Lecture # 22 – Alternative Energy Technologies

I. Where Does Our Energy Currently Come From?

- Most energy used in the US is consumed by industry and transportation
- Of the 100.3 quads consumed in 2022, 79.1 were fossil fuels. Just 13.11 quads were renewable.
    - Of the renewables, most were biomass. 29% of renewables were wind, and 14% of renewables were solar.
    - Power generation is dominated by coal, nuclear and natural gas. In 2021:
        - 37% natural gas
        - 26% coal
        - 21% nuclear
    - The role of natural gas has been increasing over the past few years, which has reduced carbon emissions.
        - Natural gas surpassed coal as primary source for electricity in 2016

- Worldwide, renewables make up about 14% of total primary energy supply.
    - Most of this is biofuels and renewable waste, which makes up 9.4% of total primary energy supply.
        - Biomass is particularly important in developing countries. Thus, they have higher shares of renewable energy.
            - Highest in Africa: 47.4%
    - Hydro is another 2.5%.
    - The remainder is geothermal, solar, wind, and oceans.

II Energy Transitions

- The climate change problem
    - Electricity generation is the main source of carbon emissions (25% of carbon emissions globally), followed by deforestation & land use (24%), industry (21%) and transportation (14%).
    - Significant reduction in emissions required to keep global temperature increases below 1.5^{o}C.

- Energy transitions have occurred throughout history.
    - Traditional biomass (wood, peat, and dung) was the main source of energy in the pre-industrial age
        - Wood became scarce in England during the 1500s and 1600s as the country grew
    - Use of coal emerged with steam engines. Coal surpassed biomass as the main source of energy in the early 1900s
        - Coal has three times the energy density of dry wood
    - Oil emerges next
        - Liquid fuel useful for transportation. It is very energy dense
    - Natural gas is cleaner, but requires special infrastructure
    - Electrification
        - Also emerged during the 20th century
        - Not a fuel, but a new way of delivering energy

- Previous energy transitions move towards fuels that are more energy dense and convenient to use. Moving to renewables adds new challenges
    - Solar energy is diffuse. It needs to be concentrated to provide energy
        - This is where technology comes in
        - Wind and solar energy sources concentrate power.
    - Renewable energy must be delivered to where it is needed.
        - Increased electrification is key to the renewable energy transition.

- The potential and problems of renewable energy sources
    - Wind
        - Global wind capacity has more than doubled since 2010
        - On-shore wind is now competitive in favorable locations.
        - Are there enough acceptable sites?
            - Good sites have sufficient wind or solar resources, are near where energy demanded (to avoid transmission losses) and are not ruled out politically.
            - Offshore sites take advantage of stronger, more consistent winds.
                - However, these are more expensive and require better technologies.
        - New transmission lines may be needed in some areas, because most productive sites aren't near population centers.
            - In 2022, the top ten states for wind production had 75% of generation, but only 32% of population
                - E.g. in New York, wind power mostly generated upstate
                - Congestion in transmission to New York City is an issue
            - Lines can over heat or shut down if too much power flows through them
            - Distance from center decreases intermittency, but increases transmission losses.
        - R&D needs include:
            - Continued cost reductions for offshore wind
                - Costs of installation are higher offshore
            - Understanding extreme wind conditions
            - Integrating wind turbines to the electric grid
            - Storage
        - Development of offshore wind turbines
            - Costs of installation are higher
            - But are becoming competitive in prime locations (e.g. U.K.)

- Solar
  - There are two types of solar
  - Solar photovoltaic
  - Concentrated solar (a/k/a solar thermal)
    - Concentrated solar uses mirrors to produce heat, which turns a turbine.
    - Can heat steam, allowing them to store power
    - Has fewer suitable sites
    - More expensive than solar PV
  - Solar has traditionally been the most expensive of currently used renewable sources, but PV costs have fallen
    - Primarily due to lower module costs
  - Solar thermal costs still high
  - Storage of solar energy remains a technical issue
  - As with wind, are there enough acceptable sites?
    - In 2022, the top ten states for solar production had 81% of generation, but only 42% of population
    - However, because high pressure areas have fewer clouds and less wind, solar is most abundant in places where wind energy is scarce.
    - Many of the best locations for concentrated solar are in developing countries.
  - What made solar R&D successful?
    - Policy support
      - Tech-push in US (e.g. R&D subsidies)
      - Demand pull (Germany and Japan)
    - PV technology is scalable
      - Could begin small and scale up
    - Could be applied to niche markets
      - Creates more demand
    - Experienced a series of incremental improvements
  - We then discussed whether the conditions that made solar R&D successful be applied to other clean technologies?

- Challenges to a renewable energy transition
    - Transportation
        - Electric motors are more efficient and simpler mechanically
        - But gasoline or diesel fuel contains 40X as much energy as current batteries
            - Usable for vehicles carrying light loads and that can charge often (e.g. passenger cars)
            - Not yet viable for long-haul trucking, aviation, or maritime shipping
        - Consumers may not see EV as perfect substitutes for gasoline-powered vehicles
            - Charging infrastructure needed
        - Prices of raw materials needed for batteries growing
    - Industry
        - Not all processes can be electrified
        - Achieving very high heat for industrial processes such as steel, cement, and glass production is difficult without burning fuel
    - Electricity
        - Increased electrification is key to the renewable energy transition.
        - But solar and wind are intermittent
        - To understand the potential of renewable energy for electricity generation, it is important to understand how the electric grid works

III. The Role of the Electricity Grid

- To understand the potential of renewable energy for electricity generation, it is important to understand how the electric grid works.
    - Electricity cannot be stored. What goes on the grid must match what comes off.
        - US has three main grids
        - New York is in the Eastern Interconnection
        - New York managed by the New York Independent System Operator (NYISO)
            - Calculates who can provide the power needed at lower cost
            - Have plants adjust every five minutes to keep the system balanced
            - Use weather forecasts to try to project production from wind and solar
    - Because of this, wholesale prices can vary by a factor of 10 or more within a given day.

- Distinguish between two types of generation sources:
  - Dispatchable: operator has temporal control over. Can decide when to shut off or turn on.
  - Intermittent: Production varies due to exogenous factors, such as amount of wind blowing.
    - Generation is out of control of the operator
    - However, these plants can be shut down easily, so there is an upper limit on generation
- Even when the owner has control, some plants can be switched on and off more quickly than others.
  - Ramping rates: how quickly plants can change the level of output.
  - There are also differences in often the plant must shut down for required maintenance.
  - Flexible sources with rapid ramping ability include:
    - Gas-fired peaker plants
      - Low fuel efficiency, but are flexible
      - Also have low start-up costs
    - Hydroelectric
  - System is designed to meet demand extremes. Some peaker plants may only run a few days a years.

- Generation costs
  - Costs are typically measured using levelized cost of electricity
    - Levelized cost is the constant price for power that would equate the net present value of revenue from the plant's output with the net present value of the cost of production.
      - Accounts for the fact that many of the initial costs are up-front capital costs, particularly for renewables.
    - Key assumptions that lead to different estimates:
      - Inflation rates
      - Real interest rates
      - How much the generator will be used
      - Productivity of the generator
        - E.g. how much will it be used and how much electricity will it produce
        - Future generation particularly relevant for renewables, as may depend on quality of the site
      - Future input costs (particularly fuel)
      - Future market prices

- Challenge: value of electricity will vary depending on how much and when generated
    - Consider fixed costs versus variable costs
        - A nuclear plant's levelized cost is lowest if run constantly (e.g. baseload power) to recoup fixed costs
        - Natural gas can be turned on and off to meet peak demand
    - Renewable energy changes this.
        - Because marginal cost of renewables is 0, it is offered to wholesale markets at very low costs
            - As a result, some utilities in Texas give consumers free electricity in the evening
        - If used during periods of peak demand, wholesale prices of electricity will be higher
            - Solar produced during day, which coincides with peak demand
    - Negative wholesale electricity prices
        - In some cases, producers find it cheaper to *pay* the grid to take their electricity than to shutdown
            - To avoid costs of ramping down and ramping up later
                - Nuclear can place low bids, because most costs are fixed costs
                - But because of these fixed costs, note that nuclear's levelized costs are larger
            - To receive subsidy from production tax credit for wind
        - Negative prices occurred 6% of the time in 2022
    - Competition from other sources has also hurt nuclear power
        - Nuclear can also place low bids, because most costs are fixed costs
            - However, because of these fixed costs, note that nuclear's levelized costs are larger
            - Competition from natural gas and wind is forcing nuclear plants to retire early
                - Some states, such as NY, are thus considering subsidizing nuclear power plants to compensate them for producing zero-carbon electricity
                    - Nuclear supporters argue that other carbon-free sources, such as wind and solar, benefit from subsidies

- Inadequate transmission infrastructure is a challenge for expanding renewable energy
    - Wind and solar must be located where resources are available
    - Electrification of other sectors will increase electricity demand, also requiring new transmission capacity
    - Problems caused by inadequate transmission
        - Curtailment: quantity of electricity provided to the grid is reduced to keep in balance has been increasing
            - Wind and solar can be immediately and temporarily reduced (e.g. by disconnecting solar from the grid) and reconnected when needed again
            - Curtailment of wind and solar has been growing as generation of each expands/
        - Negative wholesale electricity prices
            - Indicate a transmission issue because negative prices occur when other locations have positive prices
                - Thus, someone is willing to pay for the power generated, but we cannot get it to them.
    - Why is expanding transmission lines difficult?
        - Difficulty connecting new projects to the grid (new i**nterconnection** lines).
            - New connections must be reviewed and approved
                - Local grid operators must ensure the project won't cause disruptions, such as if the grid cannot handle the new power provided
                    - May require upgrades to approve a project
                - Takes four years on average
            - There is a large backlog for these projects.
                - PJM Interconnection announced a freeze on new applications until 2026 (covers territory from Illinois to NJ)
            - Fewer than 1/5 of wind and solar projects make it through the "interconnection queue"
                - Many developers submjit6 multiple proposals, knowing they won't be able to afford them all

- The US electricity grid is mostly decentralized
    - Historically, mostly disconnected individual utilities made independent decisions.
    - Fuel was delivered to power plants located near population centers
    - Regulated utility markets allow utilities to recover costs of constructing new capacity
        - But buying power from elsewhere is an operating cost that does not increase profits
- No central authority approves new transmission projects
    - New projects must be approved by a combination of federal, state, and local authorities
    - Who pays isn't clear
        - Additional transmission lines are a public good
        - But developers of projects typically asked to pay if new transmission lines required
        - Reducing congestion benefits a broader region
    - Moving power creates winners and losers
        - Moving renewable power from where it is generated lowers supply in those areas, thus raising prices
        - Owners of existing power plants in areas receiving more power will face additional competition
        - Regulated utilities do not benefit from potential cost savings

- *Policy question*: should households be rewarded for distributed generation
    - Distributed generation is producing electricity at the consumer site, such as with solar PV panels
    - Electricity generated reduces the consumer's bill, since they take less power off the grid
        - As a result, utilities have been lobbying to reduce solar incentives
    - Should they also be paid for any surplus power that they contribute to the grid (net metering)?
        - Pros:
            - Solar PV generates power at peak times, when it is more valuable
        - Concerns:
            - This doesn't reduce distribution costs
                - Some of the consumer's bill would have paid for these fixed costs
            - Consumers cannot control when the power goes on the grid
            - Richer homeowners are more likely to own solar panels. Higher subsidies mean that more of the costs of generation are paid by customers without solar panels, who tend to have lower incomes.
        - Over 40 states allow net metering
            - Since 2013, Hawaii, Nevada, Arizona, Maine, and Indiana have phased out net metering.
            - California reduced the subsidies they pay for solar in 2022.
    - How can policy address the costs of distribution?
        - Find new ways to value non-utility PV electric (NY)
        - Time of use rates that rise with demand (CA)
            - Encourages more investment in batteries
        - Fees for customers with solar panels on roofs (KS)