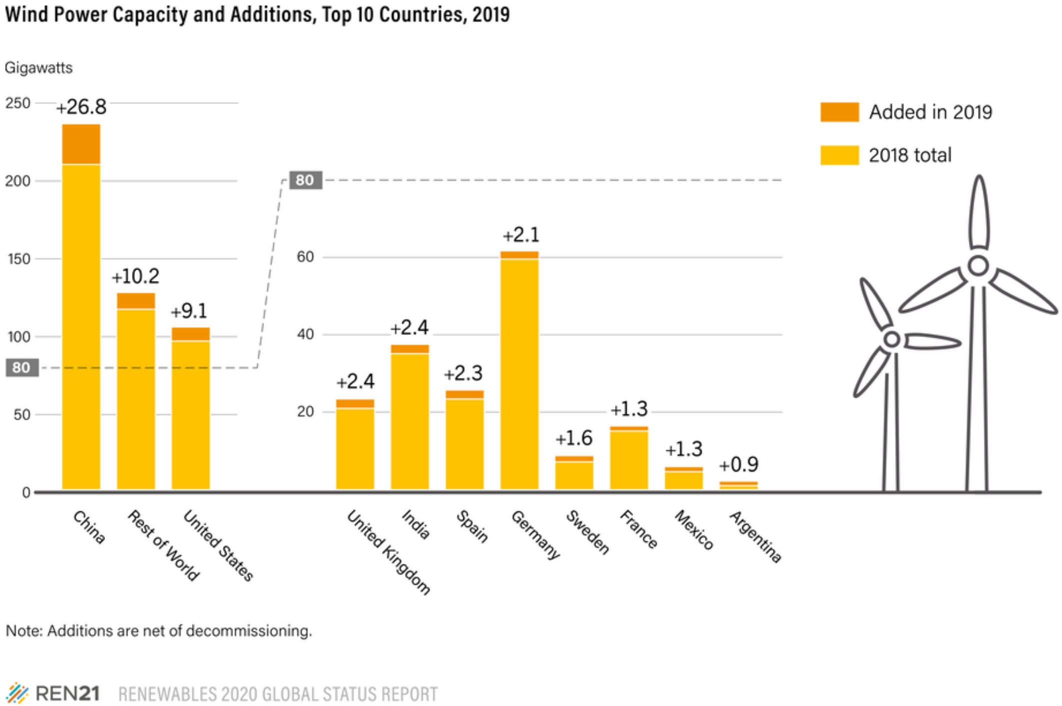
Wind power overview

class: center, middle



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Wind in the US

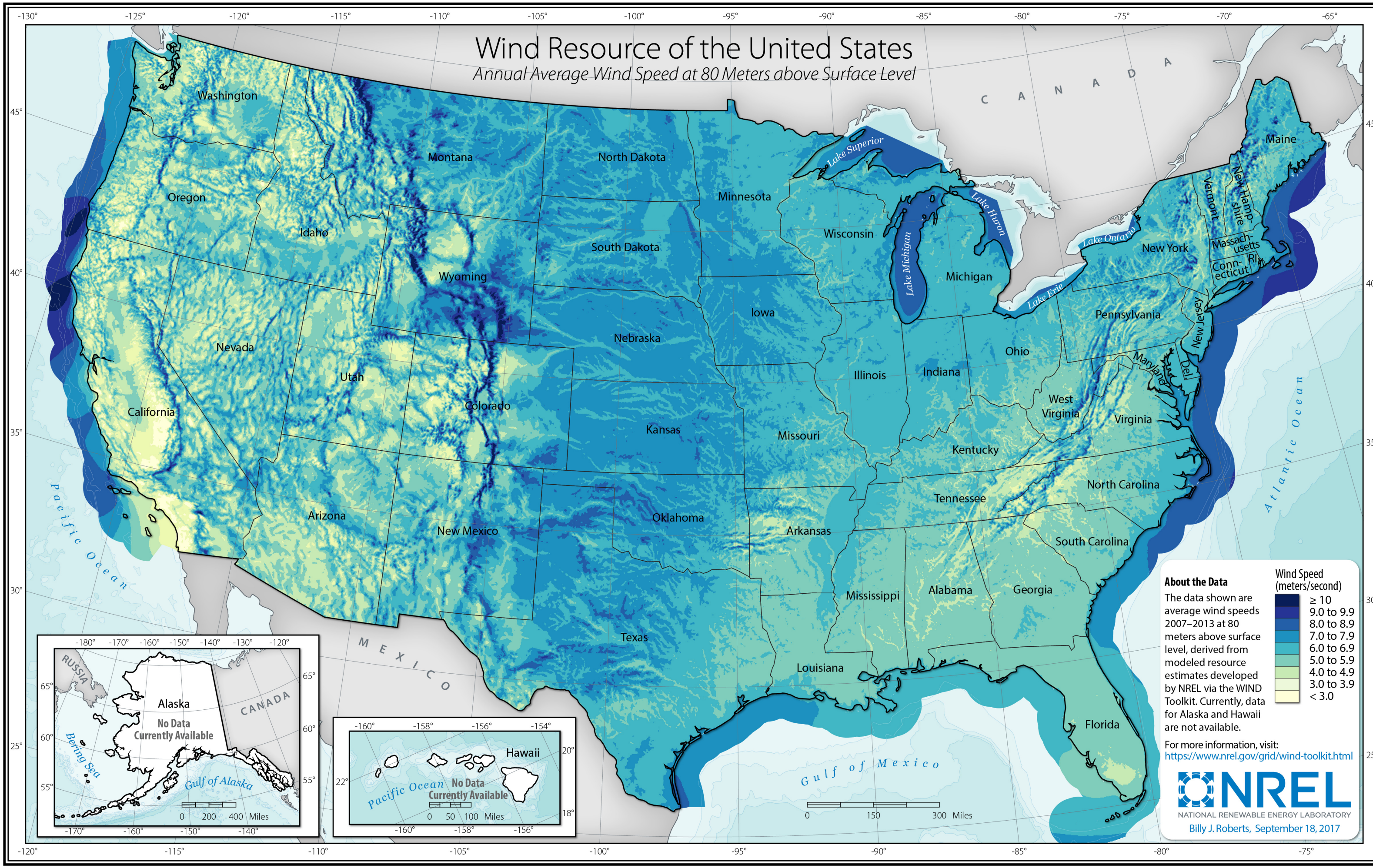
Geography is important

- Fossil fuels work about the same everywhere. Not all places have the same amount of wind

Issues:

- Wind is good in sparsely populated areas of the US
    - Long-term consideration for growth of wind capacity
    - Long-range, high-voltage DC power lines are expensive and hard to build
- Seasonal variation in wind

Wind in the US



Wind power- advantages

Marginal cost is close to zero

- Mostly just maintenance costs

Emissions are essentially zero

- Vast majority of emissions come from fossil fuel use
- No emissions from the use of windmills, only a little from production

Up-front investment costs are consistently falling

- Already the cheapest option in some places like west Texas

Resilient resource

- No supply chain to worry about
- Individual windmills aren’t too big to shut down

Generates power at night

- Advantage over solar

Wind power- disadvantages

Intermittent generation

- We are good at predicting short term wind output (even better at it when lots of windmills are spaced out)

- However, random ups and downs require support from quick-response, dispatchable resources (usually NG, oil, or energy storage)

Non-dispatchable resource

- We cannot increase generation, but we can sort of decrease it (curtailments)
- Often requires excess wind capacity

Negative externalities, such as wildlife damage

- Windmills kill 140,000 – 328,000 birds each year

- How do we value birds?

Negative externality of windmills

Windmills can clutter the horizon, lowering the aesthetic value of nearby land

- Commonly cited negative externality
- Example of a NIMBY argument

How important is this consideration?

Recall the problem of non-constant externalities

- Is this a diminishing externality?

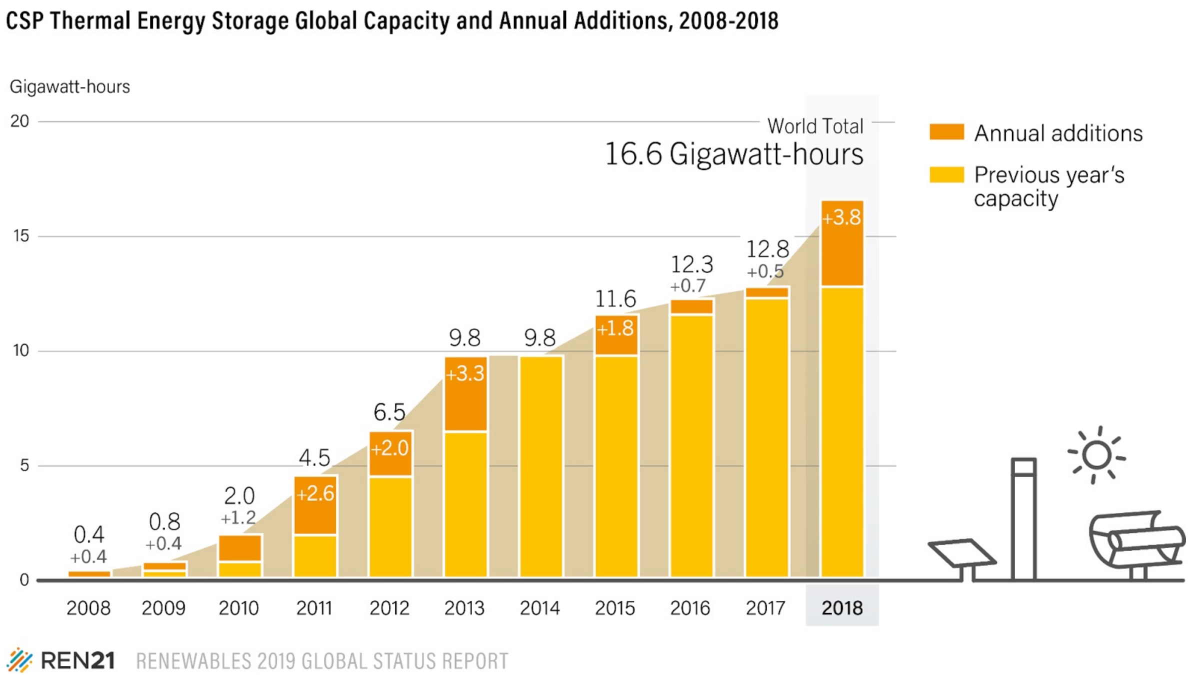
Reading for next time

- Interview with NREL Researcher: Solar power's greatest challenge was discovered 10 years ago. It looks like a duck. (online version).

Lecture 18

- Solar

Solar power overview



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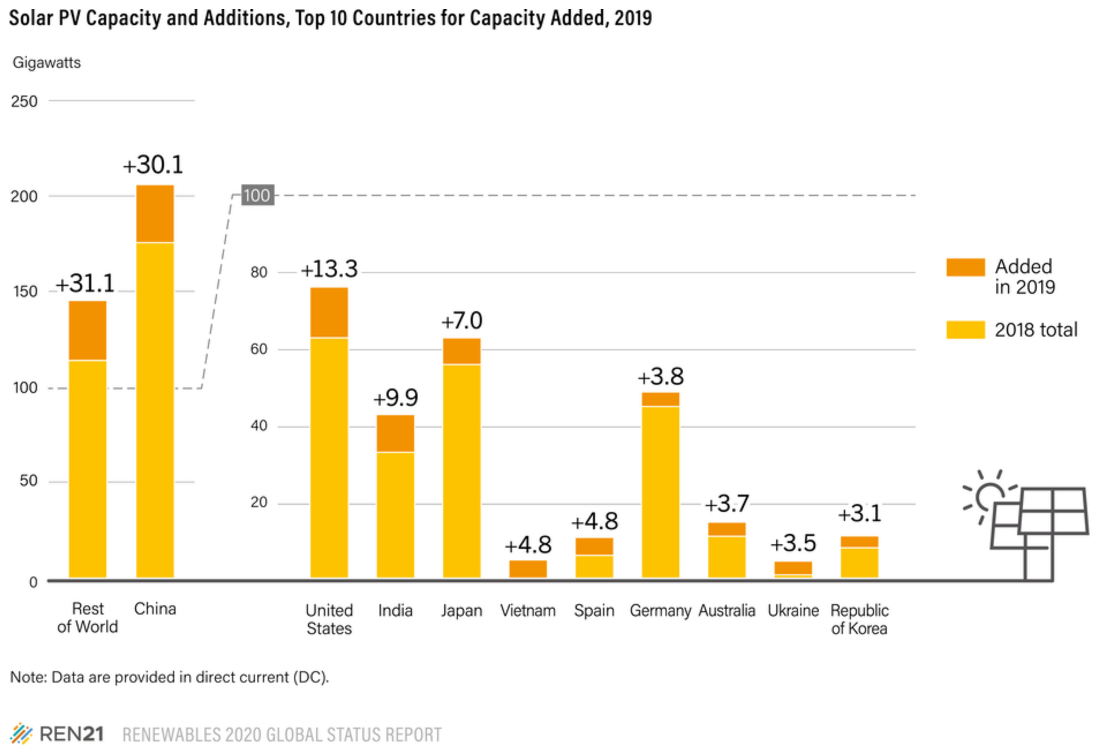
Solar power overview



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Technologies

Photovoltaic cells (Solar PV)

- Light $\rightarrow$ electricity

Solar thermal energy

- Light $\rightarrow$ heat

Price of solar

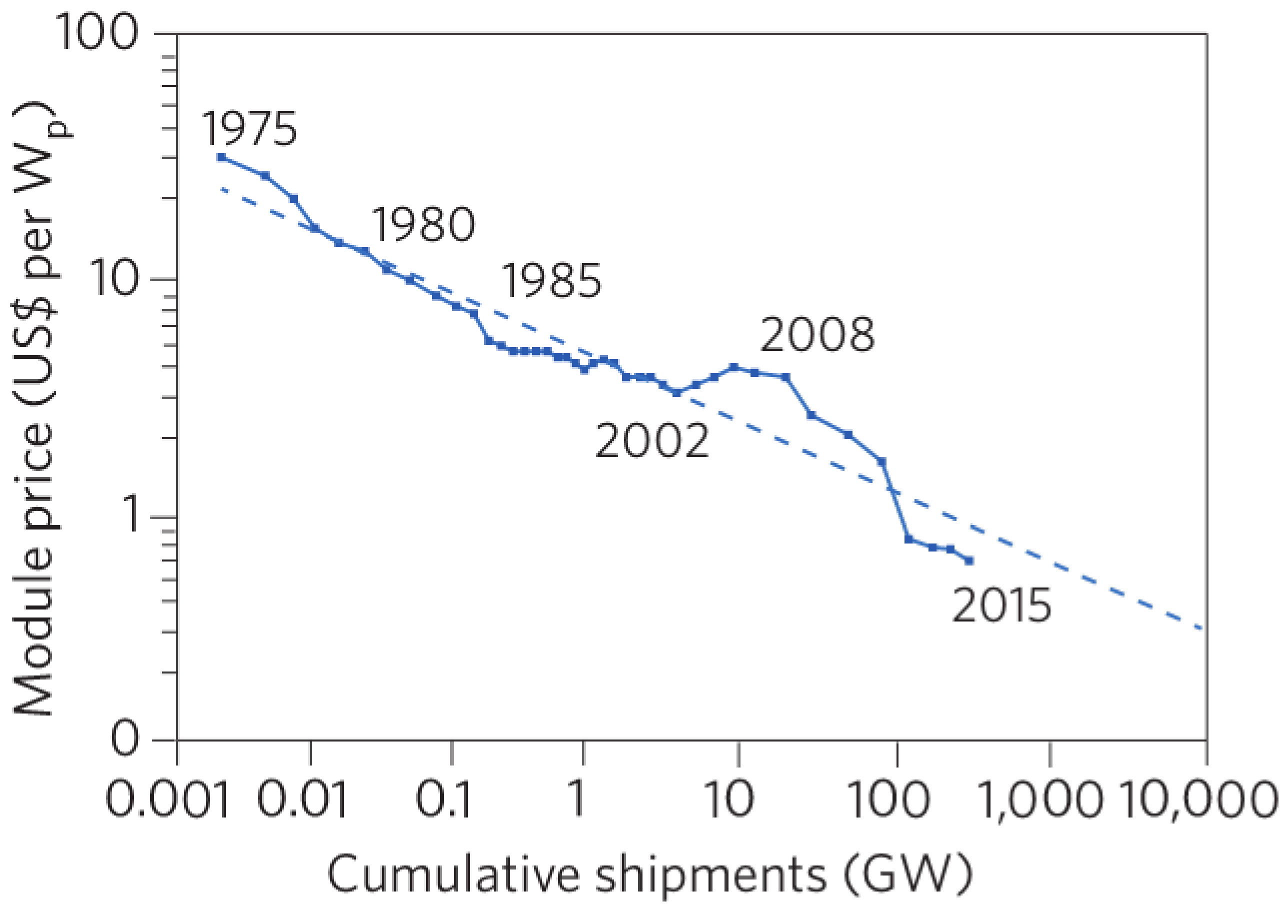


Figure 2 | Historical learning curve for PV modules.

Solar - Advantages

Most advantages are the same as wind's

- Marginal cost is close to zero
- Emissions are essentially zero
- Up-front investment costs are consistently falling
- Resilient resource

Solar power partially overlaps with peak demand

- Peak demand is usually 5pm-8pm
- Better in summer than in winter; longer sunlight hours and more need for AC during the sunny hours

Potential for expansion is maybe even better than wind

- More location options- both geographically and specific fixtures
- More power generated per unit of land area

Solar - Disadvantages

Again, most disadvantages are the same as wind's

- Intermittent generation
- Non-dispatchable resource

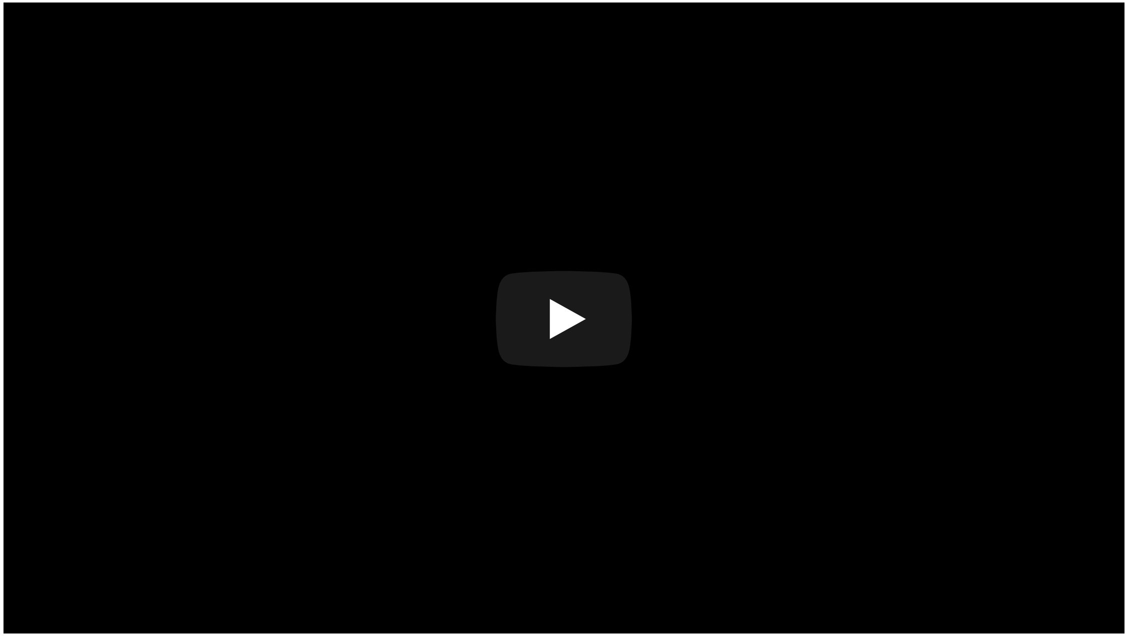
Daily cycle makes solar less useful

- No solar power at night
- Geographic spacing of solar panels does not fix this problem

Seasonal cycle makes redundancy unavoidable

- Must have extra winter capacity that goes unused in summer

The Duck Cuve



The Duck Curve

Energy grids with large amounts of solar tend to face a unique problem:

- The lines on the below graph show the amount of electricity needed from sources other than solar

When solar power declines in the late afternoon, other sources need to ramp up quickly to meet the early-evening demand peak

- Natural gas is extra valuable

Household (distributed) solar

Some electricity markets are very favorable towards rooftop solar

- Benefits home owners who are able to invest in energy cost savings, i.e. is a regressive subsidy
- Merit is hard to compare directly with utility-scale solar farms

Net metering

- Households can sell energy back to the grid when production > demand
- Becomes less useful as solar generation increases - duck curve again

In-home battery storage

- Store your excess solar power for later, go "off the grid"
- Tesla Powerwall- $6,200 for 14kwh. Average home uses 30kwh per day

Solar policies

Federal: Solar Investment Tax Credit (2005)

- Can claim 30% of your solar power investment as a tax credit
- Gradually lowers the benefit over time

Feed-in Tariffs (FIT)

- Sets guaranteed prices for the electricity generated
- Lowers risk and uncertainty for solar investors
- Challenging to balance investor confidence with overall program costs

NOTE: Tariff in this context means "negotiated price," not "import tax"

Reading for next time

- Energy Storage
- Demand Response

Lecture 19

- Energy storage
- Demand response

Energy storage

Currently, the main value of energy storage is in ancillary services

Ancillary services: Things that generators do to help the grid work better

Examples

- Frequency regulation - very short term balance of supply/demand
- Upgrade deferrals - delay the need to upgrade distribution infrastructure

Hopefully, batteries will become cheap enough to play a bigger role

- Flattening out the "duck curve"
- Pair with renewables to reduce intermittency problems
- Replace the highest-cost peaking generation

Energy storage technologies

Pumped hydro storage

- Two-way water movement. About 97% of existing storage in US is pumped hydro

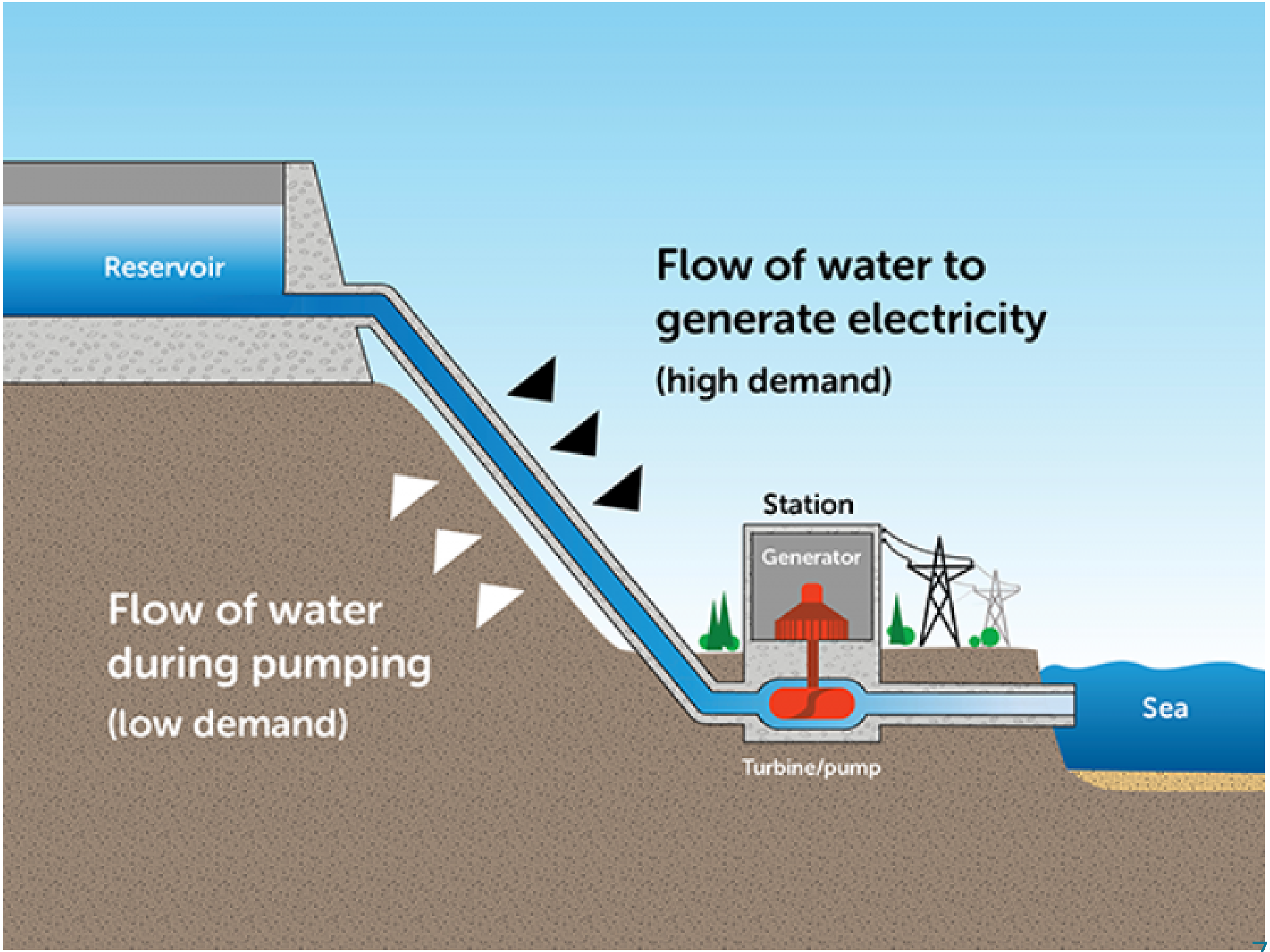
Low demand/excess generation: uses power to pump from low to high

High demand/need for generation: Water flows back down, generates power

Round-trip energy efficiency of 70-80%

- Problem- this requires a specific geological structure to work at scale

Pumpbed Hydro Storage



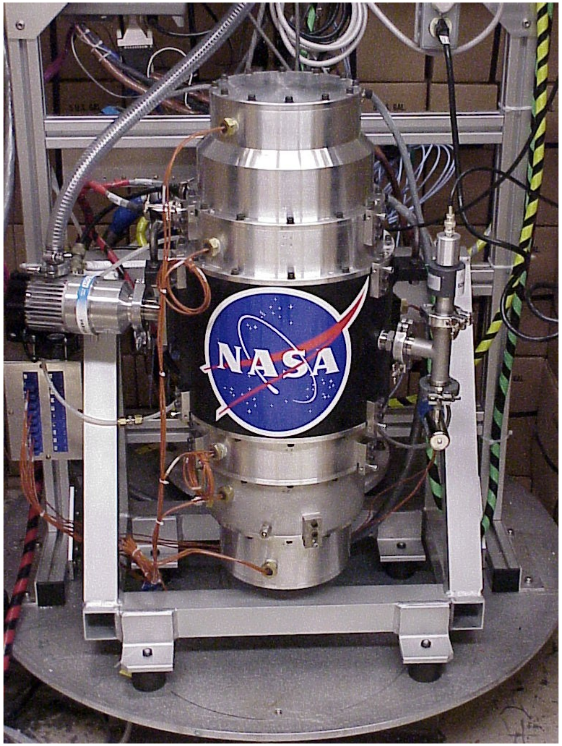
Energy storage technologies

Batteries

- Lithium-ion, vanadium redox, flow batteries
- Currently expensive for large capacity installations, but prices are falling

Flywheels

- Kinetic energy storage
- Very quick response, mostly used for ancillary grid services

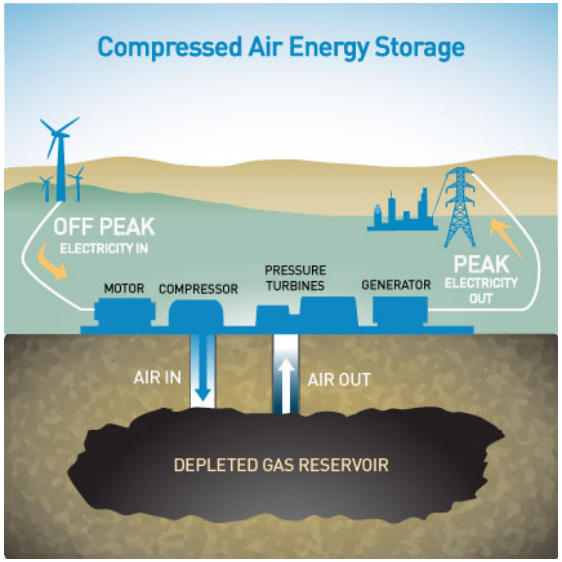


Energy storage technologies

Compressed Air Storage

Most similar to pumped hydro

- Some large projects use underground caverns
- Smaller ones use tanks



Ice Energy

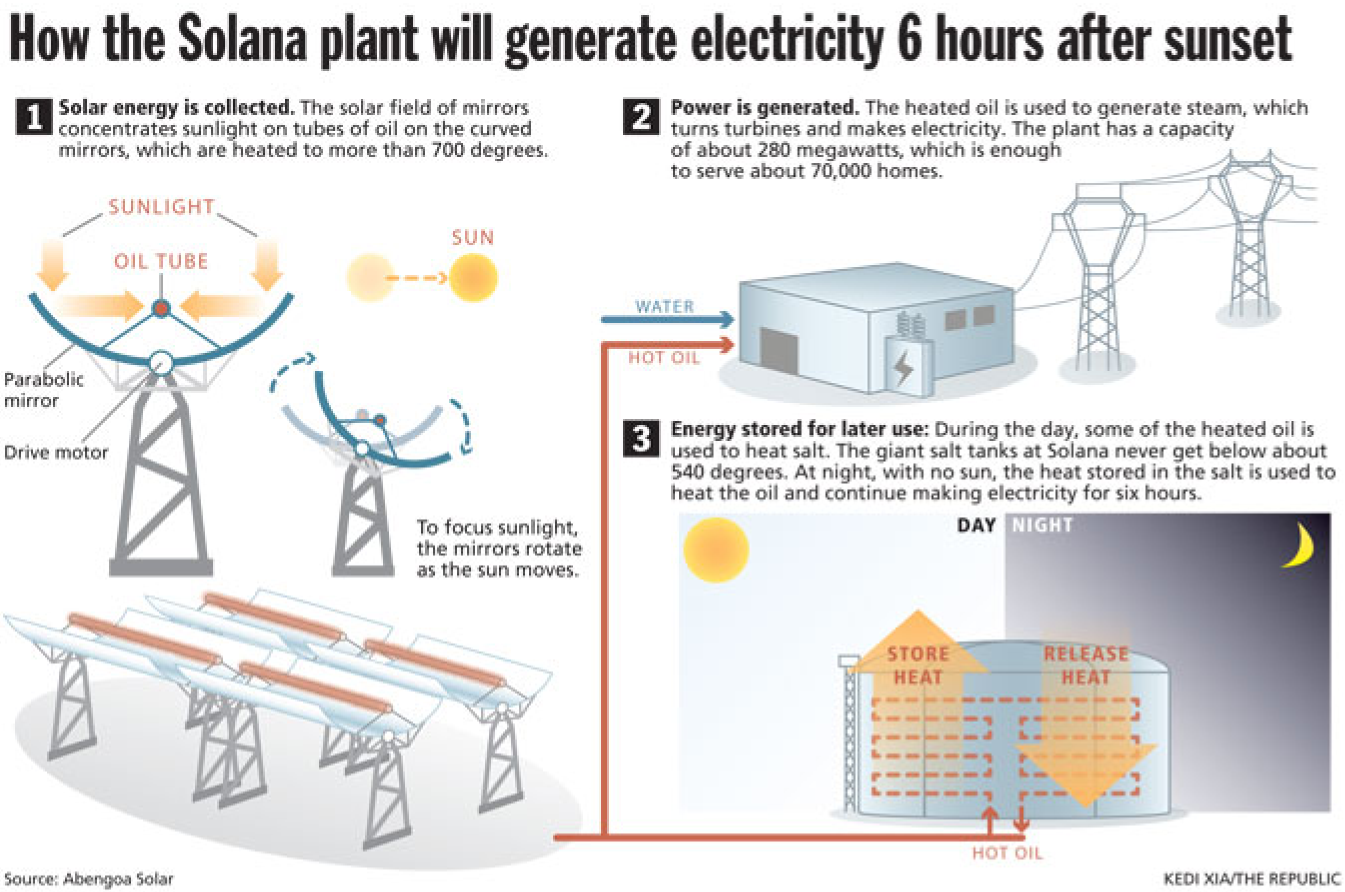
- Company sells "Ice Bear" cooling units that makes ice during off-peak hours, uses it to cool buildings during the peak hours
- Neat example of a technology that makes use of energy price arbitrage

Energy storage technologies

Thermal storage

- Several options
- Solana generating station (pictured) uses concentrated sunlight to heat piles of salt

Thermal Storage



Role of energy storage

Primary long-challenge in this industry is getting renewables to fit

- Cheap energy storage would fix a lot of these issues

Places like RMI argue that "social" benefit of energy storage significantly exceeds "private" benefit

- Challenge is getting regulators to keep up with this stuff

Need a sophisticated market-based policy for this positive externality

- More sophisticated than "$40/ton CO2 tax", even beyond prices and quantities
- Example: performance-based contracts

Two main ways to help renewables fit on the grid

- Make supply more flexible (storage)
- Made demand more flexible (demand response)

Demand response

Random demand fluctuations and the daily demand cycle impose real costs on the system

- Supply must chase demand, and peak-use resources are expensive

In some markets, the grid operator will negotiate with big electricity users (manufacturing, etc.)

- For instance, if you are able to reduce your energy consumption by 50% at a moment's notice, you could get paid to do that
- PJM paid out over $5 million in one month for DR services
- Cost savings are actually greater than $5 million

Lots of cost saving potential just by moving demand around (and facilitate renewables)

Pricing

Recall, for residential consumers, electricity demand is very inelastic (small response to price changes)

Traditionally, utility companies charged uniform rates based on monthly averages

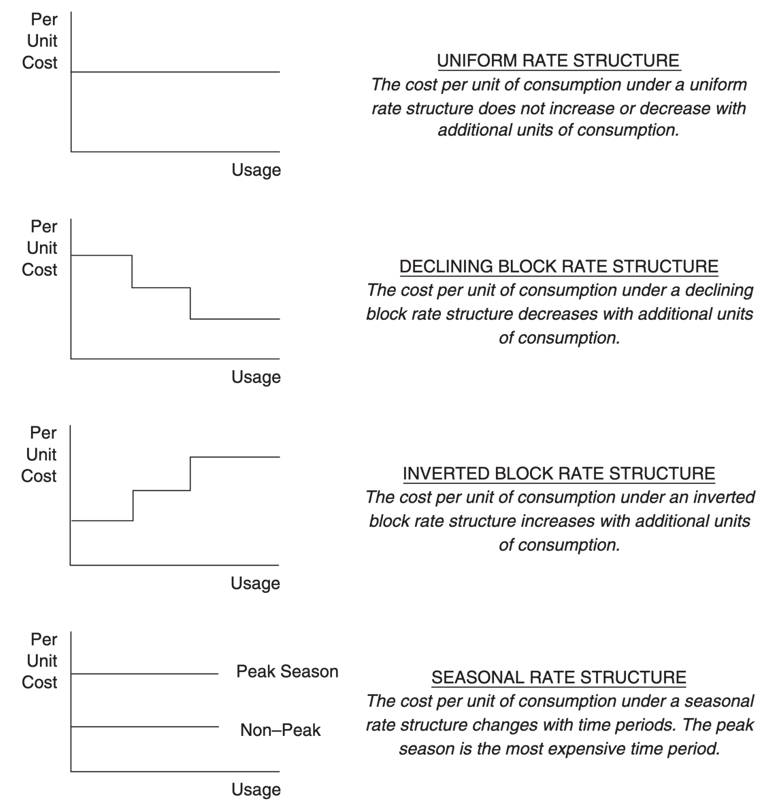
- Using another MWh of electricity costs the same for peak as non-peak

Inverted-block and seasonal rate structures somewhat improve demand response

- Steeper supply curve

Best option is probably time-of-use pricing

FIGURE 9.4 Overview of the Various Variable Charge Rate Structures



Source: Four examples of consumption charge models from WATER RATE STRUCTURES IN COLORADO: HOW COLORADO CITIES COMPARE IN USING THIS IMPORTANT WATER USE EFFICIENCY TOOL, September 2004, p. 8 by Colorado Environmental Coalition, Western Colorado Congress, and Western Resource Advocates. Copyright © 2004 by Western Resource Advocates. Reprinted with permission.

Video for next time

- The Future of Energy Storage Beyond Lithium Ion

Lecture 20

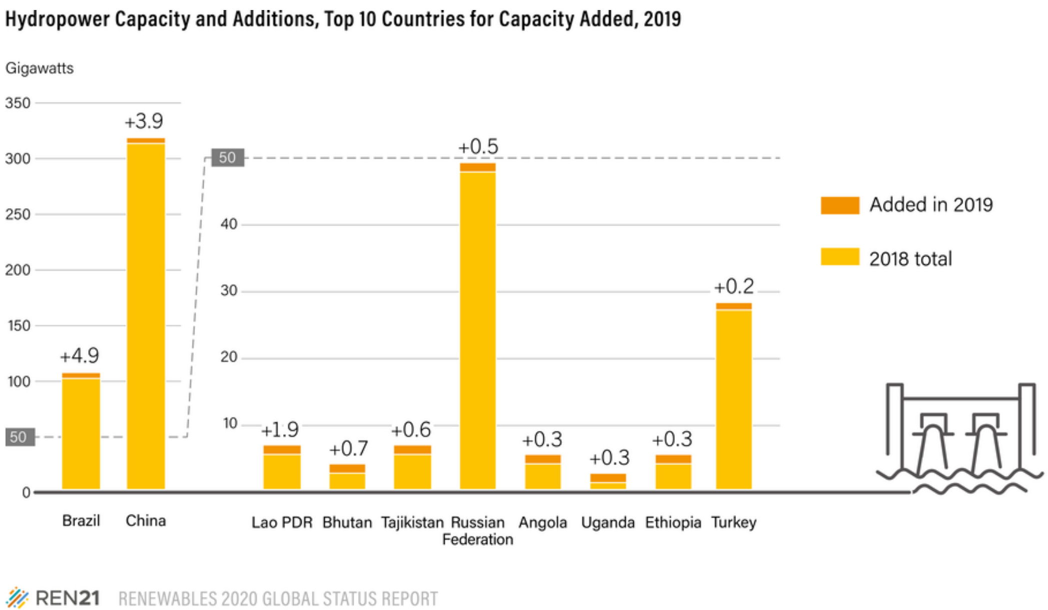
- Hydroelectric
- Biofuels

Hydroelectric power overview

Relatively mature technology

- Provides 6% of electricity in the US (other renewables add to 7%)
- Some US states heavily depend on hydro power, some have almost none
    - Washington uses hydro for more than 75%; net exporter of electricity

Hydropower overview



ren21 Report

Hydroelectric power benefits

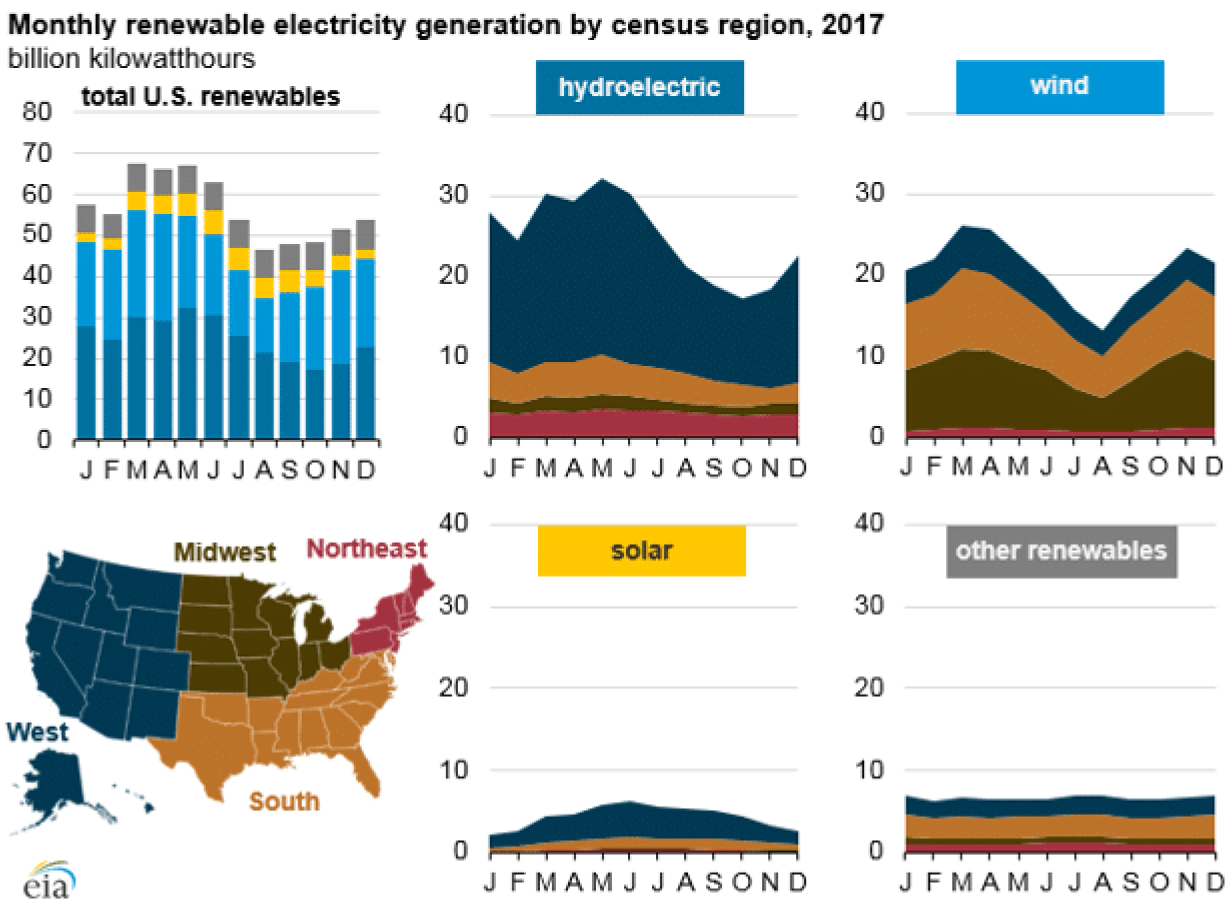
Renewable source of electricity, low marginal cost of generation

Price competitive without subsidies

Useful for baseload generation, more consistent than wind/solar in the short run

- However, seasonal variation is a concern

Seasonal Variation

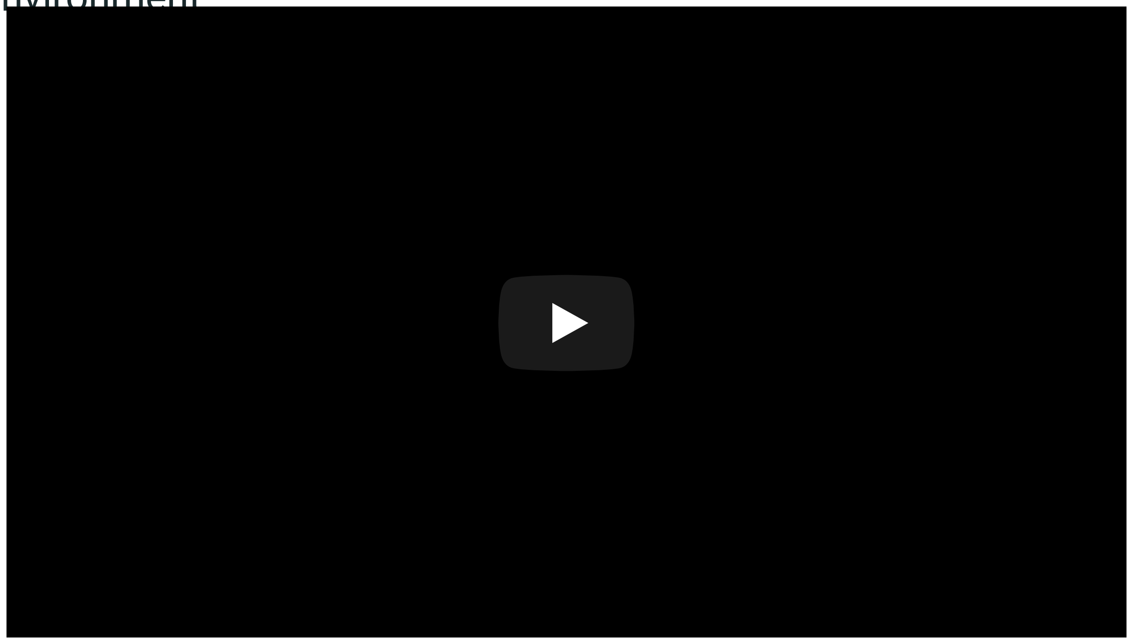


Hydroelectric power drawbacks

Ecosystem effects

- Salmon populations
- Sedimentation moves downstream
- Pollution
- Tradeoff between hydro and irrigation- water scarcity

Dams and the Environment



Hydroelectric power drawbacks

Low potential for expansion

- High investment costs, construction times
- Significant geographic limitations- the best spots are already taken
- Similar problems to nuclear’s

Biofuels

First generation biofuels

- Direct from food crops, primarily used for automobiles
- Ethanol produced from corn or sugar cane
- Biodiesel produced from oils and fats

Second generation biofuels

- Feed stock is not food-based, potential for use in electricity generation
- Switchgrass is directly burned as biomass
- Other types have a more complicated fuel extraction process
- Also includes municipal solid waste and waste vegetable oil

Biofuel policy in the US

Income tax credit (subsidy) of about $1 per gallon

- Also a protective tariff on imported biofuels from Brazil

2005 Energy Policy Act

- Established the renewable fuel standard (RFS)
- Requires transportation fuels to become increasingly based on renewable sources
- Goal of 36 billion gallons by 2022
- Includes a maximum for ethanol and a minimum for 2nd generation biofuels

2008 Farm Bill

- Subsidizes farmers who grow crops for biofuels

Ethanol

- 1 mile worth of ethanol is cleaner than one mile worth of gasoline
- However, land use change is a potentially big issue
- Clearing wilderness for agricultural land changes total GHG emissions

Biofuel policy in the US

About 1/3 of corn grown in the US is used for ethanol

Big events and policies can cause "general equilibrium effects"

- Economy re-organizes itself, capital and labor follow the profit

Subsidizing ethanol (directly or indirectly through RFS) affects several markets

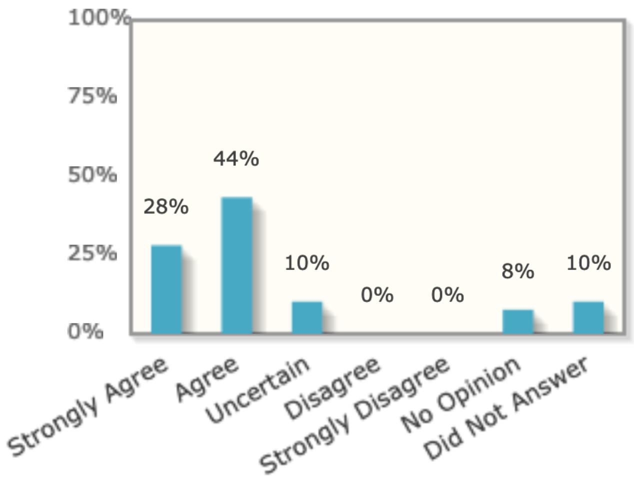
- Higher corn production and prices
- Higher farm income for most other crops
- Higher commodity and food prices
- Higher cost of feeding livestock (although post-ethanol grains can be recycled as feed)

The experts say...

Question A:

Ethanol content requirements and protectionism against imported ethanol (which includes fuel from sugarcane) raise food prices without significantly reducing carbon-dioxide emissions.

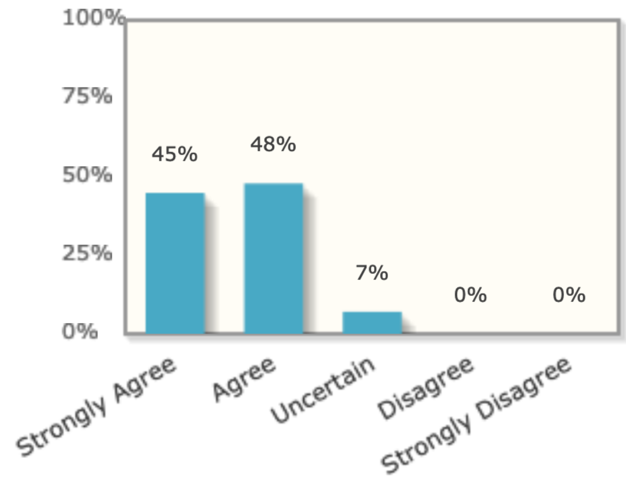
Responses



Source: IGM Economic Experts Panel

www.igmchicago.org/igm-economic-experts-panel

Responses weighted by each expert's confidence



Source: IGM Economic Experts Panel

www.igmchicago.org/igm-economic-experts-panel

Food vs fuel

Expansion of ethanol production causes two main agricultural changes

- Convert wild land to agricultural land
- Convert food crops to fuel crops

Corn and other ethanol crops are primary inputs in food markets

- Supply curve for food crops shifts to the left (decreases)
- Shift away from food crops causes food prices to rise

Ethical issues, US and international

- Rise of ethanol caused about 70% of the increase in world food prices according to World Bank, 2008

Reading for next time

- "CAFE Standards" and "Alternative Fuels and Vehicles", pages 449-453

Lecture 21

- Transportation

Transportation industry

10% of US GDP

- Plays a big role in facilitating the other parts of the economy
- Essentially #1 in vehicles per capita

25-30% of GHG emissions in the US

Several important social costs of driving

- Construction and maintenance
- Pollution
- Health cost of accidents
- Time spent in traffic

CAFE standards

Corporate Average Fuel Economy standards

- Started in 1978 and standards become stricter over time

Regulation on a manufacturer’s average fuel efficiency over the cars it sells

- Automakers can sell inefficient vehicles as long as they sell enough efficient ones
- Cars and trucks are separate categories

Big changes to the program in 2012

- Installed a cap-and-trade system for excess efficiency
- However, manufacturers can meet the new standards in some shady ways

CAFE outcomes

Imported oil fell from 47% to 27% of total oil consumption

Fuel efficiency has generally increased

- How much would it have changed without the policy?

Trucks, including SUVs, became much more popular (from ~20% to ~50% of the market)

- Lobbying prevented Congress from raising truck standards from 1985-2004

$590 million in fees paid for CAFE violations

- Almost entirely from European firms

CAFE vs gas tax

Both policies incentivize more fuel efficient cars

- More miles, fewer gallons

However, marginal cost of driving changes differently

- *Gas tax* - marginal cost of driving increases, so we do it less
- *CAFE* - once you own the fuel efficient car, driving becomes cheaper on the margin, so you will tend to drive more

Economists tend to favor a gas tax over CAFE standards

- Gas tax affects multiple externalities, not just gasoline use

If you want my hot take, ask me about Trucks in America

Efficiency and emissions

Holding mileage constant, more fuel efficient $\rightarrow$ use less fuel $\rightarrow$ lower emissions

Rebound effect

More efficient vehicles $\rightarrow$ driving is cheaper $\rightarrow$ drive more

The combination of these two effects determines the change in emissions rate

For drivers with a high price elasticity of demand for gasoline, a more efficient car increases gas consumption

- Somewhat lower gas cost $\rightarrow$ many more miles driven

Electric vehicle subsidies

Tax credits for EVs

- Federal: $2,500-$7,500 based on battery size and vehicle weight
- Colorado: up to $6,000 based on battery size and cost of the car

Subsidies improve battery and drivetrain technology development

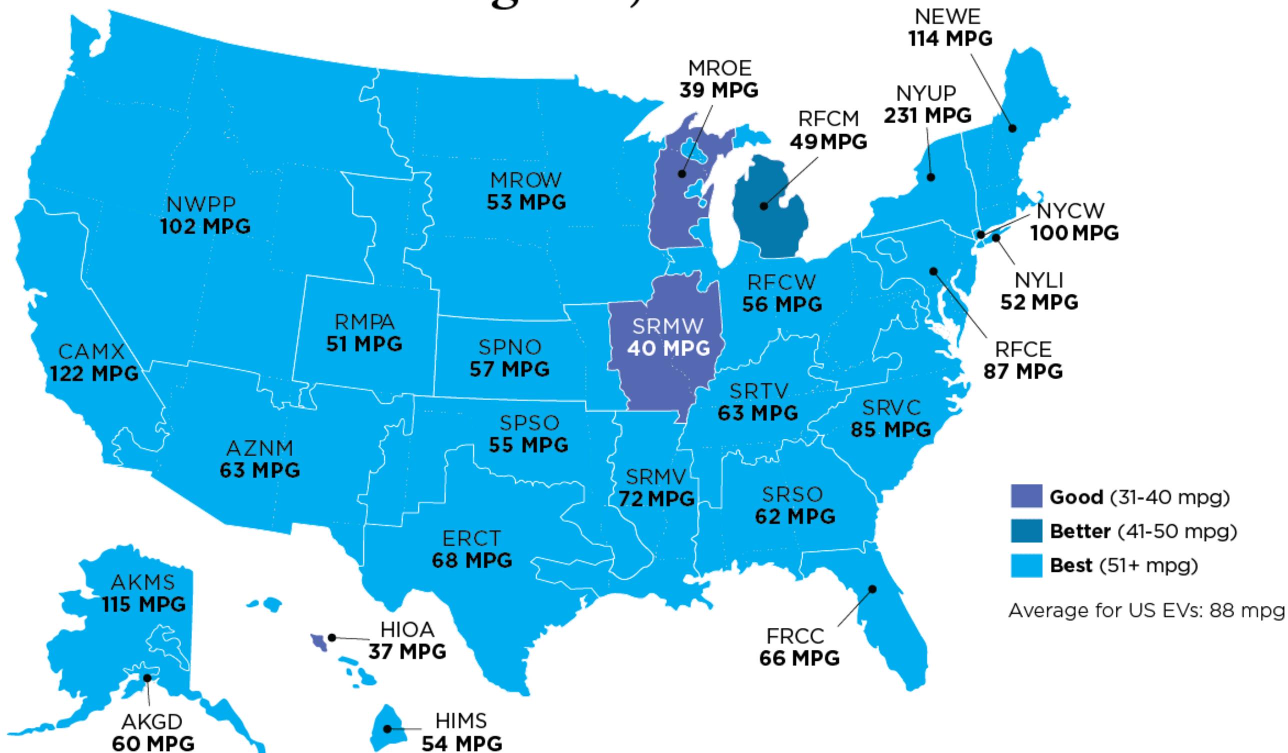
- Technology improvements carry on after the subsidy is over

However, EV subsidies are very regressive

- i.e. tend to benefit wealthier people (Tesla)
- This is a very common issue with environmental programs

EV Emissions as Gasoline MPG Equivalent

Average EV, 2018



Electric vehicles

EVs have only recently started to become more carbon efficient than hybrids and plug-in hybrids

However, local emissions tend to shift away from population centers

Really depends on how/when/where they are charged

- More charging stations are needed
- Especially in places where people park for hours during the day

Vehicle-to-grid services

- Real potential to use EVs for battery storage

Reading for next time

If Someone Replaced Your Car with a Prius, Would You Drive More? (online version).