Electricity

Who turned out the lights? It's dark in here. Don't they pay their electricity? — Roger Rabbit

Ivo Welch

2023-02-23

Warning

- Quoted numbers in these slides are ca 2021.
- Current Ukraine war effects.
- Not completely clear what future will hold
  - except that renewables will become more and more competitive!

Why Electricity?

- Clean!
- High-quality
- Jack of all Trades:
  - Fossil fuels are one-trick ponies,
  - → perfect economics only for heat.
- Already know e-tech will improve greatly.
  - No moonshots necessary but welcome.
  - PS: Read up on primary vs. nameplate power.

Heterogeneous

Electrons are electrons, but

- Time and location matter
  - Noon vs 8pm
  - Nevada vs. New York
- Allocation problems are tremendous:
  - uncertainty (supply and demand);
  - short-term (which plants to switch on);
  - long-term (which plants to build where);
  - how to move e around (transmission).

World

- Even more heterogeneous than USA.
- Discuss US / California first:
  - Illustrative only, and
  - good to explain basic workings.

It is not enough to decarbonize US!

USA Generation

U.S.	NatGas	Coal	Wind
Power	45%	20%	10%
Energy	40%	20%	9%

U.S.	Nuclear	Hydro	Solar
Power	10%	10%	5%
Energy	20%	7%	2%

Utility-Scale High Fixed Costs

- Plants are built primarily when
  - demand grows, and/or
  - old plants age out.
- US demand is mostly stable:
  - US builds new plants mostly when (old coal and nuclear plants) age out.

New Plants: USA

- For many years now, only Wind and Solar;
  - will probably continue; explain below why.
- A few new NatGas plants on East Coast.
  - 32GW (out of 500GW) in dvlpmnt pipeline, though.
  - existing NatGas plants are beginning to install solar panels to save variable cost.
- Very rare nuclear plant here and there (Terapower).
- No new coal plants, few new dams, etc.
  - PS: Oil is always uneconomic, except in emergency generators (and New Hampshire?). Used in 3rd world.

New Plants: World, Other

- China, India, etc.:
  - Large new building programs.
  - Lots of new Wind and Solar plants.
  - Some nuclear plants, some others.
  - But **huge** coal plant building programs:
- *270 GW in China*
    - And new world record in 2021;
    - And coal employs millions of people!

Transmission Grid

- Transmission grid is expensive.
  - Think $1-$50/MWh.
- Distance matters!
- → Supply is cheaper close to demand.
- Low current transmission cost only because of generation proximity.

USA Transmission Mess

- Complex regulation, tying in, etc.:
  - Regulators “captured” by > 3,000 utility companies,
  - with some good reason,
  - and a lot of lobbyists and lawyers,
  - and big hurdles for competitive clean engineering innovators inexperienced in politics.
  - and NIMBY

Electricity Allocation Problems

- Complex problems abound.
- Only known good allocation system:

Competitive but Managed Electricity Markets!

Electricity Allocation Problems

- But free market must be shepherded!
  - alternative *free-for-all* cannot work either;
  - needs regulation, but is still somewhat manipulatable and indeed manipulated.
- Compromises between scylla and charybdis.

California

- Details are fascinating stuff.
  - They are important, but vary by place
- In California (not elsewhere):
  - Capacity auctions for new plants (3 years);
  - Power auctions for delivery (daily).

California: Mar 21, 2021

Today's Outlook | Demand | Supply | Emissions | Prices

AS OF 10:35 03/21/2021

Current and forecasted demand AS OF 10:35

About demand

Capacity status

32,772 MW
Available capacity*

17,804 MW
Current demand

23,975 MW
Forecasted peak

*Available capacity varies due to outages, congestion and emergencies. View all outage reports.

32,772 MW
Available capacity*

17,804 MW
Current demand

23,975 MW
Forecasted peak

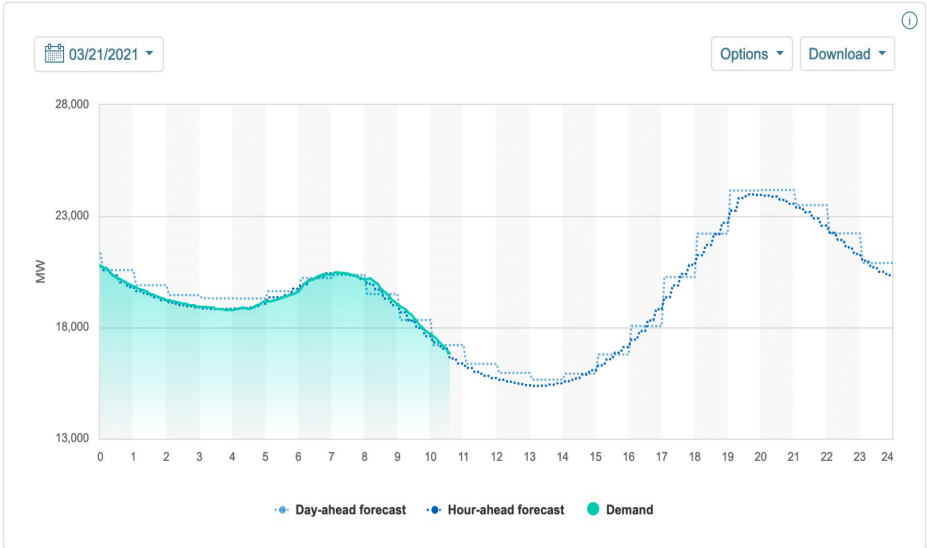
50,270 MW
Historical peak
(Jul 24, 2006)

20,836 MW
Today's peak
(00:00)

26,007 MW
Tomorrow's forecasted peak

California: Mar 21, 2021

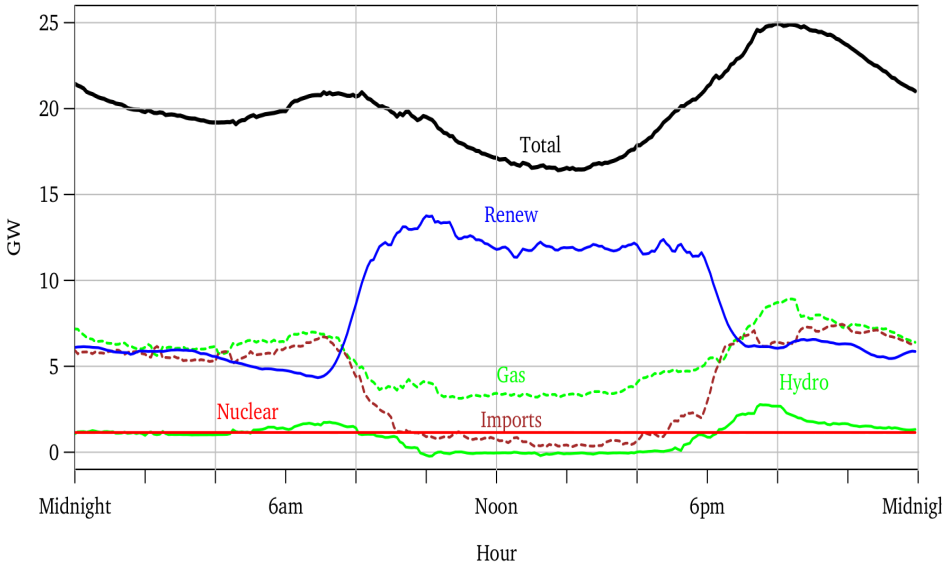
System demand, in megawatts, compared to the forecasted demand in 5-minute increments.



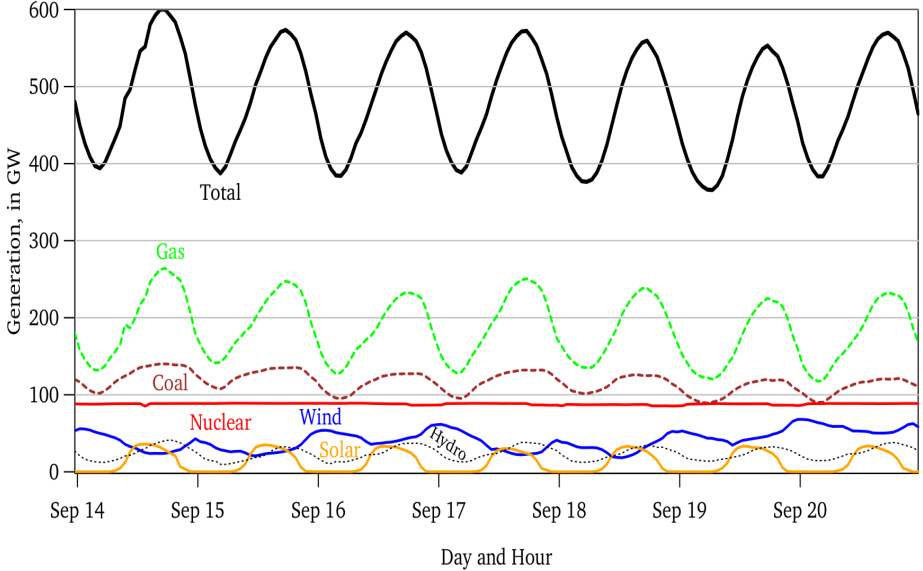
Today

https://www.caiso.com/todaysoutlook/Pages/index.html

California Power Mix, Mar 21, 2021



USA Power Mix



Today

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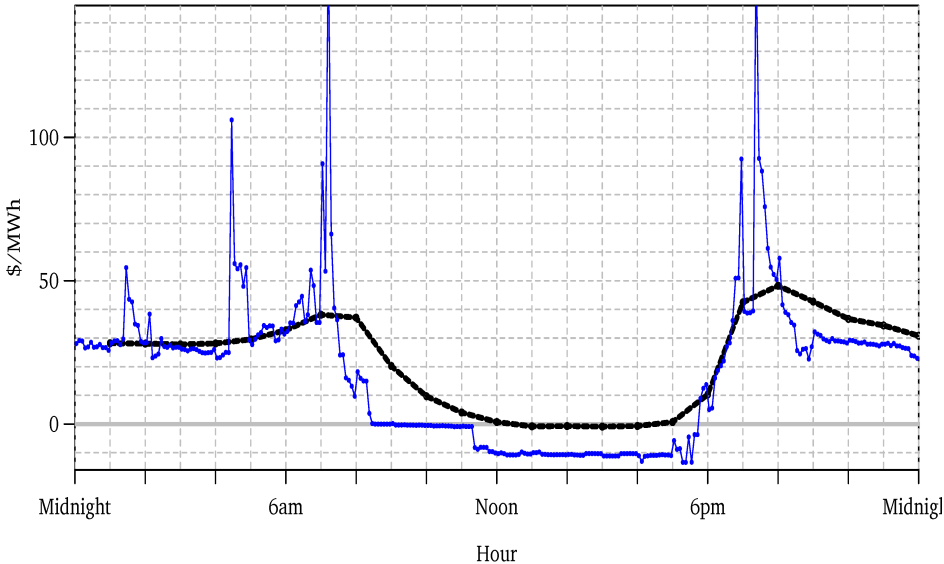
Add Pricing Info in 2021



Today (2023, Much Higher!)

https://www.caiso.com/todaysoutlook/Pages/prices.html

Inexact Classification

1. Baseload Power.
   - Think Nuclear.
2. Intermittent Power.
   - Think Wind and Solar.
3. Storage (Dispatchable Power).
   - Think Batteries and Hydroelectric Dams.

Power Mix Comparison

	Nuke	GeoT	Coal	Gas
Calif	9%	5%	3%	34%
USA	20%	1%	19%	40%
World	10%	0%	37%	24%

	Hydro	Wind	Solar	Other
Calif	18%	10%	12%	9%
USA	7%	9%	2%	2%
World	16%	5%	3%	5%

Generation Costs: Building Plants

1. Electricity's biggest cost is typically upfront plant building cost:
   - Construction / capital.
   - Plant scalability varies:
     - biggest scale needed for nuclear,
     - most flexible scale for Wind and Solar.
   - Cost of grid tie-in is high, too,
     - incl. regulatory costs,
     - ... and does not scale linearly.

Generation Costs: Running

2. Idle (Standby) Minimum Running Cost:
   - capital interest costs;
   - personnel and maintenance;
   - obsolescence.
3. Active Generation Cost:
   - Fuel and Extra Wear:
     - Highest for Fossil fuels;
     - Medium for Nuclear;
     - Lowest for Wind and Solar.

Levelized Cost Of Electricity (LCOE)

- Tries to take all costs into account.
- Projected over lifetime of plant:
  - disagreement over lifetime → different LCOEs.
  - If you got it wrong, ...
  - ... you may lose a lot of money.

Following are ballpark inflation-adjusted figures, differ by location, regulation, etc.

Ballpark LCOEs Per MWh

Type	Today	est 2050
Solar Panels, Roof	$100	$30
Solar Panels, Utility	$35	$15
Wind, onshore	$35	$20
—	—	—
Geothermal	$35	
Nuclear	$70	$60
Gas, Always On	$40	$45
Coal	$75	$65
—	—	—
Hydro	$55	

Really? Wowee!

- Wind and Solar are the cheapest large-scale sources of energy that civilization has *ever* seen!
  - … and they will become even cheaper!
  - Unbelievably cheap, too cheap to meter!
    ≈ computers
  - … but they do not always work. □

Solved Problem!

- "Clean intermittent generation for cheap" is *a basically a* solved science problem:
  - $15/MWh or $5/MWh is relatively unimportant.
  - The silicon solar cell component will soon be negligible part of solar plant cost.
  - Costs will be primarily connections / running / maintenance.
  - Often best to colocate Solar, Wind, Batteries to share connection and operation costs.

Natural Gas

- NatGas is cheapest **on-demand** source of power **in the USA**:
  - Turn off, turn on.
  - Nearly infinite capacity,
  - but not as abundant everywhere else.
- $40-$200/MWh — cheap, tough to beat.
  - on demand: $80-
  - Maybe should add $20/MWh for pollution.
    - NatGas often leaks on pipes and at EOL.
    - Makes NatGas look cleaner than it is.

Geothermal And Hydro (Storage)

- Think $100-$250/MWh
- Requires large scale:
  - Environmental opposition to hydro.
  - PS: small-scale geothermal works well for home heating cooling and is economical!
- Cheap running cost.
  - No fuel required.
- Very limited supply of good locations

PS: Also consider compressed air in caverns.

Nuclear Power (Again)

- Primary nuclear problem today:
  - Fixed cost ($20 billion/plant).
  - 10 years: potentially obsolete before open.
- Honest Disagreements:
  - Put your money where your mouth is?
  - Gates, France, China are bullish.
  - UnionCScientists, Germany are bearish.

Coal: USA

- Hated and obsolete.
- But kept alive by:
  - Abundant availability and e-needs *now*.
  - Fossil fuel subsidies and lobbies.
  - Large employment bases, pivotal voters.
  - Still, fortunately, plants are aging out now,
    - Unfortunately, just like clean nuclear plants.
- USA, 250 plants + 0 uc (construction)

Coal: Think Global

- Coal is still hated and obsolete.
- But growing countries need power *now*.
- Coal consumption and coal plants set new records in 2021!
  - Long-term, coal faces likely stagnation, not immediate obsolescence.

Coal: Think Global

- The World's Real Problem:
  - China, 1000 + 200uc .
  - India, 250 + 50uc .
  - World, 2,000 + 500uc .
- Once built, sunk-cost equation changes:
  - 30-50-year lasting impact!!
  - Any good ideas? Now is the time!

Dispatchable (Storage)

- If demand is reasonably constant, choose
  - either basepower;
  - or intermittent + storage;
  - basepower + storage is not so great.

Simplified

- Power connection infrastructure is expensive,
- *more so* for intermittent power.
- Optimal solutions are often messy mixes.
- One size “no fit all.”

Clean Energy

In sum:

Problem is No Longer Cheap Generation!

Problem Now is Cheap Energy Storage!

Solve it, and wind/solar will take over.

Lithium Batteries

- Think $200/MWh.
- Li comes in small manufactured cells.
- Cells are finicky and small.
- Not easily scalable:
  - Expensive packaging into small cells.
  - Twice the capacity is approx twice the cost.
  - Lots of mundane improvements, but
  - will likely always be finicky small-scale.

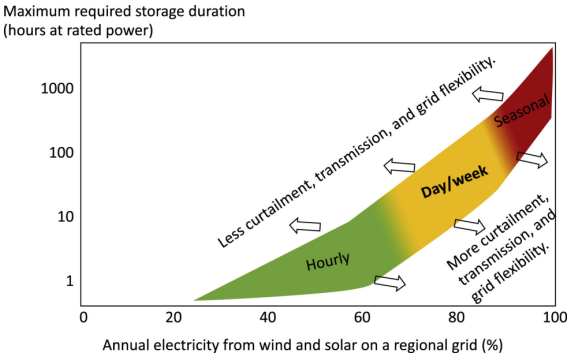
Current Big Lithium Problem

- Problem: Wear out after 1,000 cycles.
  - Anode and cathode expand and contract.
  - But very soon 3,000 - 5,000 cycles!
  - → Much cheaper for long-run use.
  - → *Very big* deal for utility-scale storage.
    - Could bring price down to $100/MWh?
  - → Use your EV car for storage?
  - PS: No scientific reason why not 50,000 cycles, either.

Utility-Scale Lithium In USA

- 2 GW power out of 450 GW total.
- 10 GWh energy out of 4,000,000 GWh.
- Problem is capacity, not power.
- Batteries rapidly expanding, but still tiny:
  - Many specialty uses (e.g. 6-10pm).
  - Still too expensive for overnight,
  - ...much less for multi-day storage.

Net Zero?


Maximum required storage duration
(hours at rated power)
1000
100
10
1
0
20
40
60
80
100
Annual electricity from wind and solar on a regional grid (%)
Less curtailment, transmission, and grid flexibility.
Seasonal
Day/week
Hourly
More curtailment, transmission, and grid flexibility.

Flow And Other Batteries

World Need:

- Giant house-sized tubs with person-sized electrodes that scale according to whim,
- with quad storage → only double cost,
- with cheap chemistries, $50/MWh,
- ***and then it will be lights-out for most power plants other than wind and solar in 20-30 years!***
- at $150/MWh, we could make it to 95%!

Rust Batteries?

Utility-Scale ***Flow*** Batteries

- Possible, even likely.
  - But not here yet.
  - Better to spend lots of $$$s now on research and development than on deployment now.
  - I am optimistic. (10 years?)

- But what if I am overoptimistic?
  - This is *not* a solved problem!

Hydro-Electric Power

- Think $250/MWh.
- Categories: Flow, Dammed, Pumped.
- Limited Potential (but still 2x today's).
- High capacity, lower efficiency than batteries:
  - Still cheaper for big energy needs.
  - Here now and can supply 8-12 hours!
  - Some even multi-day (Hoover).

Hydro-Power Problem

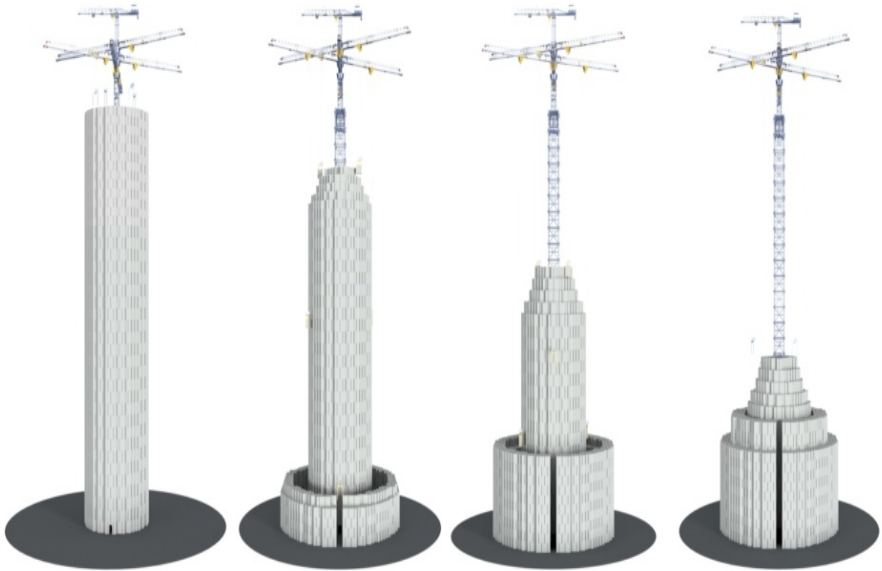
- Few suitable locations.
- Large scale only.
- Extremely high upfront fixed cost.

- What if battery power becomes cheaper more quickly than expected?

Unconventional Solutions

- Trains schlepping weights up a hill?!
- Maybe not crazy at all?:
  - Maybe $100-$200/MWh ?
  - Perhaps not great long-run solutions,
  - but temporarily not uncompetitive either (for now)?

Cranes Stacking Blocks



Longer-Term Storage

- Polar vortex-like wind/solar outages?!
- Seasonal elec-storage?
- Long-term elec-storage needs higher capacity at very low scaling cost, but lossier is ok.
  - Underground heat reservoirs?
  - Underground compressed air reservoirs?
  - Hydrogen?? (not as battery substitute!)

Heat Use Of Stored Electricity?

- Seems always like a bad idea.
  - Ignore talking heads
  - OK, may take a little bit to reliably go to industrial high heat, 2200C.
- IMHO, don't store electricity for heat later.
- Instead store heat in insulated containers.
- Heat storage can work on any scale:
  - Houses, factories, or cities.

Energy Transmission Grid

- Wind is always *somewhere*. Yet:
  - Grid transmission lines are expensive.
  - Transmission is lossy over long distance.
    - Significant variable cost ($1–$50/MWh).
  - Transmission has other issues:
    - Power line breaks,
    - causing fires,
    - or even cyber attacks.

Transmission

- *Very* complex engineering and political problems:
  - It evolved naturally for local industrial needs.
  - Total regulatory mess in USA now.
- Needs to allow more intermittent energy:
  - Intermittent adds potential wires overload.
  - → Sometimes prices turn negative!
  - Even in California, often in Germany.

Key Clean Energy Problem Now

- Storage, Storage, Storage

Secondarily, transmission grid

Feasibility/cost remain location-specific and complex.

Irony?

- Solar energy will cost $15/MWh. *Wow!*
- If we could store and release for another $15/MWh (heck, $50/MWh),
  - we could built 200+ GWh of storage,
  - plus electrify most fossil-fuel uses,
  - and ***it would be lights out for fossil fuels (for 2/3 of uses)***!
- But storage costs ca 2020 more like $200/MWh.
  - Maybe $100/MWh in 10 years with some luck.

Not Covered

- Reliability is hugely important.
  - When electricity goes out, the world stops.
  - All industry and jobs depend on it.
- Inefficient to have too many decentralized backup generators everywhere.
  - Lebanon or South Africa today.
  - France and Germany barely escaped in 2022-2023.

Energy Provision 2015, TWh

	Coal	NatGas	Nuke	Hydro
USA	1,410	1,317	797	249
China	3,860	148	161	1,103
World	9,621	5,585	2,440	3,843

	Wind	Solar	(Oth)	Total
USA	191	39	(2.2%)	4,092
China	186	45	(1.1%)	5,562
World	828	263	(2.6%)	23,171

Energy Forecast 2050, Twh

	Coal	NatGas	Nuke	Hydro
USA	593	1,953	594	294
China	3,556	803	1,002	1,448
World	8,115	7,306	3,025	5,548

	Wind	Solar	(Oth)	Total
USA	790	1,071	(3.0%)	5,458
China	1,001	3,379	(0.4%)	11,230
World	6,833	10,152	(2.3%)	41,953

Electricity Conclusion

- Generation is basically a solved problem.
- Storage is the unsolved problem.
- Wish nuclear plants were a lesser conundrum.
- NatGas is economic challenge for c.e.
  - Wish we had a reasonable fossil-fuel tax!
- Coal plants outside OECD remain vexing.