

# Quick Out-of-Time Summary of Ch 12-

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# Etiquette

- ▶ Do not leave your computer or notebook open when we have speakers.
- ▶ Please pay attention, and ask good questions.

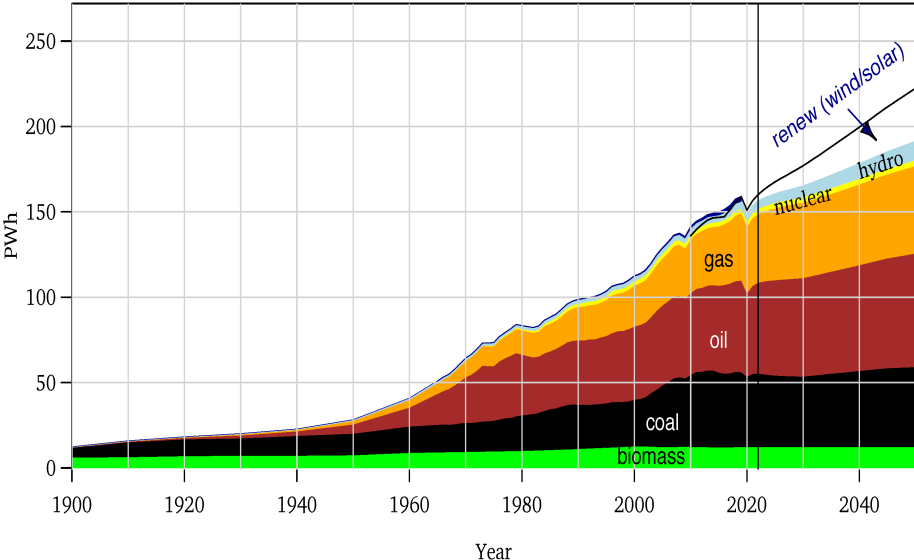
# READ

- ▶ You must read the book for the final and information.

# More Energy and Power

- ▶ Book contains explanations about Watts and Watt-hours, power and energy.
- ▶ We need to wrangle about 150 PWh of energy within one generation.

# Situation Today



# Green Hydrogen

- ▶ Hopeless, because it is too expensive.
  - ▶ Green = 10x NatGas cost today; maybe 2x in 40 years?
- ▶ Unknown Use Cases. Given whatever E cost:
  - ▶ Think batteries for overnight storage (whatever price of E)
  - ▶ Think E → salt → heat , instead of E → hydrogen → heat
- ▶ Long-Distance Transport
  - ▶ Maybe...if competitive

# Nuclear Power

- ▶ Painful regulation.
  - ▶ Some regulation is absolutely needed,
  - ▶ though much NRC regulations has remained just stupid.
  - ▶ (Even dumber in Germany now.)
- ▶ Did NRC regulation kill nuclear power?
  - ▶ probably not
  - ▶ same problem have appeared in *every* country
  - ▶ → not *just* NRC

- ▶ Hopeless, because today's reactors are economically uncompetitive against NatGas and clean energy.
  - ▶ Future (small?) reactors could become competitive...maybe
  - ▶ Humanity could sure use more energy solutions.
  - ▶ Fusion plants are *economically* no different.
  - ▶ If someone solves the clean-energy storage problem, nuclear plants could be obsolete before they even open.
- ▶ Many other problems, too, but probably solvable
  - ▶ Absolutely *dead-serious* and need consideration, though.



# Batteries

- ▶ Not good enough for energy density and for cost today for *complete* takeover.
  - ▶ grid means some places need just 4h; Li already great!
  - ▶ not cost-effective for 12 hours (NatGas).
- ▶ Improving every year. They will be good enough.
  - ▶ → optimal choice: go slow!

# Lithium Chemistries

- ▶ Modest toxicity, clean mining, water reactive.
- ▶ Anode and cathode make huge difference
  - ▶ dendrites (tendrils); capacity.
  - ▶ component costs
- ▶ Batteries are getting much better every year, soon 3,000 cycles; could perhaps become 100,000 cycles!
- ▶ Plenty of lithium (e.g., Salton Sea)
- ▶ price: \$1,200/KWh in 2010; \$150/KWh in 2020!  
\$75/KWh in 2035?

# Other Chemistries

- ▶ Many different possible chemistries
  - ▶ Watch out for flow batteries, etc.
- ▶ Solve the storage cost problem and fossil fuels are done.
  - ▶ Clean energy generation is already much cheaper.

# Clean Energy (=Usually Electricity)

- ▶ Lots of FUD, often surreptitious.
- ▶ Recycling of turbines is *not* a problem.
- ▶ Large area needed is *not* a problem.
  - ▶ size of Massachusetts?
  - ▶ compare to agriculture (and not competing!)
  - ▶ should be placed close to use and grid



- ▶ Huge energy transition takes lots of time.
- ▶ Optimal deployment is slow while costs are coming down.
- ▶ There will be many short-term delays and hickups

# Dispatchable (Storage)

- ▶ All heat plants that don't operate 24/7 are very cost inefficient.
- ▶ Even otherwise cheap NatGas plants.

# Grid/Allocation problems

- ▶ Tremendous
  - ▶ Time and Location matters
  - ▶ uncertainty (supply and demand);
  - ▶ short-term (which plants to switch on);
  - ▶ long-term (which plants to build where);
  - ▶ how to move E around (transmission).
- ▶ Balancing Act: Markets and Regulation
  - ▶ historically encumbered in the USA



# World

- ▶ Even more heterogeneous than USA.

*It is not enough to decarbonize US! In fact, it's almost useless.*

# USA

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

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U.S.	Nuclear	Hydro	Solar
Power	10%	10%	5%
Energy	20%	<b>7%</b>	<b>2%</b>

# Power/Energy Mix Comparison

	Nuke	GeoT	Coal	Gas
USA	20%	1%	19%	<b>40%</b>
World	10%	0%	<b>37%</b>	24%

	Hydro	Wind	Solar	Other
USA	7%	<b>9%</b>	2%	2%
World	<b>16%</b>	5%	3%	<b>5%</b>

# Utility-Scale High Fixed Costs

- ▶ Almost all cases: First-order is fixed cost
  - ▶ built or not built
  - ▶ 30-year replacement or new needs
- ▶ Rest (variable cost) is often much lower.
- ▶ Amazingly, solar PV fixed cost is now getting so cheap that NatGas plants are installing it to save on NatGas!

# New Plants: USA / OECD / China+India+

- ▶ Within the OECD:
  - ▶ For many years now, really only new Wind and Solar plants have made sense;
  - ▶ will probably continue; explain below why.
- ▶ Beyond the OECD:
  - ▶ Lots of Coal.
  - ▶ usually near coal mine and near pop centers
  - ▶ already or soon economically obsolete

# Levelized Cost Of Electricity (LCOE)

- ▶ Tries to take all costs into account.
- ▶ Projected over lifetime of plant:
  - ▶ disagreement over lifetime → different LCOEs.
  - ▶ If you get 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
Nuclear	\$70	\$60
Gas, Always On	\$40	\$45+
Coal	\$75	\$65+

Probably have triple the variable costs in 2022, but LCOE is about planning for 30-50 years. Price probably more likely more like 2020 than 2022.

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



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Type	Today	est 2050
Solar Panels, Utility	\$35	\$15
Wind, onshore	\$35	\$20
—	—	—
Hydro	\$55	
Gas, Dispatch	\$200	

# Clean Energy

In sum:

***Problem is No Longer Cheap Generation!***

***Problem Now is Cheap Energy Storage!***

Solve it, and wind/solar will take over.

# Energy Storage / Batteries

- ▶ Think \$200/MWh
  - ▶ it costs \$10 to buy lunch and \$100 to eat it in 20 minutes!
- ▶ Main Li Problem: wears out after 1,000+ cycles.
  - ▶ see above. If 10,000+ cycles at same price, good-bye fossil fuels for electricity and short transport.
  - ▶ heat is different. think half-price on E.
  - ▶ oversea transport is different.

## Energy Provision 2015, Twh

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	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

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	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

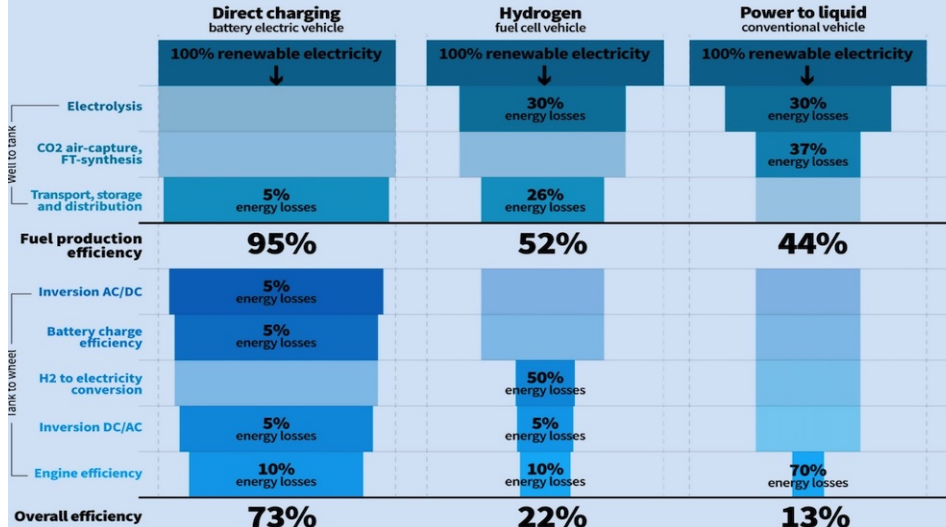
	Coal	NatGas	Nuke	Hydro
USA	593	1,953	594	294
China	3,556	803	1,002	1,448
World	8,115	7,306	3,025	5,548

	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

# Hydrogen: Bad Idea, Cars

## Cars: Battery electric most efficient by far



# OTHERS NOT DISCUSSED

- ▶ Emissions not primarily a US but global problem
- ▶ Industrial, Steel, Cement Heat and Inputs
- ▶ Agriculture: Very tough.
- ▶ Methane super-emitters (plus many small issues)
- ▶ Sequestration (Timber! Algae, etc.)
- ▶ Geoengineering
  - ▶ 1/10,000 the cost; but also problems
- ▶ Lots of good changes, many more modest