6 Global power

Fission is in Fashion

Thermal power: 19,000 GW

Electric power: 3,000 GW

Developing demand

CO_2 emissions

Electrify everything: 12,000 GWe

IEA: biofuels, carbon capture

Hydrogen, synfuels

Sector power use vision

Wade Allison: Energy options facing society today

Adam Smith: “Science is the great antidote to the poison of enthusiasm and superstition.”

	“Renewables”	Chemical (electronic)	Nuclear
Fuels	Water, wind, sun	Fossil fuels, food, biofuels	Uranium, Thorium
Primed or renewed	Daily and seasonal sunshine	Sunshine in geological epochs	Pre-solar stellar collapse (supernova)
Energy density kWh/kg	0.0003	1 to 7	20 million
Fuel for a whole life	10 million tonnes	1000 tonnes	0.001 tonnes (1 kg)
Pro	Familiar, accepted	Reliable, available 24/7	Reliable, safe, compact, resilient, available 24/7
Con	Unreliable, weak, damaging to nature	Emissions, safety	Public apprehension, failed education

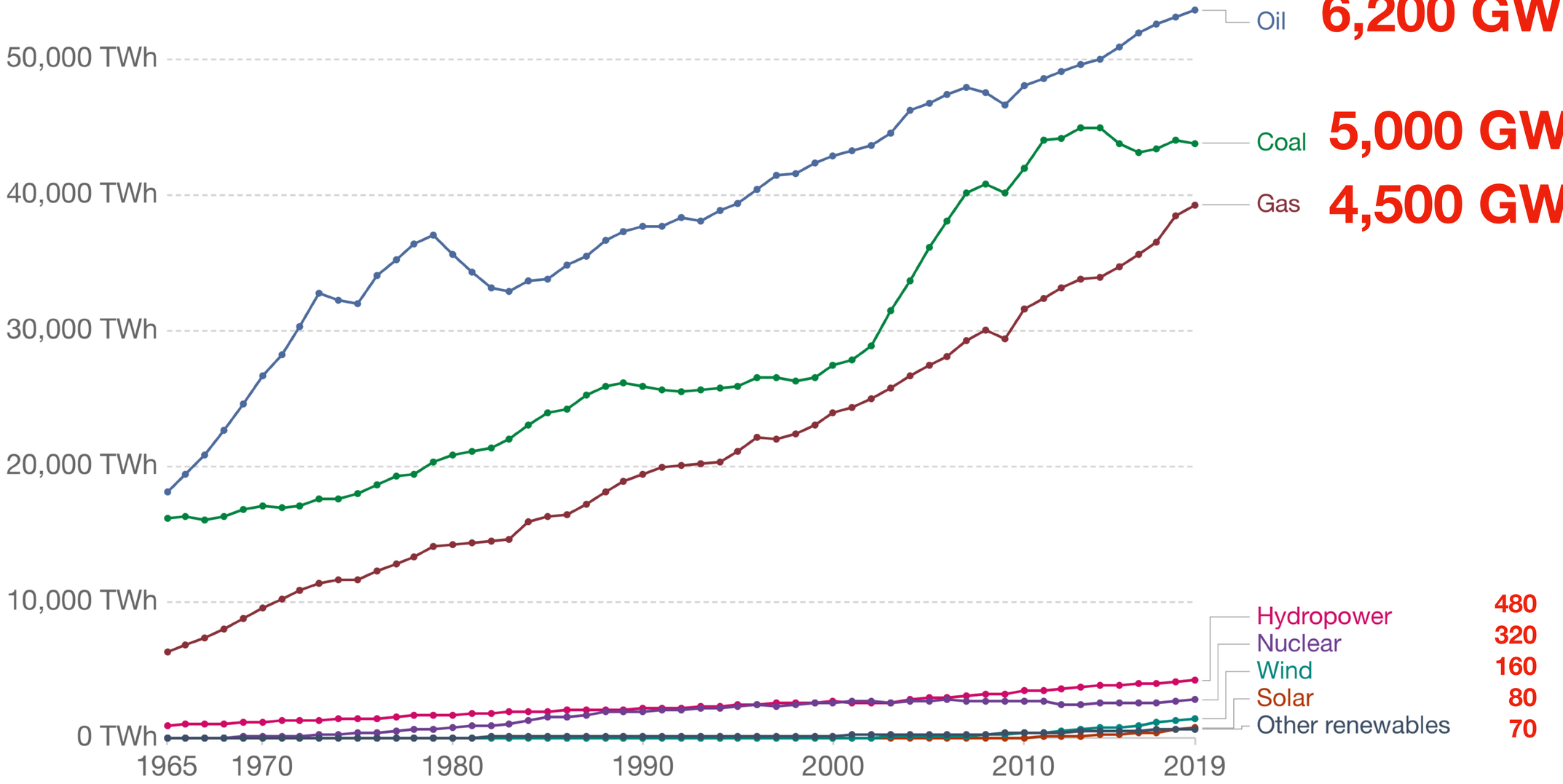
https://www.researchgate.net/publication/339629356_Nature_Energy_and_Society_A_scientific_study_of_the_options_facing_civilisation_today

Global power sources

Energy consumption is shown as direct primary energy. This means this does not correct for fossil fuel inefficiencies in conversion to useful energy estimates.

Oil 53,620 TWh/year

6,200 GW(t)



5,000 GW(t)

4,500 GW(t)

	GW(e)
Hydropower	480
Nuclear	320
Wind	160
Solar	80
Other renewables	70

Source: BP Statistical Review of Global Energy

OurWorldInData.org/energy • CC BY

Note: Includes only commercially-traded fuels (coal, oil, gas), nuclear and modern renewables. As such, it does not include traditional biomass sources.

https://ourworldindata.org/grapher/primary-energy-consumption-by-source?year=latest&time=1965..2019

Handy math trick from Google:

50,000 TWh/year in gigawatts

All News Images Shopping Videos More

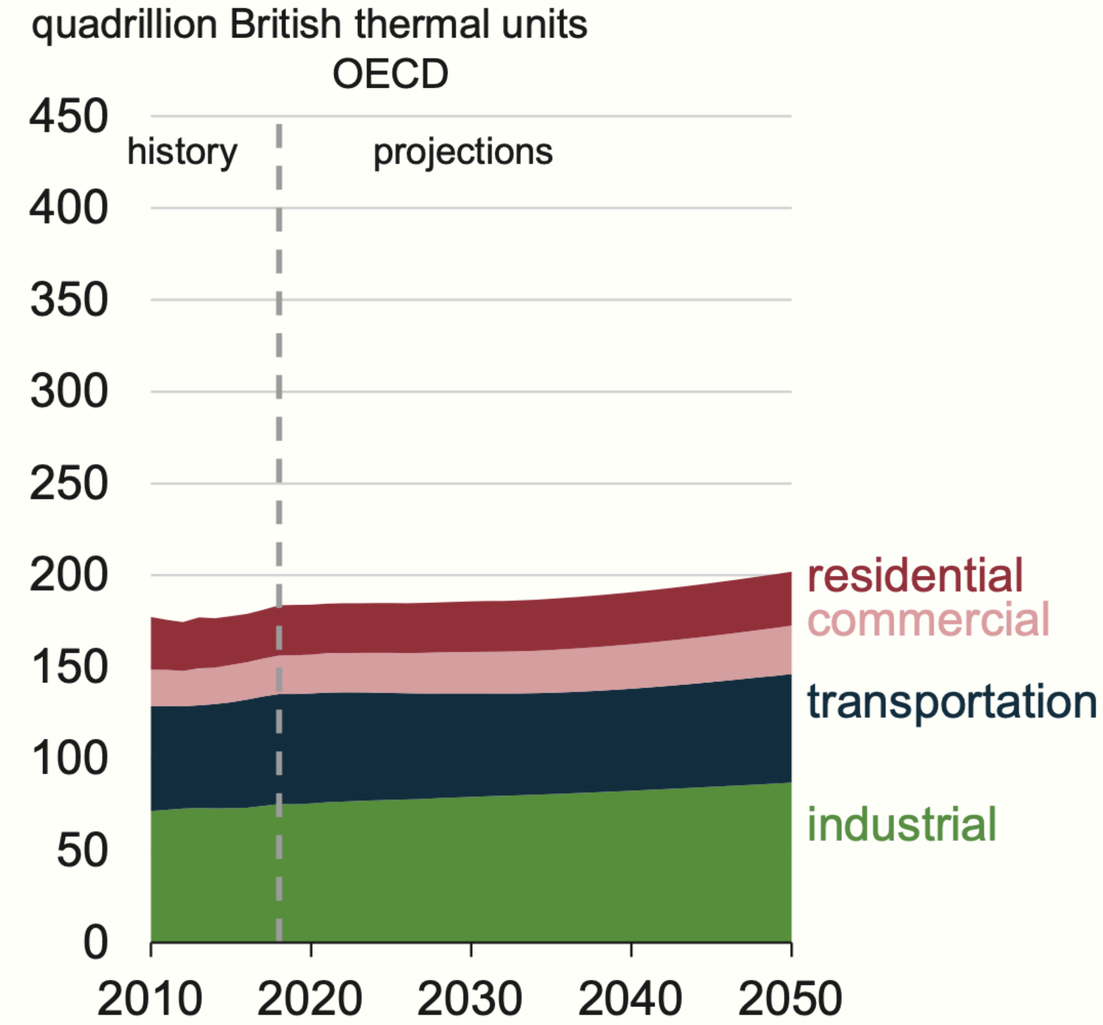
About 116,000 results (0.51 seconds)

50 000 (terawatt hours / year) =

5 703.97764 gigawatts

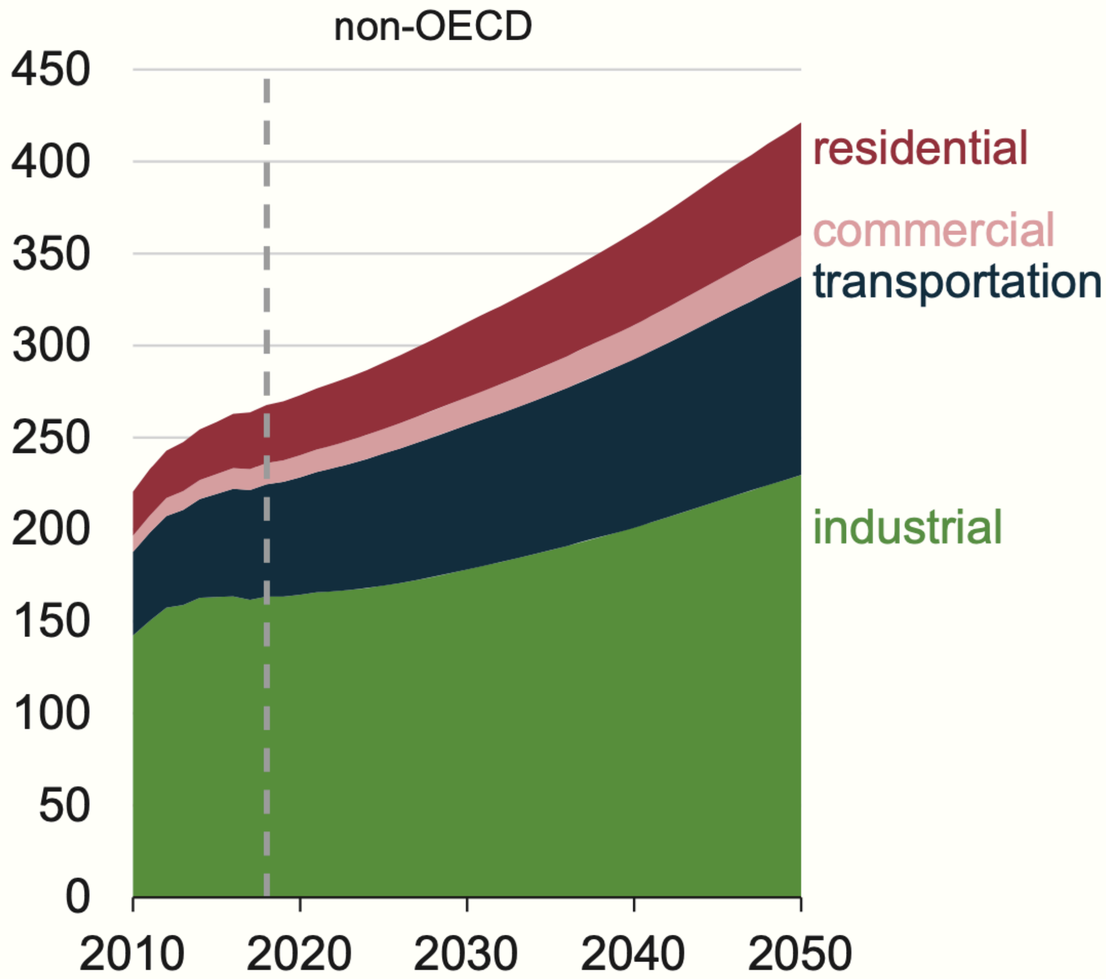
OECD energy

180 quadrillion BTU/year ~ 6,000 GW(t)



non-OECD energy

270 quadrillion BTU/year ~ 9,000 GW (t)

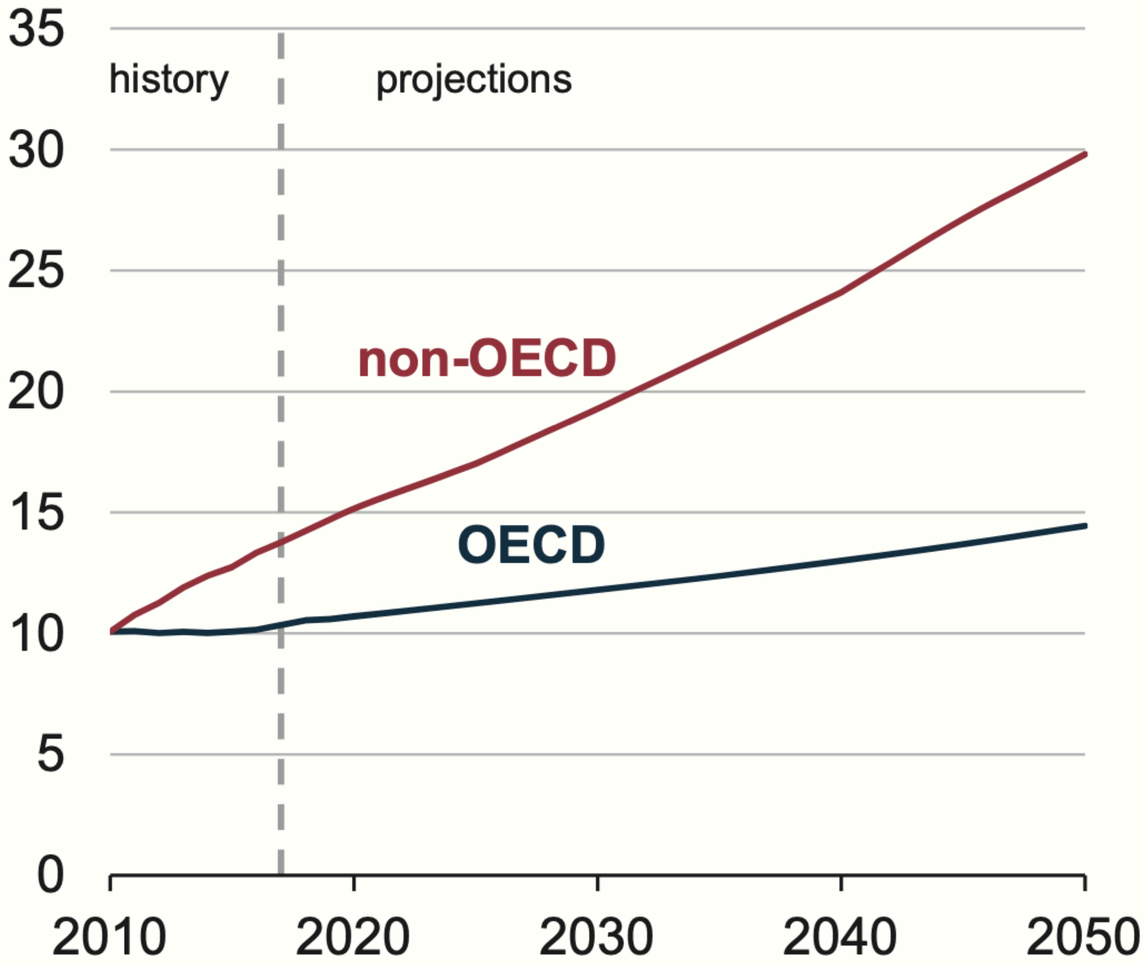


https://www.eia.gov/outlooks/ieo/pdf/ieo2019.pdf

Global electricity use ~3,000 GW(e).

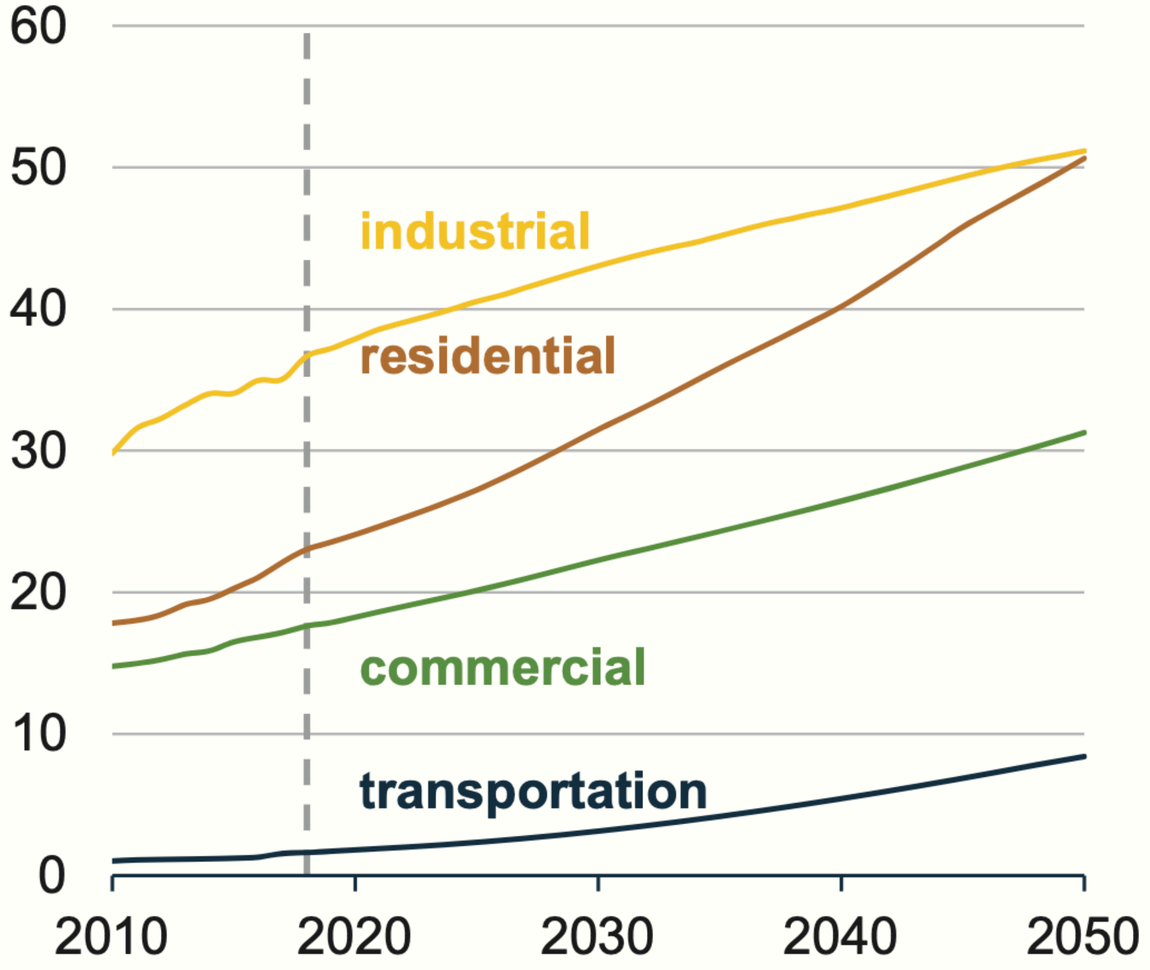
by economic class

Net electricity generation, world
trillion kilowatthours



by use

Electricity use by sector, world
quadrillion British thermal units



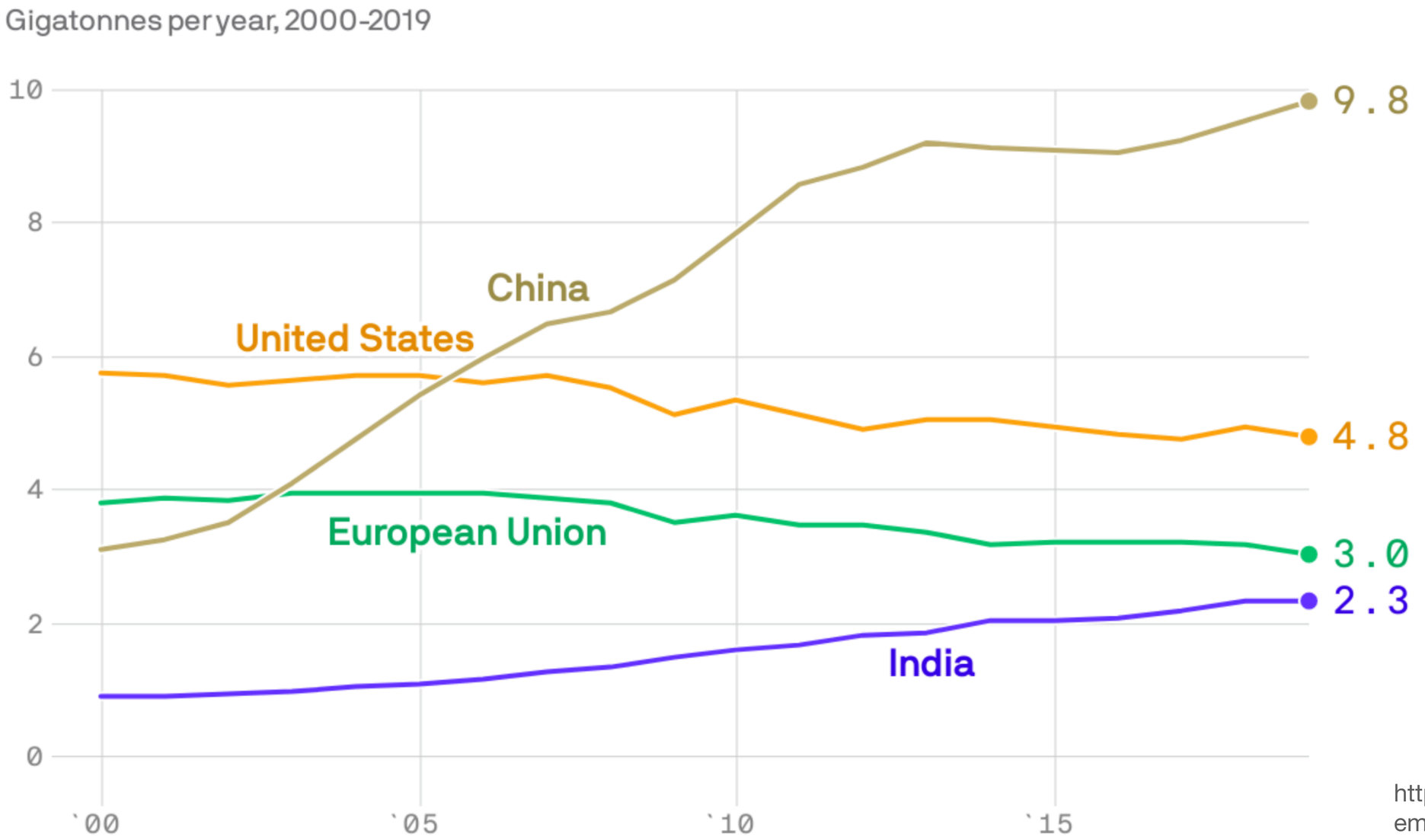
https://www.eia.gov/outlooks/ieo/pdf/ieo2019.pdf

IEA World thermal power (Mtoe/year) Gigawatts

	2000	2019		Sustainable Development Scenario 2040	Sustainable Development Scenario 2070		Stated Policies Scenario 2070	
uses								
Industry	2 054	3 278	4,400	3 162	3 077		4 513	
Transport	1 961	2 865	3,800	2 537	2 461		3 923	
Buildings	2 345	3 087	4,100	2 648	2 868		4 193	
Other	950	1 153		1 310	1 081		1 639	
Total	**7 310**	**10 384**	**13,800**	**9 657**	**9 486**	**12,600**	**14 269**	**19,000**
sources								
Coal	732	1 327		824	398		1 326	
Oil	3 292	4 048		2 823	1 099		4 561	
Natural gas	1 104	1 659		1 357	426		2 362	
Electricity	1 076	1 943	2,600	2 909	4 507	6,000	4 004	
Heat	240	312		272	187		356	
Hydrogen	0	0		98	539		91	
Ammonia	0	0		18	133		9	
Bioenergy	859	1 035	1,400	1 035	1 315	1,700	1 285	
Synfuels	0	0		32	254		0	
Other renewables	7	60		290	629		275	
Total	**7 310**	**10 384**		**9 657**	**9 486**		**14 269**	

https://webstore.iea.org/download/direct/4165

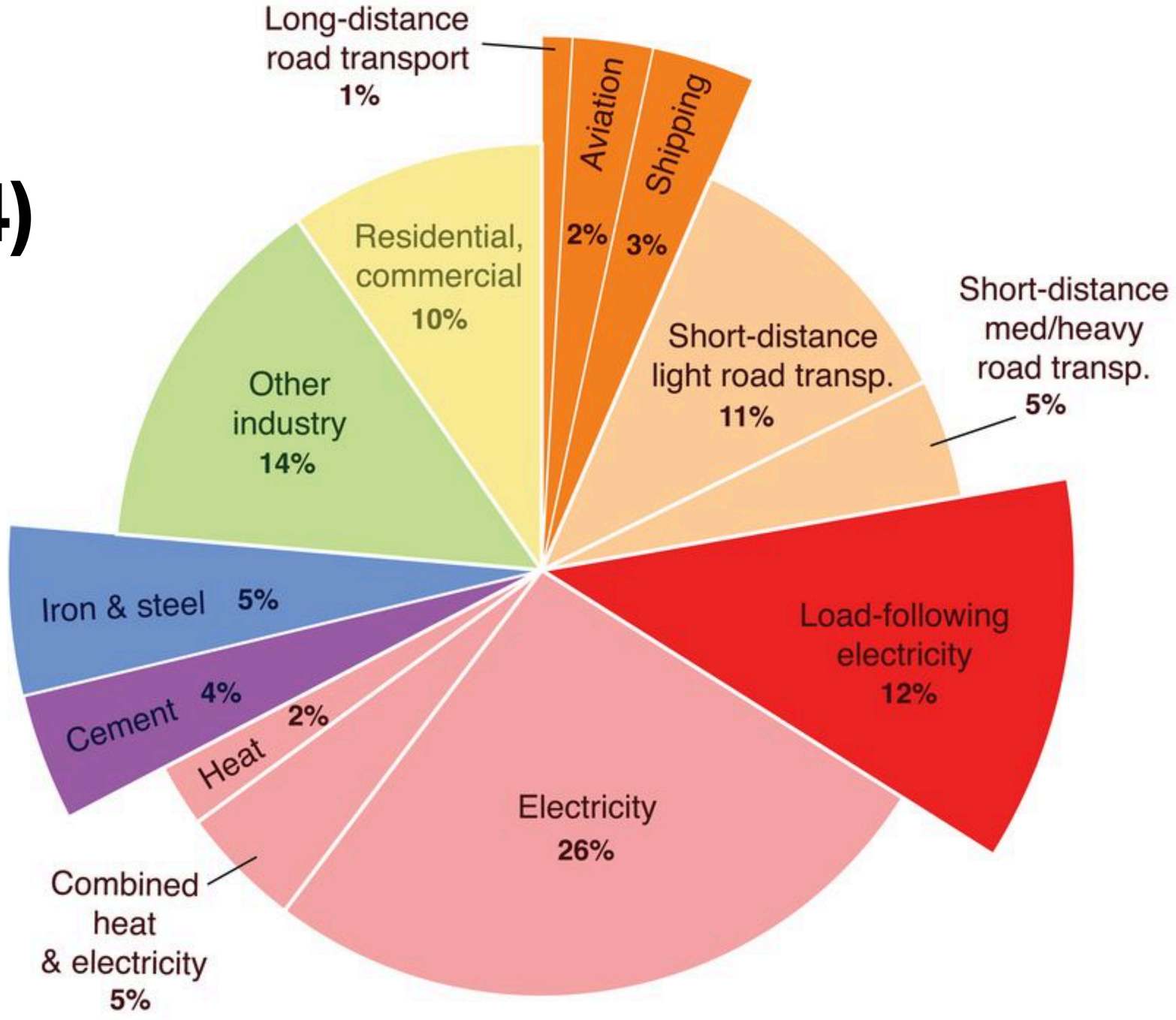
IEA: China, US, EU, and India emit most of the 32 Gt-CO2/year from fuel consumption.



https://www.iea.org/reports/co2-emissions-from-fuel-combustion-overview

Emissions
23 Gt CO2 (2014)

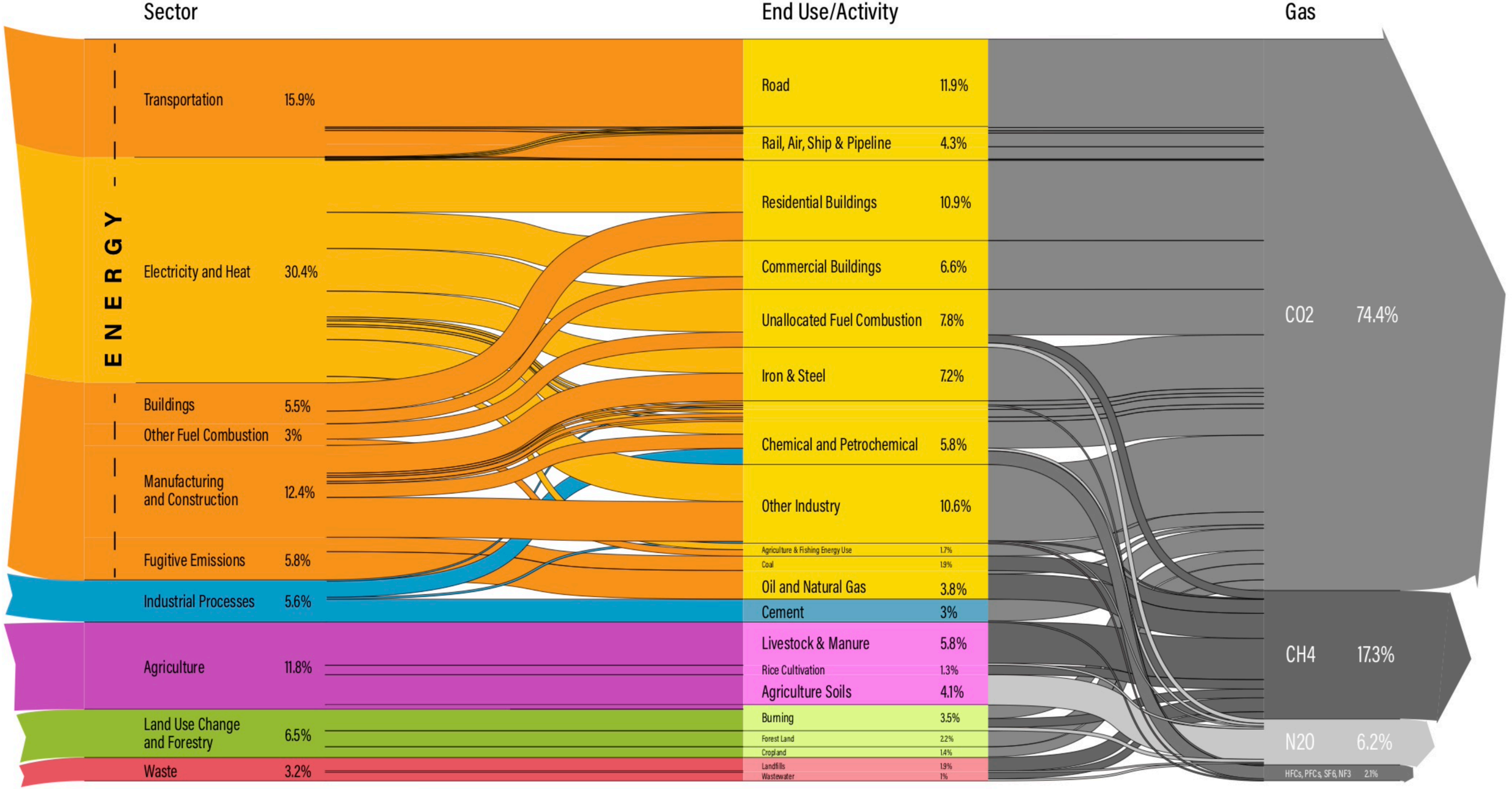
excluding agriculture,
land use changes, waste



https://science.sciencemag.org/content/360/6396/eaas9793

Emissions 49 Gt CO2-eq (2016)

https://www.wri.org/blog/2020/02/greenhouse-gas-emissions-by-country-sector

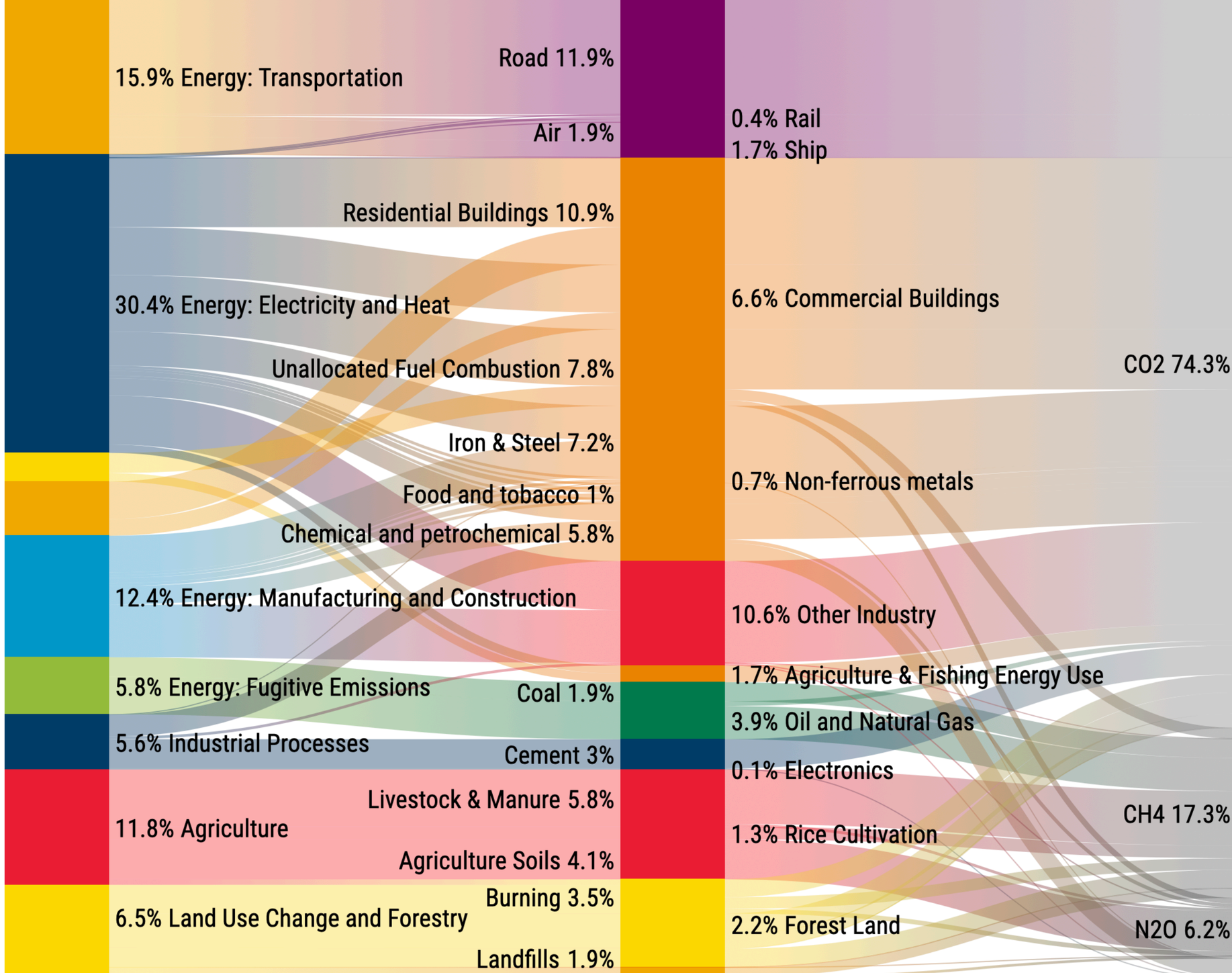


Emissions: 49 Gt CO2-eq (2016)

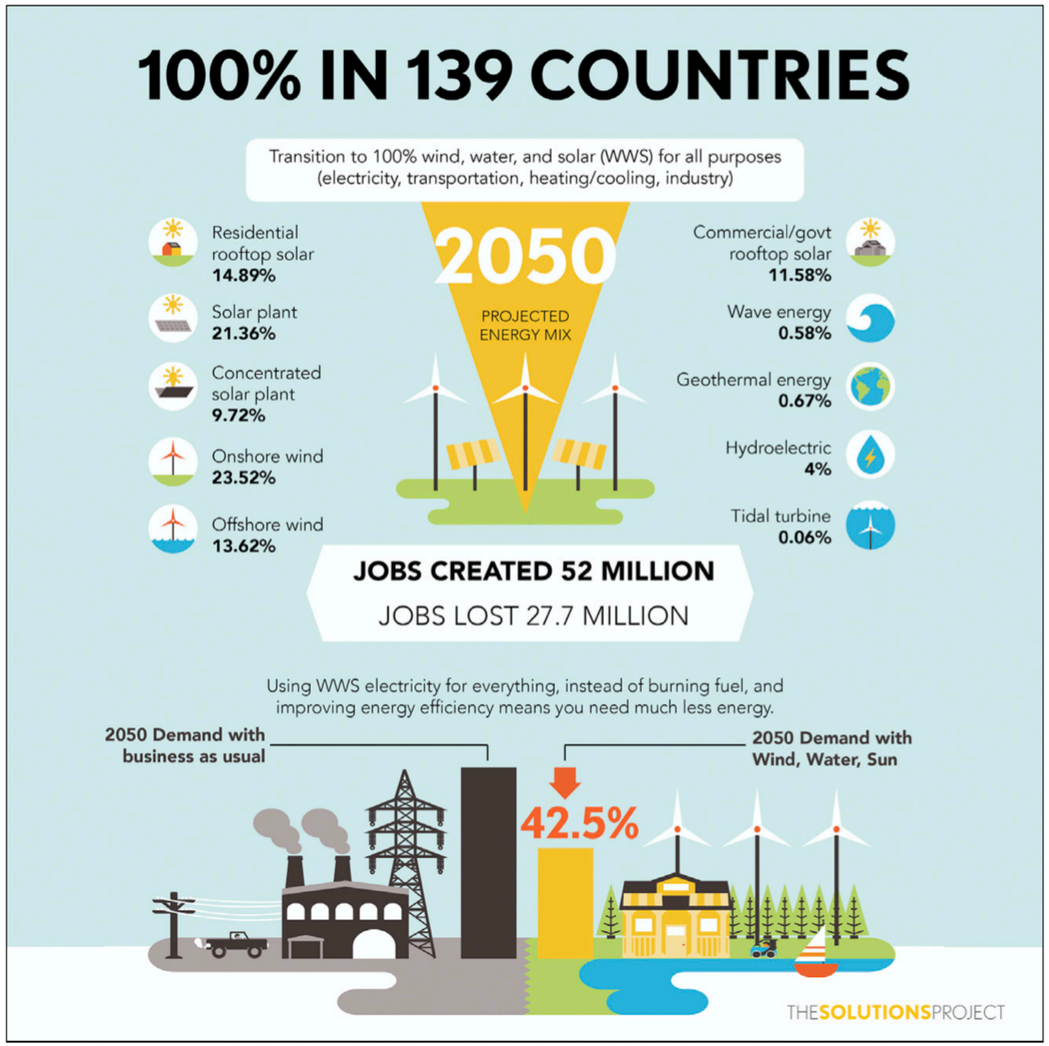
by source and use

World Resources Institute

https://www.wri.org/blog/2020/02/greenhouse-gas-emissions-by-country-sector



Mark Z. Jacobson WWS (water/wind/solar) article



- **16,519 GW(t)** combustion power replaced by WWS sources.
- Everything is electrified, including transportation, industry.
- 2050 electricity demand grows to **11,800 GW(e)**.

https://web.stanford.edu/group/efmh/jacobson/Articles/I/CountriesWWS.pdf

Jacobson WWS issues

1. 59-85% of power demand must adjust to availability.
2. 49,900 GW(e) nameplate capacity to generate 11,800 GW(e)
3. Capital investment: $125 trillion.
4. Electricity cost: 11 cents/kWh.
5. The energy storage cost of 0.8 cents/kWh is far too low.
6. New, global, public policies needed to force adoption.

https://web.stanford.edu/group/efmh/jacobson/Articles/I/CountriesWWS.pdf

Let’s power up our world with 12,000 GW(e).

Using fossil fuel combustion

19,000 GW(t) 2019, BP

9,705 GW(t) 2012, Jacobson

16,519 GW(t) 2050, Jacobson, business as usual

CO2-free electrification of everything

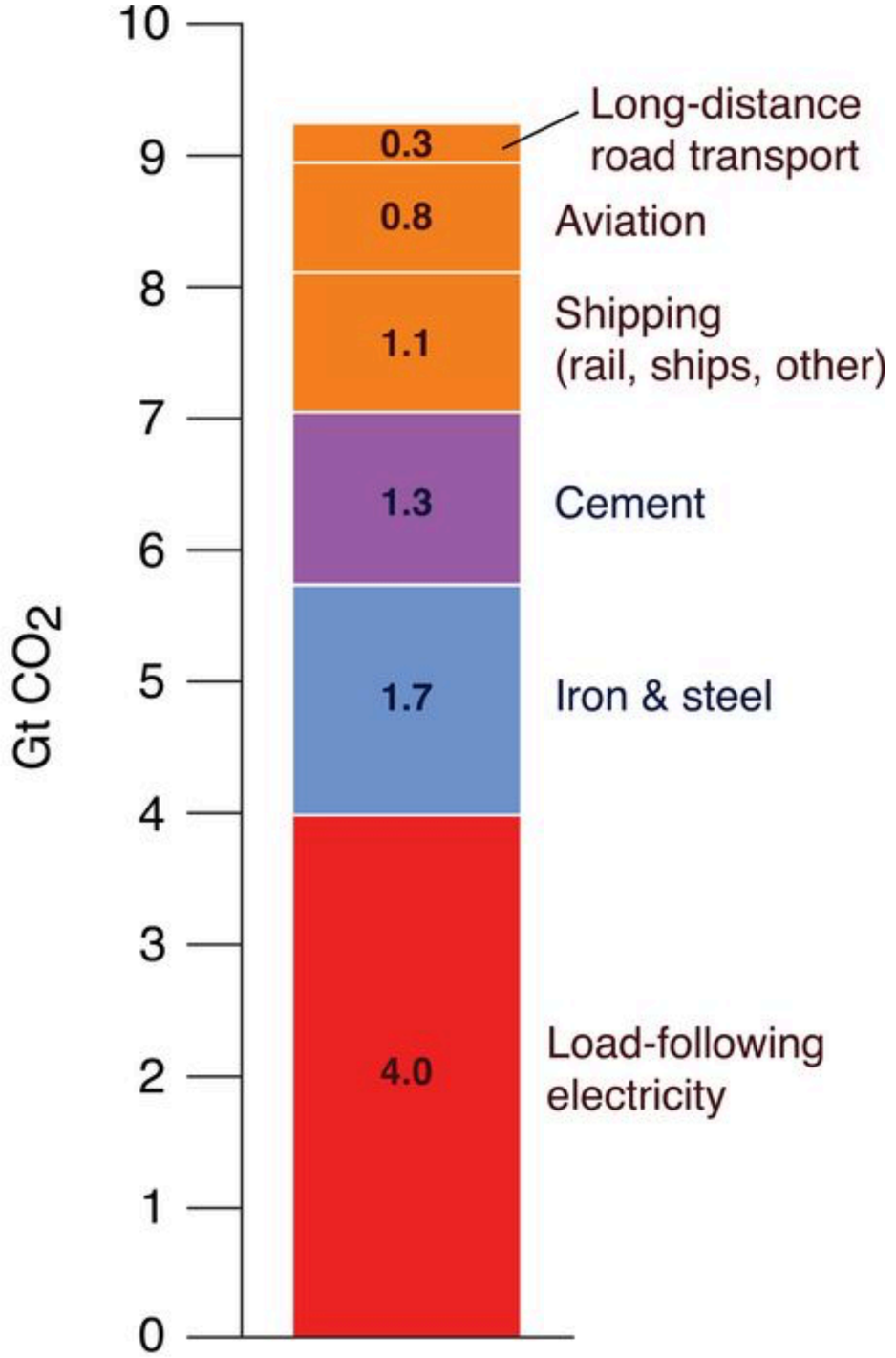
11,800 GW(e) 2050, Jacobson WWS, writing in 2012

9,000 GW(e) 2020, Hargraves/Uhlik, in 2017

Goal: generate **12,000 GW(e)** CO2-free, cheap, 24x7 power

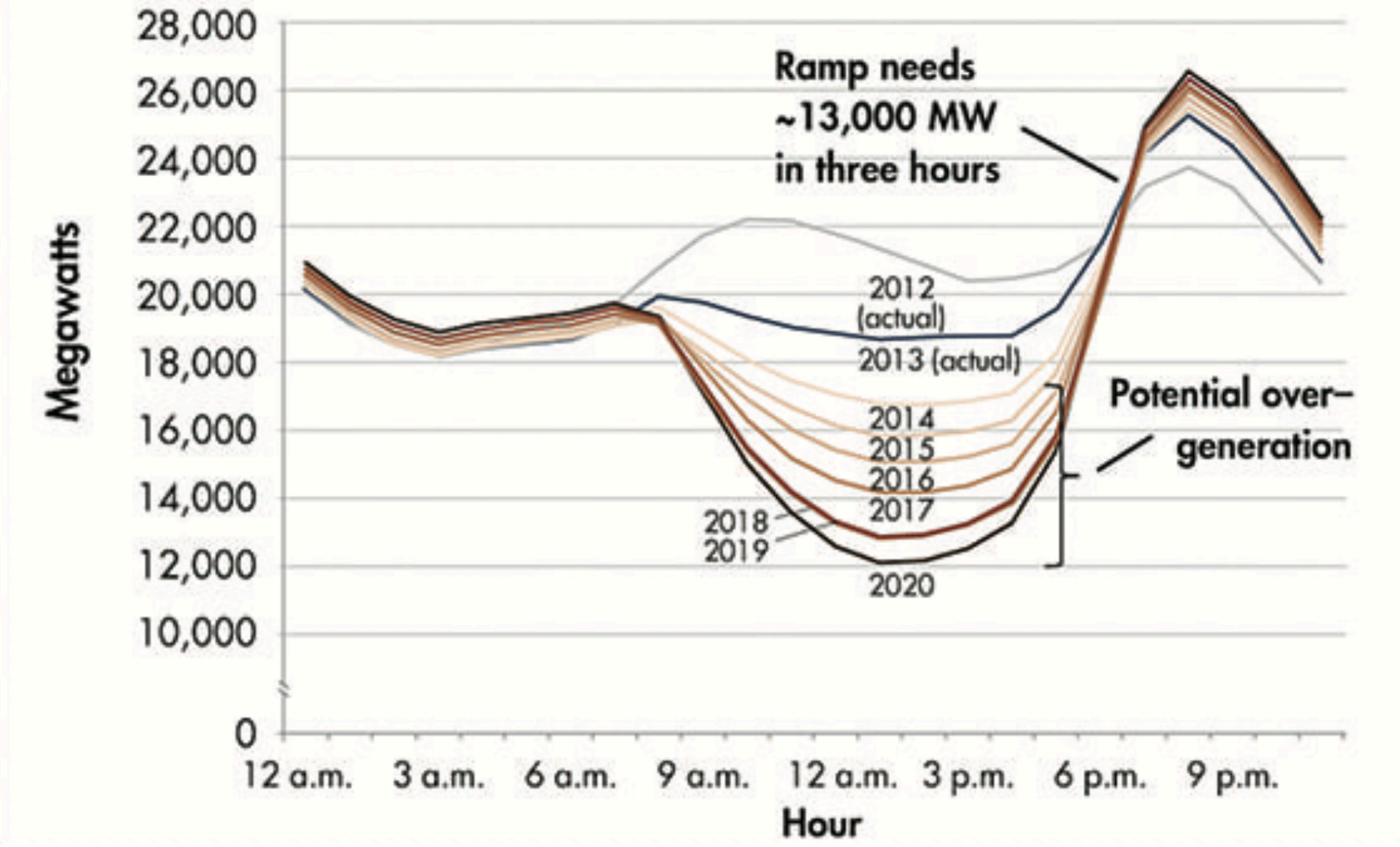
https://atomicinsights.com/clean-doable-liquid-fission-lf-energy-roadmap-%E2%80%A8powering-world/

Difficult to eliminate emissions
9 Gt CO2 (2014)



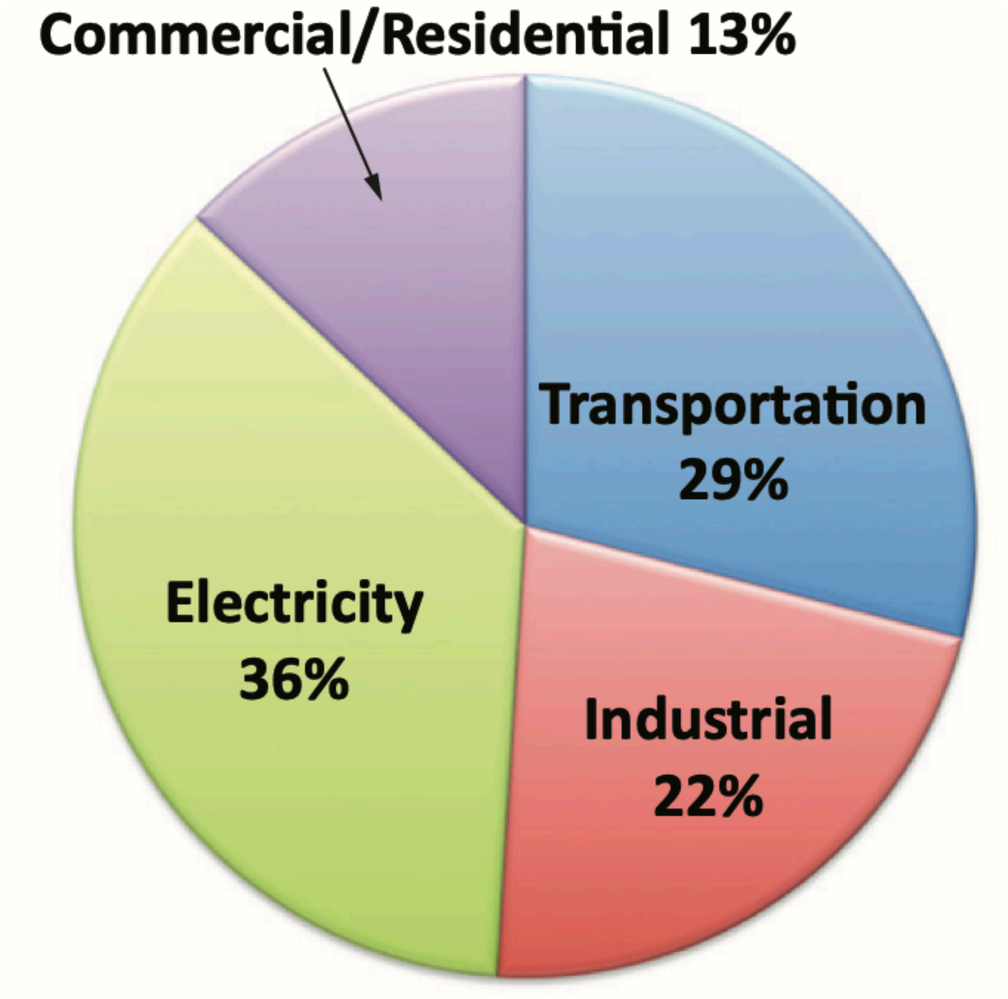
https://science.sciencemag.org/content/360/6396/eaas9793

Subsidized solar helped create the “difficult” load-following demand.

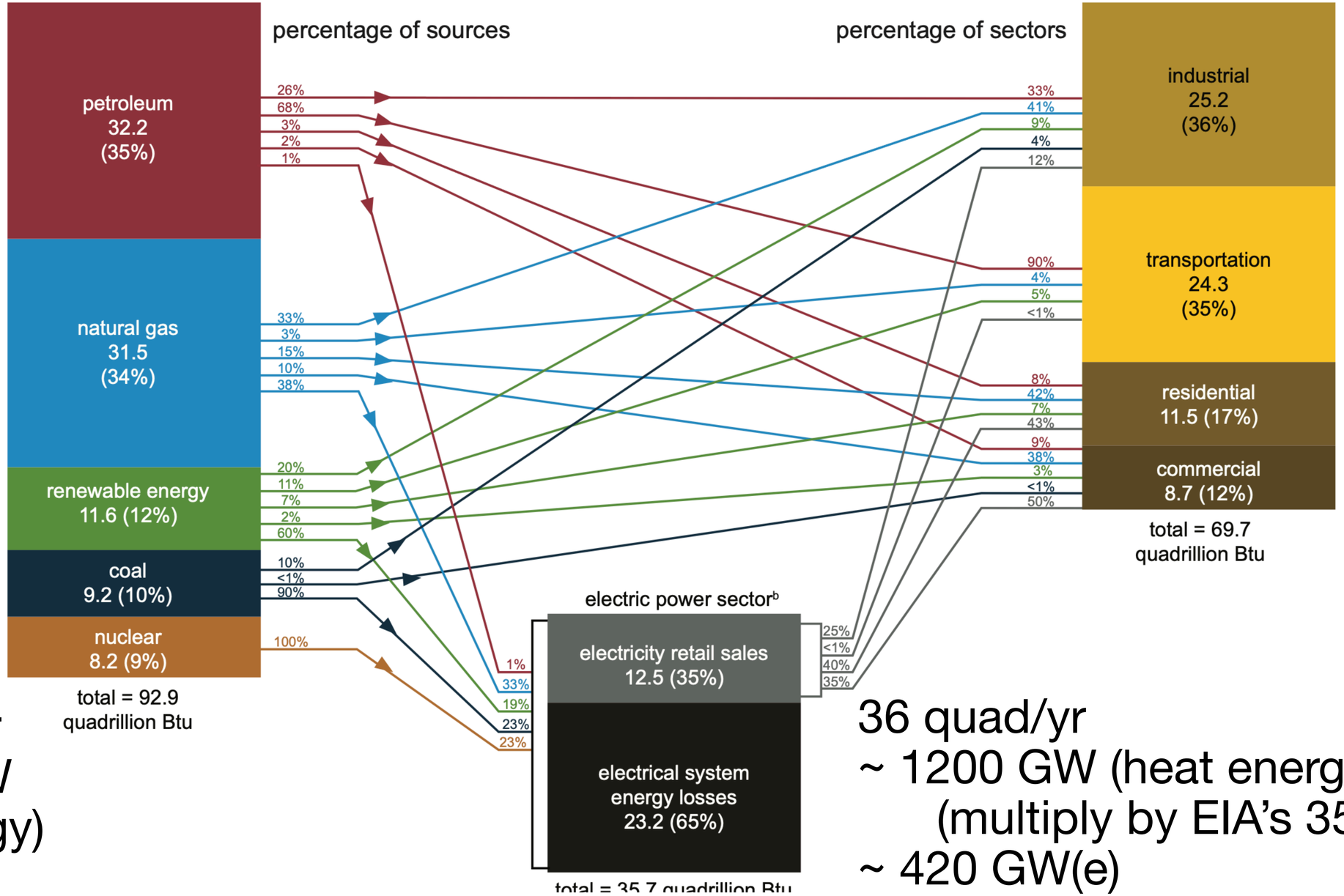


https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy

US DOE EIA energy by use sector



US energy consumption, from source, to sector, 2020



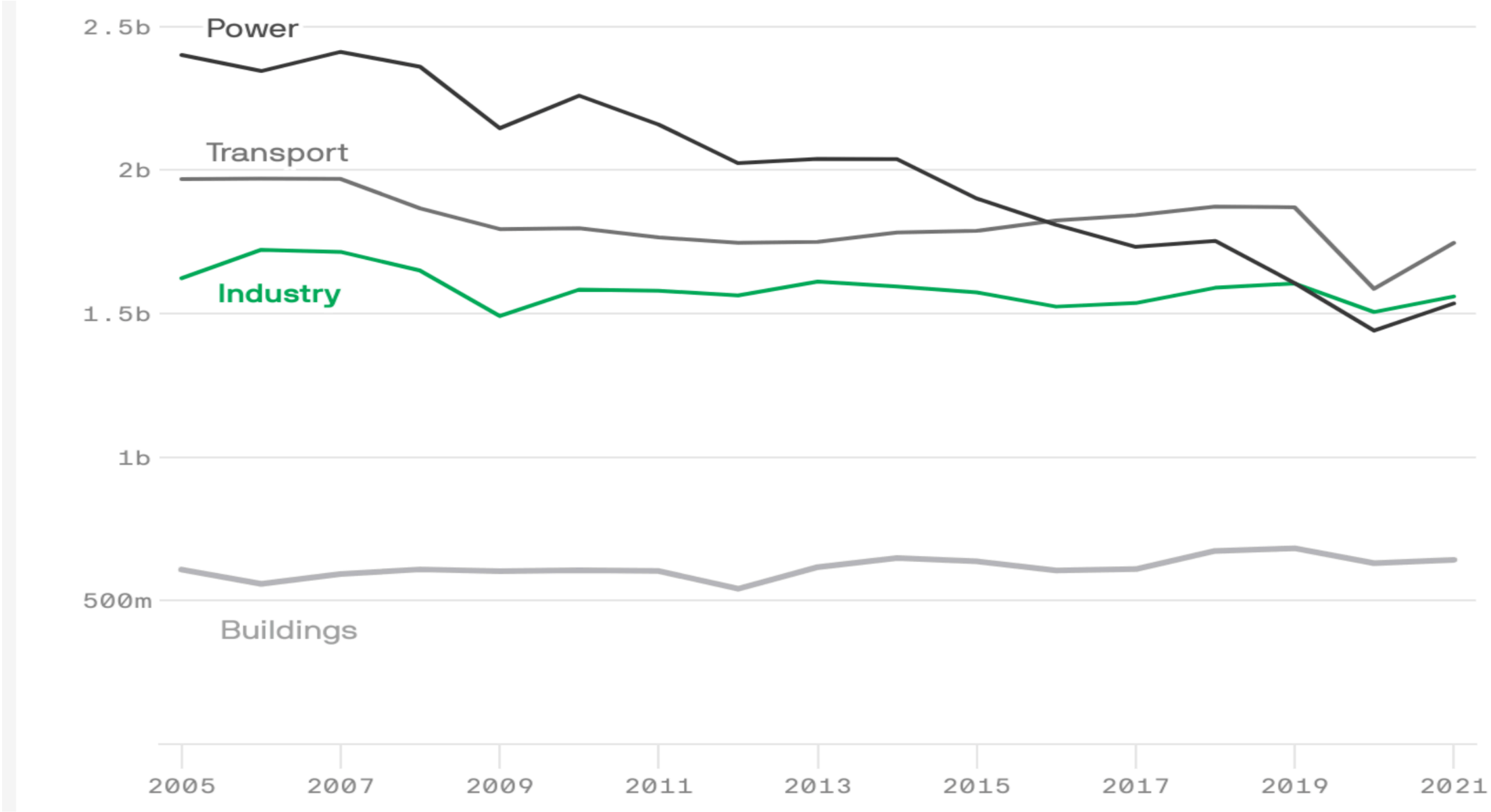
EIA
error in adding
kW(e) to kW(t)

93 quad/yr
~ 5000 GW
(heat energy)

36 quad/yr
~ 1200 GW (heat energy)
(multiply by EIA's 35% to get
~ 420 GW(e)

https://www.eia.gov/energyexplained/us-energy-facts/images/consumption-by-source-and-sector.pdf

US annual CO2-eq emissions, tons. Axios/Rhodium



https://www.axios.com/newsletters/axios-generate-d6e39fe0-39f4-4082-a19c-3e59f68b459c.html

Mark Z Jacobson strategy is a 100% water/wind/solar zero-CO_2 solution.

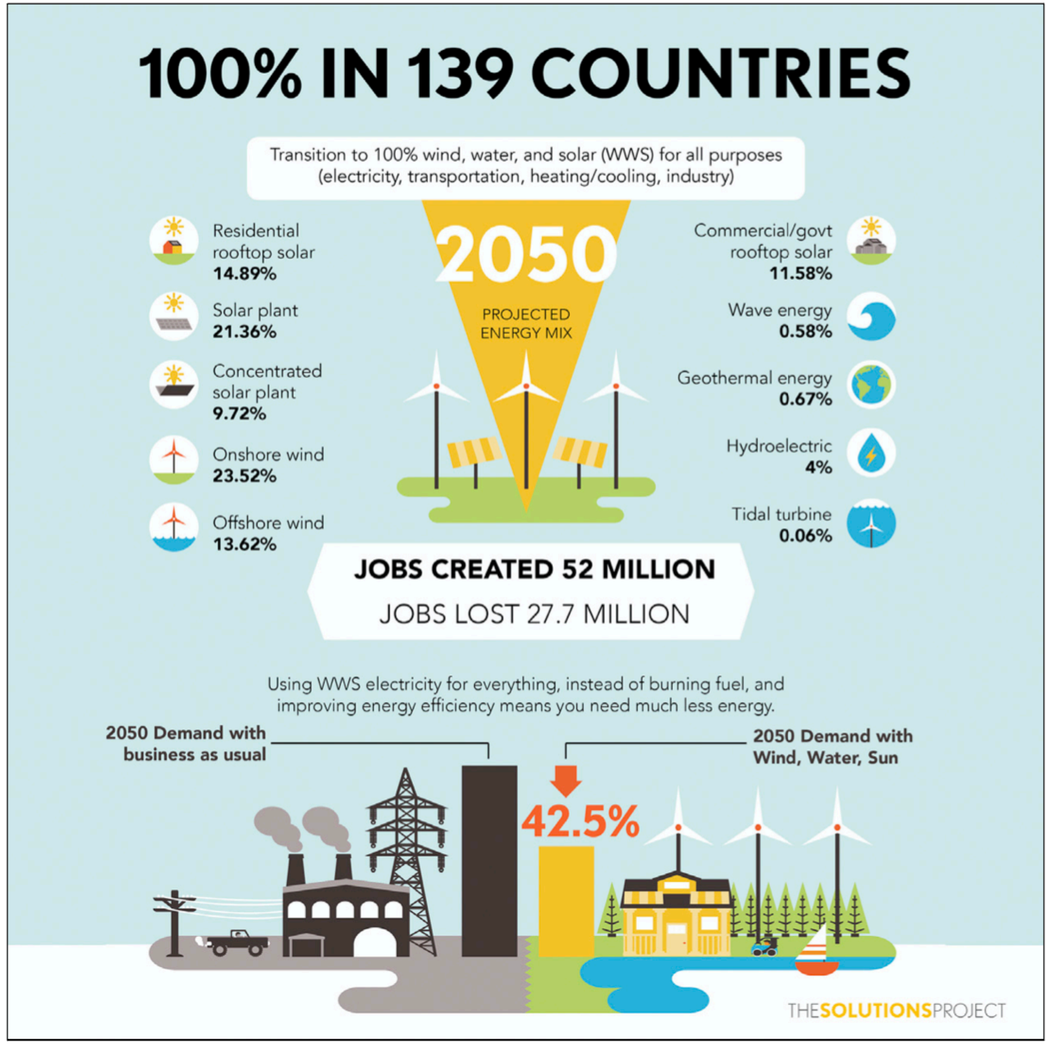
Inspired Green New Deal.

Refuted, discredited.

Jacobson sued refuting authors.

https://web.stanford.edu/group/efmh/jacobson/Articles/I/CountriesWWS.pdf

100% Clean and Renewable Wind, Water, and Sunlight All-Sector Energy Roadmaps for 139 Countries of the World



Mark Z. Jacobson, Mark A. Delucchi, Zack A.F. Bauer, ..., Jingfan Wang, Eric Weiner, Alexander S. Yachanin

jacobson@stanford.edu

HIGHLIGHTS

Roadmaps for 139 countries to use 100% wind-water-solar in all energy sectors

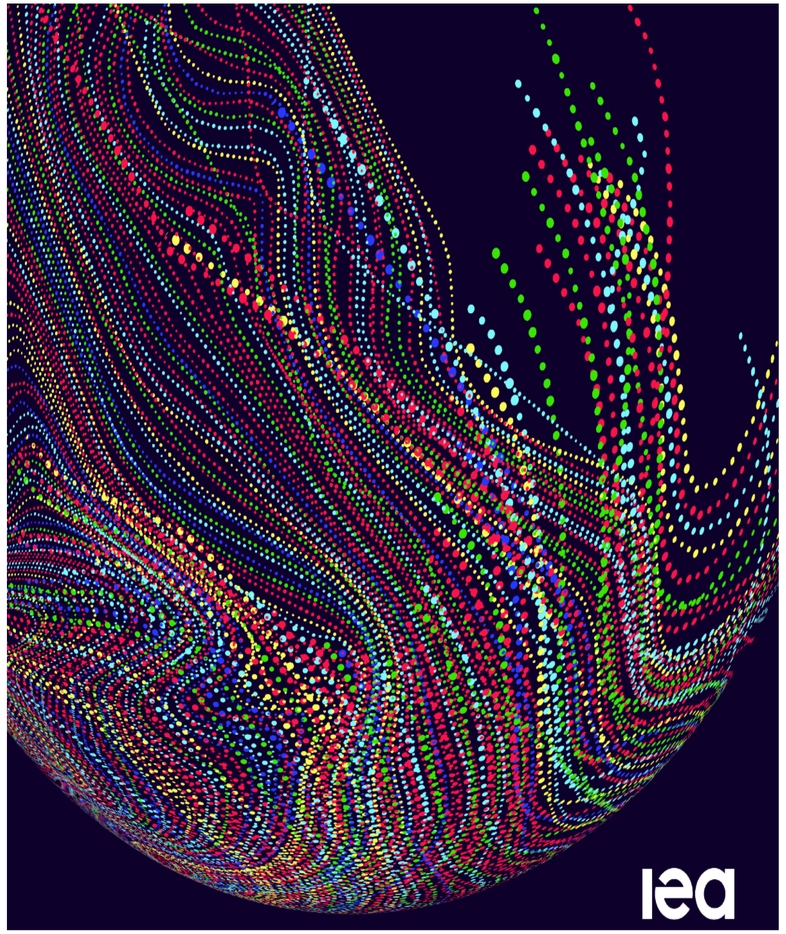
Roadmaps avoid 1.5°C global warming and millions of annual air-pollution deaths

Roadmaps reduce social cost of energy and create 24.3 million net long-term jobs

Roadmaps reduce power disruption and increase worldwide access to energy

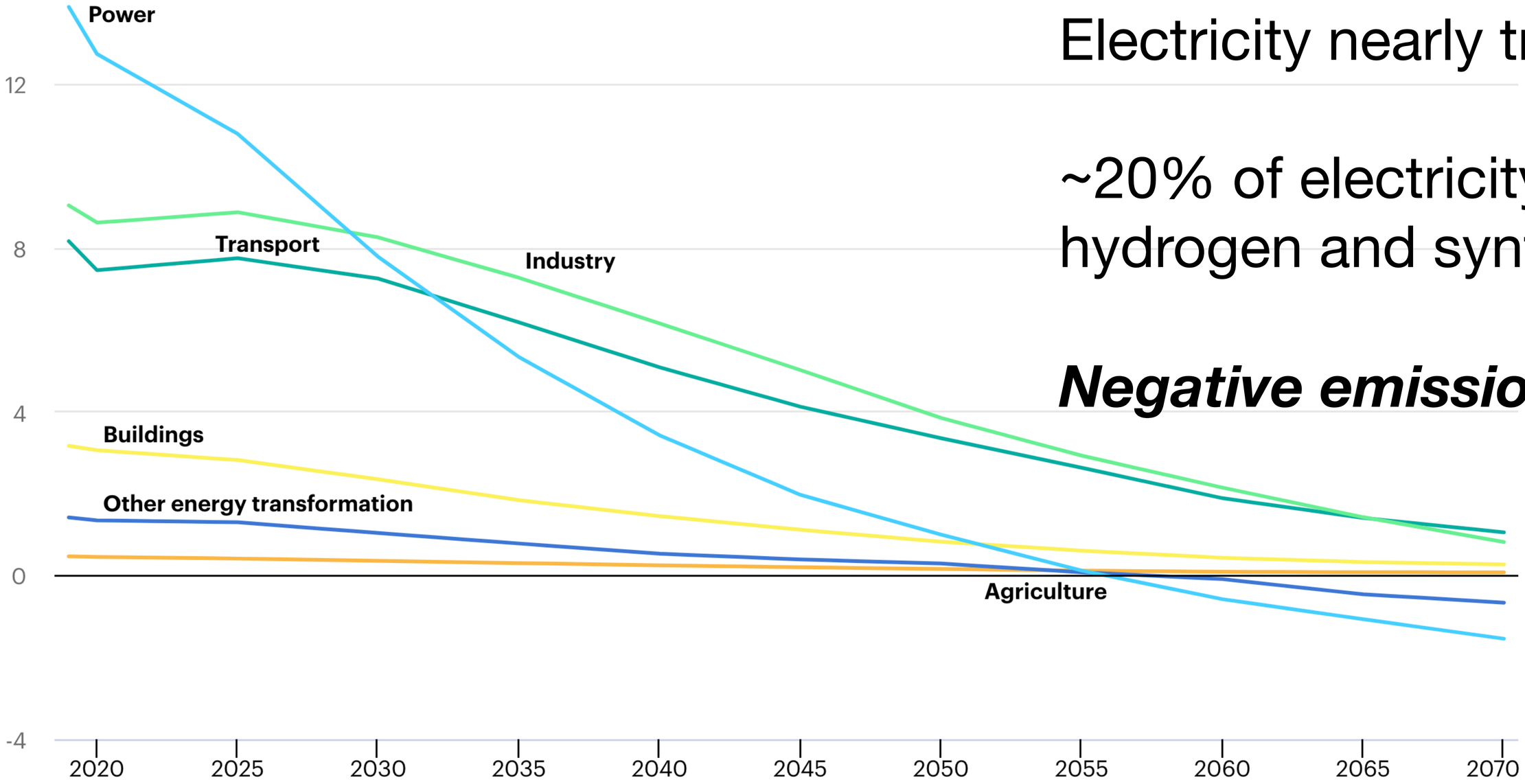
IEA strategy (Sept 2020)

1. Transforming the **power sector** alone would only get the world **one-third** of the way to net-zero emissions.
2. **Spreading the use of electricity** into more parts of the economy is the single largest contributor to reaching net-zero emissions.
3. **Hydrogen** extends electricity's reach.
4. Carbon capture and bioenergy play multifaceted roles.
5. **Long-distance transport and heavy industry** are the hardest emissions to reduce.



https://www.iea.org/reports/energy-technology-perspectives-2020

IEA strategy: annual CO2 emissions over 50 years.



Electricity nearly triples.

~20% of electricity for hydrogen and synfuels

Negative emissions?!

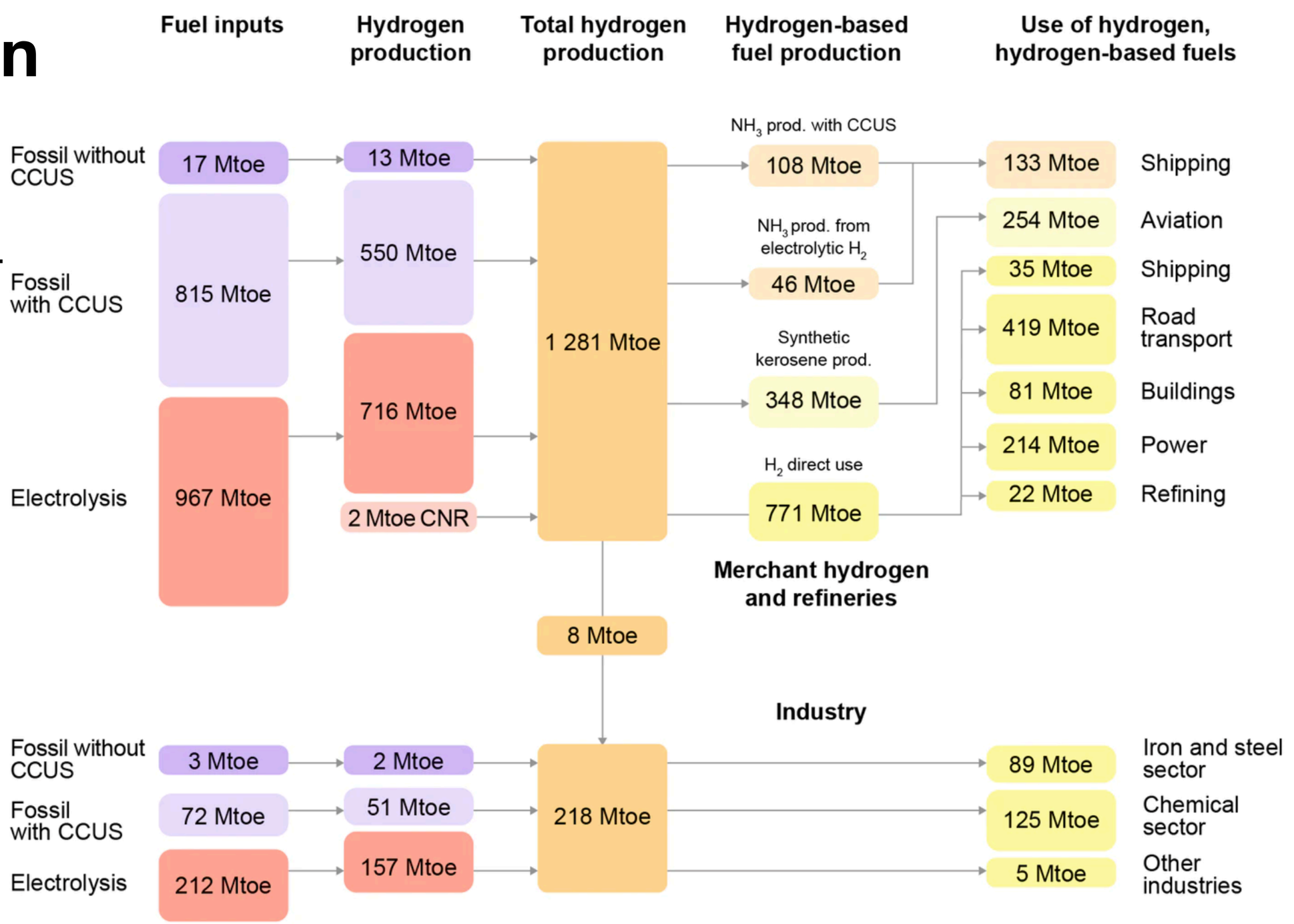
https://www.iea.org/reports/energy-technology-perspectives-2020

IEA Hydrogen strategy

Electrolyze 300 Mt-hydrogen per year (half H2 demand)

Total H2 prod = 1,281+218 = 1500 Mtoe/year = **2,000 GW**(t) of H2

CCUS = carbon capture underground storage



https://www.iea.org/reports/energy-technology-perspectives-2020

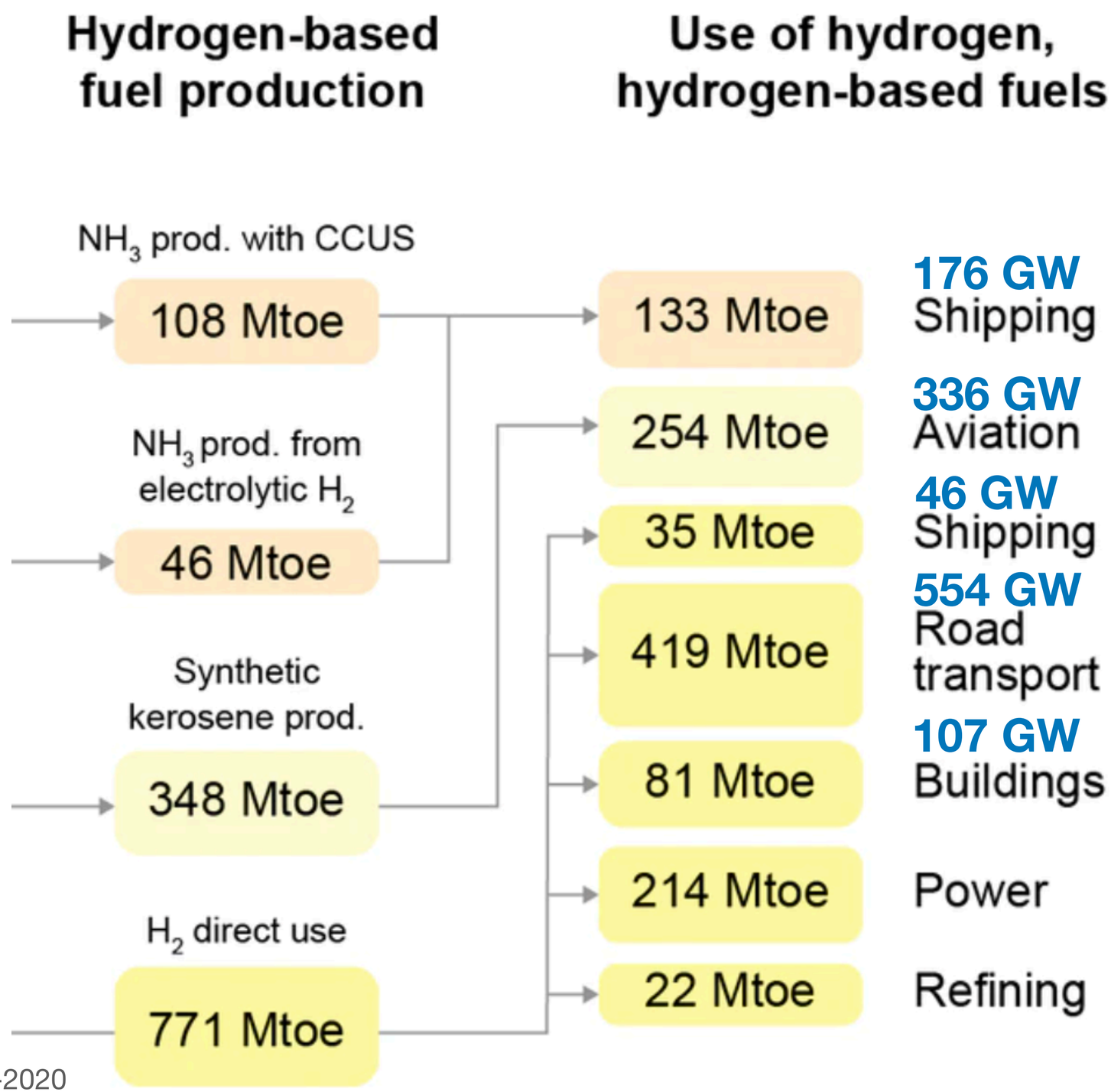
IEA synfuel strategy

154 Mtoe/year of ammonia =
204 GW NH3 for shipping

348 Mtoe/year kerosene =
462 GW aviation fuel

771 Mtoe/year hydrogen =
1000 GW H2 fuel

Note expectation of CCUS, carbon capture underground storage



https://www.iea.org/reports/energy-technology-perspectives-2020

Lucid Catalyst hydrogen synfuel strategy.

Lucid Catalyst fossil fuel replacement strategy.

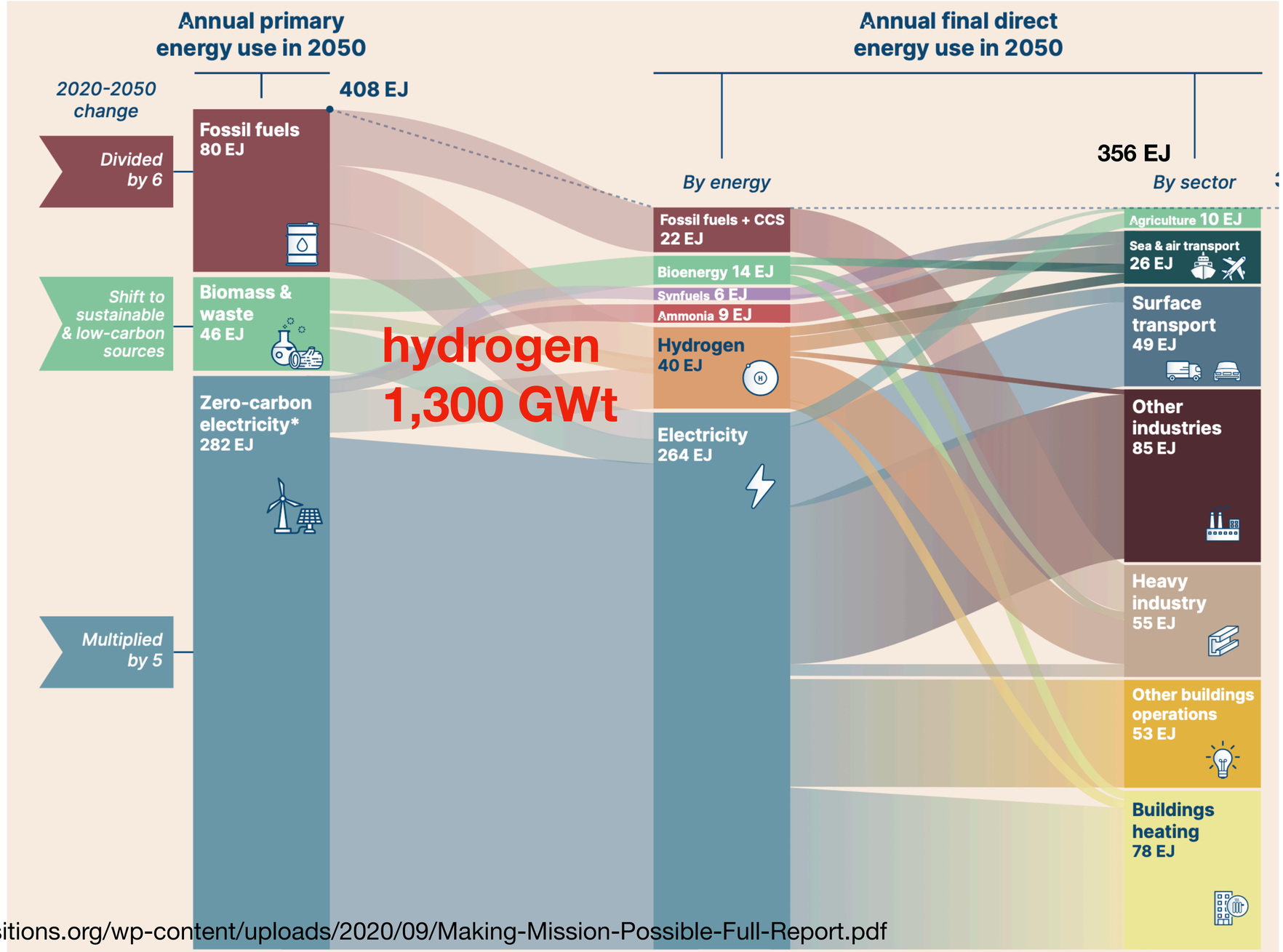
1. **Clean hydrogen**, as fuel or feedstock.
2. **High temperature electrolysis**, to make hydrogen at 95% efficiency.
3. **Cheap electricity**, source of hydrogen energy.
4. **Full-time operation**, to minimize capital costs.
5. **Clean heat**, for industrial processes.
6. **Synfuels**, such as ammonia, for shipping.
7. **Shipyard mass production**, of power plants, electrolyzers, and factories.

Energy Transitions Commission 2050 strategy (RMI, BNEF, ...)

fossil fuels
2,500 GWt

biomass
1,500 GWt

electricity
9,000 GWe



total
11,000 GWe

transport
2,400 GWe

lite industry
2,700 GWe

hvy industry
1,800 GWe

bldg ops
1,700 GWe

heating
2,500 GWe

https://www.energy-transitions.org/wp-content/uploads/2020/09/Making-Mission-Possible-Full-Report.pdf

Fission energy grand strategy

Electricity
- Ample, cheap, 24x7 electric power

Transportation
- electrify rail, light vehicles
- synfuels for air, sea, heavy land transport

Buildings
- building codes, heat pumps
- district heating

Industry
- high heat: electric arcs, plasma torches
- new processes, H2 reduction

Key technologies

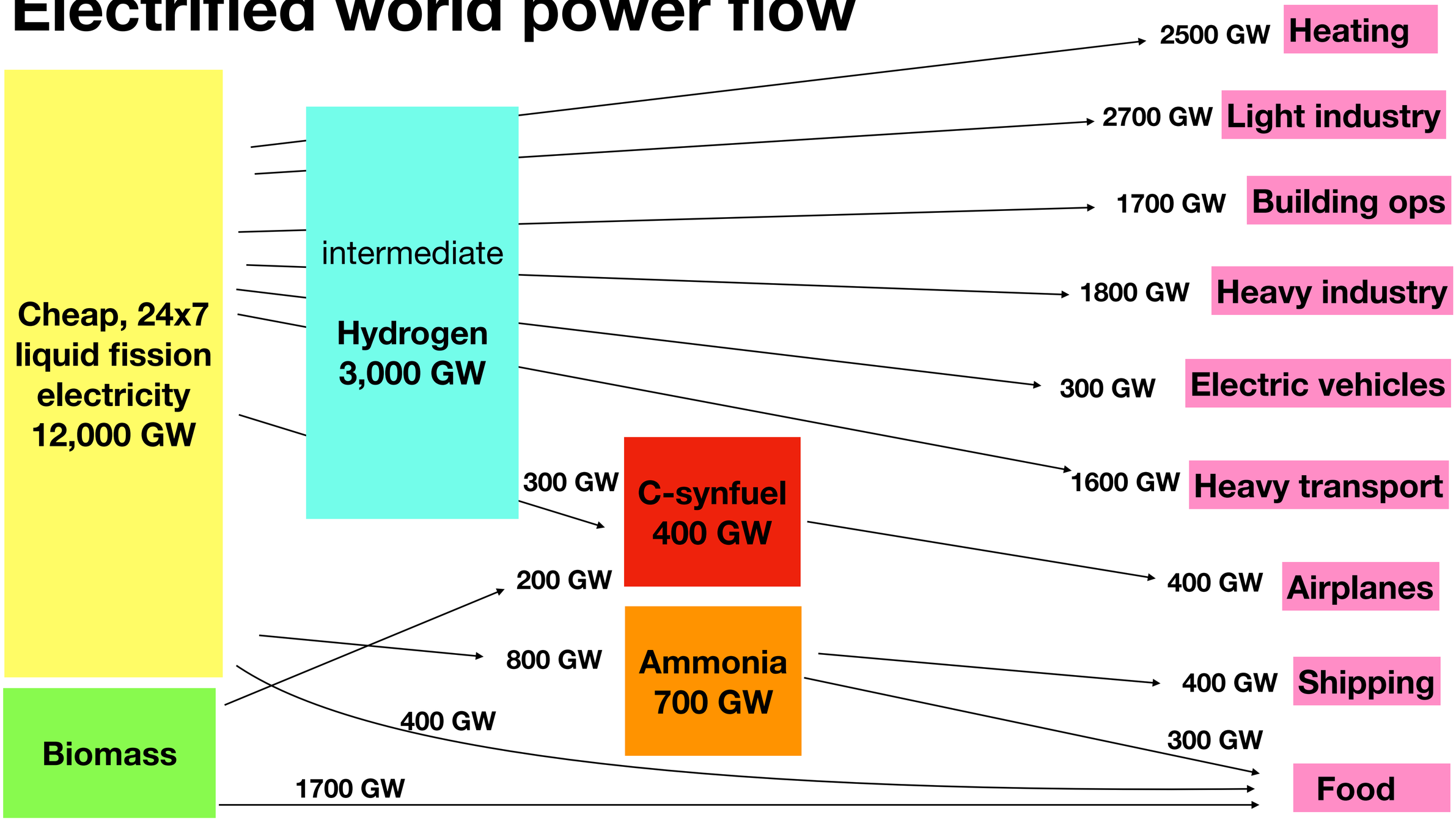
Liquid fission
- high temp, low press
- liquid fuel

Hydrogen
- water electrolysis

Ammonia
- fuel, fertilizer

Shipyard manufacturing
- fast, efficient
- power plants
- factories

Electrified world power flow



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