

Nuclear Energy

EES 3310/5310

Global Climate Change

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Class #35: Wednesday, April 14 2021

Reviewing Emissions Regulation Game

Review of Game

- Command and Control:
 - Each company emits the same amount
 - 1: 14 total, 7 each
 - 2: 26 total, 13 each
- Cap-and-trade:
 - Give each company equal permits.
 - Let them trade
 - 1: 7 permits each, Alpha buys 2 for \$64
 - 2: 13 permits each, Alpha buys 0 for \$0
- Carbon Tax:
 - Put a price on CO₂ emissions
 - Each company can emit as much as it wants to
 - But it must pay the tax on every ton.
 - 1: \$28/ton
 - 2: \$52/ton

Default

Default

Actor	Emissions	Profit	Cost	Net
Alpha	15	\$630		\$630
Beta	15	\$420		\$420
Society			-\$930	-\$930
Total	30	\$1050	-\$930	\$120

Deadweight loss = \$456 million

Optimal

Actor	Emissions	Profit	Cost	Net
Alpha	9	\$540		\$540
Beta	7	\$308		\$308
Society			-\$272	-\$272
Total	16	\$848	-\$272	\$576

Command & Control (Group 1)

Actor	Emissions	Profit	Cost	Net
Alpha	7	\$462		\$462
Beta	7	\$308		\$308
Society			-\$210	-\$210
Total	14	\$770	-\$210	\$560

Deadweight loss = \$16 million

Optimal

Actor	Emissions	Profit	Cost	Net
Alpha	9	\$540		\$540
Beta	7	\$308		\$308
Society			-\$272	-\$272
Total	16	\$848	-\$272	\$576

Cap & Trade (Group 1)

Actor	Permits	Bought	Sold	Emissions	Price	Profit	Cost	Net
Alpha	7	2		9	-\$64	\$540		\$476
Beta	7		2	5	\$64	\$240		\$304
Society							-\$210	-\$210
Total	14	2	2	14		\$780	-\$210	\$570

Deadweight loss = \$6 million

Optimal

Actor	Emissions	Profit	Cost	Net
Alpha	9	\$540		\$540
Beta	7	\$308		\$308
Society			-\$272	-\$272
Total	16	\$848	-\$272	\$576

Carbon Tax (Group 1): \$28/ton

Actor	Emissions	Tax	Profit	Cost	Net	Rebate	Net with Rebate
Alpha	10	-\$280	\$570		\$290	+\$238	\$528
Beta	7	-\$196	\$308		\$112	+\$238	\$350
Society		+\$476		-\$306	\$170	-\$476	-\$306
Total	17		\$878	-\$306	\$572		\$572

Deadweight loss = \$4 million

Optimal

Actor	Emissions	Profit	Cost	Net
Alpha	9	\$540		\$540
Beta	7	\$308		\$308
Society			-\$272	-\$272
Total	16	\$848	-\$272	\$576

Command & Control (Group 2)

Command & Control (Group 2)

Actor	Emissions	Profit	Cost	Net
Alpha	13	\$624		\$624
Beta	13	\$416		\$416
Society			-\$702	-\$702
Total	26	\$1040	-\$702	\$338

Deadweight loss = \$238 million

Optimal

Actor	Emissions	Profit	Cost	Net
Alpha	9	\$540		\$540
Beta	7	\$308		\$308
Society			-\$272	-\$272
Total	16	\$848	-\$272	\$576

Cap & Trade (Group 2)

Actor	Permits	Bought	Sold	Emissions	Price	Profit	Cost	Net
Alpha	13			13		\$624		\$624
Beta	13			13		\$416		\$416
Society							-\$702	-\$702
Total	26			26		\$1040	-\$702	\$338

Deadweight loss = \$238 million

Optimal

Actor	Emissions	Profit	Cost	Net
Alpha	9	\$540		\$540
Beta	7	\$308		\$308
Society			-\$272	-\$272
Total	16	\$848	-\$272	\$576

Carbon Tax (Group 2): \$52/ton

Actor	Emissions	Tax	Profit	Cost	Net	Rebate	Net with Rebate
Alpha	10	-\$280	\$570		\$290	+\$238	\$528
Beta	7	-\$196	\$308		\$112	+\$238	\$350
Society		+\$476		-\$306	\$170	-\$476	-\$306
Total	17		\$878	-\$306	\$572		\$572

Deadweight loss = \$126 million

Optimal

Actor	Emissions	Profit	Cost	Net
Alpha	9	\$540		\$540
Beta	7	\$308		\$308
Society			-\$272	-\$272
Total	16	\$848	-\$272	\$576

Summary of Deadweight Losses

Summary of Deadweight Losses

Group	Default	Command & Control	Cap & Trade	Tax
Group 1	456	16	6	4
Group 2	456	238	238	126

Group 1:

- EPA had good estimates of optimum emissions
- Very small deadweight losses
- Cap & Trade was better than Command & Control
- Taxes performed best
 - For both groups, taxes gave the lowest deadweight losses

Group 2:

- EPA had poor information, made poor estimates of optimum emissions
- Even so, deadweight losses from very inefficient regulations were much smaller than with no regulations

Summary of Net Profit/Cost

Group 1

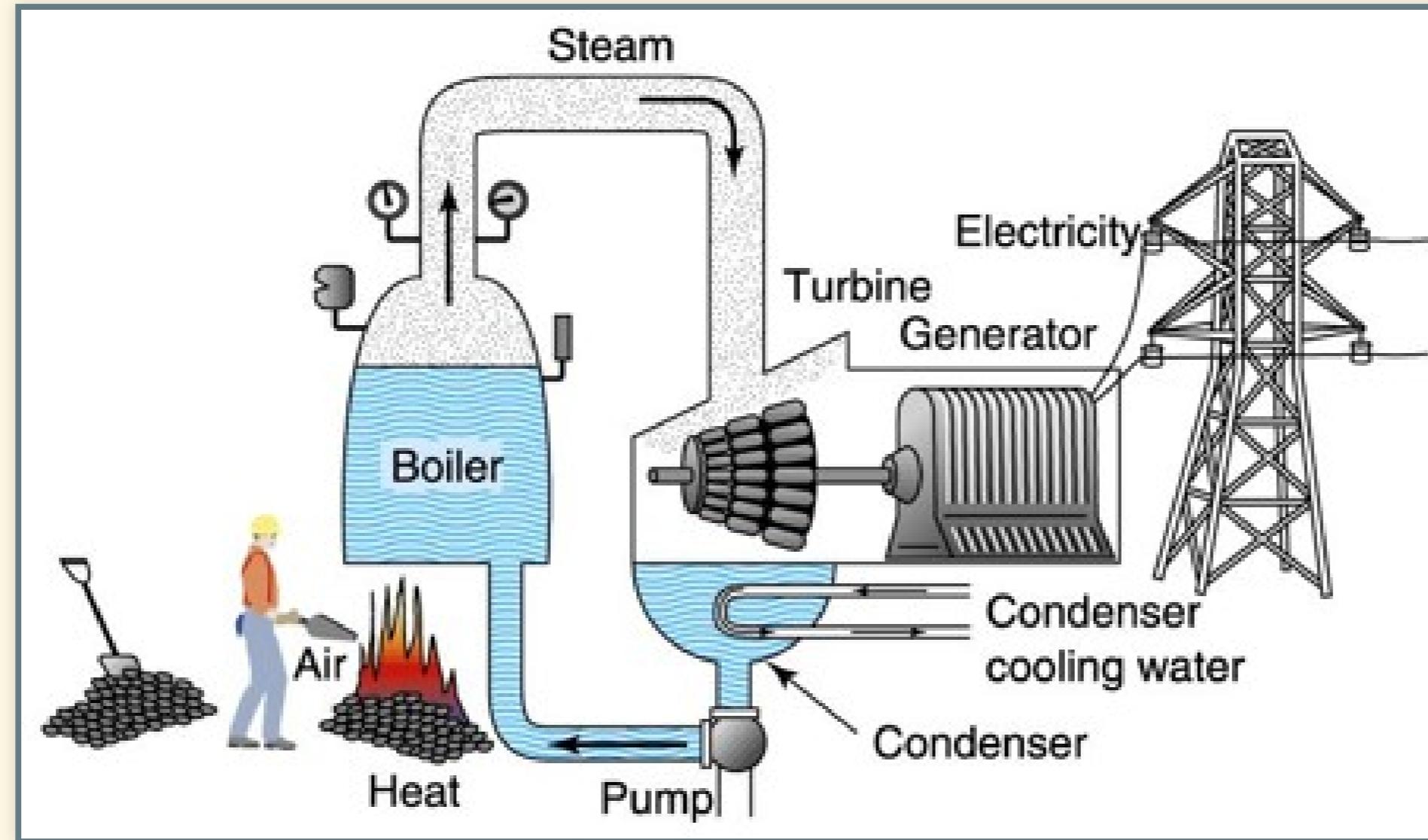
	Default	Cmd & Ctrl	Cap & Trade	Tax	Tax & Rebate
Alpha profit	630	462	476	290	528
Beta profit	420	308	304	112	350
Social cost	-930	-210	-210	170	-306
Total	120	560	570	572	572

Group 2

	Default	Cmd & Ctrl	Cap & Trade	Tax	Tax & Rebate
Alpha profit	630	624	624	102	310
Beta profit	420	416	416	4	212
Social cost	-930	-702	-702	344	-72
Total	120	338	338	450	450

Thermal Electricity Generation

Thermal Electricity Generation



- Coal, nuclear:
 - Heat boils water
 - Steam spins turbine
 - Turbine turns generator, makes electricity
- Thermodynamics limits efficiency
 - Coal plant: 33% efficient
 - Nuclear plant: 33% efficient
 - Advanced gas plant: 43% efficient

Kingston Fossil Plant (TN)



- 1450 megawatts
- 14,000 tons of coal per day (140 train cars)

Fuel Requirements for a 1000 MW Plant

- Coal: 10,000 tons/day (100 rail cars)
- Diesel: 40,000 barrel/day (1 tanker/week)
- Gas: 240 million cubic feet/day
- Nuclear: 3 kg/day of ^{235}U

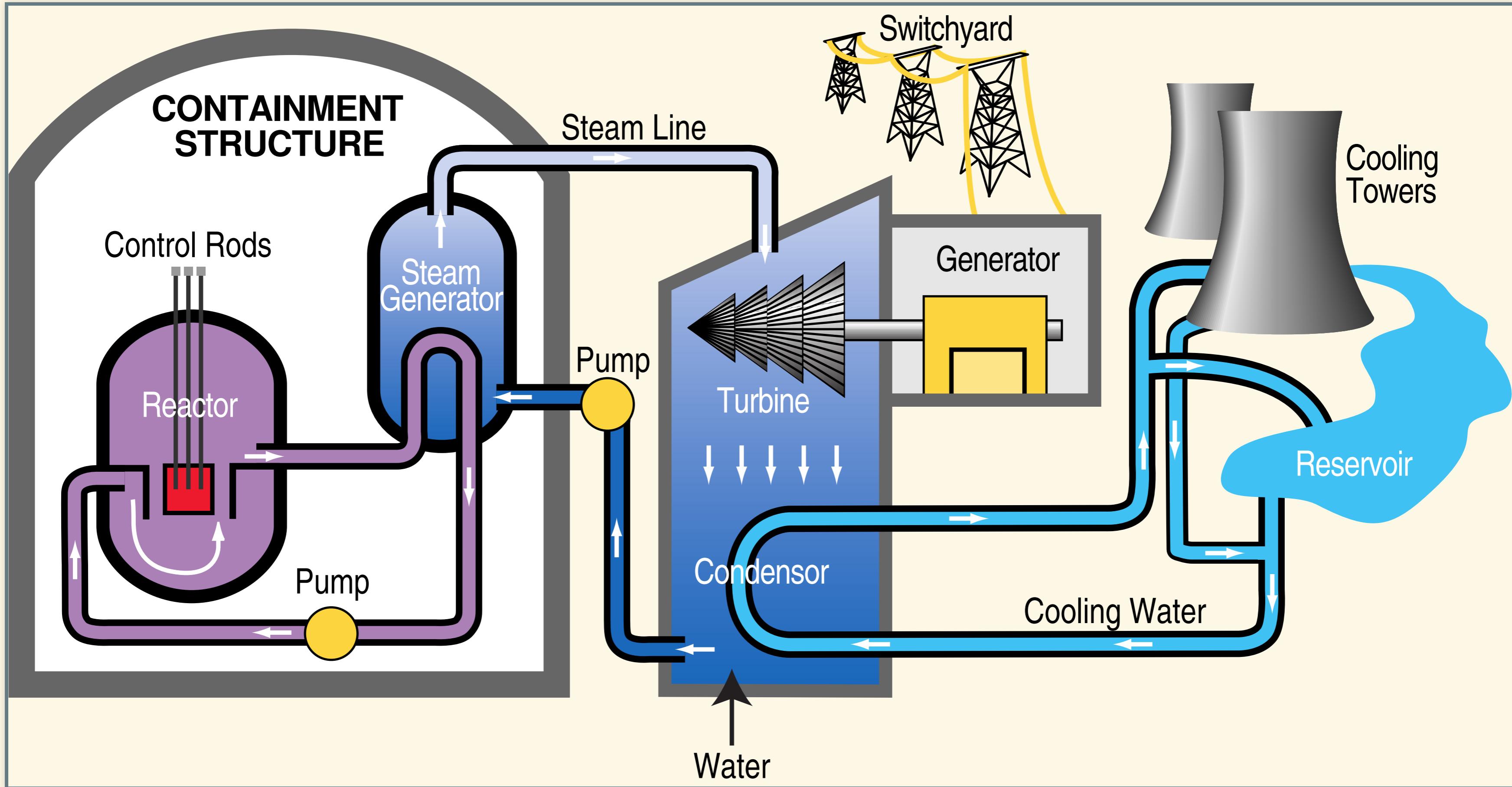


Watts Bar Nuclear Plant



- 2300 megawatts (two units)
- 2.3 tons enriched uranium per year

Nuclear Reactor



Getting Energy from Nuclear Fission

- Nuclear chain reactions produce lots of energy
- Natural uranium:
 - ^{238}U (99.3%): won't fission
 - ^{235}U (0.7%): will fission
 - Must enrich natural uranium:
 - Reactor fuel: 3–5% ^{235}U
 - Bomb: >80% ^{235}U
 - 1 ounce enriched uranium produces as much heat as 2–3 tons coal
- Other fissionable substances:
 - ^{239}Pu (plutonium)
 - Can be produced by hitting ^{238}U with a neutron
 - Byproduct of uranium chain reactions
 - **Breeder reactors**
 - ^{233}U
 - Produced by hitting ^{232}Th with a neutron
 - **Thorium reactors**

Feasibility of Nuclear Power

Feasibility of Nuclear Power

- Nuclear is much safer than coal or gas
 - Properly operating coal power plants in the U.S. alone kill more people in one month than all the nuclear reactor accidents in history in the entire world.
- The biggest challenges are:
 - Irrational public fear
 - Cost
 - In early 2000s, forecast of “nuclear renaissance”
 - Costs of natural gas, wind, and solar fell much faster than anyone imagined
 - New nuclear plants went way over-budget, behind schedule
 - Investor fears:
 - Costs of nuclear much less predictable than other technologies
 - Accidents are far more costly than other technologies

Industry View

*Exelon, the nation's biggest nuclear utility, with 17 plants, estimates that new nuclear plants are **more expensive than any other energy source** except [solar] photovoltaic.*

—Washington Post, 3/16/2011

Investor View

*Wall Street learned [from Three-Mile Island] that a group of licensed operators no worse than any other could transform a **billion-dollar asset** into a **two billion dollar clean-up** in ninety minutes*

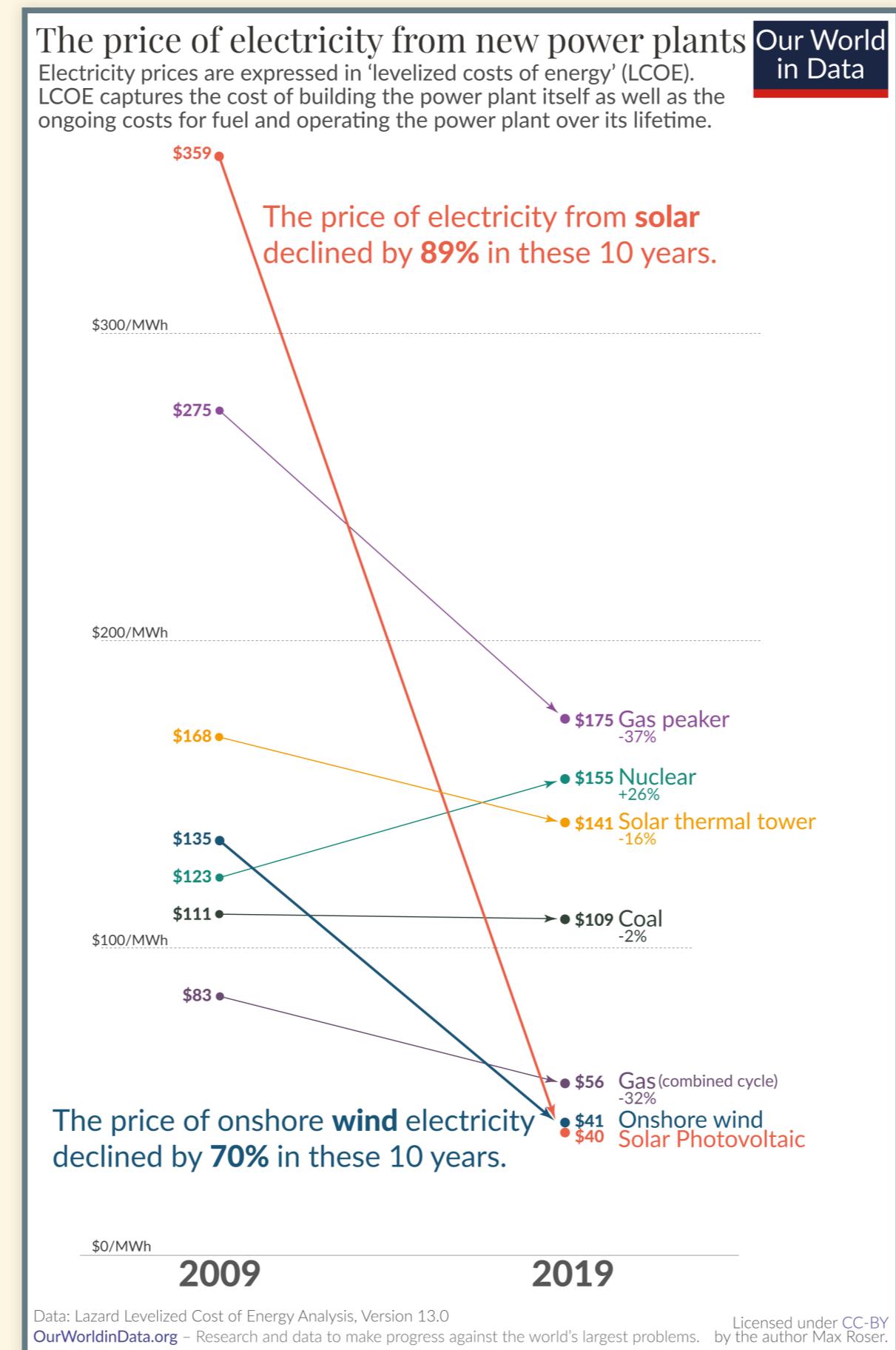
*—Peter A. Bradford,
Former Commissioner,*

Nuclear Regulatory Commission Senate Testimony

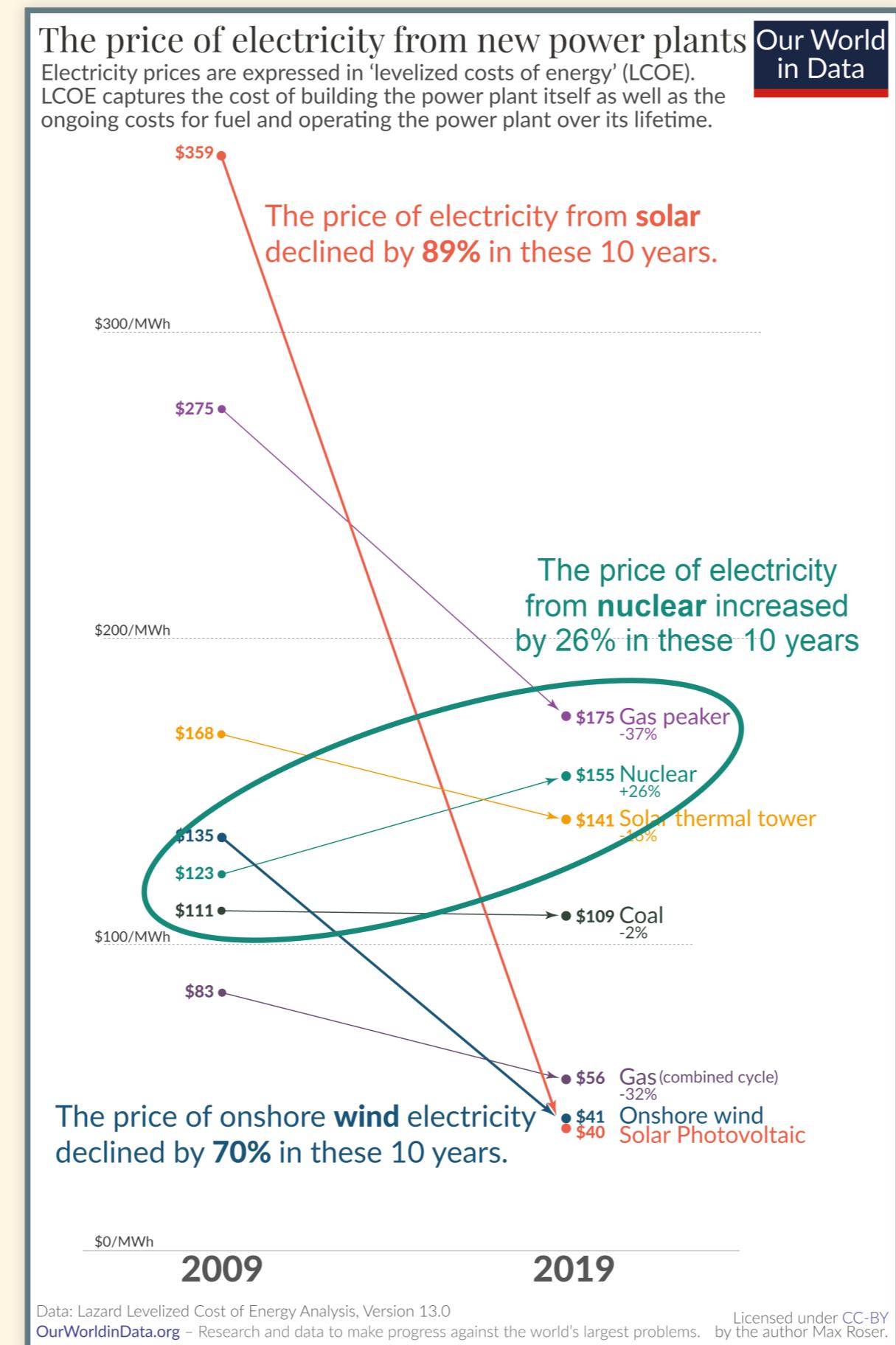
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Recent Trends in Nuclear

Recent Trends

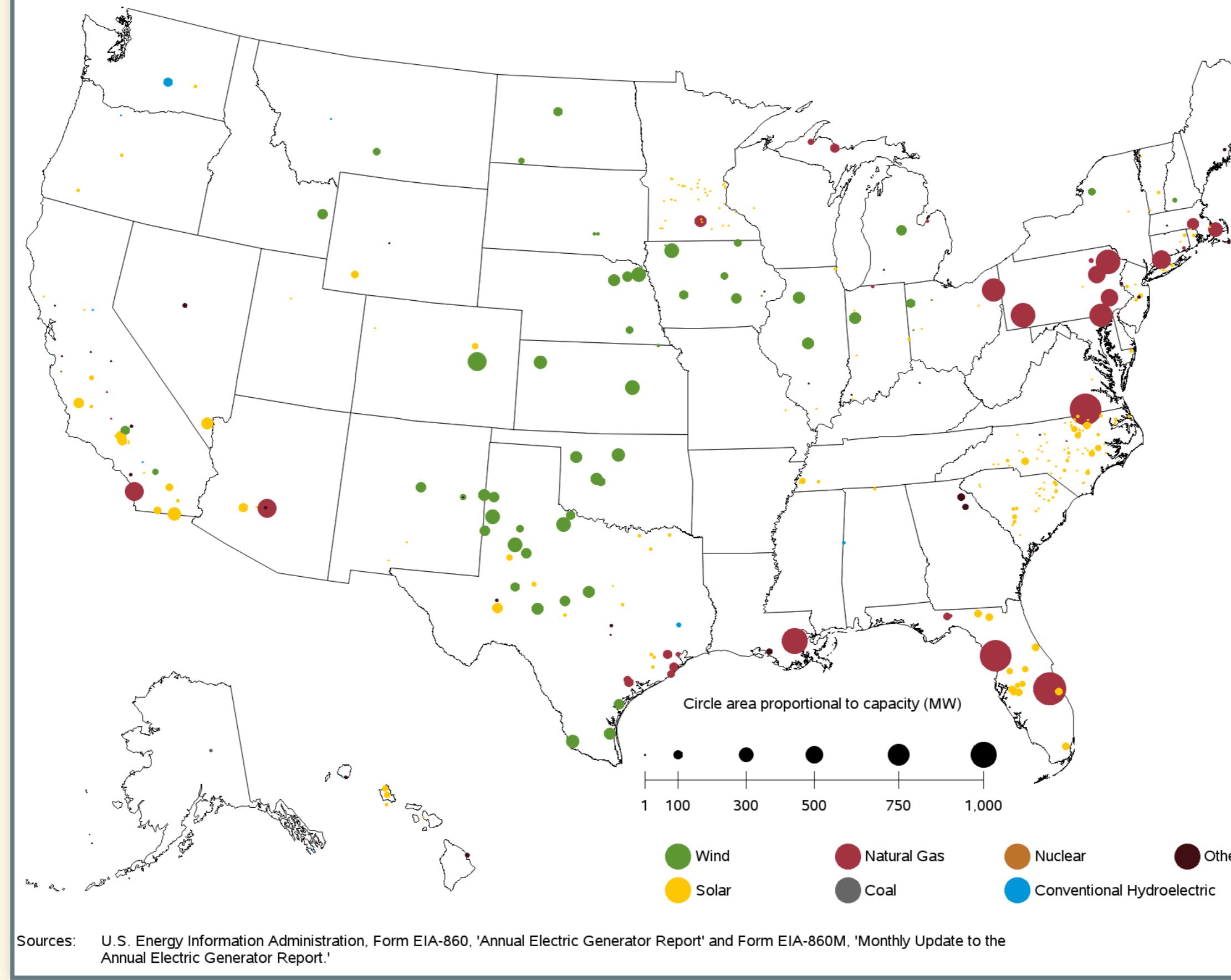


Recent Trends

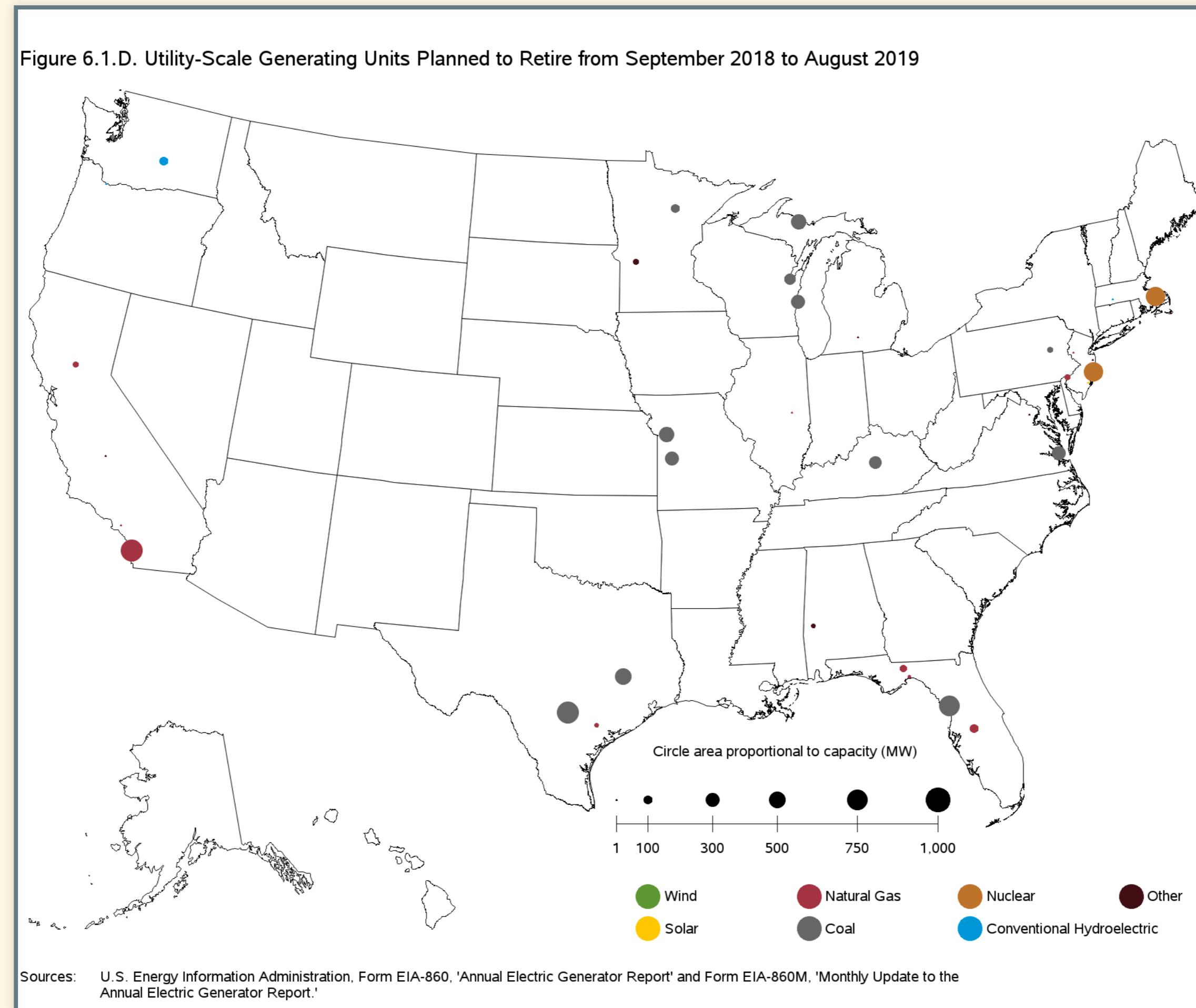


New Power Plants for 2018–2019

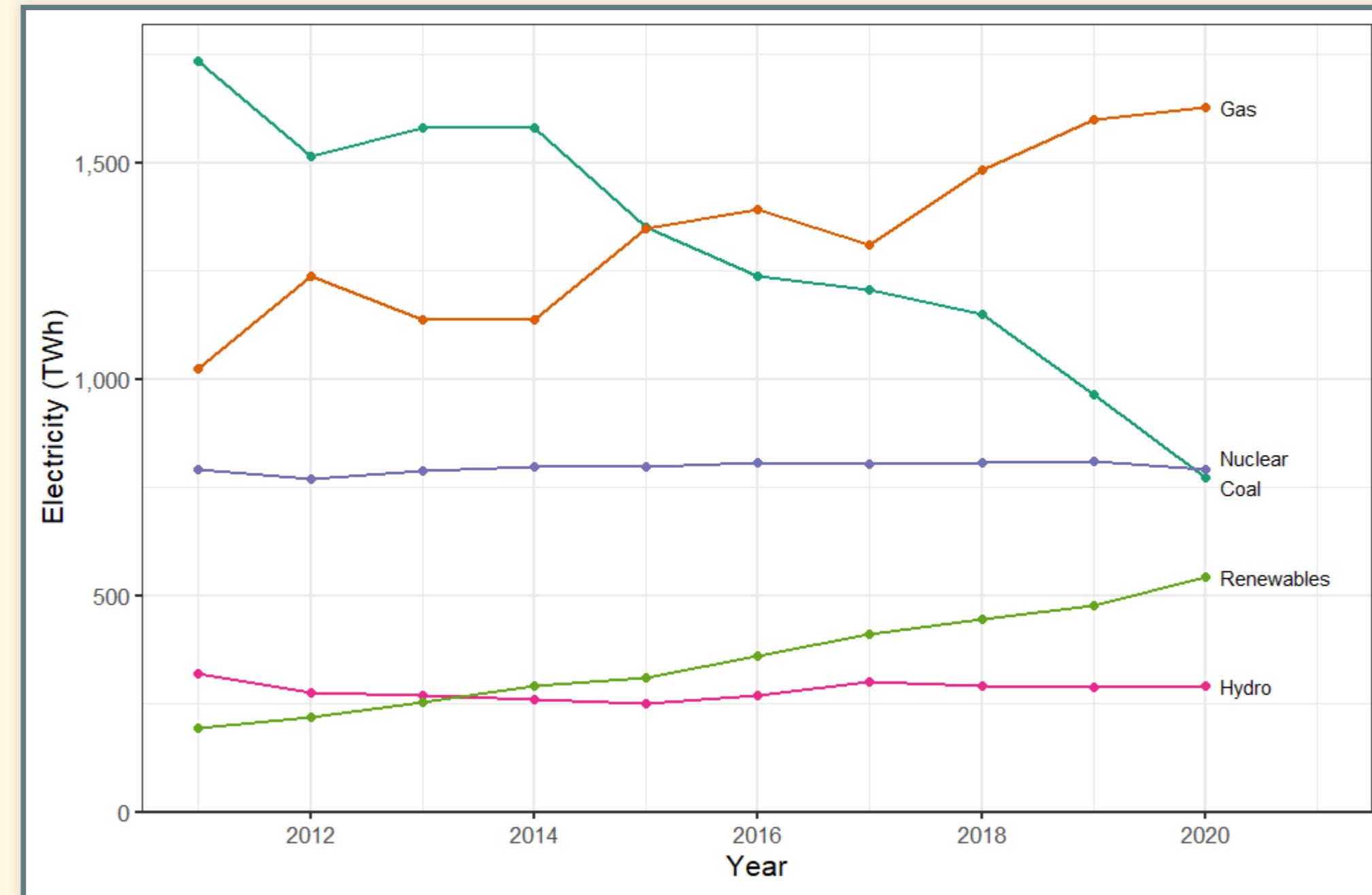
Figure 6.1.C. Utility-Scale Generating Units Planned to Come Online from September 2018 to August 2019



Power Plants Retiring in 2018–2019



Trends in Electricity



Growth Rates

Coal	Gas	Nuclear	Hydro	Renewables
-7.8%	4.7%	0.3%	0.2%	11.3%

Promise for Nuclear

Promise for Nuclear

- China, Russia, and India are investing heavily in nuclear:
 - 19 reactors under construction in China, 7 in Russia, 6 in India
- Private sector is investing heavily:
 - 30 research and development projects
 - \$1.3 billion in private investment
 - TerraPower (founded by Bill Gates)
 - Interest in standardized small modular reactors (SMR)
 - Intrinsically safe
 - Benefits of mass production: learning, economies of scale
 - Many sites don't need 1000–2000 megawatts

Challenges for Nuclear

- Currently nuclear is very expensive
 - French Flamanville 3 reactor:
 - Started construction 2007
 - Planned launch: 2012
 - Budget: \$4 billion
 - Now estimated to launch 2022
 - 10 years late
 - Current budget: \$20 billion
 - 5 times original
- But as renewables become a greater fraction of all power, intermittency becomes a greater, more expensive challenge.
- Fear is a great challenge.

