Our Burning Economy, Siren Song, and Fission Promise

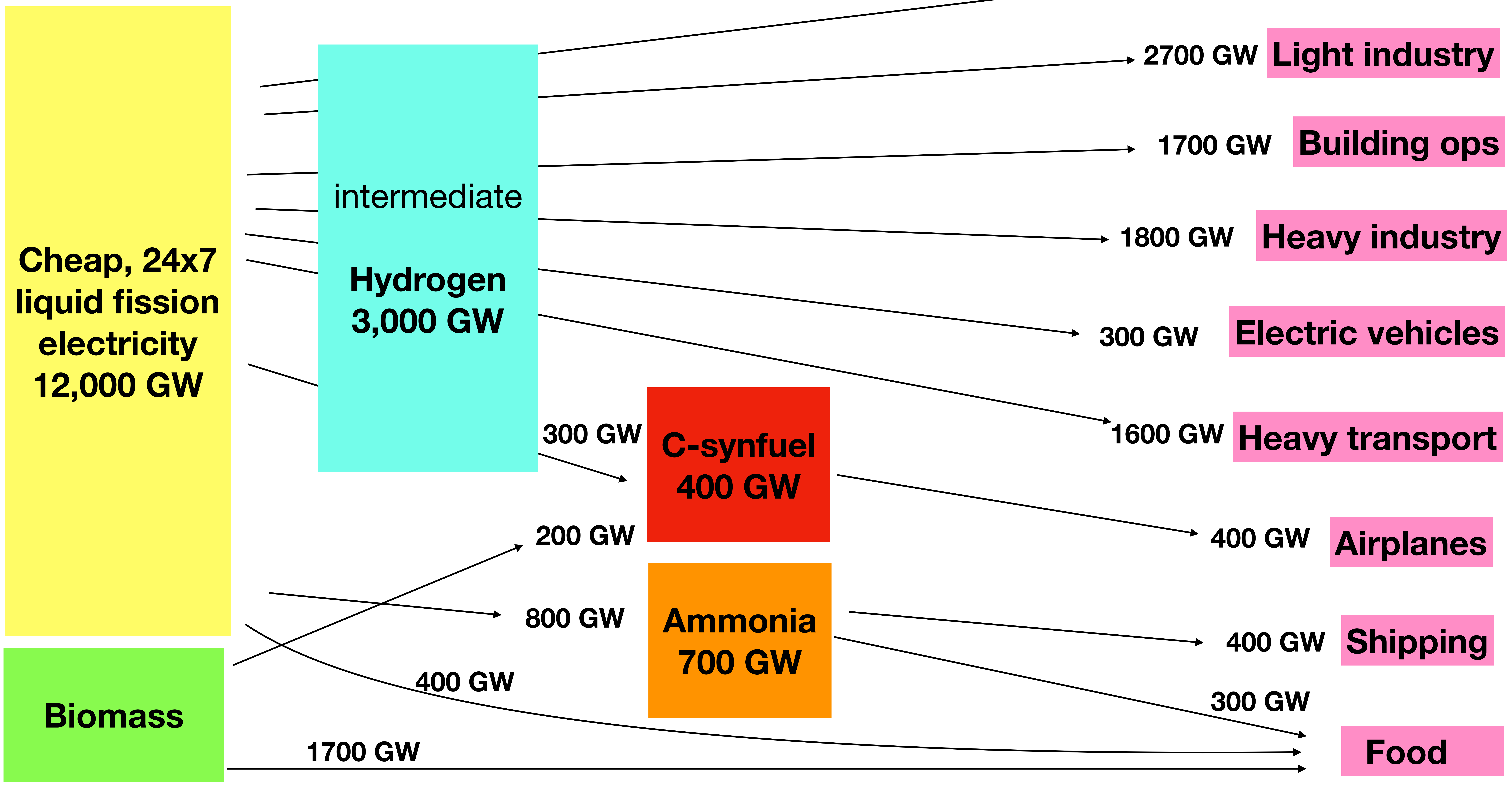
Hydrogen, Transportation, Buildings, Industry, Policy

Osher @ Dartmouth

Robert Hargraves

Jan 25, 2023

Transportable hydrogen energy



Steam methane reforming produces 95% of world H2.

$$CH_4 + H_2O \rightleftharpoons CO + 3\ H_2$$

$$\underline{CO + H_2O \rightleftharpoons CO_2 + H_2}$$

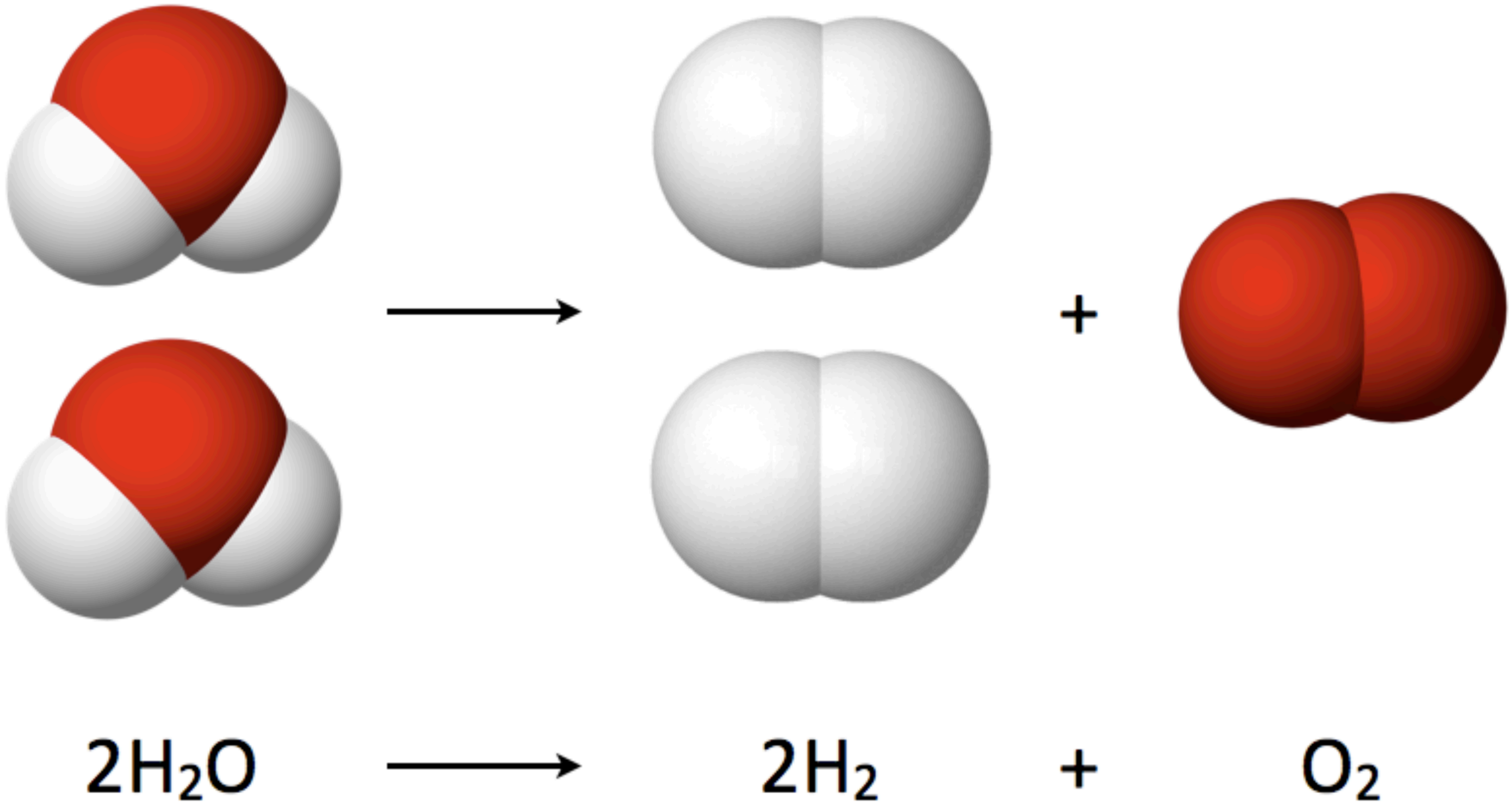
====================

$$CH_4 + 2\ H_2O \rightleftharpoons CO_2 + 4\ H_2$$

1. SMR generates 9.3 kg-CO2 per 1 kg-H2.
2. Nearly 1 Gt-CO2 released annually.
3. H2 used in oil refining and ammonia (NH3) production.
4. Stored chemical energy of H2 = 143 MJ/kg or 40 kWh/kg.
5. $1.6 to $2 per kg SMR-produced H2, varies with CH4 cost.

https://www.sciencedirect.com/topics/engineering/hydrogen-production-cost

Electrolyzers can convert H2O to H2 (and O2)



Today's costs ~ $10/kg do not compete with SMR @ $2/kg.
US offering $3/kg subsidy.

https://www.hydrogen.energy.gov/pdfs/review19/p148B_boardman_2019_p.pdf

Sunfire SOEC electrolyzer, for H2 for steel manufacturing.

Salzgitter, Germany

steam @ 850°C

200 Nm3/hr

720 kW(e) input

600 kW(t) output

83% ‘efficiency’ =

kWh(t) / kWh(e)

$7/kg-H2

https://www.green-industrial-hydrogen.com/fileadmin/user_upload/220413_GrInHy2.0_Flyer_v6.pdf

https://www.h2bulletin.com/salzgitter-and-sunfire-complete-grinhy2-0-project/

Shell starts up Europe’s largest hydrogen electrolyser.

Cologne, Germany

$24 million

1,300 tonnes-H2/year

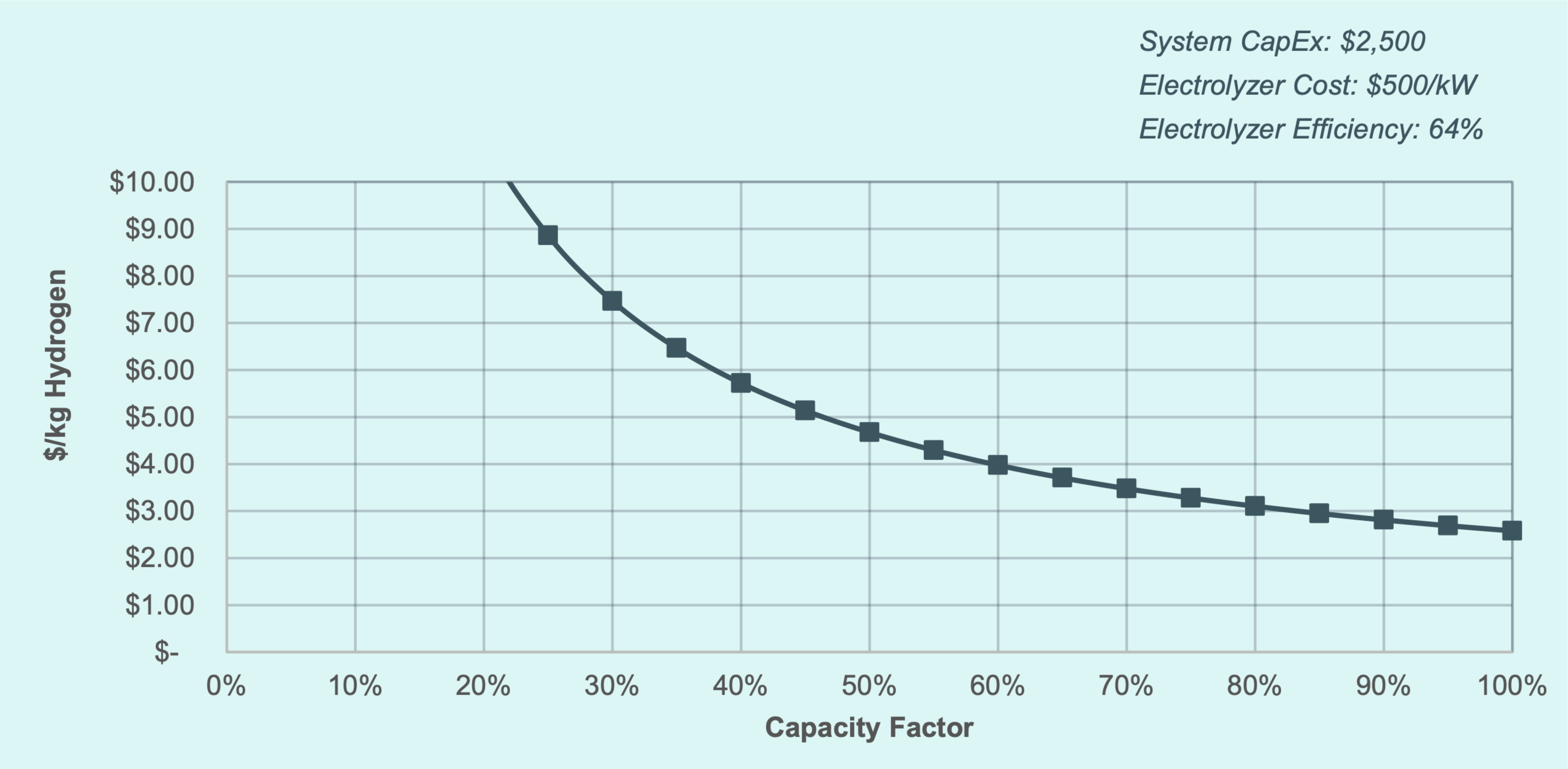
10 MW(e) input

4.9 MW(t) output

49% ‘efficiency’

https://www.thechemicalengineer.com/news/shell-starts-up-europe-s-largest-pem-green-hydrogen-electrolyser/

Electrolyzer capacity factor affects H2 $/kg.



https://85583087-f90f-41ea-bc21-bf855ee12b35.filesusr.com/ugd/2fed7a_0d2e1cc06bff412cb3031fd4bdf93cb0.pdf

Lucid Catalyst: cost of electrolytic hydrogen can be competitive with steam methane reforming.

"We find that a **new generation of advanced modular reactors**, hereafter referred to as advanced heat sources, with new manufacturing-based delivery models, could deliver hydrogen on a large scale for $1.10/kg, with further cost reductions at scale reaching the target price of $0.90/kg by 2030."

https://85583087-f90f-41ea-bc21-bf855ee12b35.filesusr.com/ugd/2fed7a_0d2e1cc06bff412cb3031fd4bdf93cb0.pdf

Value of thermal energy of 1 kg-H2, @ $1

- **142 MJ** (HHV)
- **120 MJ (**LHV, lower heating value)
- **33 kWh** (t)
- **1 gallon** gasoline or diesel (approx)
- **1 GJ** costs $7
- **1 kWh**(t) costs 3 cents

https://afdc.energy.gov/files/pdfs/hyd_economy_bossel_eliasson.pdf

Energy Transitions Commission estimates mid-century H2 production of 500 to 800 Mt/year.

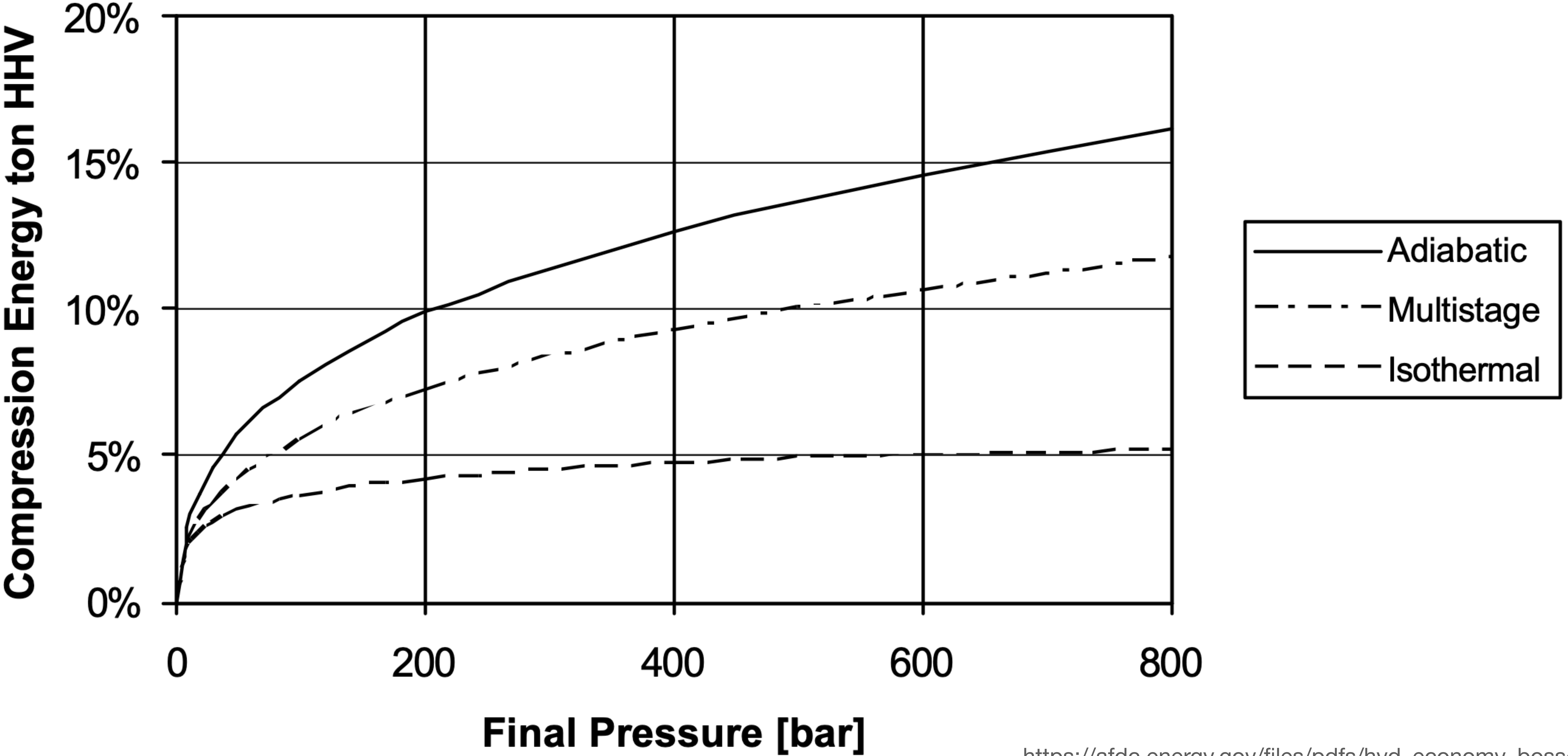
(here Mt means million tonnes, not metric tons)

800 Mt/year demand ($800 billion/year @$1/kg)
x 33 kWh/kg ÷ 24 h/day ÷ 365 day/year
= 3,000 GW(t) chemical potential energy flow,
@ 100% ‘efficient’ electrolyzers,
~ 3,000 GW(e)

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

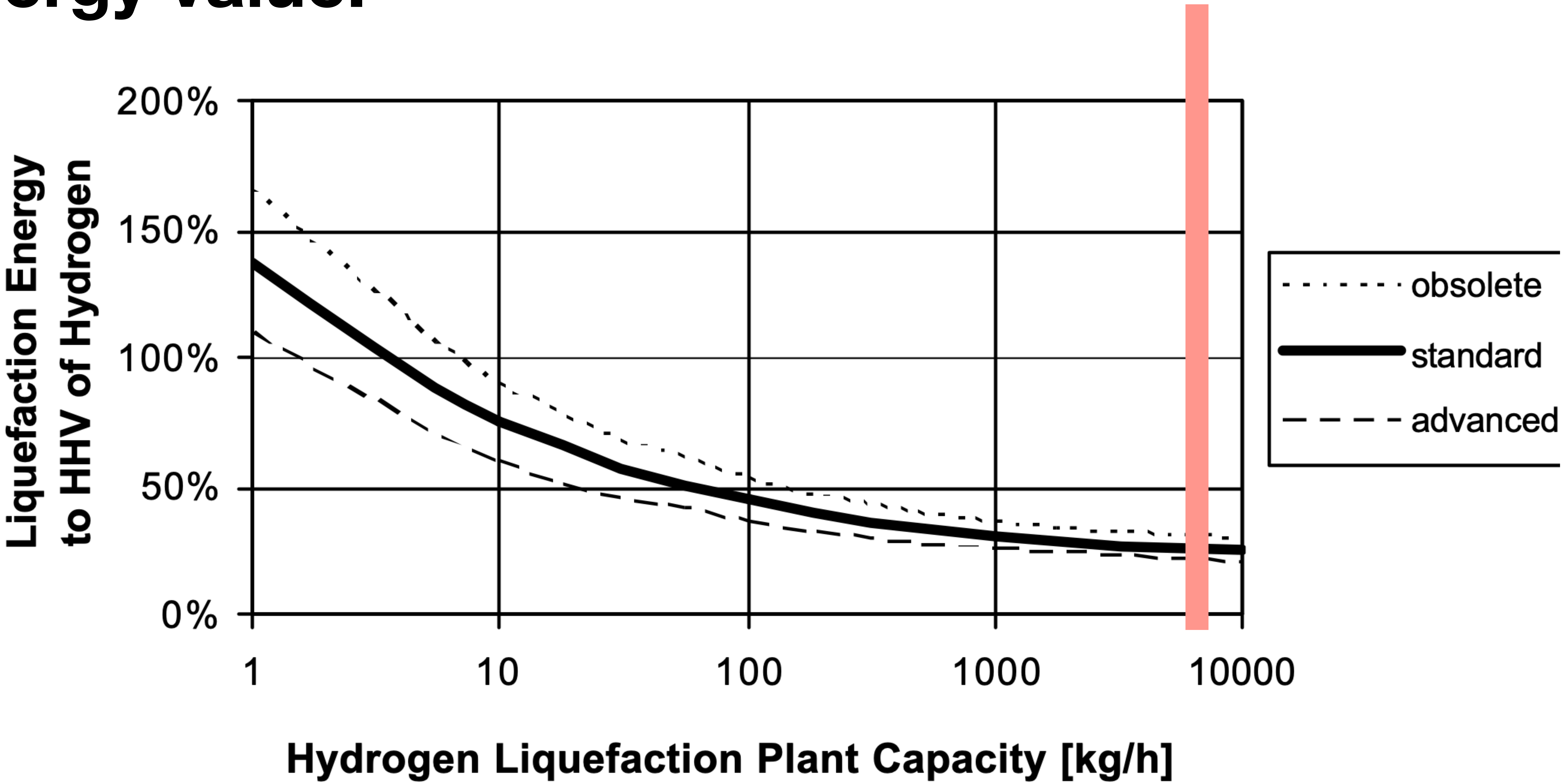
https://afdc.energy.gov/files/pdfs/hyd_economy_bossel_eliasson.pdf

Fuel-cell vehicles tanks want H2 compressed to 350 or 700 bar, using ~8-16% of energy value.



https://afdc.energy.gov/files/pdfs/hyd_economy_bossel_eliasson.pdf

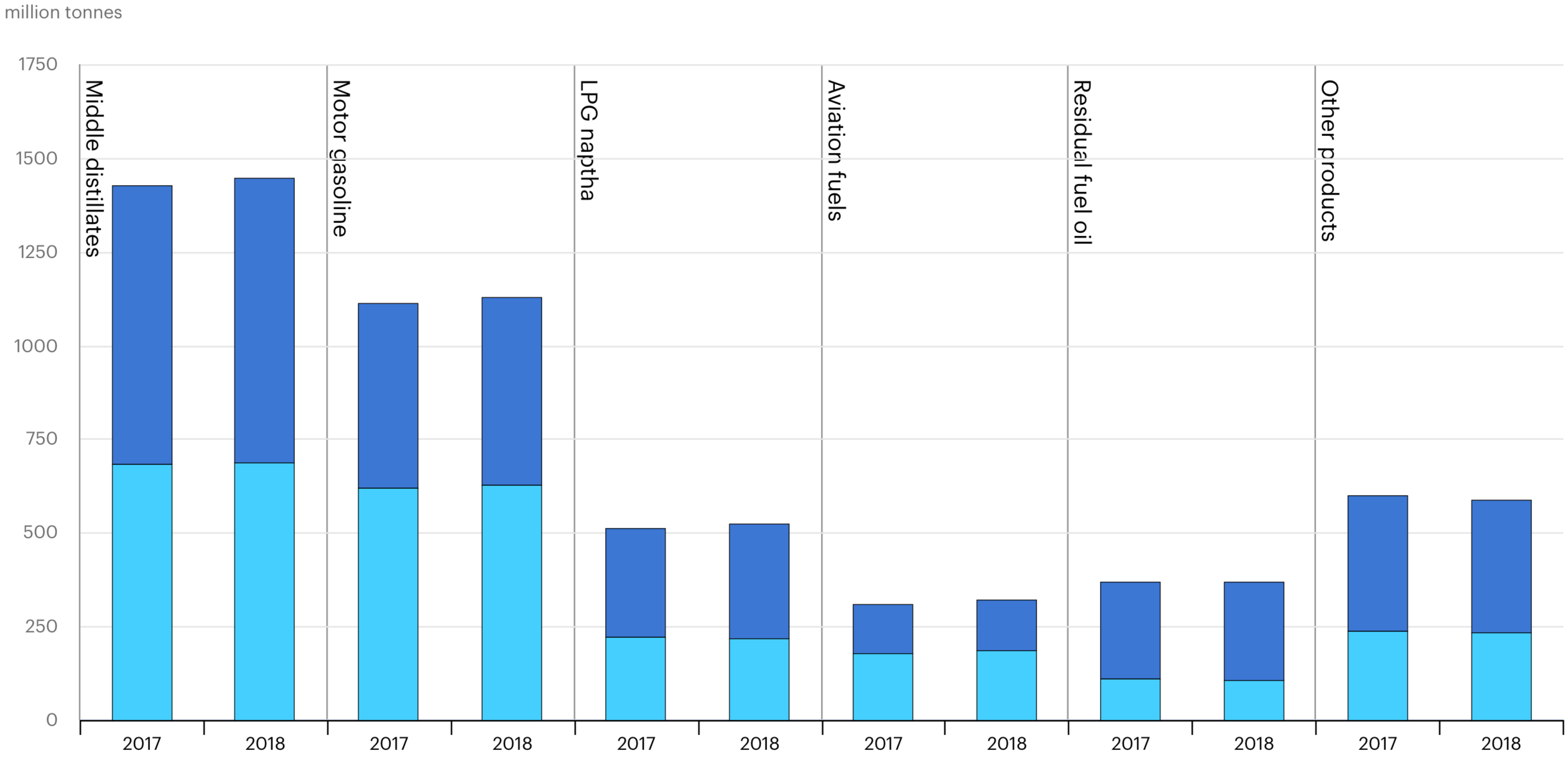
Liquefaction of H2 to -253°C costs 30% of its energy value.



https://afdc.energy.gov/files/pdfs/hyd_economy_bossel_eliasson.pdf

World gasoline consumption is ~ 1700 GW.

IEA reports 1136 million tonnes for 2018



https://www.iea.org/reports/oil-information-overview

Fuel weight and volume are critical for vehicles.

Fuel	kWh/kg	kWh/L
Petroleum, C-synfuel	13	11.0
Hydrogen liquid, -253°C	33	2.4
Hydrogen gas, 700 bar	33	1.2
Ammonia liquid	5	3.3
Methane, 250 bar	15	9.0
LNG, -160°C	15	6.1
Lithium ion battery	0.2	0.8

https://en.wikipedia.org/wiki/Energy_density

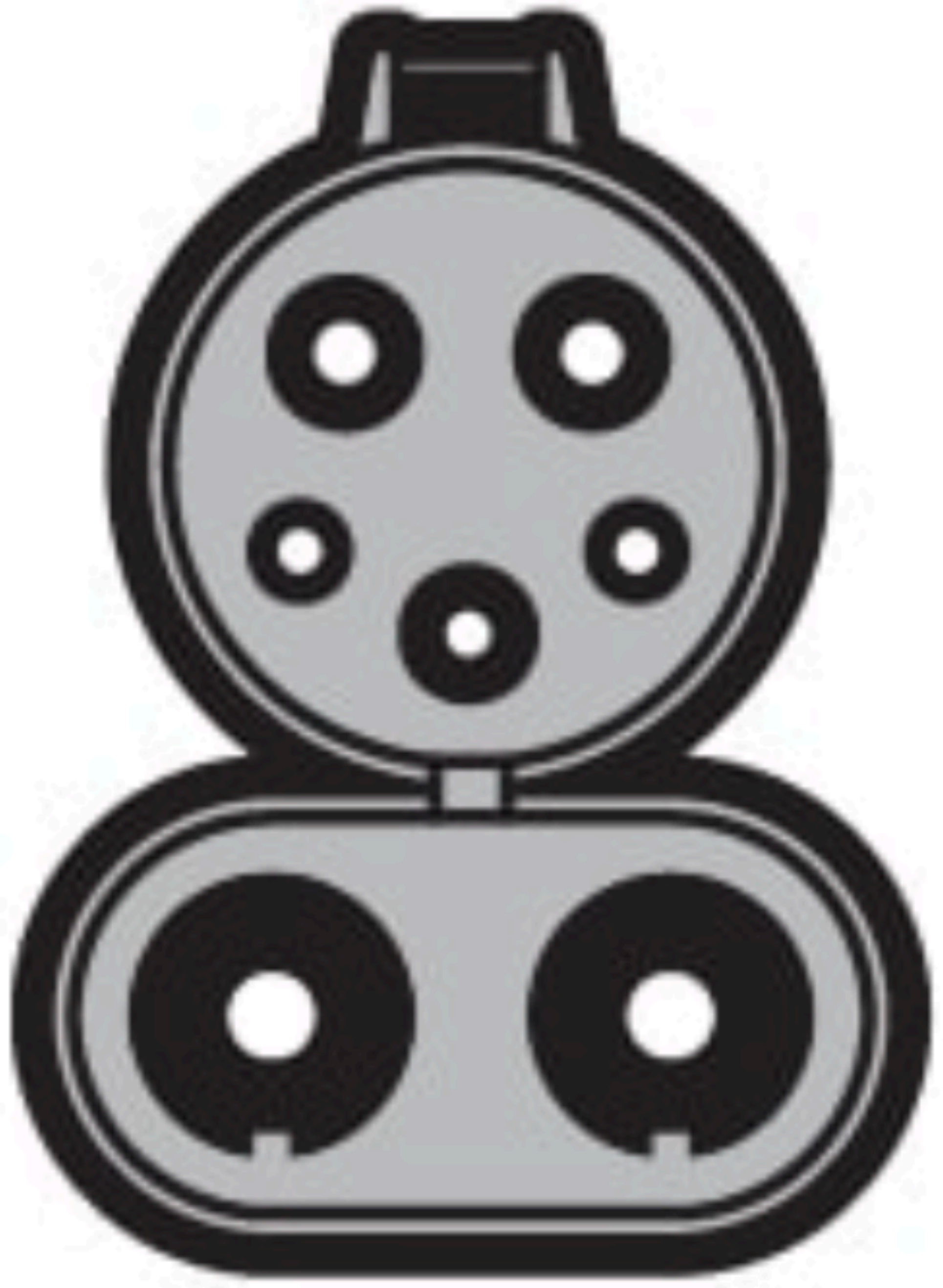
One billion electric cars will need 250 GW of electric power, on average.

writes Green Car Reports in 2011

https://www.greencarreports.com/news/1065070_its-official-we-now-have-one-billion-vehicles-on-the-planet

There are several EV charging station standards, and 800 charging networks in the US.


Level 1 & 2 J1772
Charge Port


DC Fast Charging
SAE/CCS Combo

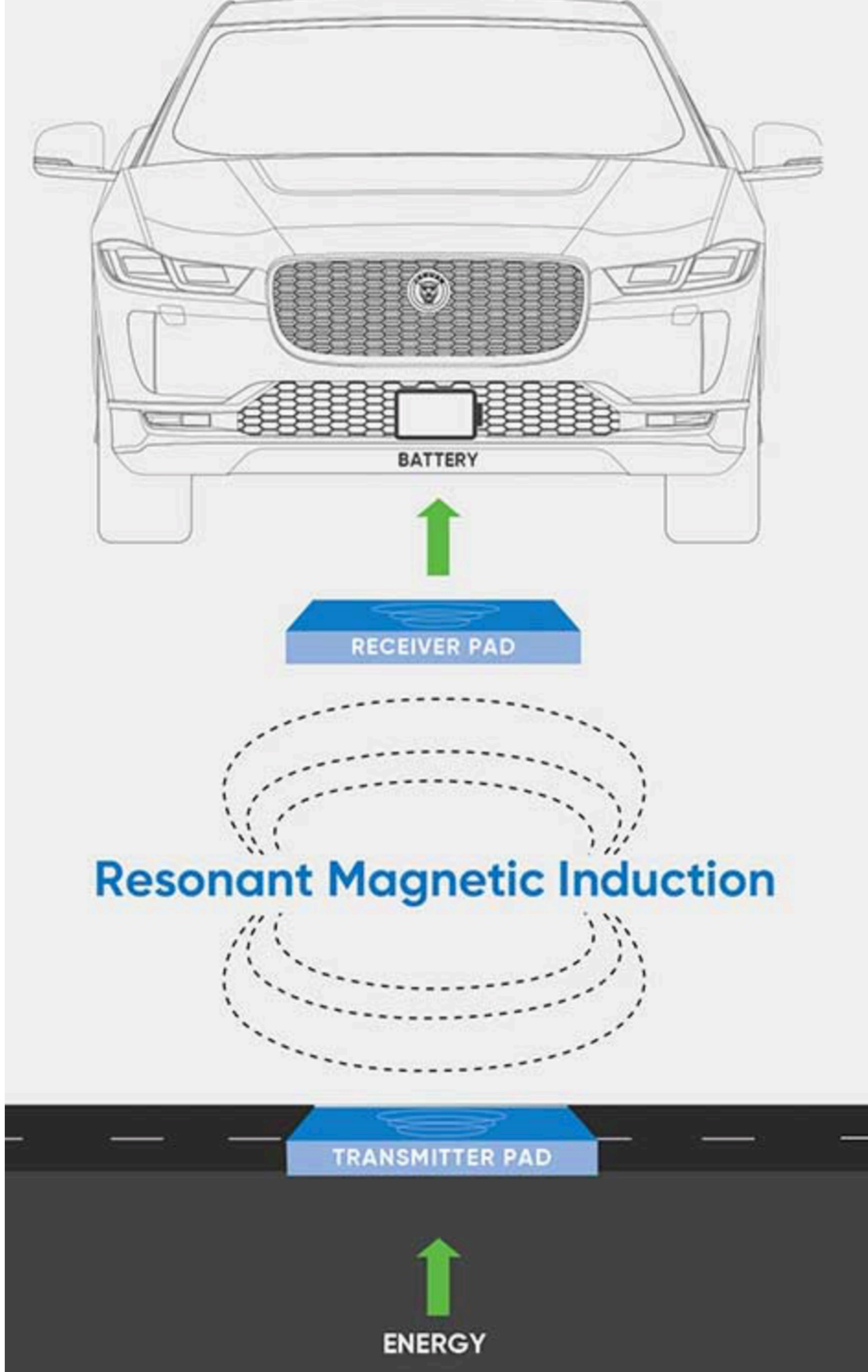

DC Fast Charging
CHAdeMO


DC Fast Charging
Tesla

For local driving, home-based charging solves this.

Resonant inductive charging system can deliver 200 kW @ 94% efficiency.

- Add 80 km of range for every 15 min of hovering.
- May enable use of lower-capacity, less-expensive, less weighty batteries.



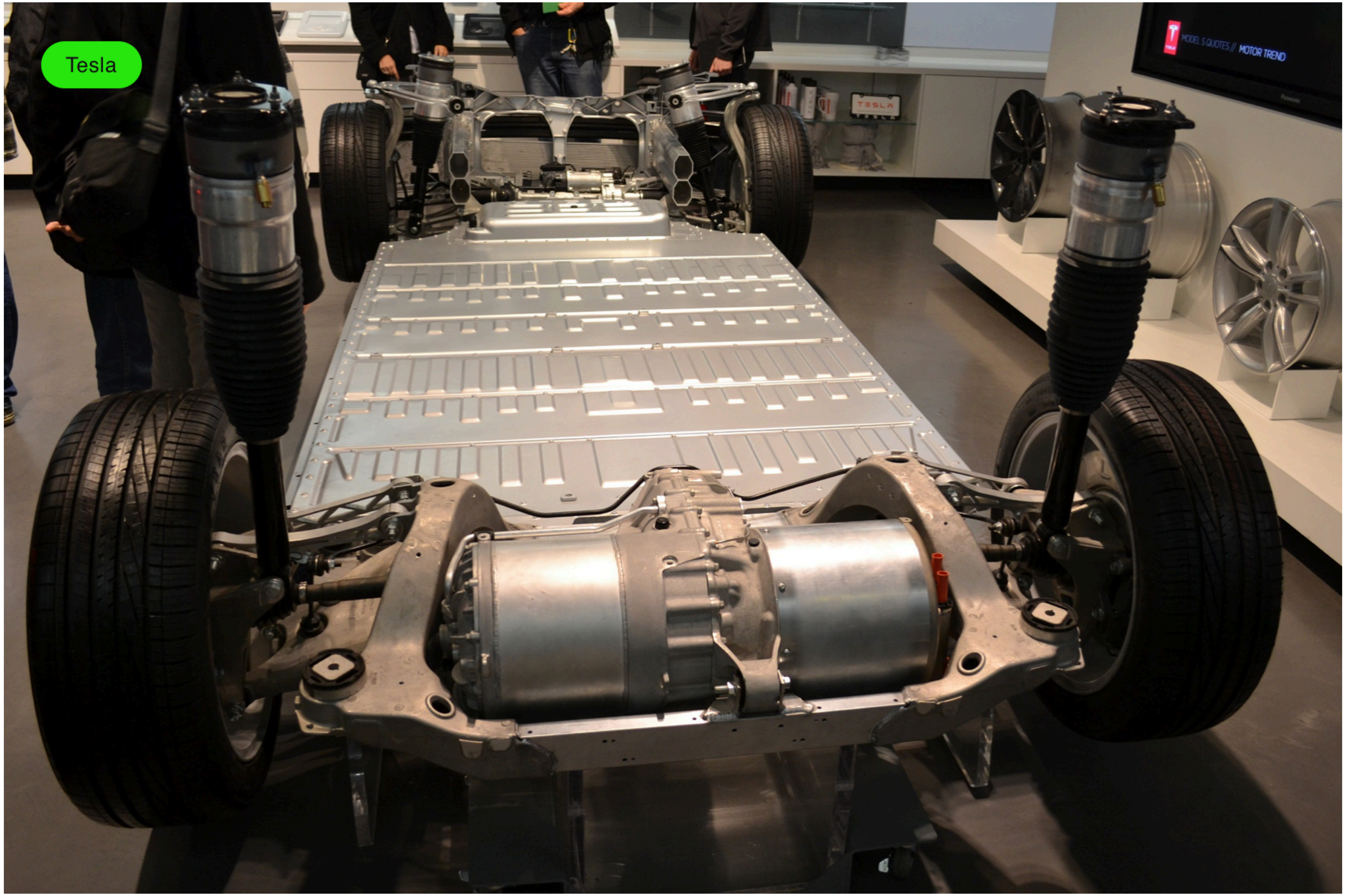
https://spectrum.ieee.org/cars-that-think/transportation/advanced-cars/wireless-charging-tech-to-keep-evs-on-the-go

ElectReon system delivers 45 kW to trucks traveling on 4.1 km SmartRoad Gotland.

- Objective: charging at 125 kW at highway speeds.
- ElectReon is powering up a 2 km roadway in Tel Aviv, and one in Detroit.

https://www.greencarreports.com/news/1127520_world-first-in-road-charging-test-for-trucks-successful-highway-speeds-next https://www.timesofisrael.com/israeli-smart-road-startup-to-debut-wireless-charging-infrastructure-in-us/

EV batteries contain precious Li, Fe, P, Co, Ni, Cu metals.



Tesla examples

Model S	544 kg
Model 3	478 kg
Roadster	833 kg

https://enrg.io/tesla-battery-weight-overview-all-models/

EV batteries contain precious Li, Fe, P, Co, Ni, Cu metals.

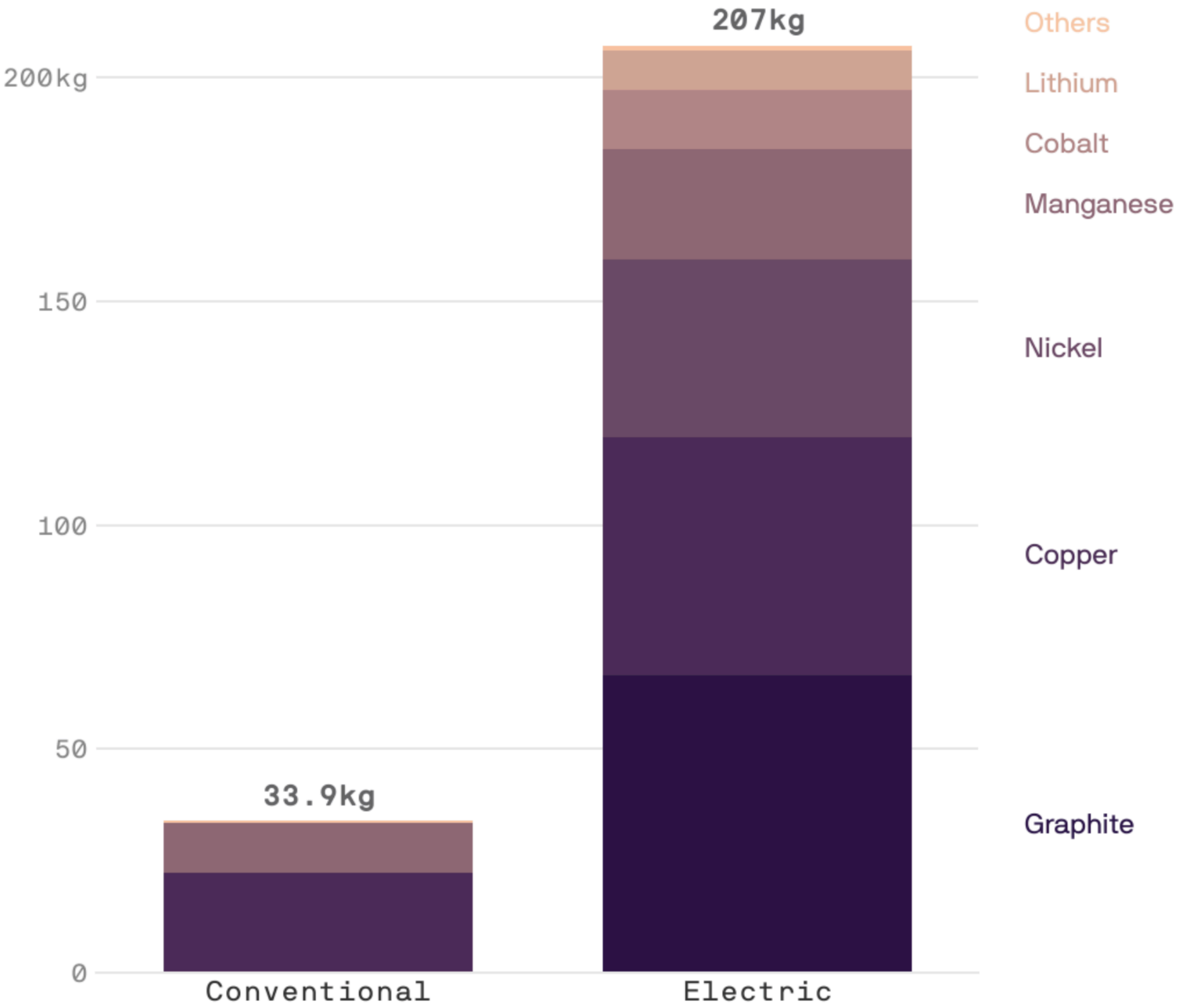
To build
1,000 pound battery

Mine
90 tons of ore

Remove
500 tons overburden

https://bfrandall.substack.com/p/another-mining-truth-bomb-from-john?r=1rapbo&utm_campaign=post&utm_medium=web

EVs increase demand for more technical metals



https://www.axios.com/newsletters/axios-generate-441d89bd-0543-45d5-9745-d703a5de0d59.htm

15 of 19 Congo cobalt mines in Congo were owned or financed by Chinese companies.

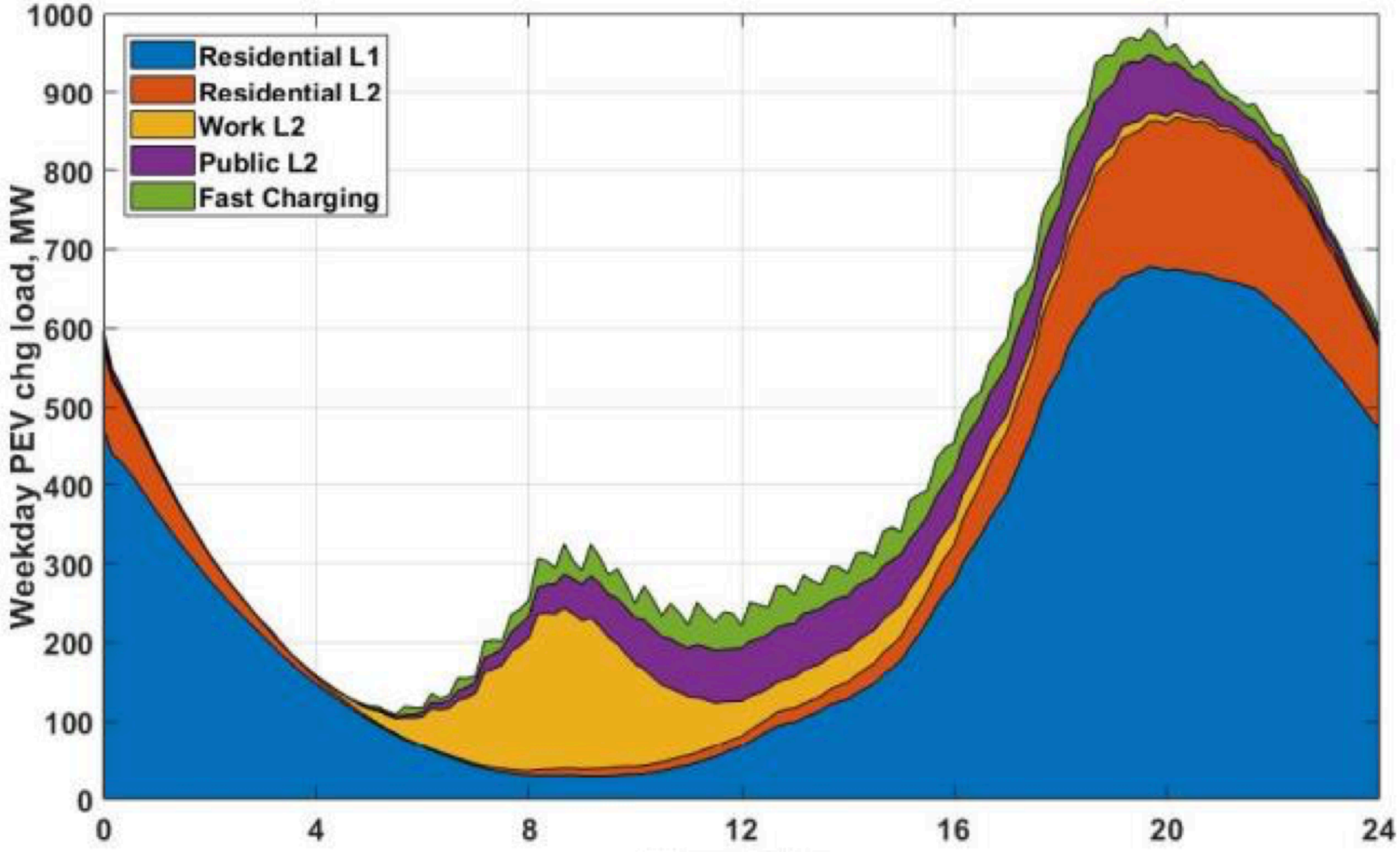
60% of cobalt supply from Democratic Republic of Congo.

Annual demand rising to ~400,000 tonnes by 2030.

Exceeds world refining capacity.

https://www.nytimes.com/2021/11/20/world/china-congo-cobalt-explained.html

Plug-in hybrids avoid EV range anxiety, recharger anxiety, grid power anxiety.



https://www.nrel.gov/docs/fy18osti/70893.pdf

Smaller, cheaper batteries.

Shaves capital intensive power peaks.

California Energy Commission grid analysis.

Motorcycles in Jakarta traffic

Grab is a two-wheel taxi service in Indonesia cities.

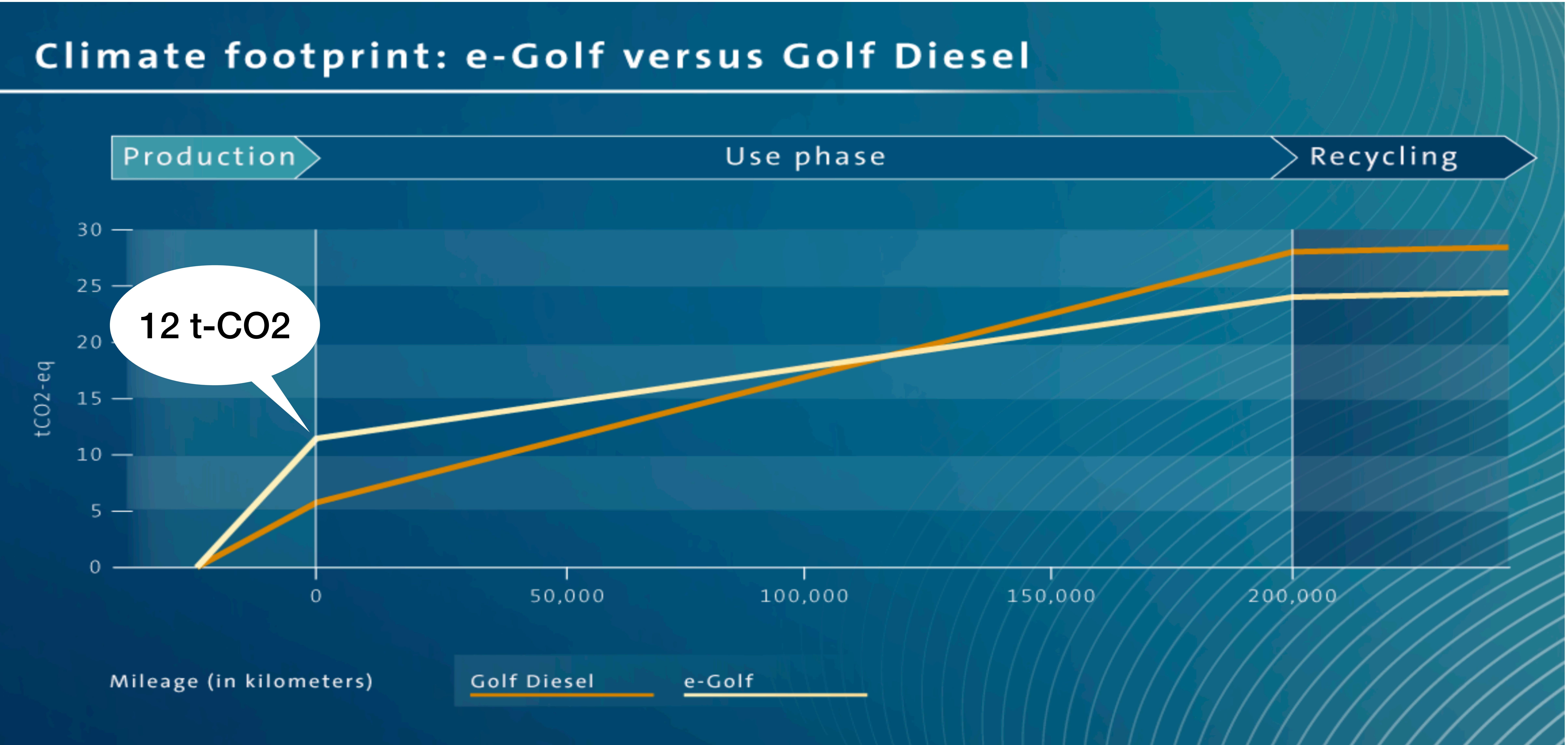
Electric motorbikes share bus lanes in Xi’an (2016).

China produces 36 million two-wheelers/year, with 300 million on the road in 2020.

- Gasoline powered two-wheelers are the largest sources of pollution in many cities.
- Gasoline fuel powered ones are prohibited in many China cities.
- Worldwide 350 million electric two/three wheelers in 2019.
- Reduced more pollution than have electric cars.
- India is catching up.

https://www.livemint.com/auto-news/china-is-racing-ahead-of-india-in-adopting-evs-11594740695583.html

Will EVs save the climate?



Electric car driving costs *can be* 1/3 gasoline fueled costs.

Gasoline cars: 25 mpg
1 billion use 1700 GW(t)

90 kWh(t) per 100 km
25 mpg = 40 km per gal
$10.00 per 100 km @ $4.00/gal

Electric cars: 20 kWh/100 km
1 billion use 250 GW(e)

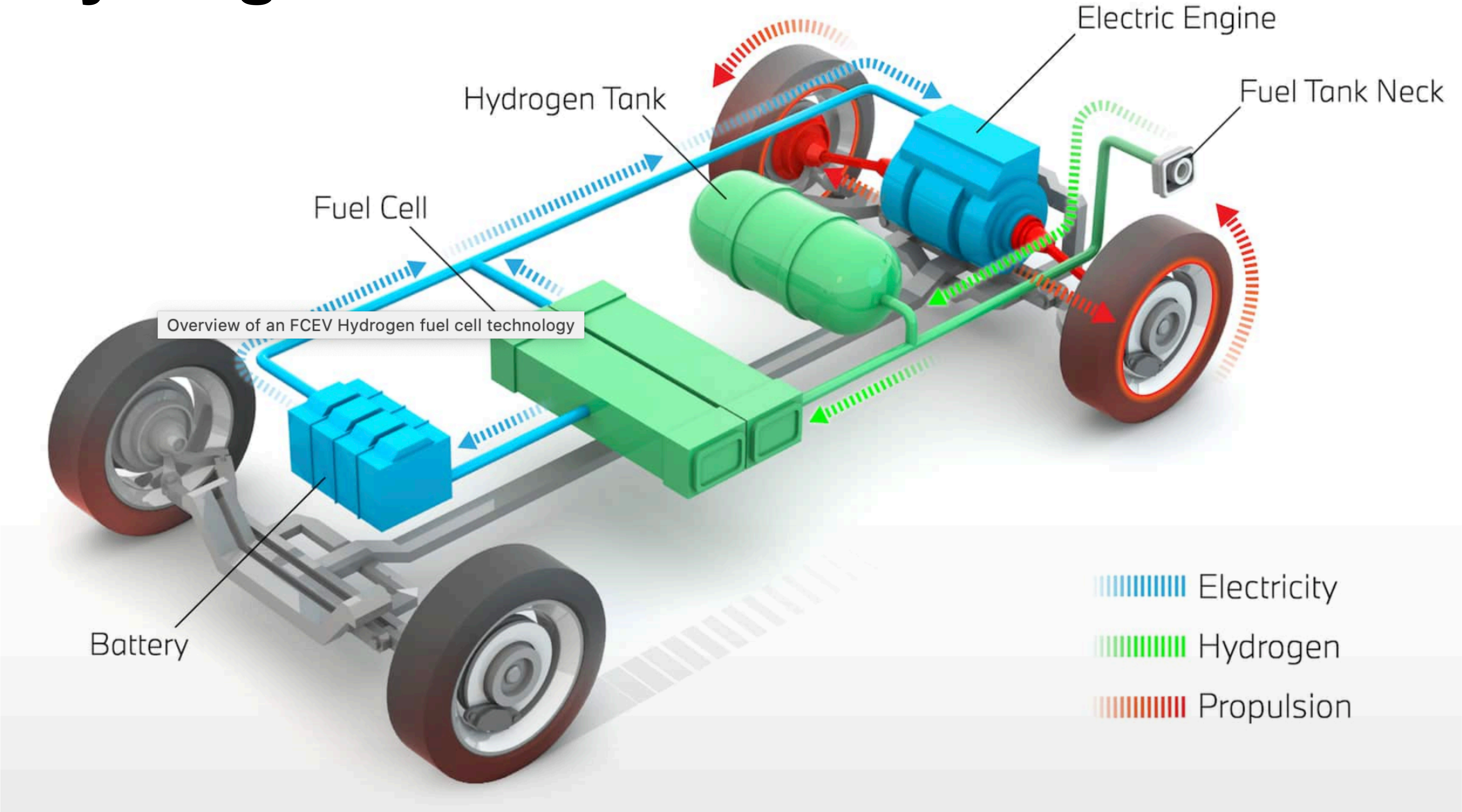
20 kWh(e) per 100 km

$4.00 per 100 km @ $0.20/kWh

CO2 emissions of 2022 ICE, hybrid, plug-in, EV autos.

	Corolla	Prius	Prius Prime	Tesla 3, LFP
$ purchase	$20,075	$24,025	$28,220	$44,990
Battery kWh			8.8	50
Battery range miles			25	253
MPG	33	58	54	
Electricity $/100 km @$0.20/kWh, 80% eff			$5.50	$3.10
Gasoline $/100 km @$4/gal	$7.60	$4.30	$4.60	
Embedded kg CO2/100 km @200,000 km life	2.7	3	3.8	6
Driving kg CO2/100 km @390 g/kWh, 8.9 kg/gal	16.91	9.5	10.7	6.0

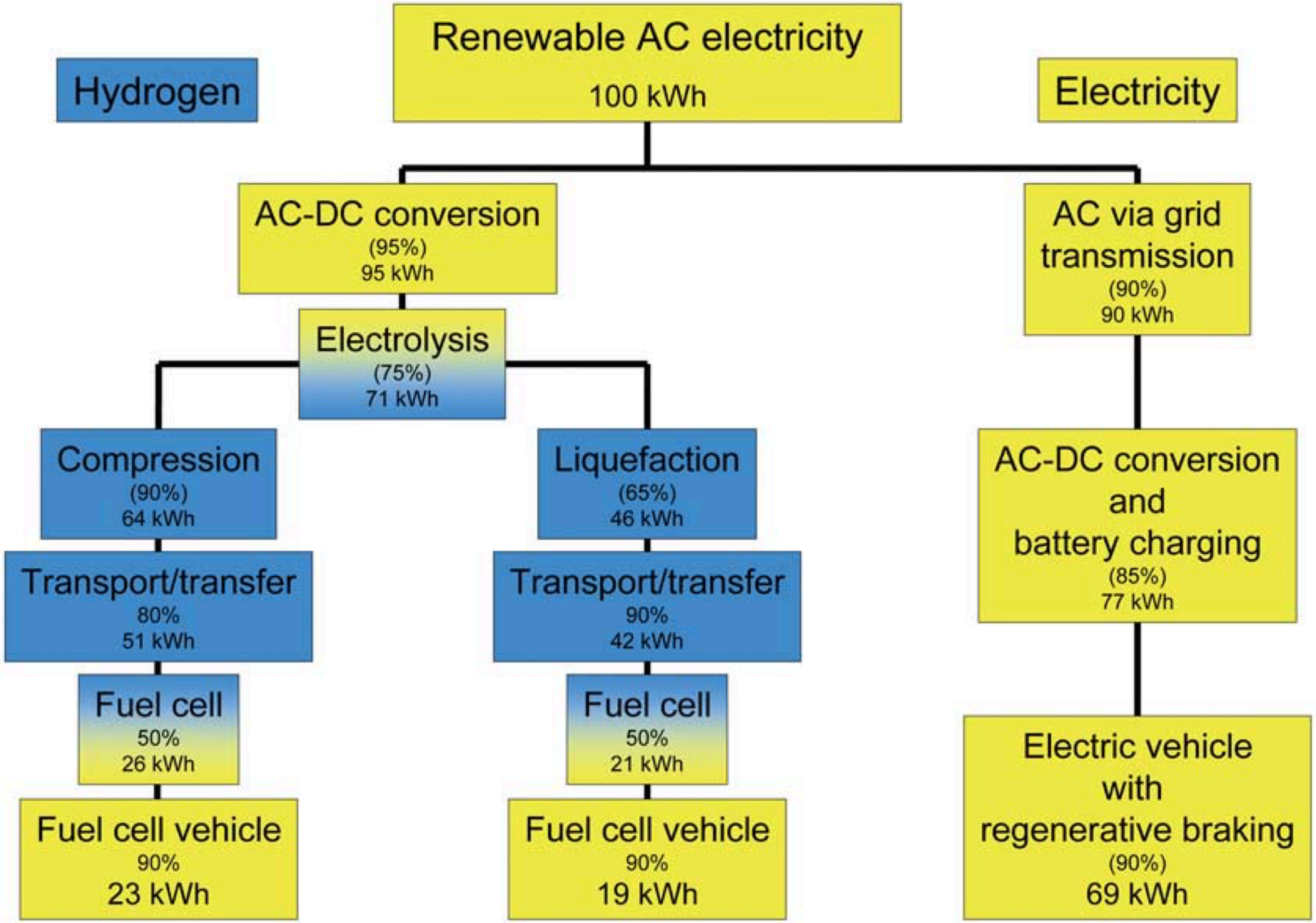
Honda, Toyota, Hyundai, BMW have provided ~10,000 hydrogen fuel cell cars.



IEA reports 12,500 fuel cell vehicles sold in 2019.

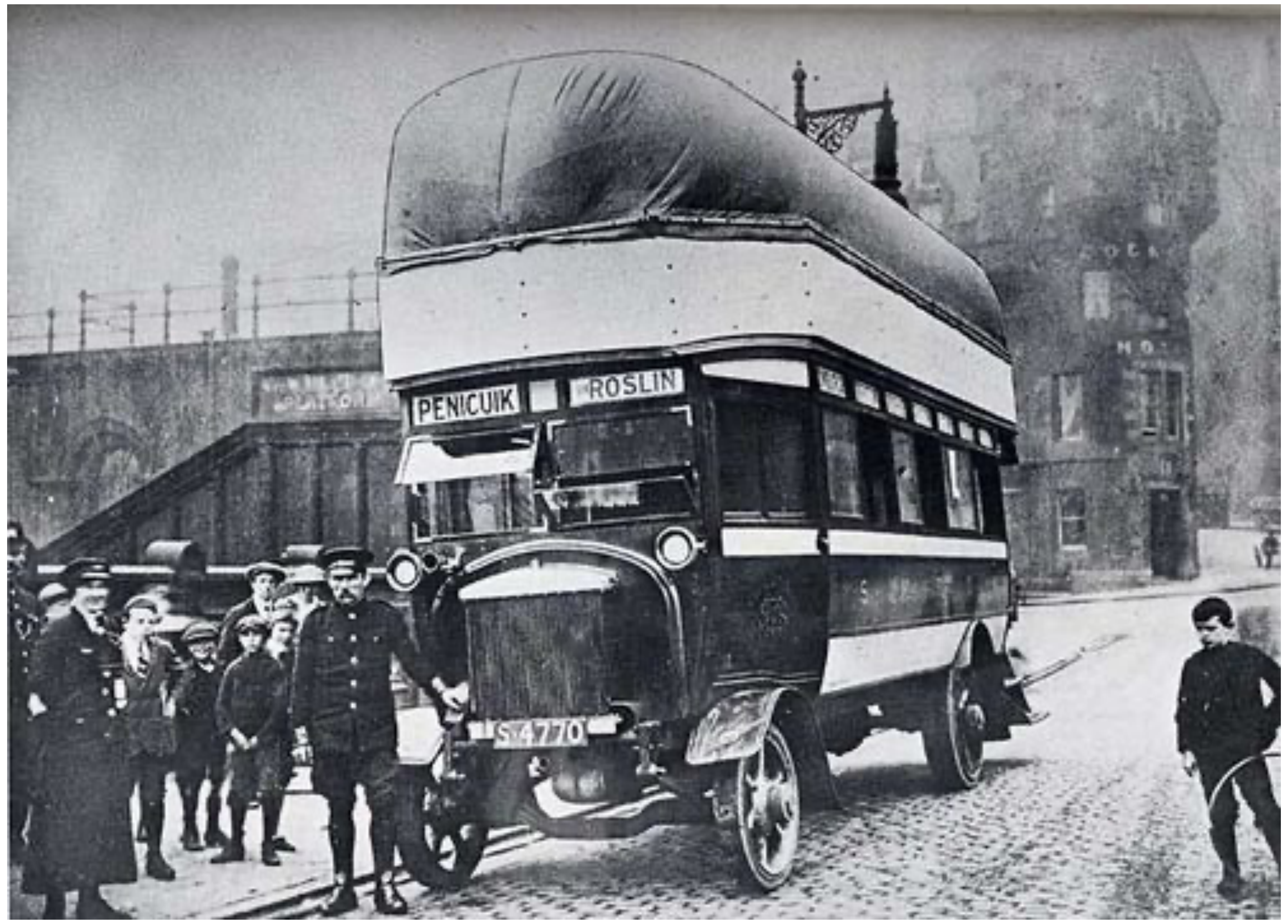
https://www.bmw.com/en/innovation/how-hydrogen-fuel-cell-cars-work.html#

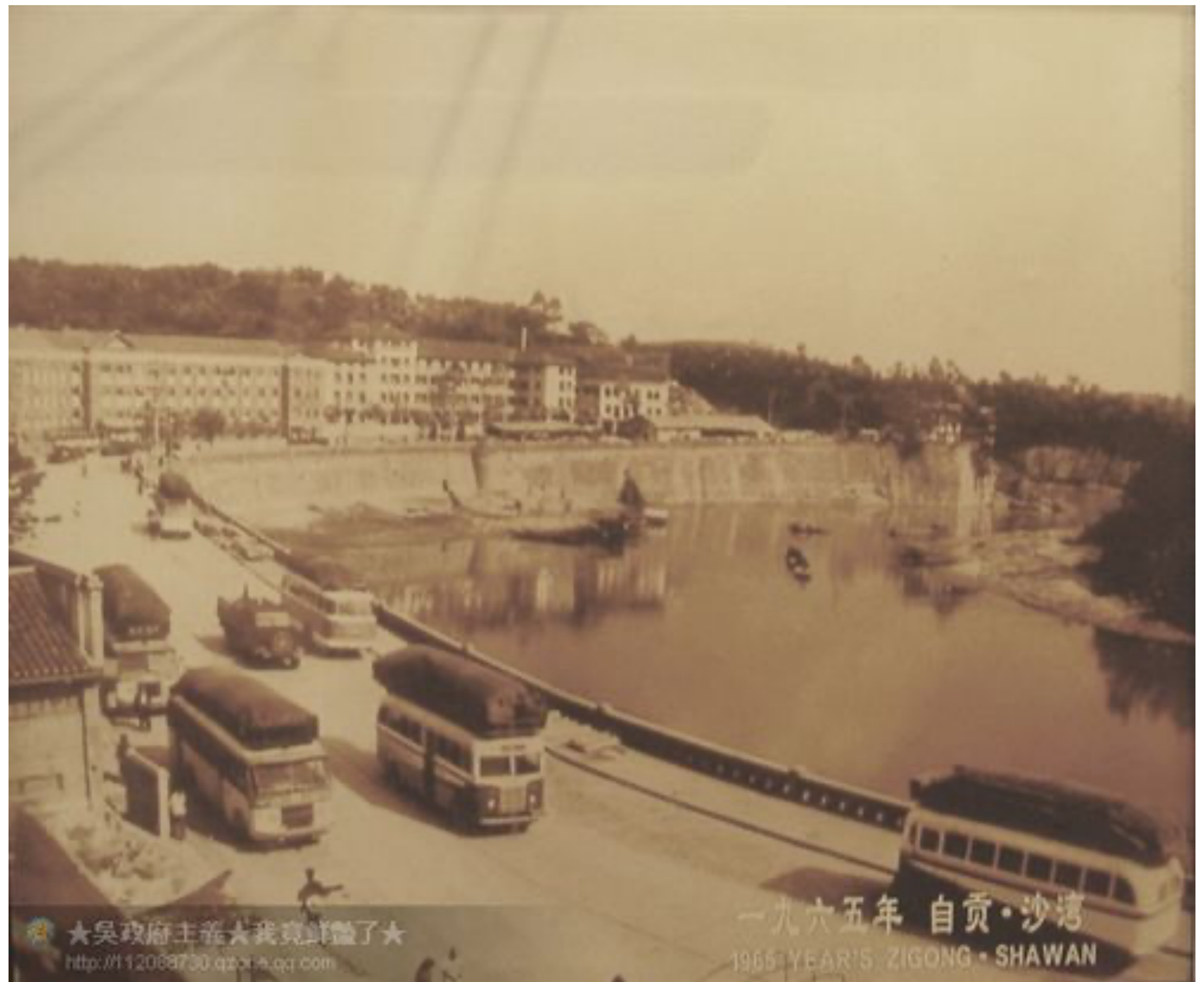
Lower H2 vehicle efficiency may not matter if EV battery materials are scarce or energy is cheap.



https://www.industrializedcyclist.com/ulf%20bossel.pdf

Gas-bag buses in Holland, France, Germany, China

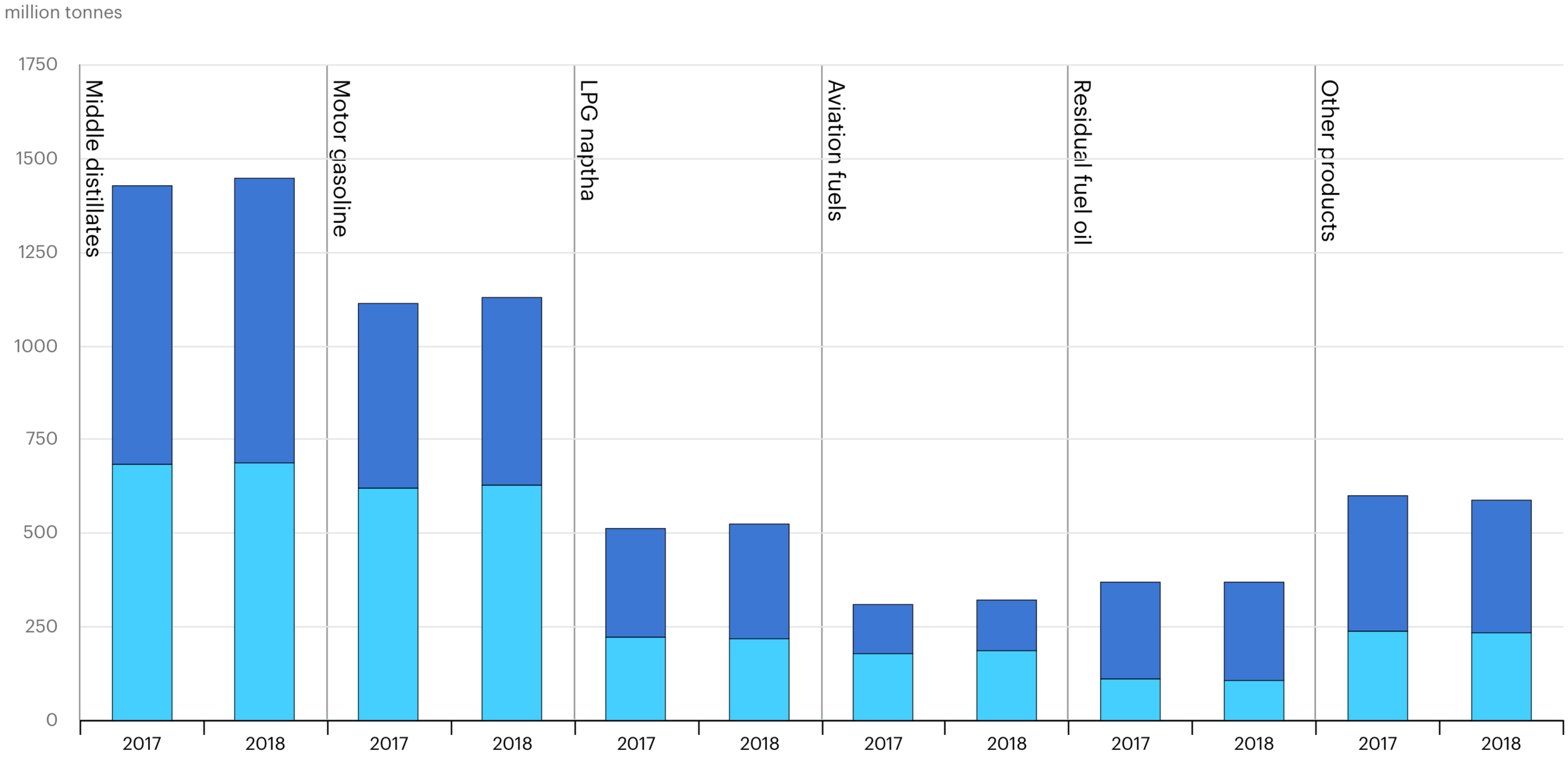




https://www.lowtechmagazine.com/2011/11/gas-bag-vehicles.html

World diesel fuel consumption is ~ 2100 GW.

IEA reports 1446 million tonnes for 2018



https://www.iea.org/reports/oil-information-overview

Largest US refinery produces 40 GW(t).

IRENA estimates heavy transport energy use.

Energy-intensive freight & long-haul transport sectors

Road freight	Aviation	Shipping
1000 GW	**400 GW**	**400 GW**
In 2017:	In 2017:	In 2017:
➔ Consumed 32.3 EJ of energy	➔ Consumed 13.5 EJ of energy	➔ Consumed 11.3 EJ of energy
➔ Only 1.5% was from renewables	➔ A negligible share was from renewables	➔ A negligible share was from renewables
➔ Emitted 2.3 Gt of CO_2	➔ Emitted 0.9 Gt of CO_2	➔ Emitted 0.9 Gt of CO_2

CO2 emissions --> | **2 Gt/y** | **1 Gt/y** | **1 Gt/y**

https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Sep/IRENA_ReachingZero_Summary_2020.pdf

Amazon will deploy 10,000 electric delivery vehicles by 2023.

- 100,000 by 2030.
- 200 mile range.
- 1800 Mercedes vans in EU by 2022.
- 25,000 Rivian i.
- USPS to buy 66,000 electric vehicles.

https://www.nytimes.com/2022/03/10/business/rivian-earnings.html?action=click&pgtype=Article&state=default&module=styln-electric-vehicles&variant=show&region=MAIN_CONTENT_1&block=storyline_top_links_recirc
https://blog.aboutamazon.com/transportation/introducing-amazons-first-custom-electric-delivery-vehicle\

Daimler Freightliner eCascadia, Q4 2021 production

- Electric trucks are burdened by their batteries.

- But feasible if overnight charging is practical.

- Short-haul, last-mile logistics
- 80,000-lb. gross vehicle weight
- Heavy-duty highway tractor designed for local and regional distribution and drayage

HORSEPOWER	525 hp (391 kW)
MILE RANGE	250
USABLE CAPACITY	Up to 475 kWh
RECHARGE	80% in 90 min.

https://freightliner.com/e-mobility/

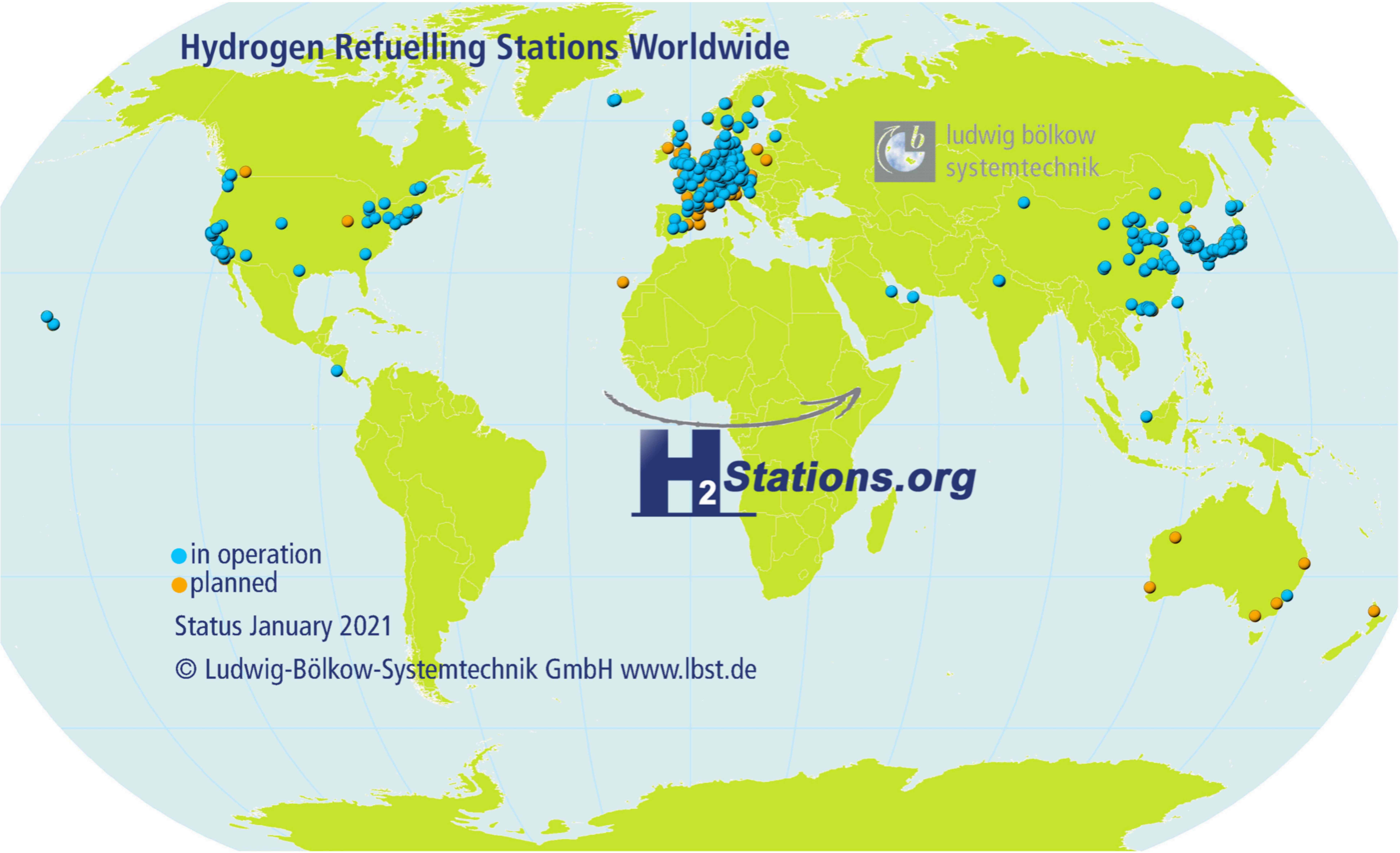
Kenworth, Toyota T680 Hydrogen Fuel Cell Truck

10 hydrogen fuel cell electric trucks for Port of Los Angeles

300 mile range per fill

https://www.truckinginfo.com/330270/toyota-and-kenworth-unveil-jointly-developed-hydrogen-fuel-cell-truck

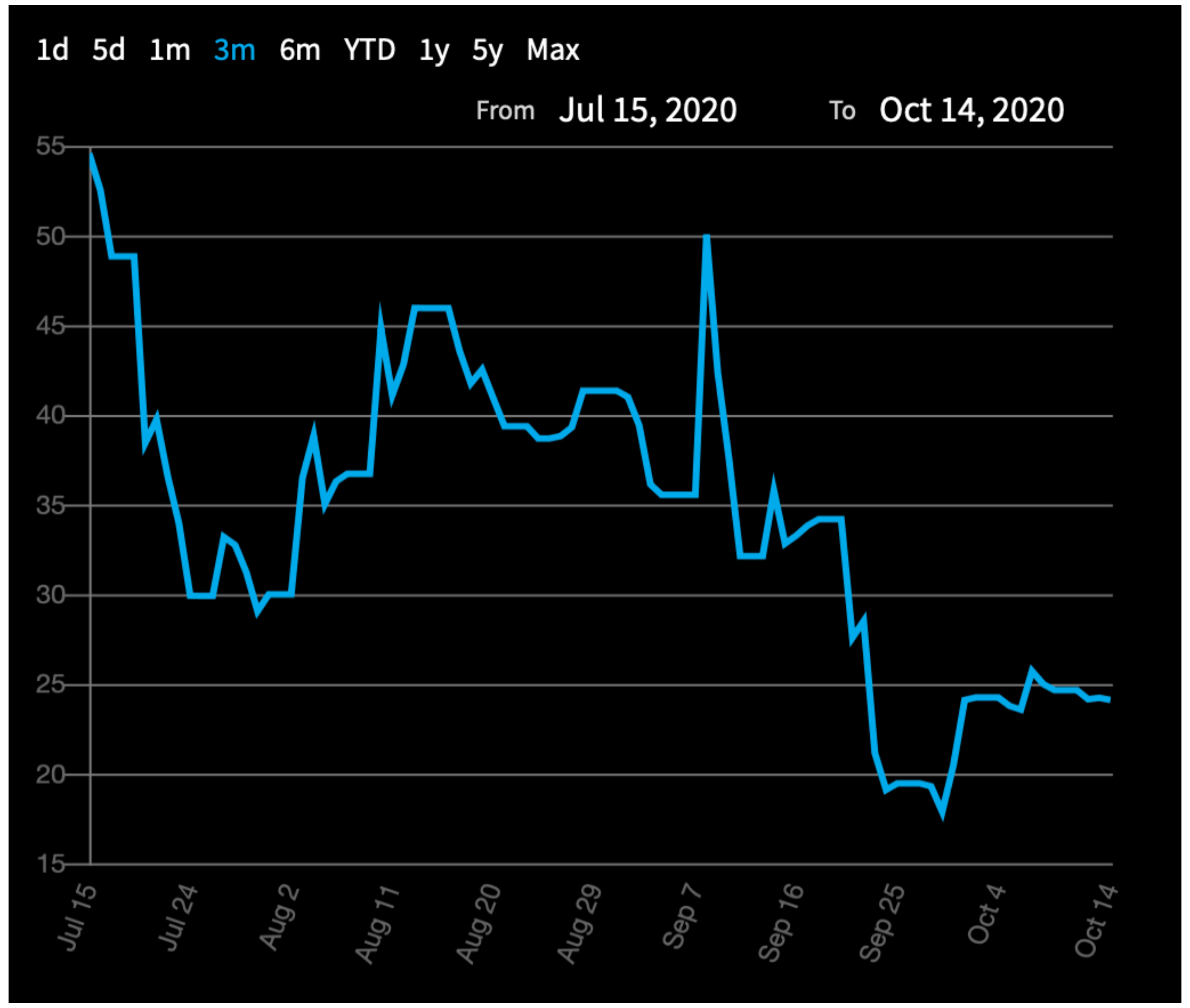
142 hydrogen fueling stations worldwide, 47 in California.



https://energynews.biz/hydrogen-filling-stations-count-goes-to-142-worldwide-and-new-250-planned-in-europe/

Nikola strategy is hydrogen-powered trucks and H2 fueling station network.

- Few heavy, bulky batteries to transport.
- Fast refueling, relative to battery charging.
- Volatile stock price!



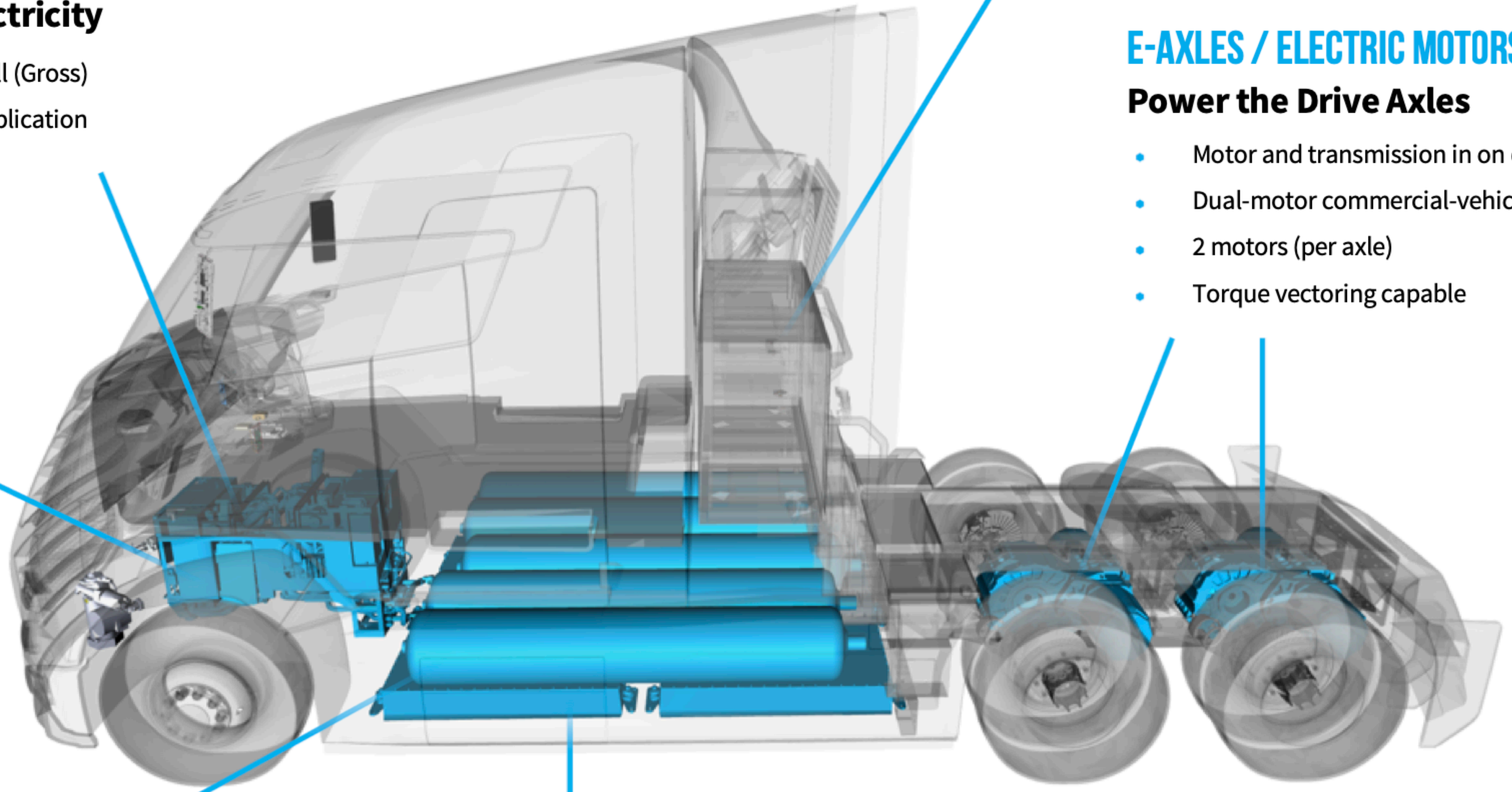
Nikola TWO FCEV ALPHA PROTOTYPE

POWER ELECTRONICS / DISTRIBUTION UNIT
Distributes energy to axles and vehicle
- Energy Flow & Conversion

DUAL STACK FUEL CELL
Generates Electricity
- 240 kW Fuel Cell (Gross)
- Heavy-Duty Application
- Custom Build

E-AXLES / ELECTRIC MOTORS
Power the Drive Axles
- Motor and transmission in on compact unit
- Dual-motor commercial-vehicle eAxle
- 2 motors (per axle)
- Torque vectoring capable

INDEPENDENT SUSPENSION
Independent Control
- Stability
- Improved ride



HYDROGEN TANKS
Hydrogen Storage
- 61 kg

BATTERIES
Handle Dynamic Load Conditions (Acceleration, Regenerative Braking)
- 250 kWh, 710 Volt capable battery pack

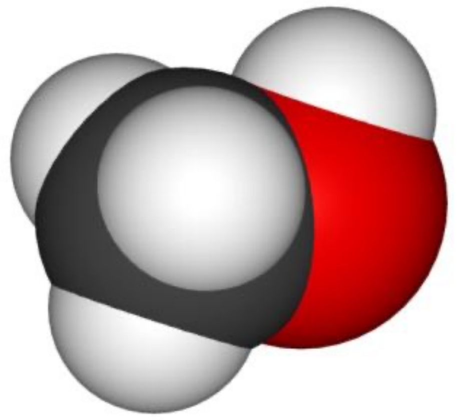
https://d32st474bx6q5f.cloudfront.net/nikolamotor/uploads/investor/presentation/presentation_file/19/Nikola_Mission_Hydrogen_Presentation2.pdf

Carbon-based fuels have strong advantages.

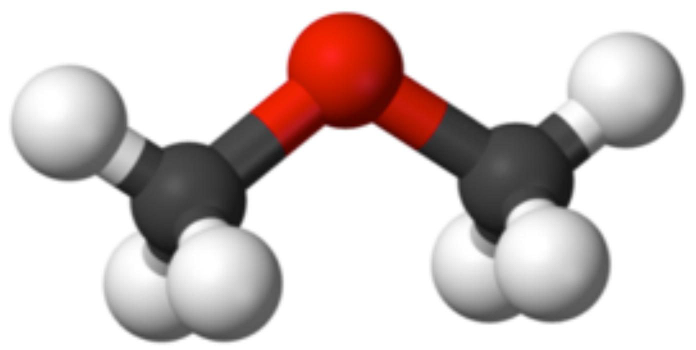
Fuel	kWh/kg	kWh/L
Petroleum, C-synfuel	13	11.0
Hydrogen liquid, -253°C	33	2.4
Hydrogen gas, 700 bar	33	1.2
Ammonia liquid	5	3.3
Methane, 250 bar	15	9.0
LNG, -160°C	15	6.1
Lithium ion battery	0.2	0.8

https://en.wikipedia.org/wiki/Energy_density

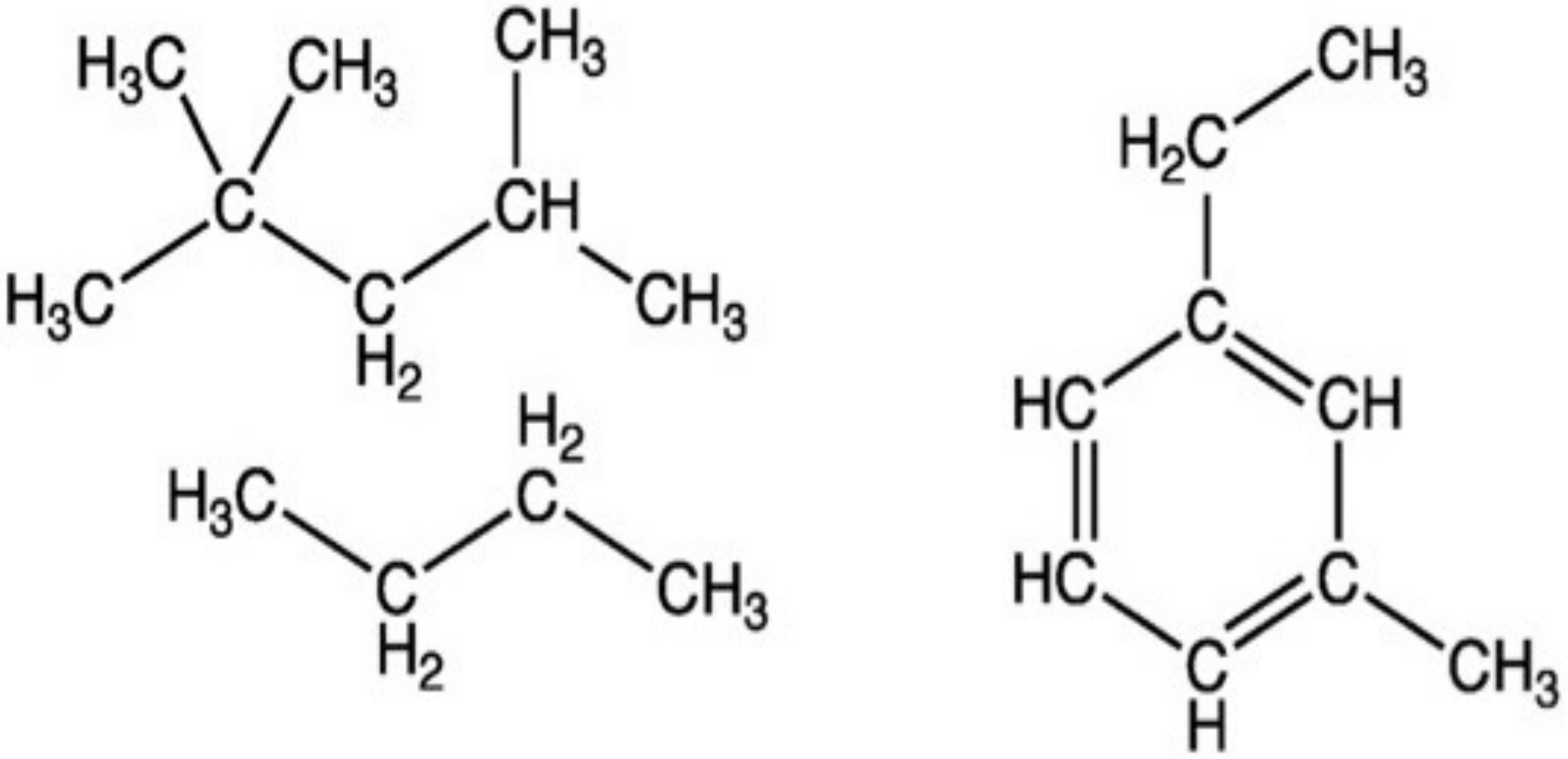
Where to get carbon to make carbonaceous synfuels?



Methanol
CH_3OH



Dimethyl ether
H_3COCH_3



Gasoline

CO_2 from burning crops is said to be climate neutral.

Carbon Engineering removes 1 t-CO2 using 8.81 GJ from burning natural gas, releasing 0.44 t-CO2.

Expects $100 per tonne CO2 removal cost.

https://www.forbes.com/sites/walvanlierop/2020/02/27/our-carbon-problem-is-a-multibillion-dollar-opportunity/#5cd91bdd3649
https://carbonengineering.com/our-technology/ https://www.cell.com/joule/fulltext/S2542-4351(18)30225-3

Farming for energy produces only ~ 4 kW per hectare.

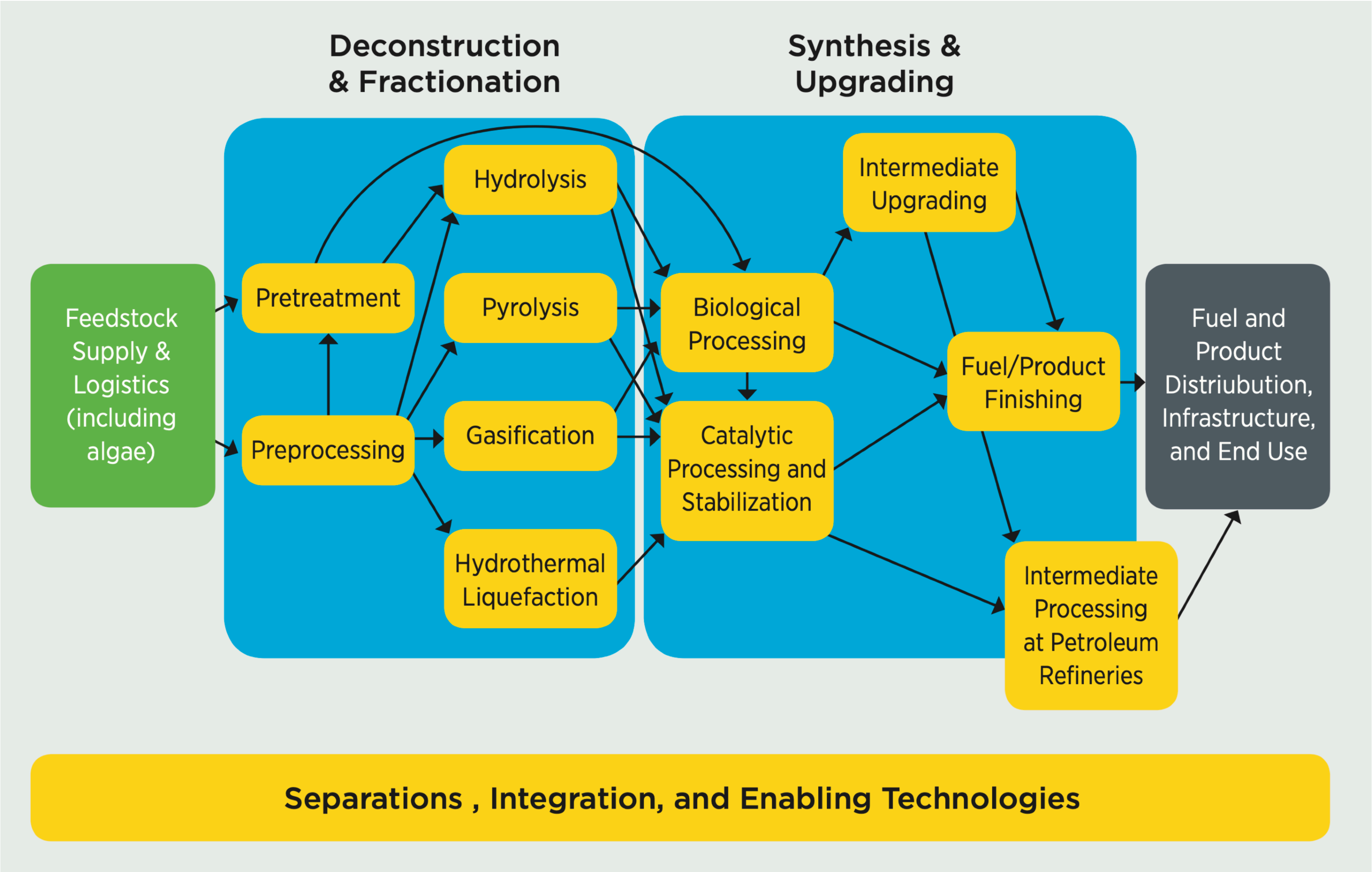
Fuel	Net CV	Annual yield per ha	Energy per ha p.a.	
Forest Research	MJ/kg	tonne/ha.a (odt/ha.a)	GJ/ha.a	MWh/ha.a
Wood (forestry residues, SRW, thinnings, etc.) @ 30% MC	13	2.9 (2 odt)	37	10.3
Wood (SRC Willow) @ 30% MC	13	12.9 (9 odt)	167	46
Miscanthus @ 25% MC	13	17.3 (13 odt)	225	63
Wheat straw @ 20% MC	13.5	3.5 (2.8 odt)	47	13
Biodiesel (from rapeseed oil)	37	1.1	41	11.3

33 MWh per hectare per year
divide by
365 days/year
24 hours/day
= 3867 watt per hectare

Compare to Vaclav Smil at https://en.wikipedia.org/wiki/Biomass

https://www.forestresearch.gov.uk/tools-and-resources/biomass-energy-resources/reference-biomass/facts-figures/potential-yields-of-biofuels-per-ha-pa/

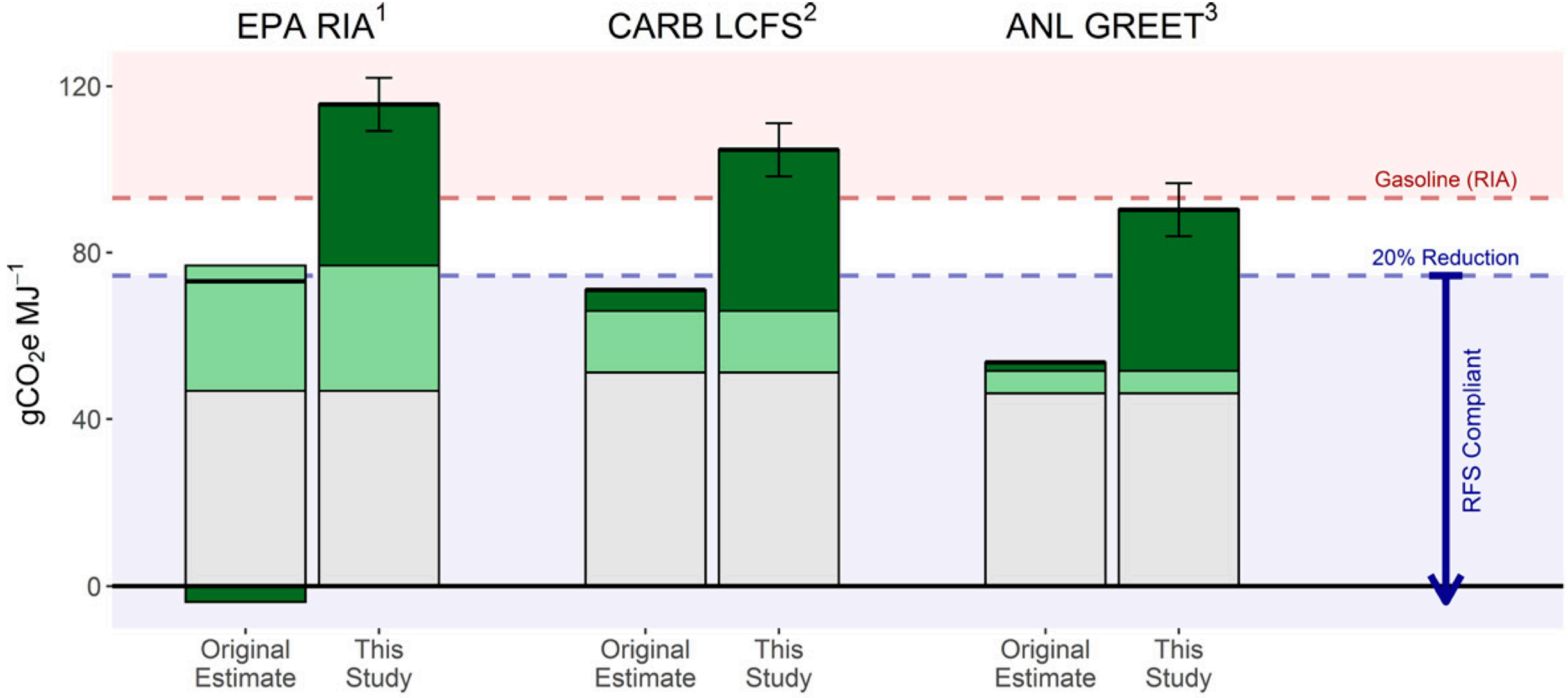
US DOE promotes making fuels like ethanol from biomass, but adding hydrogen is a more efficient use of crop carbon.



https://www.energy.gov/sites/prod/files/2016/07/f33/conversion_factsheet.pdf

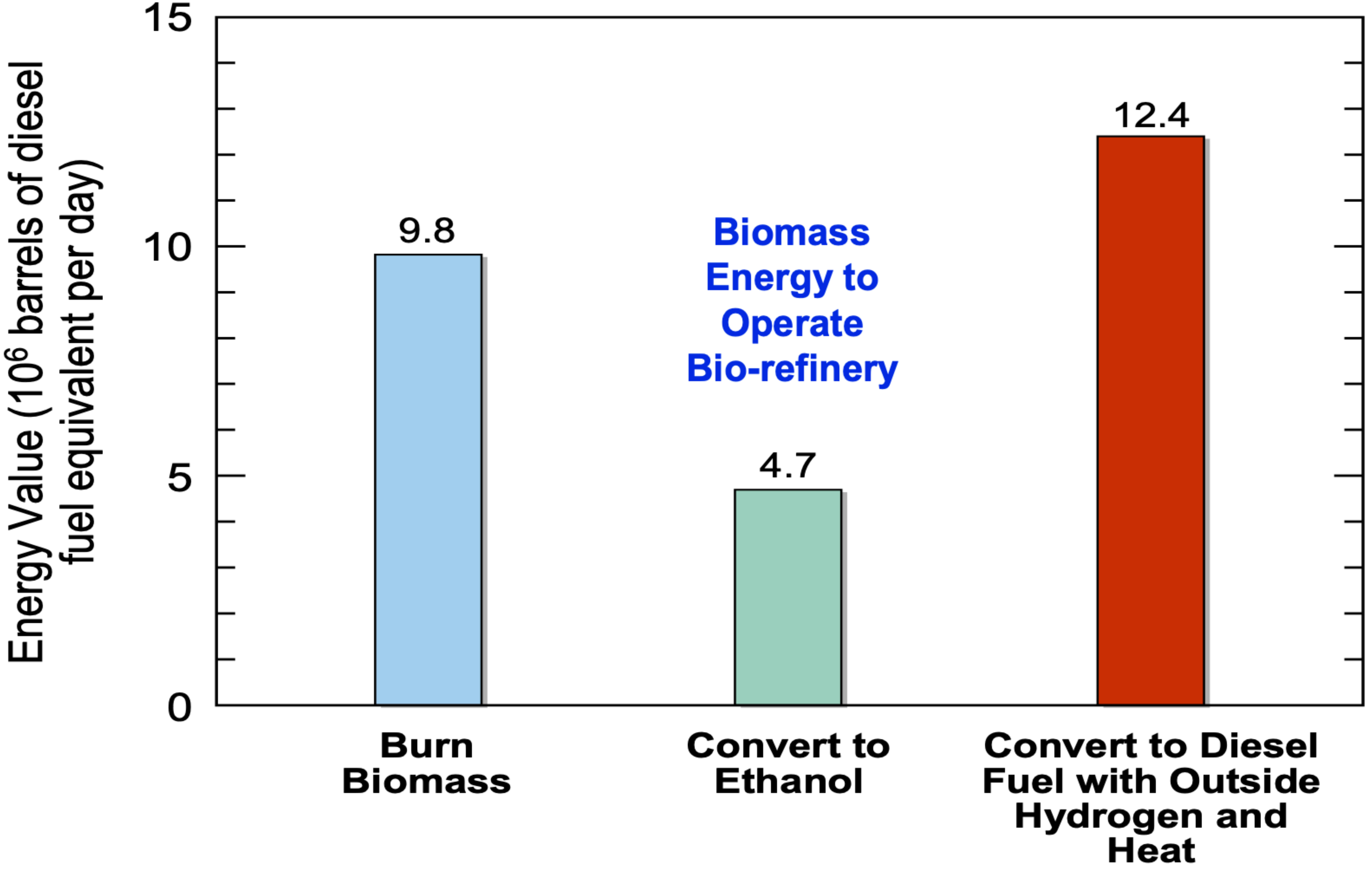
RFS goal to reduce CO2 by 20% not met.

2 of 3 studies: RFS CO2 emissions exceed gasoline's.



https://www.pnas.org/content/pnas/119/9/e2101084119.full.pdf

Hydrogen and heat triple fuel yield from biomass.

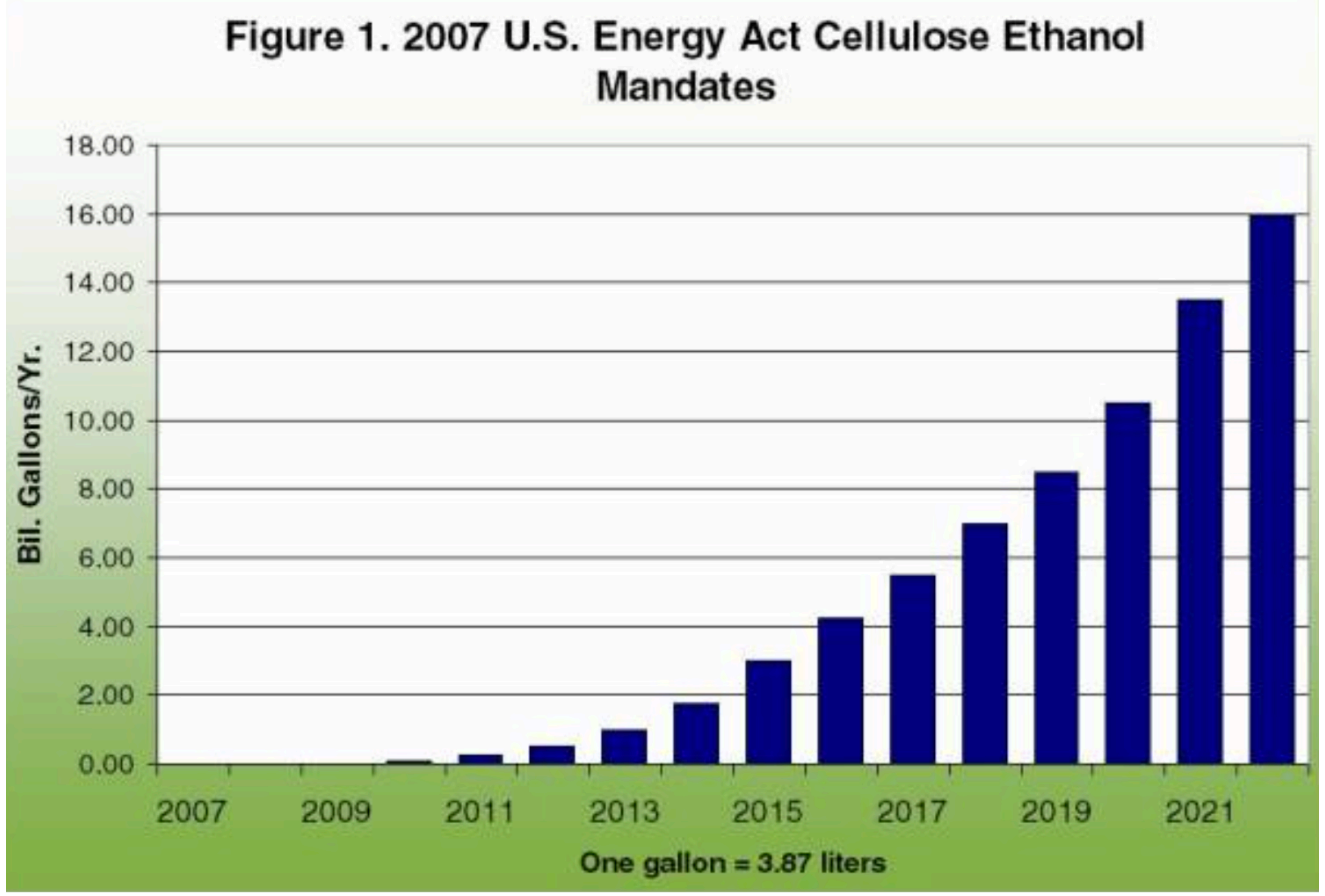


3X

https://www.brookings.edu/wp-content/uploads/2012/04/powerpoint_forsberg.pdf

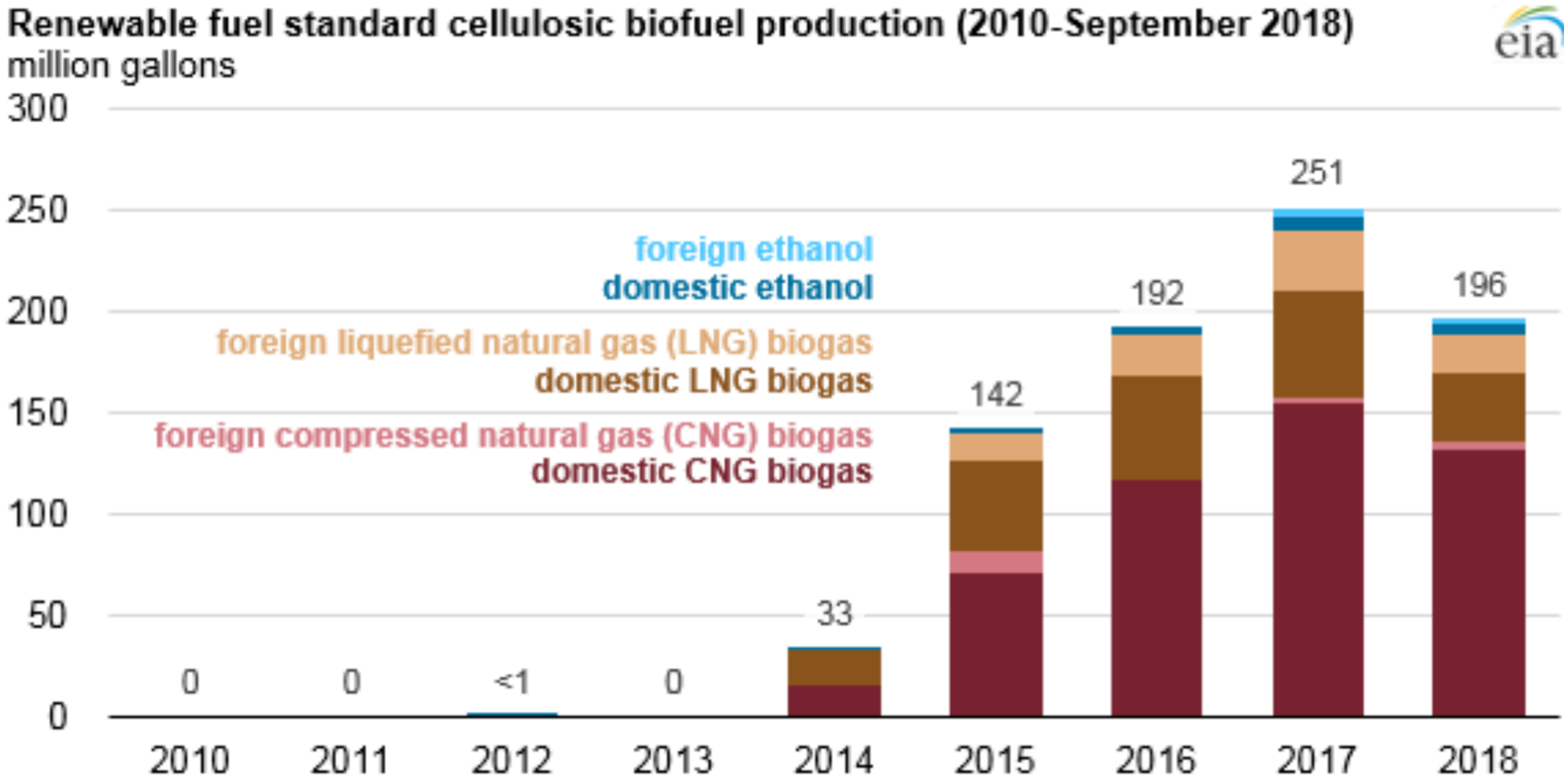
Mandates often don't work; thousand-to-one example:

Renewable Fuel Standard



US Congress mandated **cellulosic ethanol**: 5.5 **billion** gallons (2017)

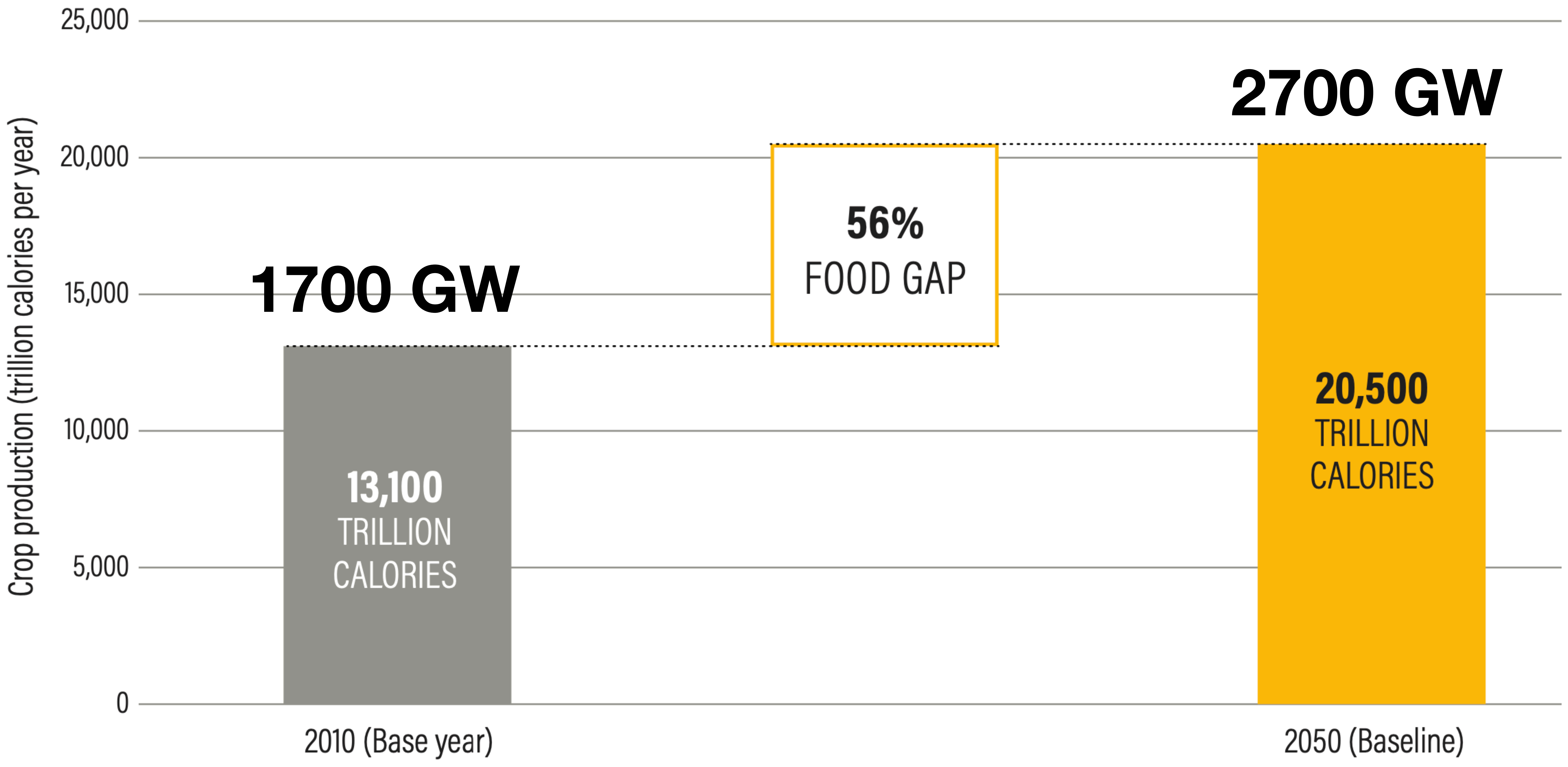
https://www.agmrc.org/renewable-energy/renewable-energy-climate-change-report/renewable-energy-climate-change-report/september-2009-newsletter/cellulosic-ethanol-will-the-mandates-be-met



EIA reports: "About 10 **million** gallons of cellulosic ethanol was used to comply with the RFS in 2017, about **half** of which was produced domestically. A 2014 final rule expanded EPA's **definition** of cellulosic biofuel to include certain types of biogas."

https://www.eia.gov/todayinenergy/detail.php?id=37712

World Resources Institute: The world needs to close a food gap of 56 percent by 2050.



https://research.wri.org/sites/default/files/2019-07/WRR_Food_Full_Report_0.pdf

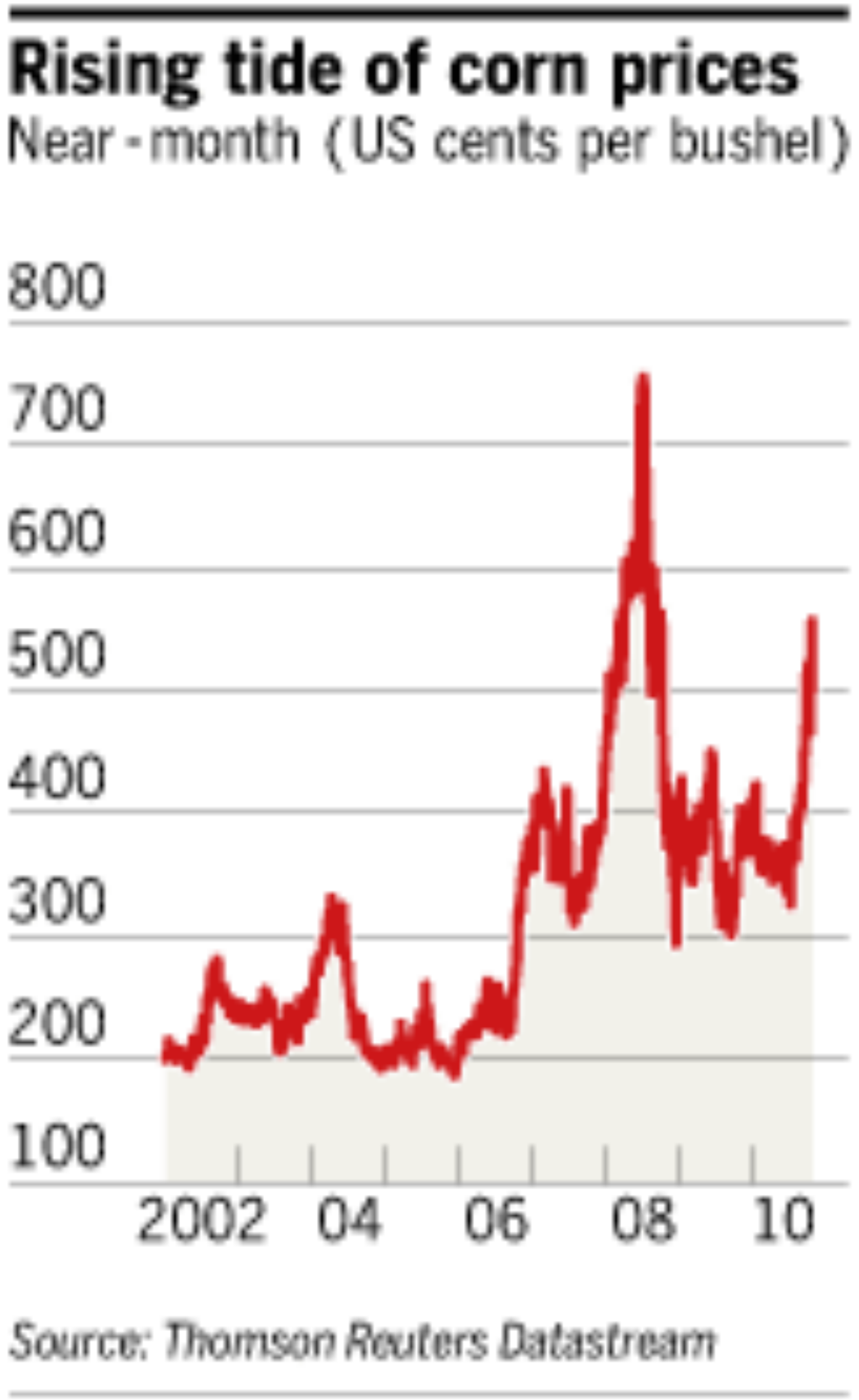
Food and ethanol compete for corn.

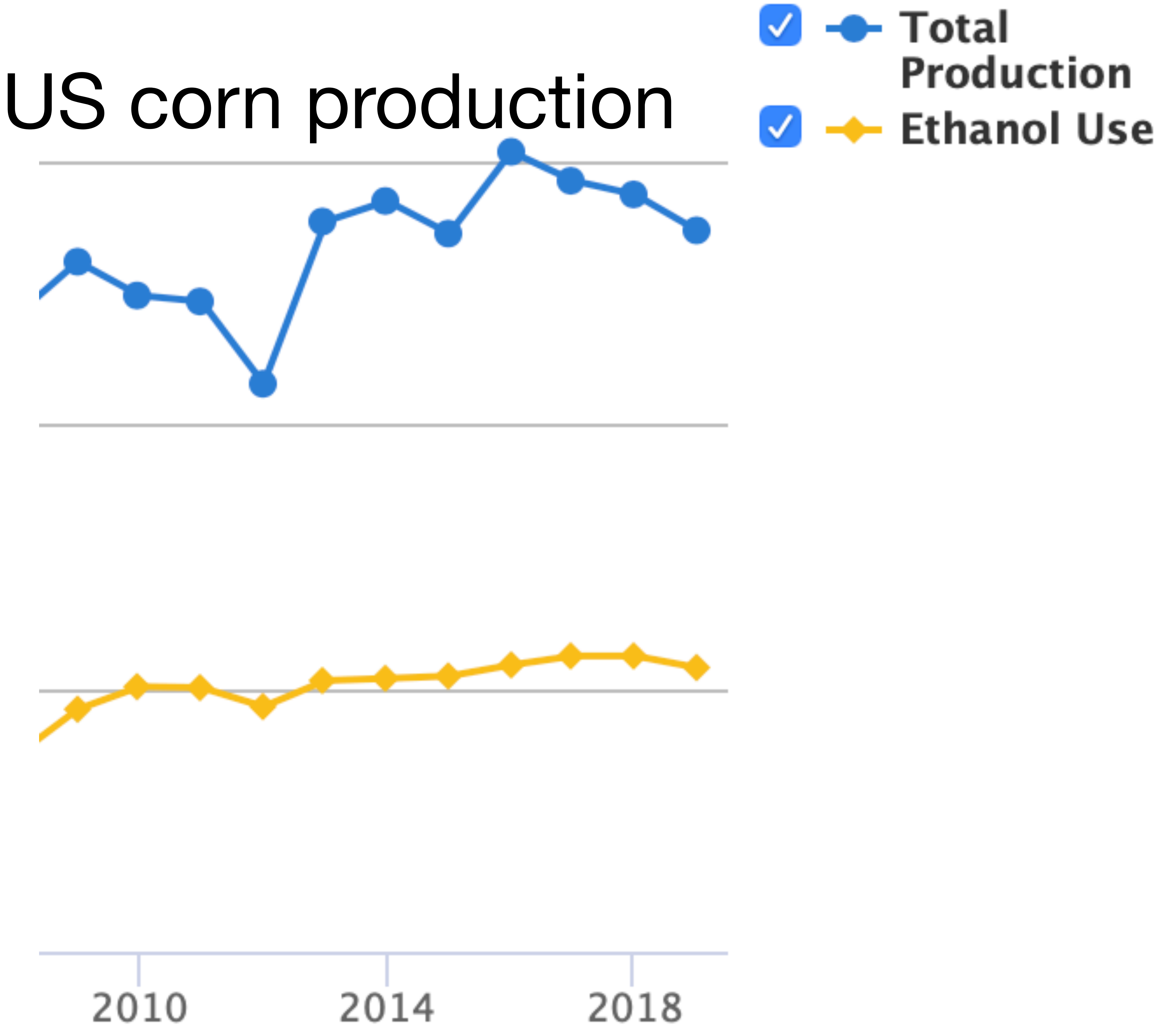
Thousands in Mexico City Protest Rising Food Prices

By Elisabeth Malkin

Feb. 1, 2007

Corn tortilla prices doubled.





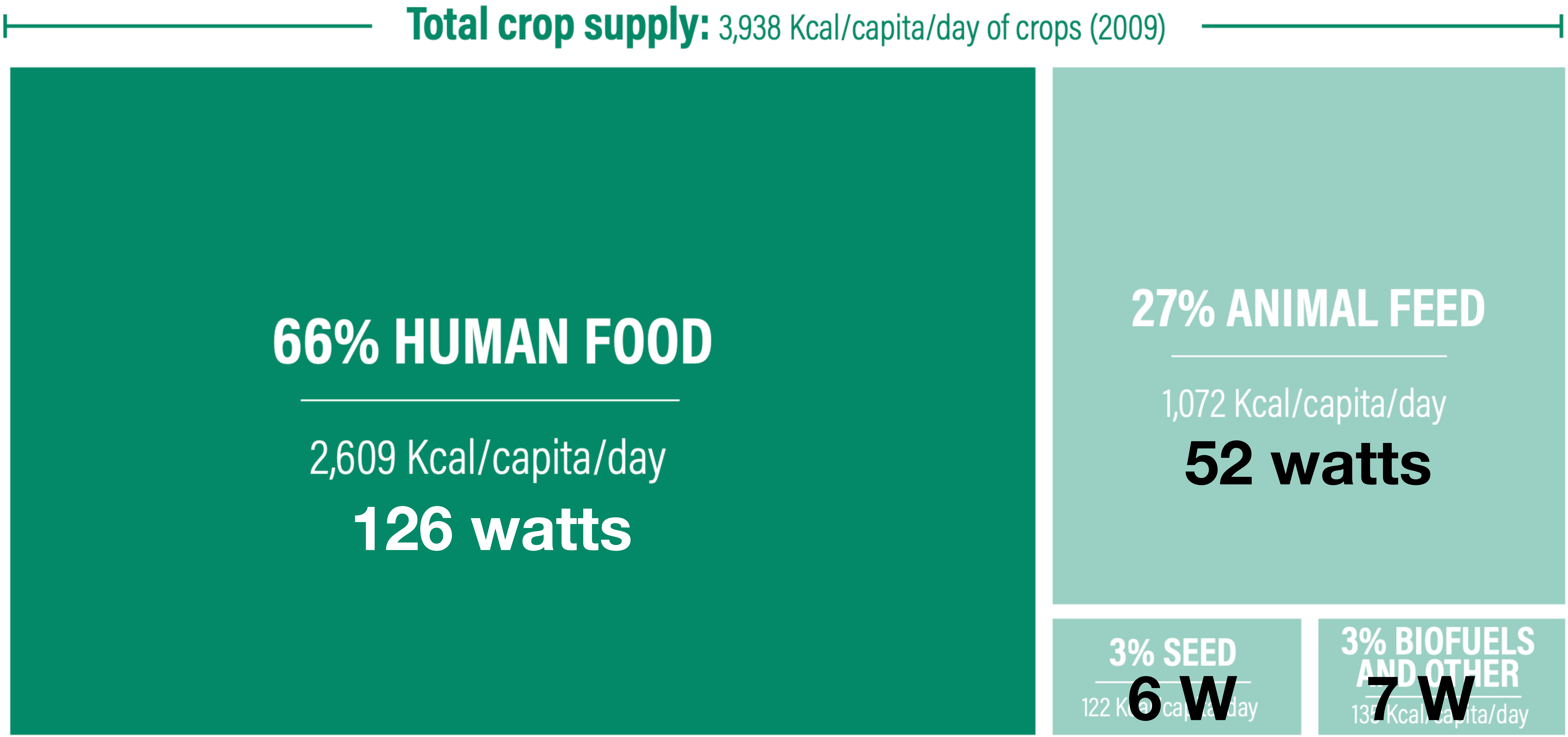
38% used for ethanol
38% used for animal feed
<8% used for human food

"The poor eat an average of 14 ounces of tortillas daily, giving them 40 percent of their protein"

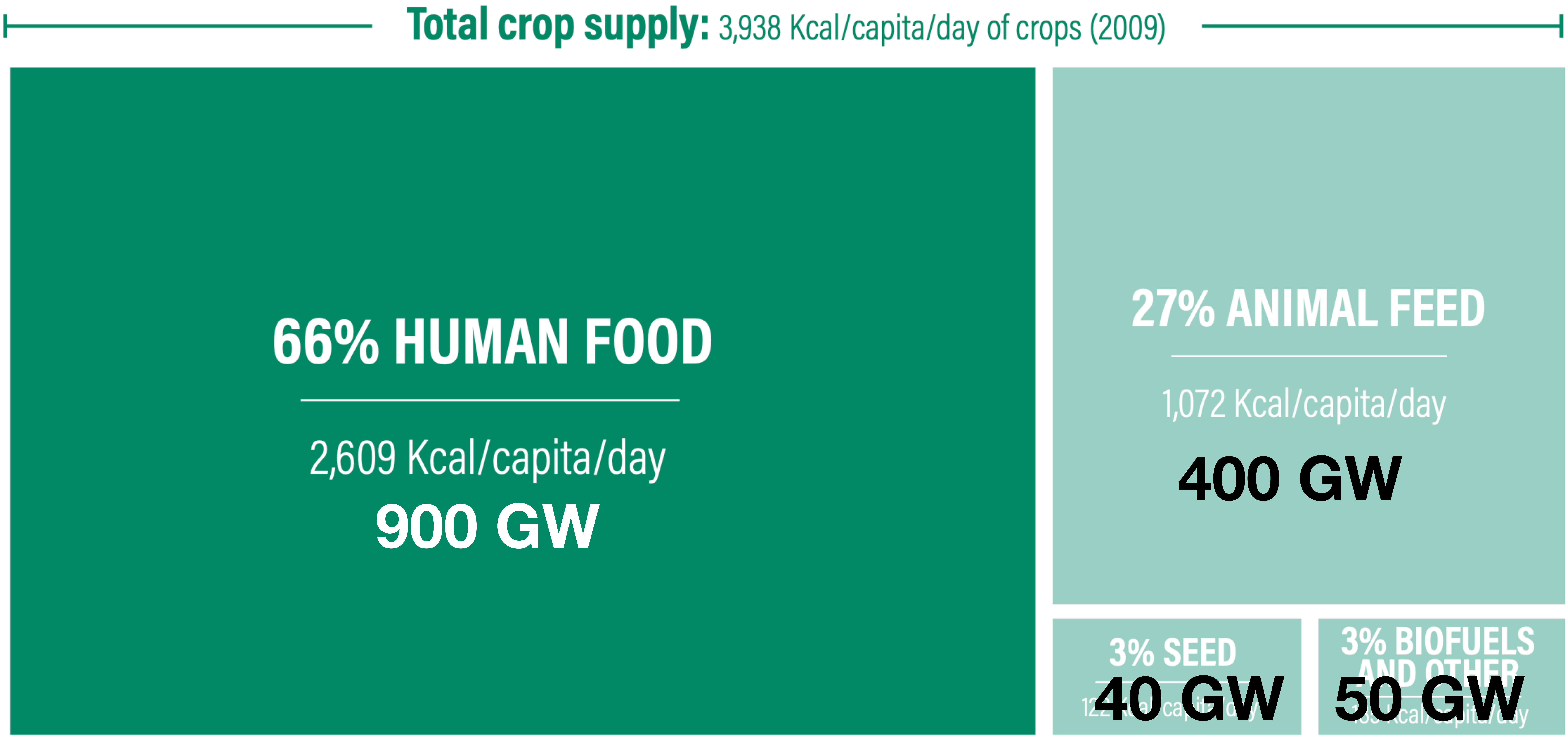
https://www.nytimes.com/2007/02/01/world/americas/01mexico.html

https://www.agmrc.org/renewable-energy/renewable-energy-climate-change-report/renewable-energy-climate-change-report/july-2018-report/corn-use-for-ethanol-in-201819

Per capita energy flow from food crops



Yet IEA proposed 4,600 GW from burning biomass.



2100 GWt of world diesel with biomass would use 75% of world agricultural land (25% if hydrogenate biomass)

3 MW(e) Cummings QSK95-Powered Diesel Locomotive

Powering just airplanes with biofuel would use 15% of world agricultural land. (5% if we hydrogenate biomass)

Aircraft consume 96 billion gallons of jet fuel per year.
@142 million joules/gal = 432 GW

Jet fuel from biomass
183 gallons of fuel per dry tonne of biomass using hydrogenation (Dietenberger).

~ 2 tonne biomass per hectare/year

96 billion gallons / 183 / 2 = ~ **250 million ha** for the **432 GW** of jet fuel.

World agricultural land: **5100 million hectares**

We might limit use of biofuels to airplanes.

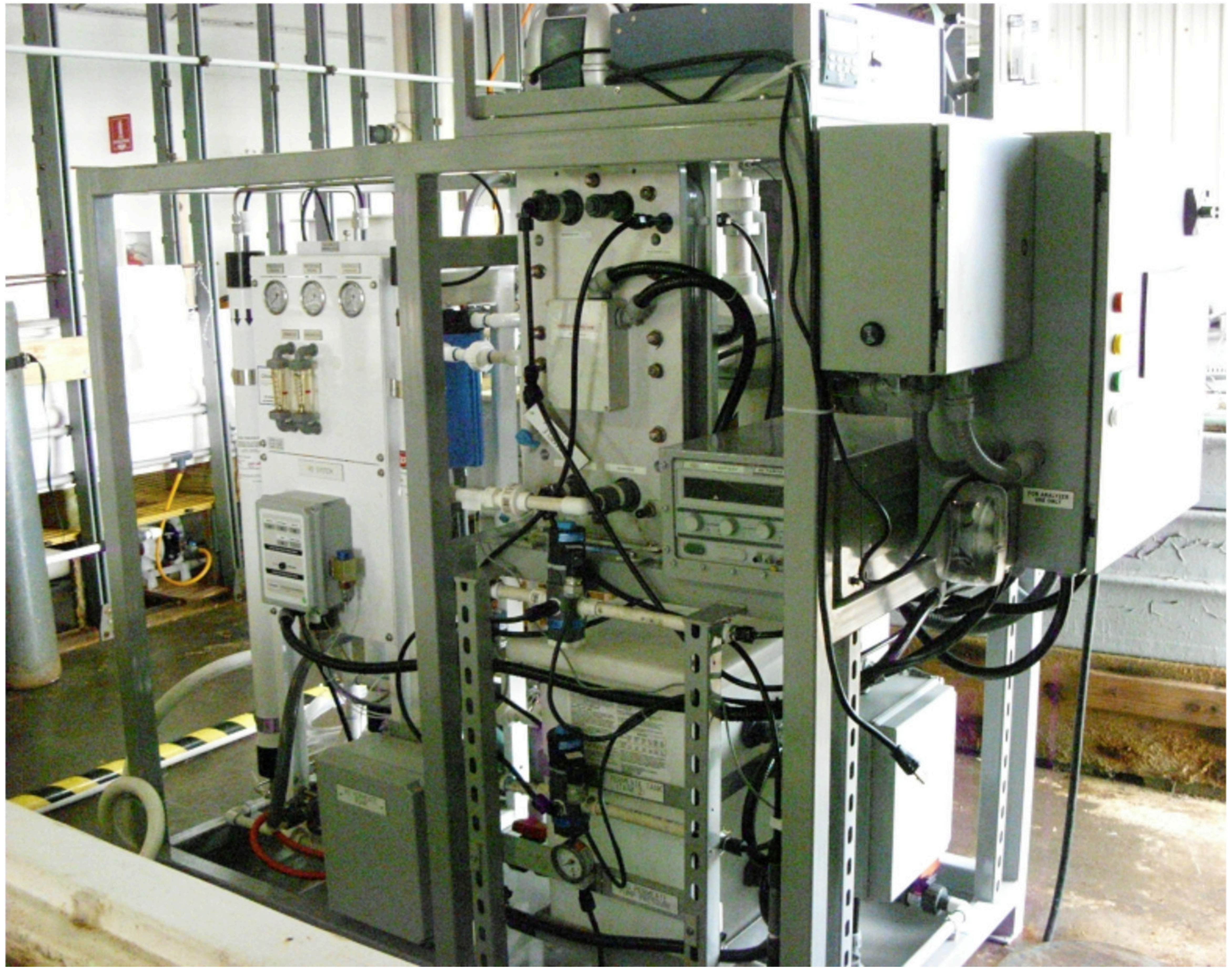
SAF, Sustainable Aviation Fuel, hype by Neste, BP

From french fries to jet fuel

air bp Fuelling a sustainable future

https://www.bp.com/en/global/air-bp/news-and-views/views/what-is-sustainable-aviation-fuel-saf-and-why-is-it-important.html

US Navy Research Labs demonstrated capturing CO_2 from seawater H2O to make $5/gal jet fuel.



Acidification cell, reverse osmosis unit, power supply, pump, carbon dioxide recovery system, and hydrogen on skid.

US Navy has experience using nuclear power at sea.

https://pubs.acs.org/doi/pdf/10.1021/acs.energyfuels.6b02586

Heather Willauer 2017 video of NRL seawater to jet fuel synthesis technology: <u>1.0 kW(e) → 0.6 kW(t)</u>

That's 56 kWh/gallon.
@ $0.03/kWh = $1.67 electricity cost

Pros:

Clean burning fuel production with net carbon neutral footprint when and where you need it

Near inexhaustible, renewable source of primary fuel production raw materials (CO_2 and H_2) from seawater

Current cost estimates for synthetic JP5 of $6/gallon (J. Renewable Sustainable Energy 2012, 4, 03311). Helps to stabilizes future naval energy availability and provides long-term predictability for JP5/F76 fuel costs

Cons:

Thermodynamically, for every kilowatt hour of electricity consumed to make the final liquid hydrocarbon fuel approximately 0.60 kilowatt hours of power is stored in the liquid hydrocarbon

Alternatives:

Bio-based fuel from camelina and algae must be produced on land and transported from source ports (primarily CONUS) and requires a source of H_2 for upgrade

https://en.wikipedia.org/wiki/Heather_Willauer https://pubs.acs.org/doi/pdf/10.1021/acs.energyfuels.6b02586 youtube.com/watch?v=TOCepaqnCOc

Fuel weight and volume are critical for airplanes.

Fuel	kWh/kg	kWh/L
Petroleum, C-synfuel	13	11.0
Hydrogen liquid, -253°C	33	2.4
Hydrogen gas, 700 bar	33	1.2
Ammonia liquid	5	3.3
Methane, 250 bar	15	9.0
LNG, -160°C	15	6.1
Lithium ion battery	0.2	0.8

https://en.wikipedia.org/wiki/Energy_density

Russia 's Tupolev-155 with liquid hydrogen fuel flew in 1988.

Beta Technologies COO: “It turns out building an aerospace company is a lot like setting piles of money on fire”

“In May 2021, the South Burlington electric aircraft pioneer landed $368 million in venture capital … secured another $375 million in financing... “

SEVEN DAYS

https://www.sevendaysvt.com/vermont/beta-technologies-lands-another-375-million-in-venture-funding/Content?oid=35390560

Electric trains can compete with airplanes that demand limited jet fuel.

Typical TGV

- 10 MW
- 25 kV
- **300 km/hr**
- 400 passengers
- 400 tonnes

Country	Electrified km	% of network
China	100,000	70
India	40,000	64
US	2,000	1
World	1,400,000	33

Average short haul airline flight
defined as < 3 hours
800 km

https://en.wikipedia.org/wiki/List_of_countries_by_rail_transport_network_size
https://www.sbb.ch/en/leisure-holidays/travel-europe/laender/france/new-lyria.html

More nuclear reactors in ships than power plants in 1990 !
US built just one nuclear powered merchant ship.

"A very attractive ship": The NS Savannah, pictured in 1962

https://www.bbc.com/news/magazine-28439159


Mirai, Japan

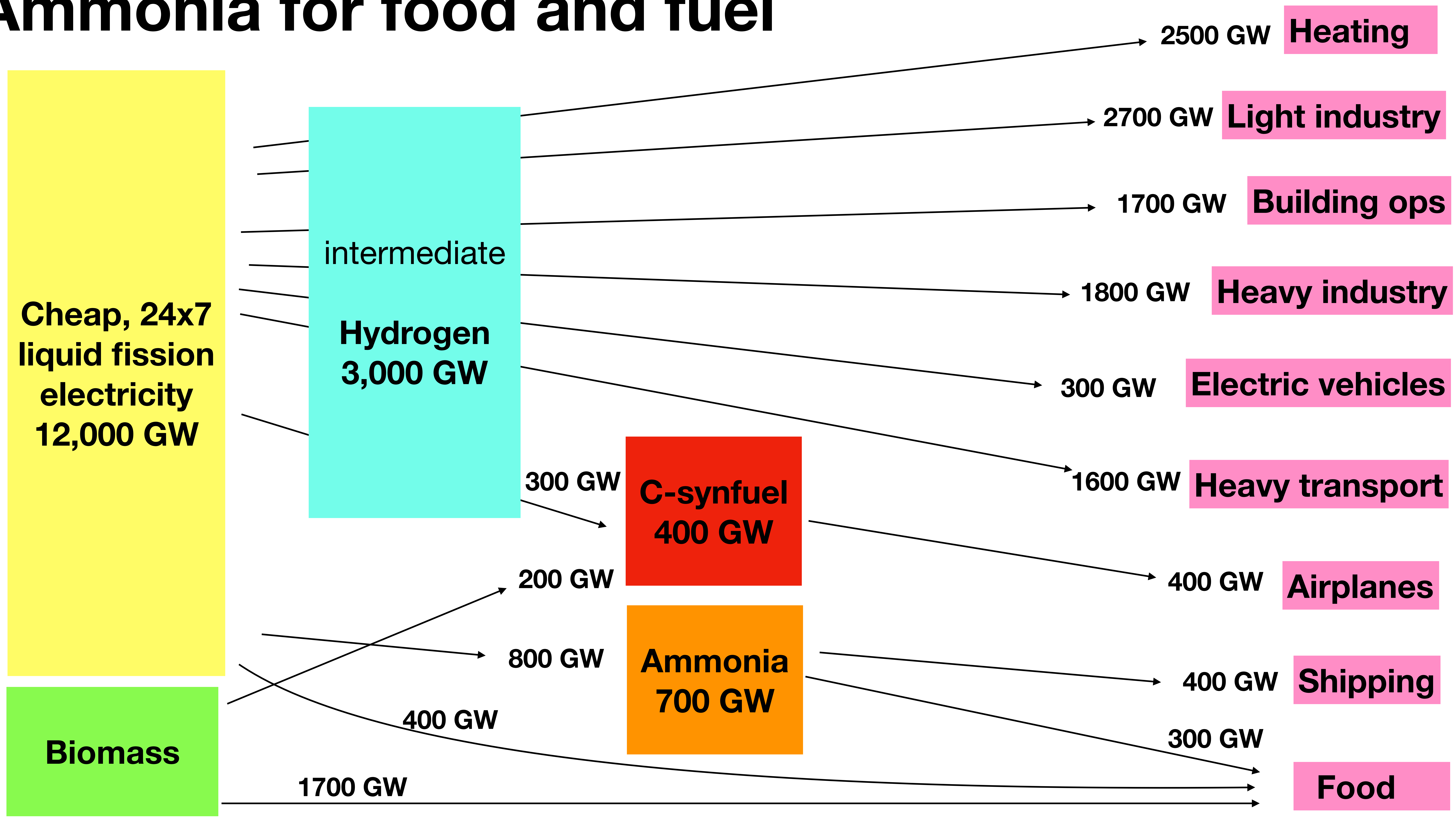

Otto Hahn, Germany


Dozen icebreakers, Russia


11 carriers, 100+ submarines, US

Fission powered shipping is a good emissions solution, ignored.

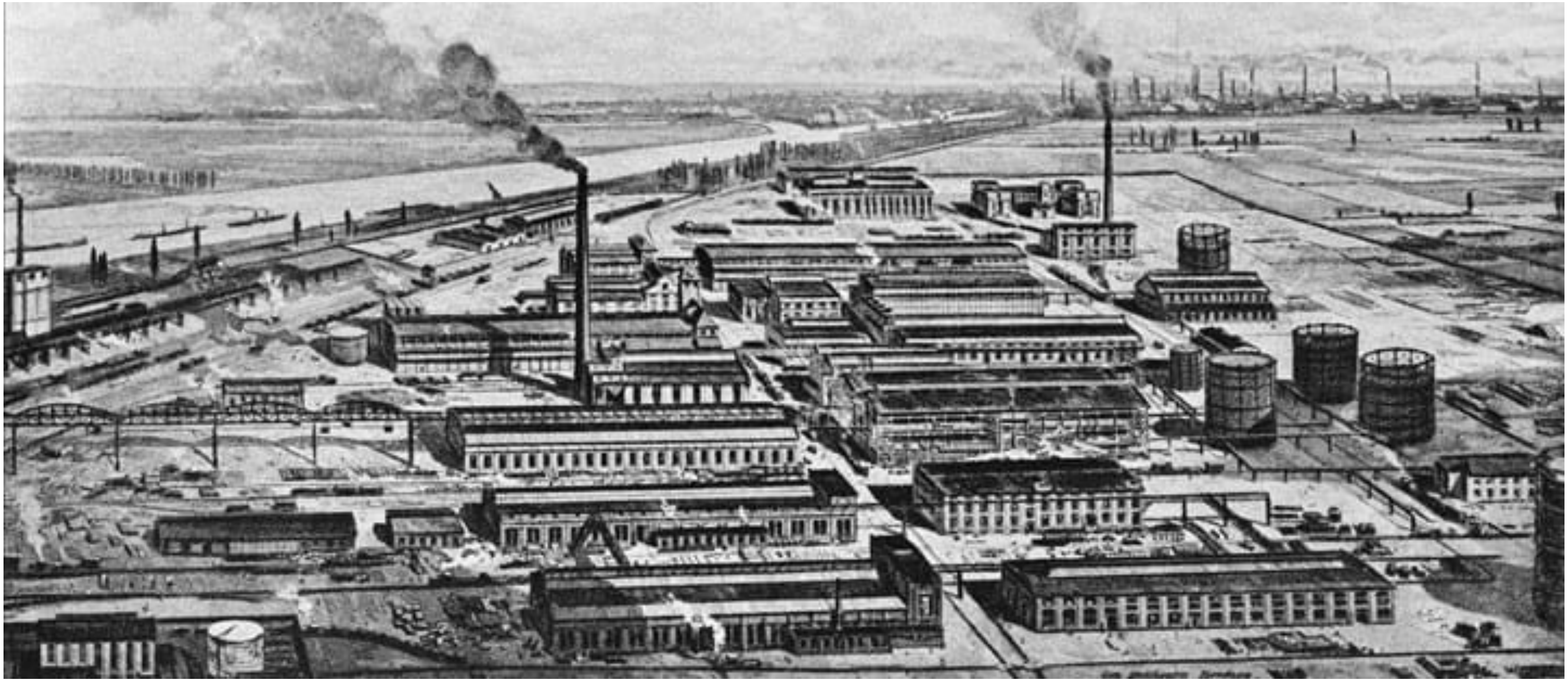
Ammonia for food and fuel



Century-old Haber-Bosch process makes NH_3 (ammonia) from CH_4 (natural gas).

$CH_4 + O_2 \rightarrow CO_2 + 2H_2$

$N_2 + 3H_2 \rightarrow 2NH_3$



https://www.thechemicalengineer.com/features/cewctw-fritz-haber-and-carl-bosch-feed-the-world/

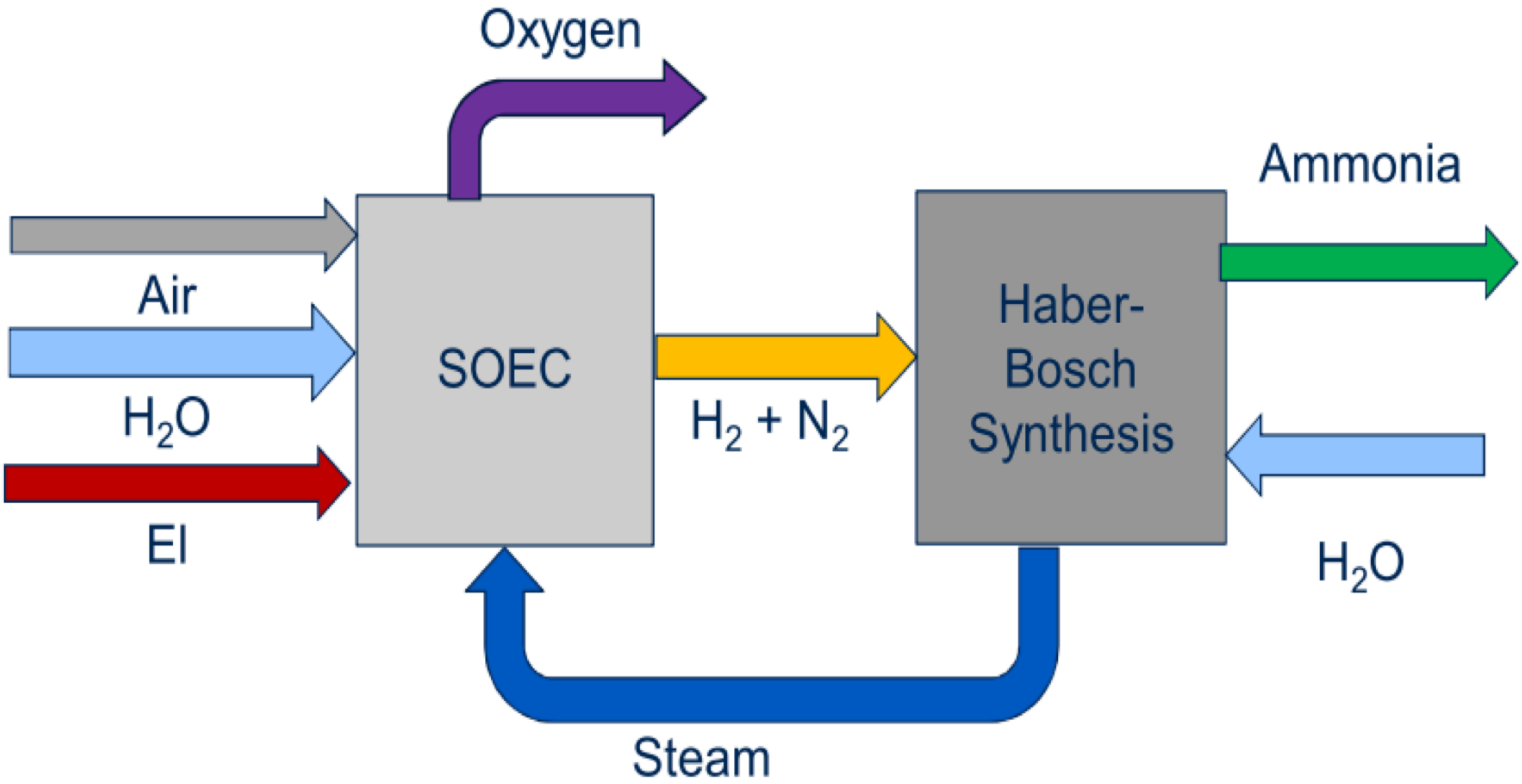
Ammonia fertilizer: basis of the Green Revolution, feeds nearly half the world.

https://iowaagliteracy.wordpress.com/2019/03/20/why-do-they-do-that-anhydrous/

- The knife slices the soil and injects the fertilizer 6 to 8 inches into the soil.
- The ammonia (NH_3) ions react with moisture in the soil and convert to ammonium (NH_4).
- Ammonium ions are bonded to negatively charged soil particles like clay and organic matter.
- These ammonium ions can be taken in by plants and used directly in proteins.
- In time they convert to nitrate (NO_3) fertilizer.

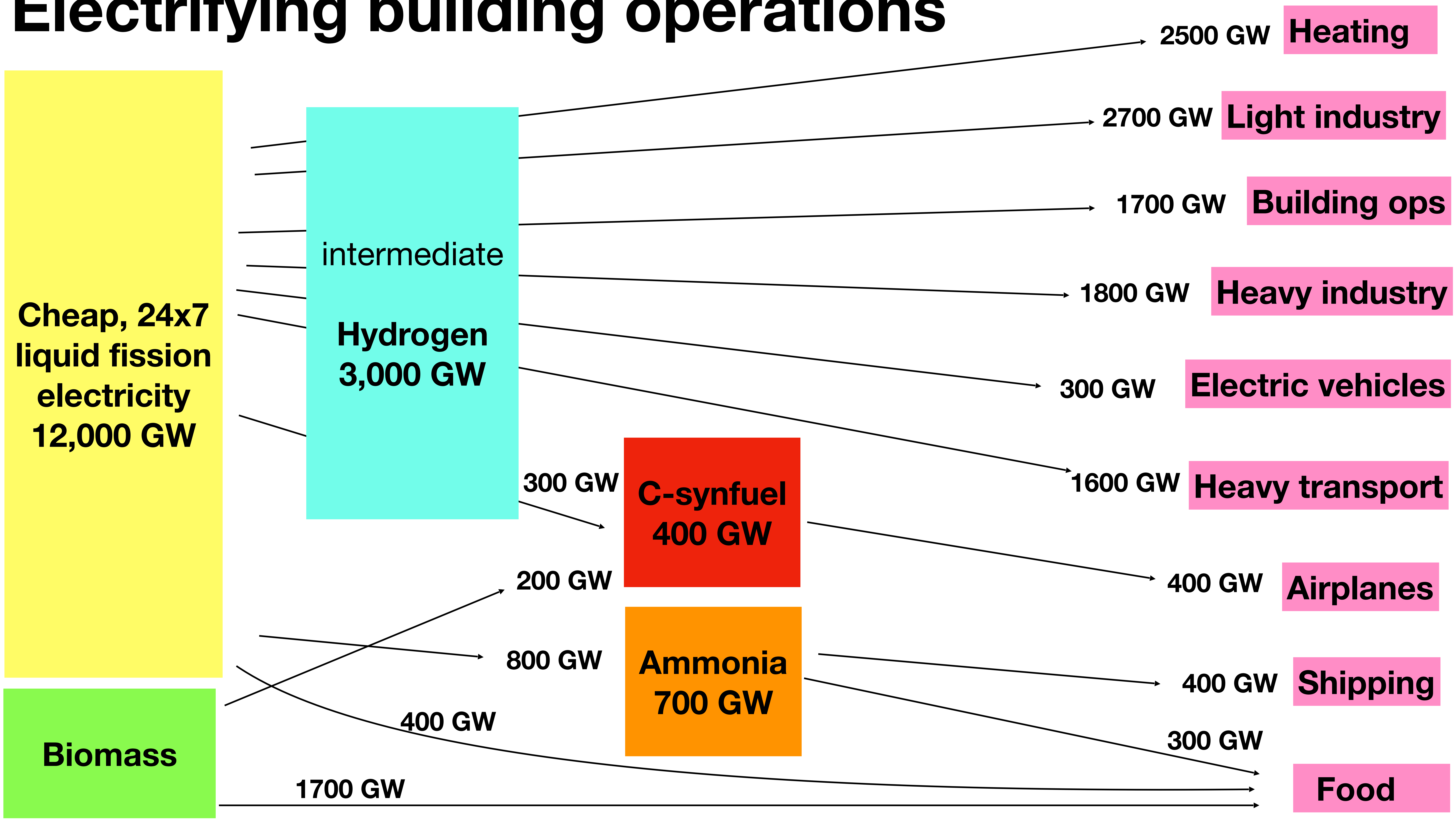
Ammonia fueled Belgium motor-buses.

Haldor Topsoe solid oxide NH3 synthesis, @ 7 kWh(e)/kg



https://www.ammoniaenergy.org/wp-content/uploads/2019/08/20191112.0800-NH3-Topsøe.pdf

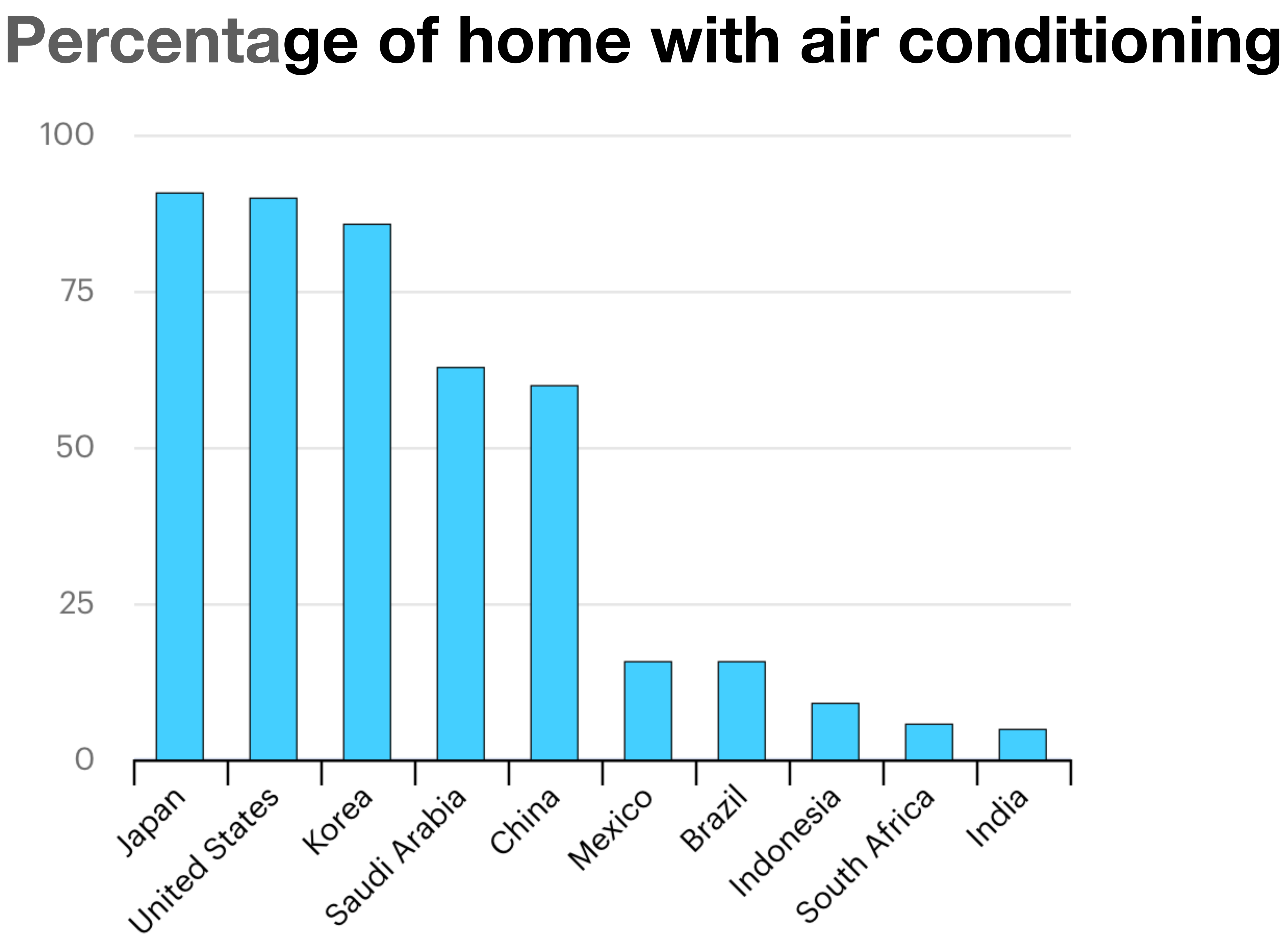
Electrifying building operations

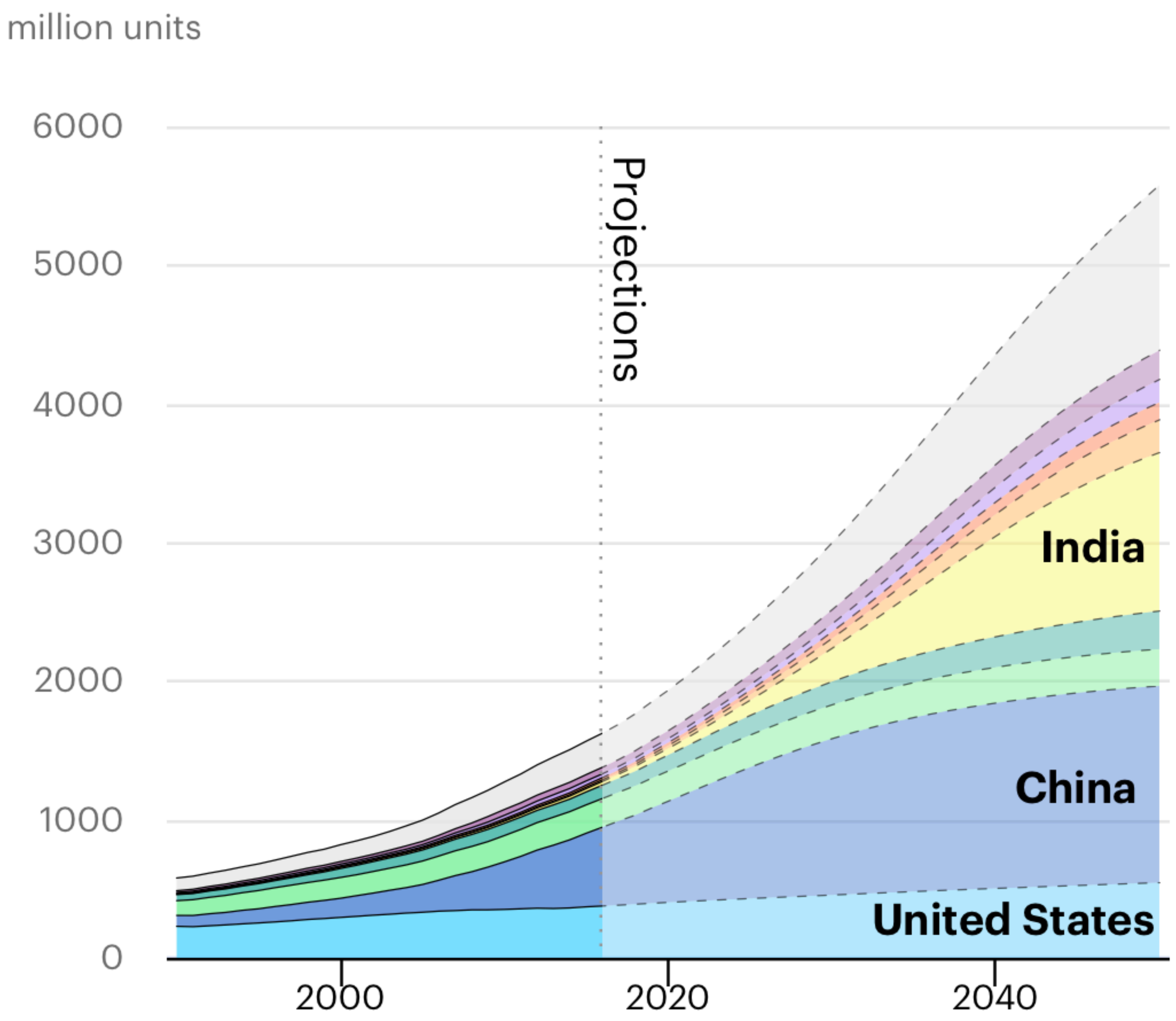


Cooling consumes > 8% of all electricity.

Responsible for 1 Gt CO2 emissions.
2 billion units in operation use **<u>250 GW.</u>**
Unit sales increasing 10-15% per year.
Ave COP efficiency could double, to 6.

Air conditioning units will triple, with electricity consumption of **700 GW** by 2050.





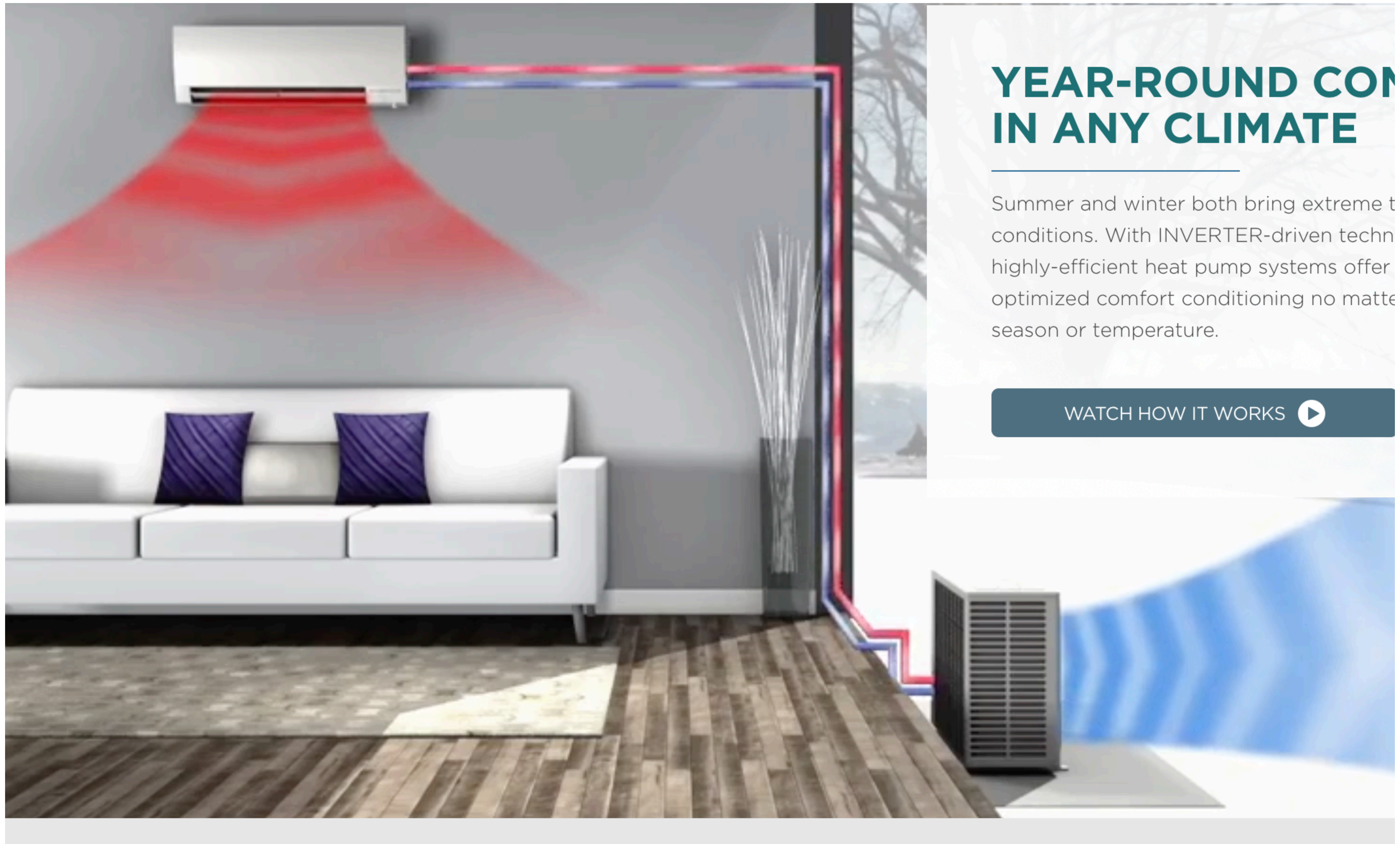
https://www.iea.org/reports/the-future-of-cooling https://www.technologyreview.com/2020/09/01/1007762/air-conditioning-grid-blackouts-california-climate-change/

Heat pump examples:

LG air conditioner

For cooling

Mitsubishi air source heat pump



For heating and cooling

Well insulated buildings are #1 priority to reduce heat demand.

Example specification: well sealed, well insulated Vermont 2000 sq ft home)

- Passive solar features
- R40 walls
- R60 ceiling
- R20 basement
- R7 triple-glazed windows
- R8 doors

- Air in-leakage less than 1.0 air changes per hour at 50 pascal.
- HVAC whole-house, forced-air ventilation of 0.5 air changes per hour.
- Air-to-air heat recovery exchanger.
- Space heating demand at -10°F, 6 kW(t).

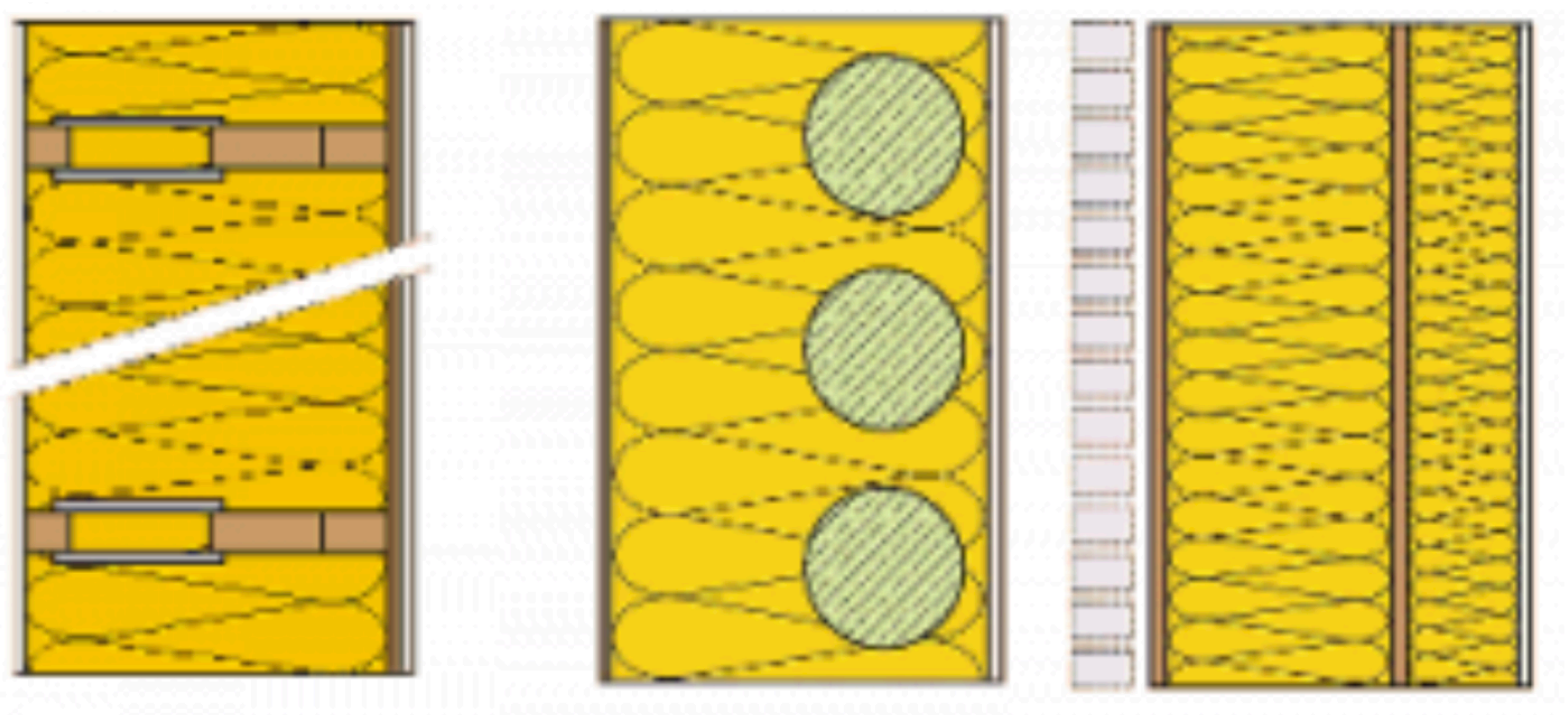
Caveats for air source heat pumps in Vermont:

- At 44°F Mitsubishi heat pump delivers 6 kW(t), uses < 2 kW(e); but at -10°F delivers nil.
- Home might survive -10°F with 6 kW(e) resistive heating (2 stovetop burners plus oven).
- Propane heater and tank are rational backup for power failure or extreme cold.

Willem Post, P.E.

LEED, Passivehaus can be $$$ certification regimes.

Making Passive House homes affordable



Examples of super-insulated external wall superstructures suitable for Passive Houses

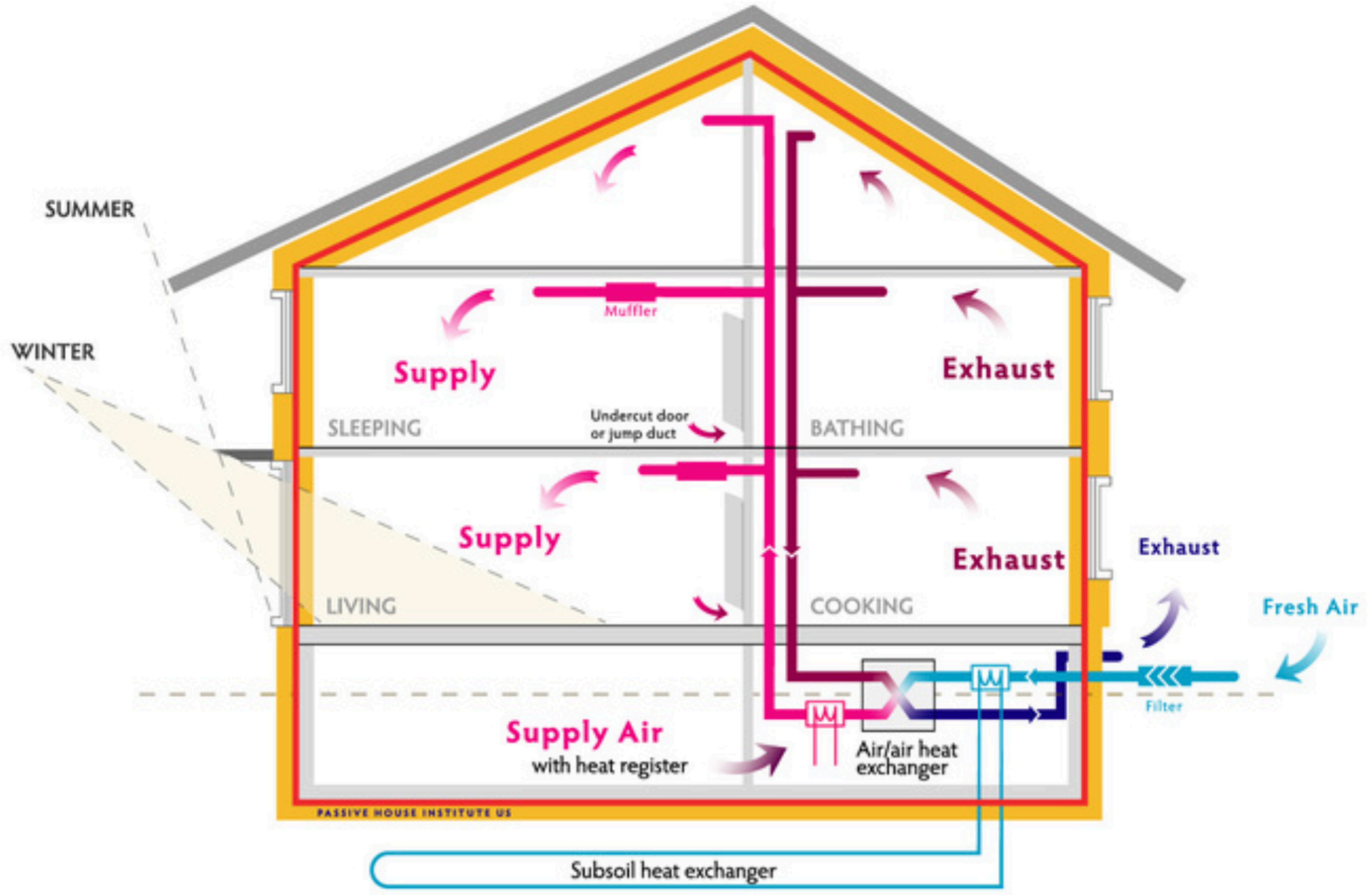
https://passipedia.org/planning/thermal_protection/integrated_thermal_protection

THE UN-CERTIFIED BUT 'DAMN NEAR' PASSIVE HOUSE.

One of the first steps was to convince people to pay more for the construction of the building, instead of a cheaper building with higher energy bills.

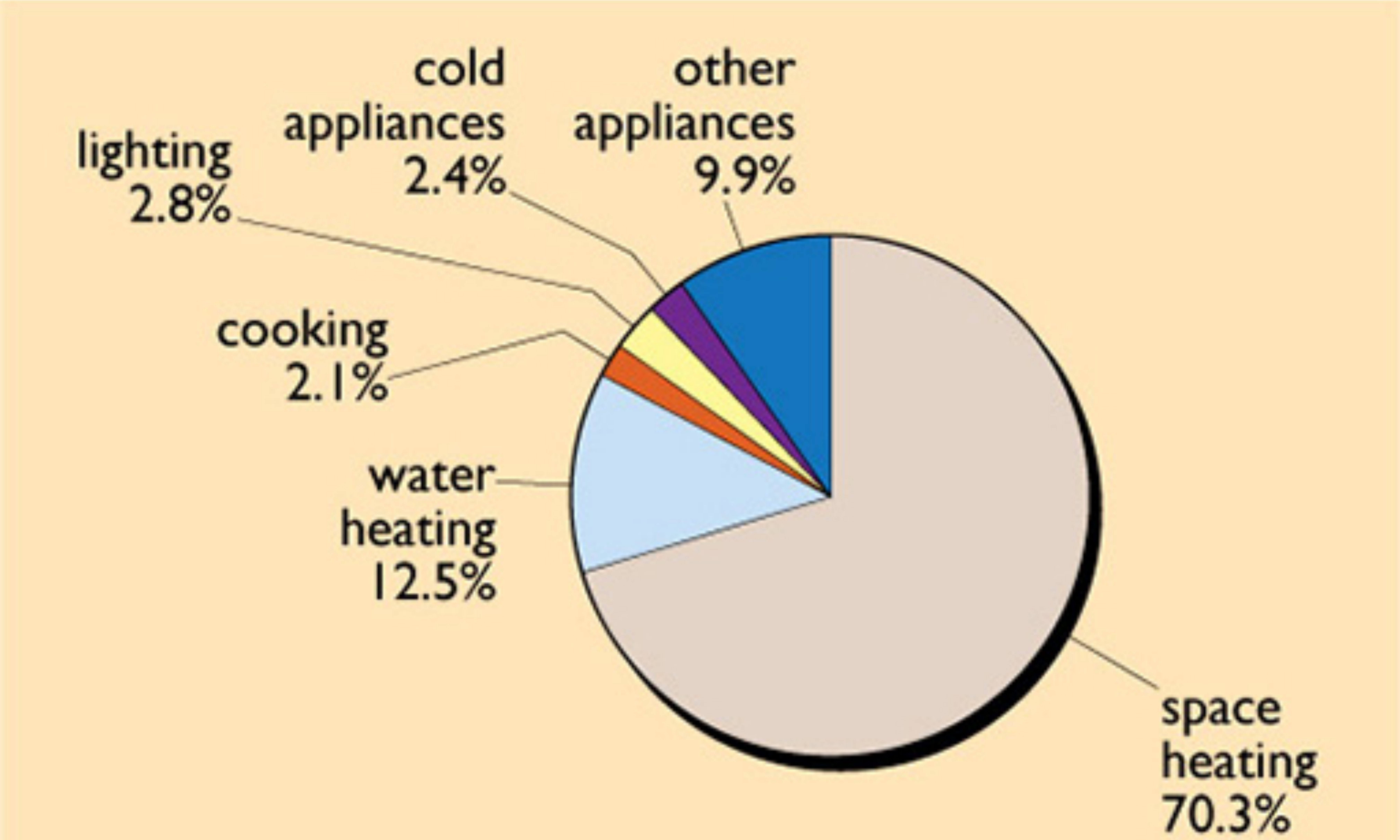
https://www.ecohome.net/guides/1482/the-un-certified-but-damn-near-passive-house/

Air/air heat exchanger needed in air-tight home.



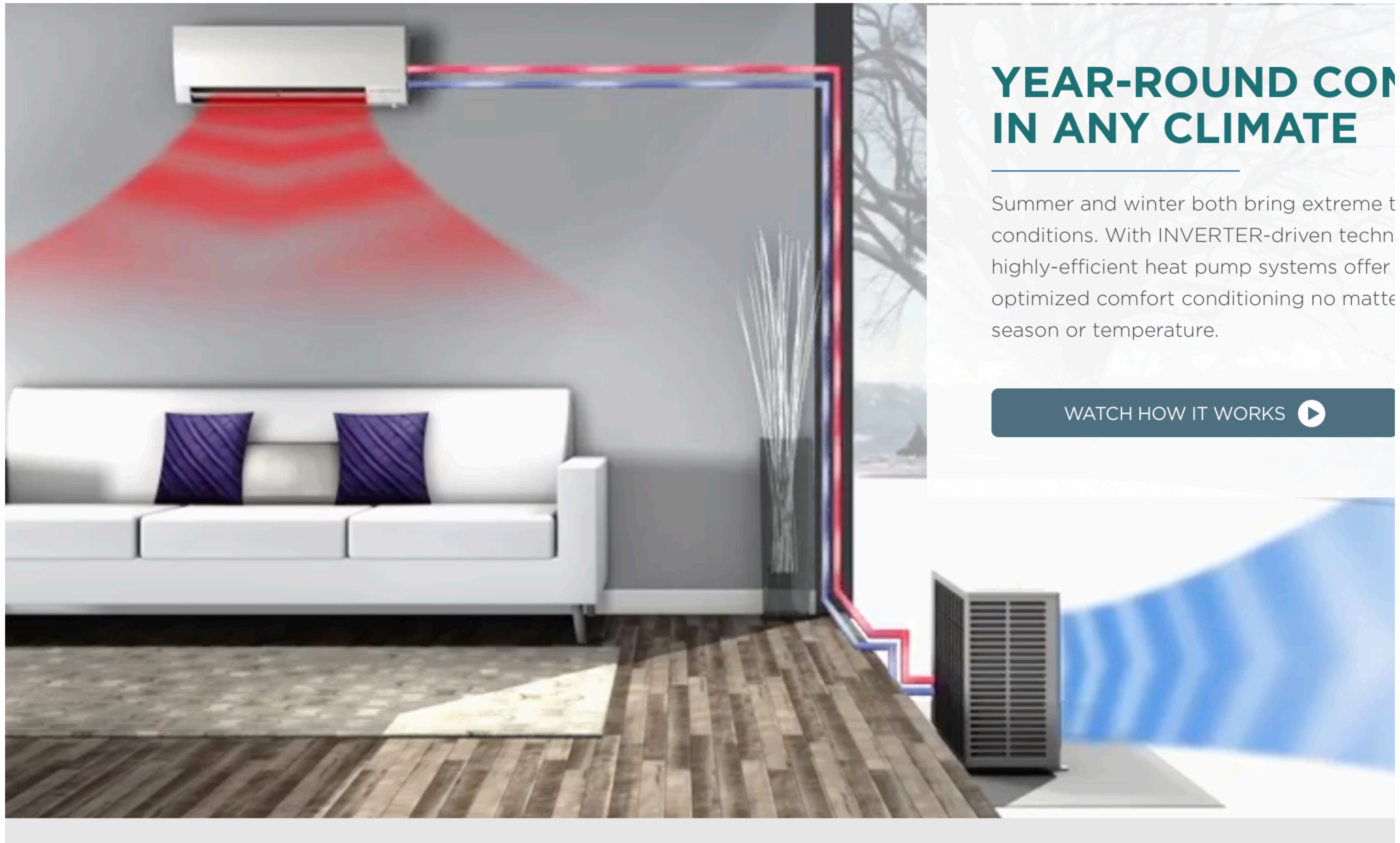
https://www.phius.org/what-is-passive-building/passive-house-principles

Electric resistance heating is common in UK (and Quebec).



https://www.open.edu/openlearn/ocw/mod/oucontent/view.php?printable=1&id=21281

Air source heat pumps can do heating and cooling.



Coefficient of Performance
= kW(t) output / kW(e) input

Gov't: HSPF (BTU/Wh) = 3.41 x COP

Heating COP drops with temperature.

Utilities burn more natural gas as electricity demand goes up.

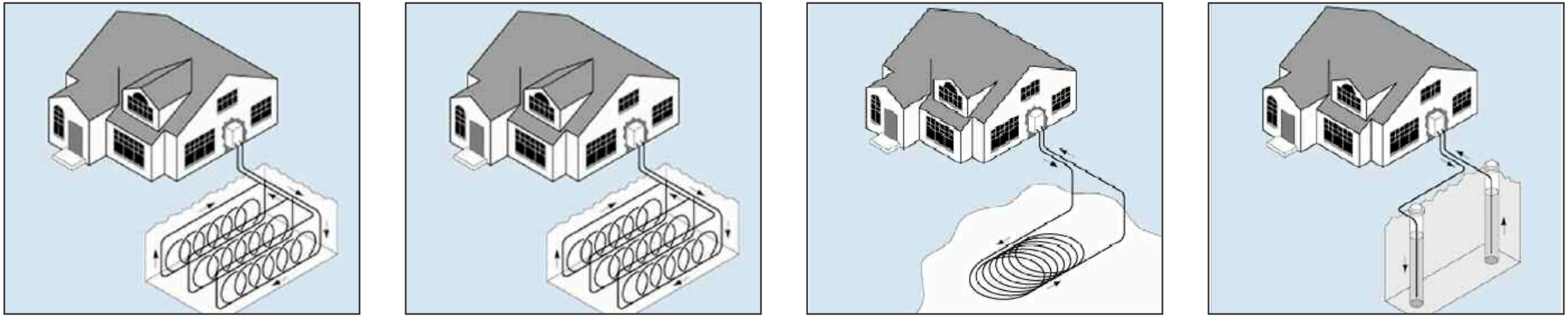
Below 20-35°F home furnaces use less natural gas than utility would.

Near 0°F COP ~1, like resistive heat.

Hybrid heating: keep gas or oil furnace for backup, for lower CO2.

https://www.linkedin.com/pulse/lets-run-towards-hybrid-heat-pumps-benefits-climate-harvey-michaels/

Ground source heat pumps work better, cost more.



Closed Loop Systems Horizontal

Closed Loop Systems Vertical

Closed Loop Systems Pond/Lake

Open Loop Systems

HDPE tubing has ~50 year lifetime.

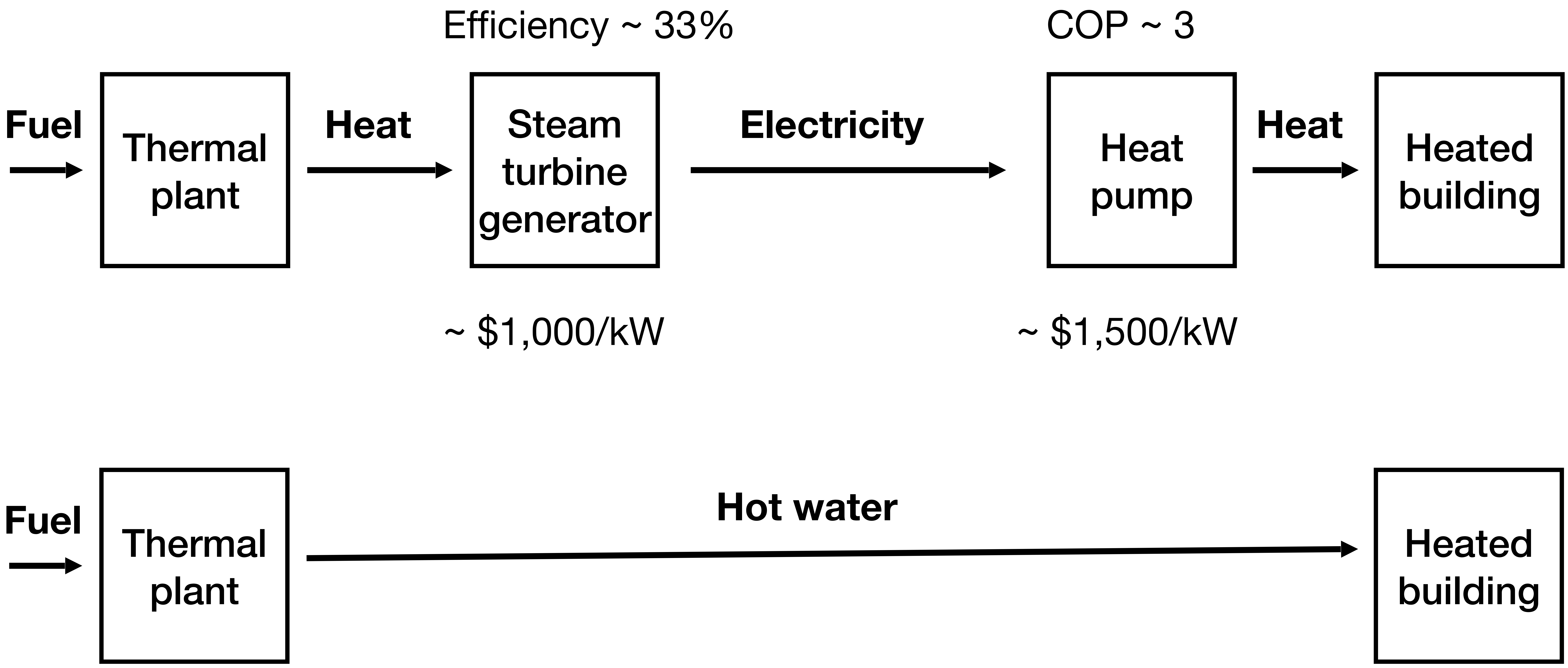
Suited to college campuses.

Harvard’s 19, 1500-foot-deep wells provide partial heating/cooling for 6 buuildings.

Economics? “…’simple payback’ is often a misleading metric…”

https://www.nwf.org/~/media/PDFs/Campus-Ecology/Reports/Geothermal%20Guide%20FINAL%203-1-11.ashx

District heating can bypass thermal-electric, electric-thermal conversions.



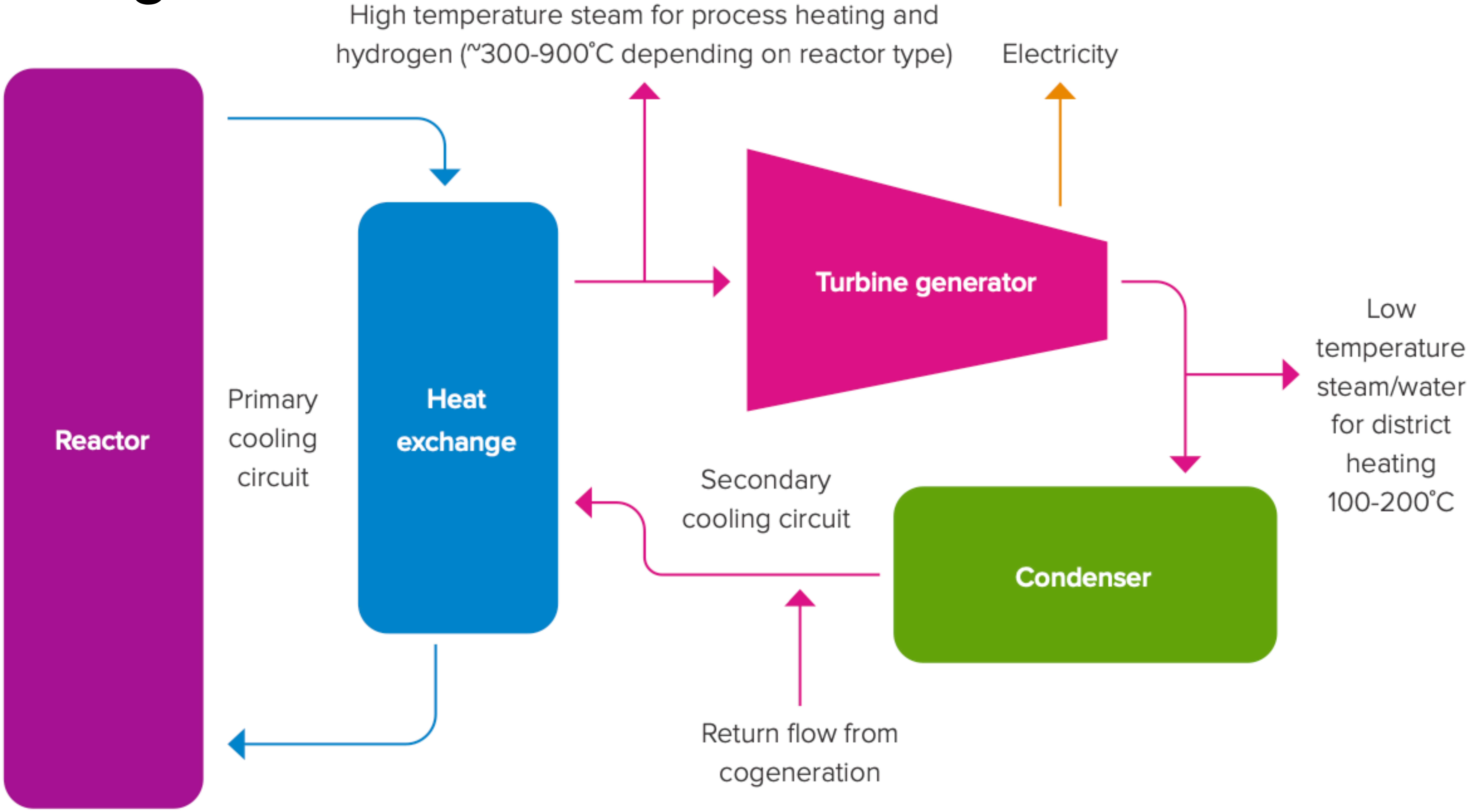
District heating reactors will be located in China cities.

CGN – The NHR200-II reactor is a low-temperature district heating reactor. Its design is described by CGN as "mature", having passed National Nuclear Safety Administration review in the 1990s. In February 2018 it was announced that CGN and Tsinghua University were carrying out a feasibility study on constructing China's first district heating nuclear plant using the NHR200-II design.

CNNC – The District Heating Reactor-400 (DHR-400) or 'Yanlong' is a low-temperature **400 MW pool-type reactor**. It is designed to provide **heat at 90°C for up to 200,000 three-bedroom apartments.** The reactor prototype achieved 168 hours of continuous heat supply in November 2017 – seen by its developers, CNNC, as the first major step towards commercialization of the design.

SPIC – The Advanced Happy200 is similar to the Yanlong, **200 MW and producing hot water at 110°C**. Pre-feasibility studies suggest first commissioning in 2022. In February 2019, SPIC contracted to build the Baishan Nuclear Energy Heating Demonstration Project in Jilin province.

Co-generation uses rejected heat from steam turbine for district heating.



https://royalsociety.org/-/media/policy/projects/nuclear-cogeneration/2020-10-7-nuclear-cogeneration-policy-briefing.pdf

Do both! China is using two Westinghouse AP1000 power reactors for district heating.

NUCLEAR ENGINEERING INTERNATIONAL

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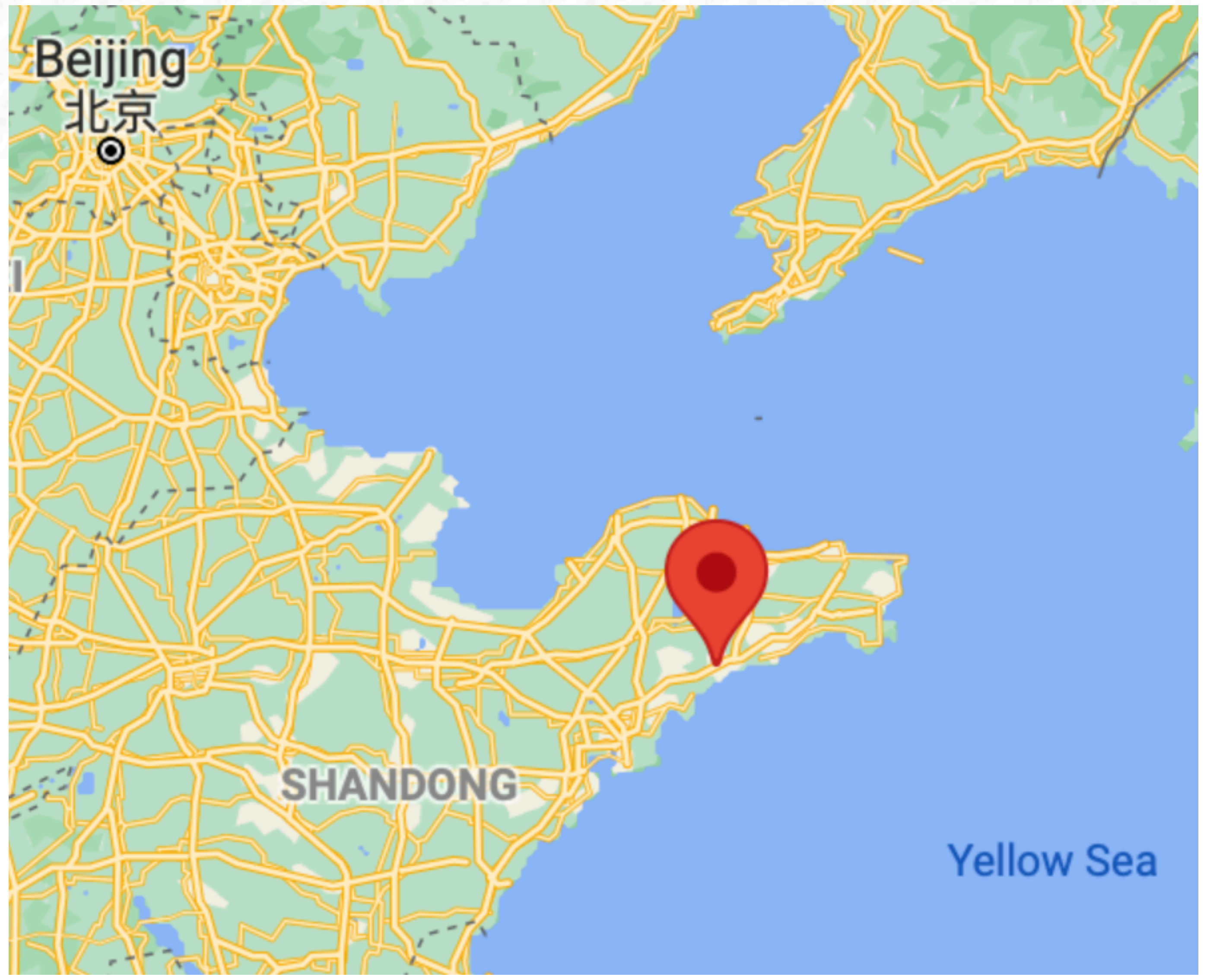
Second phase of China's Haiyang nuclear heating project begins operation

23 November 2021

Haiyang population 350,000



Haiyang 1&2 could heat 30 million square metres…

eventually provide heating to more than 200 million square metres of housing within 100 km

avoiding the use of about 6.62 million tonnes of coal.

Up to six CAP1000 units are planned for the Haiyang plant.

https://www.neimagazine.com/news/newssecond-phase-of-chinas-haiyang-nuclear-heating-project-begins-operation-9267335

Nuclear option to heat the campus

Valley News July 5, 2021

The University of Illinois is planning to heat its Urbana campus with a new, underground nuclear reactor with a fuel cartridge that lasts 20 years. The university is working with Seattle-based Ultra Safe Nuclear Corp. to partially replace a coal-fired plant, seeking Department of Energy funding and preparing a Nuclear Regulatory Commission license application.

Dartmouth College has already rebuilt its hot-water circulating district heating system in anticipation of plans for a wood chip burning plant, now dropped. Dartmouth continues to burn 3.5 million gallons of No. 6 fuel oil annually as it seeks a better energy source. The Ultra Safe Nuclear Corp. reactor generates 15 megawatts of heat, approximately the demand from the Dartmouth campus.

ROBERT HARGRAVES

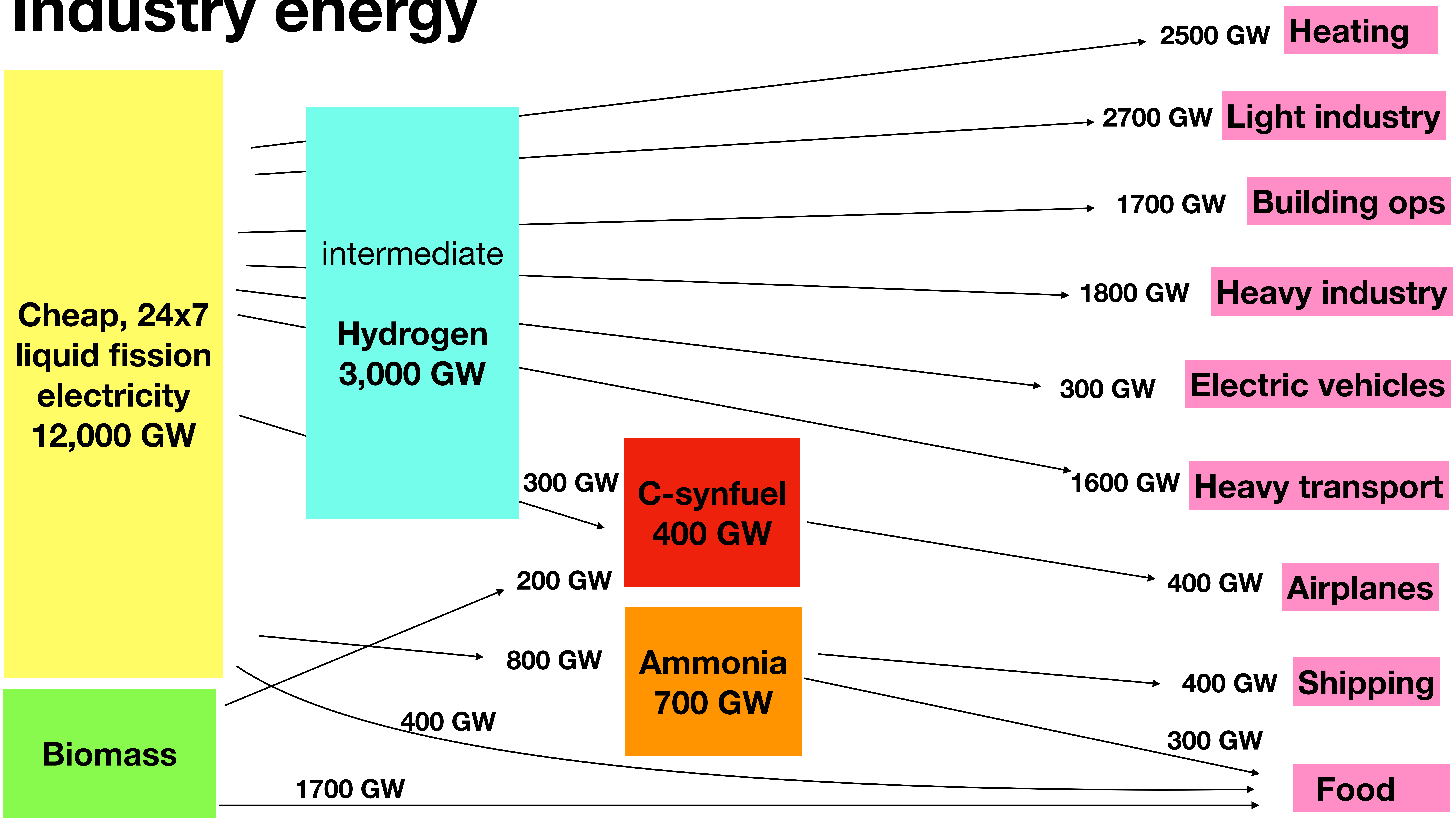
https://www.vnews.com/Forum-July-5-41265620

Purdue and Duke Energy to explore potential for clean, nuclear power source for campus

April 27, 2022

https://www.purdue.edu/newsroom/releases/2022/Q2/purdue-and-duke-energy-to-explore-potential-for-clean,-nuclear-power-source-for-campus.html

Industry energy



IRENA has industry power use estimates.

Energy-intensive industrial sectors

Iron and steel

1000 GW

In 2017:

- Consumed 32 exajoules (EJ) of energy
- Only 4% was from renewables
- Emitted 3.1 gigatonnes (Gt) of CO_2

3 Gt/y

Chemicals and petrochemicals

1500 GW

In 2017:

- Consumed 46.8 EJ of energy
- Only 3% was from renewables
- Emitted 1.7 Gt of CO_2

2 Gt/y

Cement and lime

500 GW

In 2017:

- Consumed 15.6 EJ of energy
- Only 6% was from renewables
- Emitted 2.5 Gt of CO_2

3 Gt/y

Aluminium

150 GW

In 2017:

- Consumed 4.5 EJ of energy
- 16% was from renewables
- Emitted 0.4 Gt of CO_2

<1 Gt/y

Some of 1500 GW of chemical and petrochemical power consumption related to fuel refining will not be needed.

https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Sep/IRENA_ReachingZero_Summary_2020.pdf

GREAT BOOK FREE at http://www.withbotheyesopen.com/read.php?c=9

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SUSTAINABLE MATERIALS
WITH BOTH EYES OPEN

Materials, transformed from natural resources into the buildings, equipment, vehicles and goods that underpin our remarkable lifestyles, are made with amazing efficiency. But our growing demand is not sustainable, so this optimistic, entertaining and richly informed book evaluates all the options . . . with both eyes open.

Julian M Allwood
Jonathan M Cullen

with Mark A Carruth, Daniel R Cooper, Martin McBrien, Rachel L Milford, Muiris C Moynihan, Alexandra CH Patel

Follow us on Twitter @SMWBEO

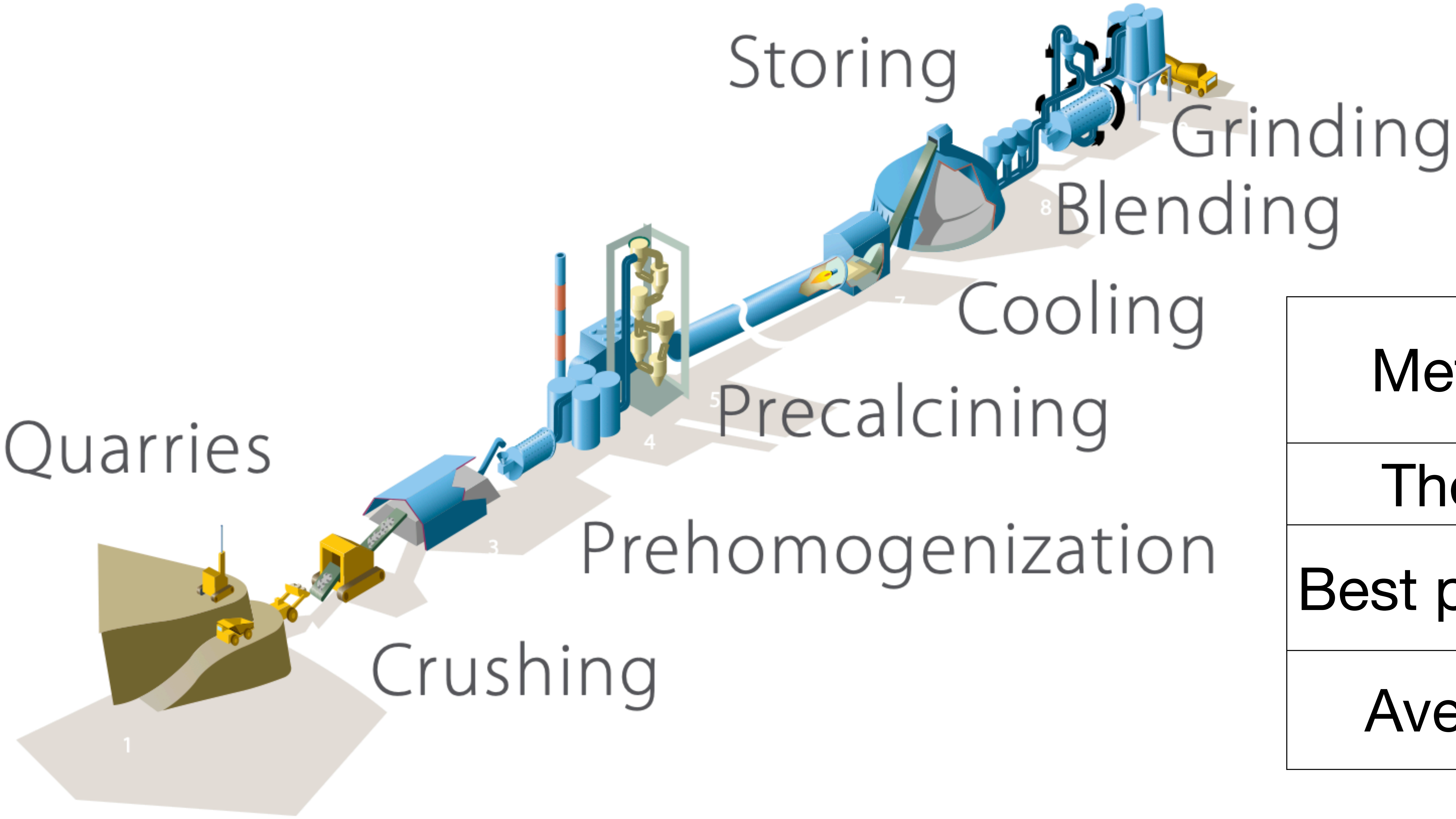
Top 5 materials produced

Material	Global annual production (Mt)	Energy intensity (GJ/t)	Carbon intensity ($t\,CO_2/t$)	Power
Cement	2,800	5	1	444 GWt
Steel	1,400	35	3	1553 GWt
Plastic	230	80	3	583 GWt
Paper	390	20	1	247 GWt
Aluminium	70	170	10	377 GWe

http://www.withbotheyesopen.com/read.php

Cement energy use and emissions can be improved.

Sustainable Materials with Both Eyes Open



Method	Energy use GJ/t
Theory	1.8
Best practice	2.9
Average	5.0

Fission-powered plasma arc heating to 1500°C for cement?

http://www.withbotheyesopen.com/read.php

1400 Mt of steel are used every year.

Steel product catalogue

Transport

Cars and light trucks

93 Mt
9 %

An average car contains 960 kg of steel and iron. 34 % is in the body structure, panels and closures (doors and bonnets), consisting of welded, profiled sections produced by stamping formable cold rolled sheet. This provides high strength and energy absorption in case of a crash. 23 % is in the drive train, consisting of grey cast iron for the engine block and machinable carbon steel for the wear resistant gears. 12 % is in the suspension, using rolled high strength steel strip. The rest is spread between the wheels, tyres, fuel tank, steering and braking systems.

Trucks and ships

28 Mt
3 %

The basic steel components described for the car also apply to trucks, but unlike cars, all truck engine blocks are steel. Frame rails and cross members are usually high tensile steel, and the cab structure and outer skin is often made from galvanized steel. Steel for the ship hull is rolled primary mild steel, providing strong, tough, dimensionally consistent plates that are welded together.

Industrial equipment

Electrical equipment

27 Mt
3 %

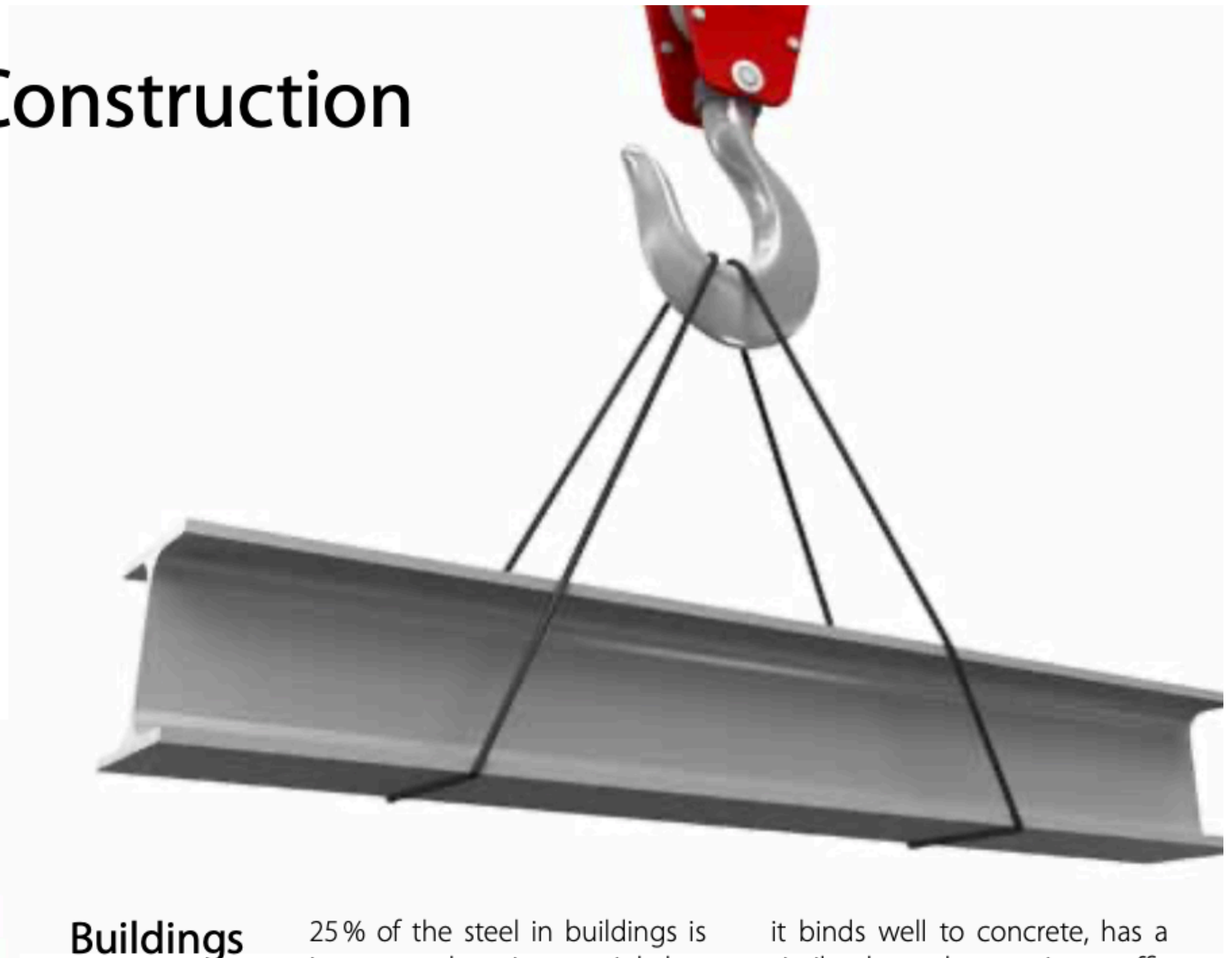
30 % of steel in electrical equipment is high silicon content electrical steel forming the cores of transformers or the stator and rotor parts of electrical motors. Other major uses include pylons (constructed from bolted, cold-formed, galvanized L-sections forming a light-weight durable tower); and steel reinforced cables (where wound galvanized steel wires provide the strength to carry conducting aluminium in long span transmission cables).

Mechanical equipment

137 Mt
13 %

This covers a wide range of equipment from small workshop tools to large factory-based robotic machinery and rolling mills. 40 % of the steel is plate or hot rolled bar; tubes contribute a further 22 %, as do hot and cold rolled coils. Cast products and wire rod contribute the remainder.

Construction



Infrastructure

150 Mt
14 %

For infrastructure: 24 % of steel is in structural sections; 54 % is reinforcing bars; 6 % is hot rolled train rails (providing a strong, wear and fatigue resistant contact surface); 16 % is in pipes formed by welding rolled steel, with high corrosion and fatigue resistance, and high strength to resist internal pressure and installation stresses.

Buildings

433 Mt
42 %

25 % of the steel in buildings is in structural sections, mainly hot rolled sections but also some welded plate. Sections form a strong, stiff structural frame. 44 % is in reinforcing bars, adding tensile strength and stiffness to concrete. Steel is used because it binds well to concrete, has a similar thermal expansion coefficient and is strong and relatively cheap. 31 % is in sheet products such as cold-formed purlins for portal frame buildings and as exterior cladding.

Metal products

Metal goods

134 Mt
12 %

Other metal goods include a multitude of products, from baths and chairs to filing cabinets and barbed wire. 30 % of steel entering this product group is hot rolled coil; 20 % is hot rolled bar; and the remainder is either plate, narrow strip, or cast iron.

Consumer packaging

9 Mt
1 %

Steel use in packaging is dominated by tin-plated rolled steel, which doesn't corrode. 60 % of this steel is made into food cans, providing durable packaging for the subsequent cooking and distribution. 40 % is used for aerosols.

Domestic appliances

29 Mt
3 %

Appliances are dominated by white goods (up to 70%). The vast majority of steel used here is cold rolled coil, often galvanized or painted. Most of this steel is used for panelling. Other applications including washing machine tubs (welded rolled steel strip), motors, expanders in fridge/freezers and cast parts for transmissions.

Figure 3.1—Steel product catalogue

We make over 1,000 Mt of steel products every year, equivalent to a 1 metre square band of steel wrapped around the equator more than three times. Global steel production is divided into 4 sectors and 9 categories of end-use products. The amount of steel in each category is given in millions of tonnes Mt and the fraction of global steel as a percentage %, with the images sized to reflect this fraction. The end-use of steel is dominated by construction (56 %). These numbers are derived from data for 2008.

Steelmaking uses 900 GW(t) plus 600 GW(e).

Sustainable Materials with Both Eyes Open

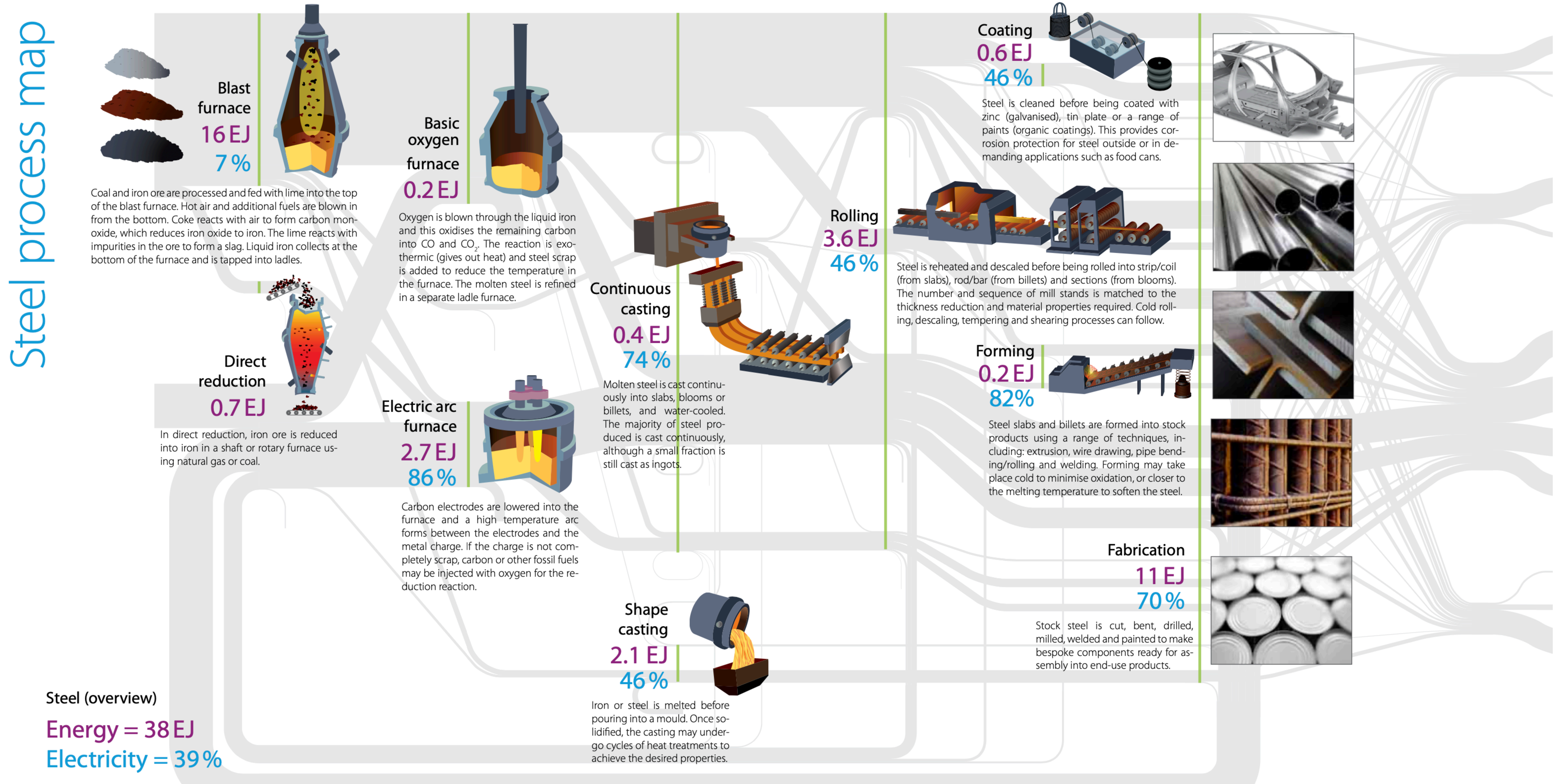
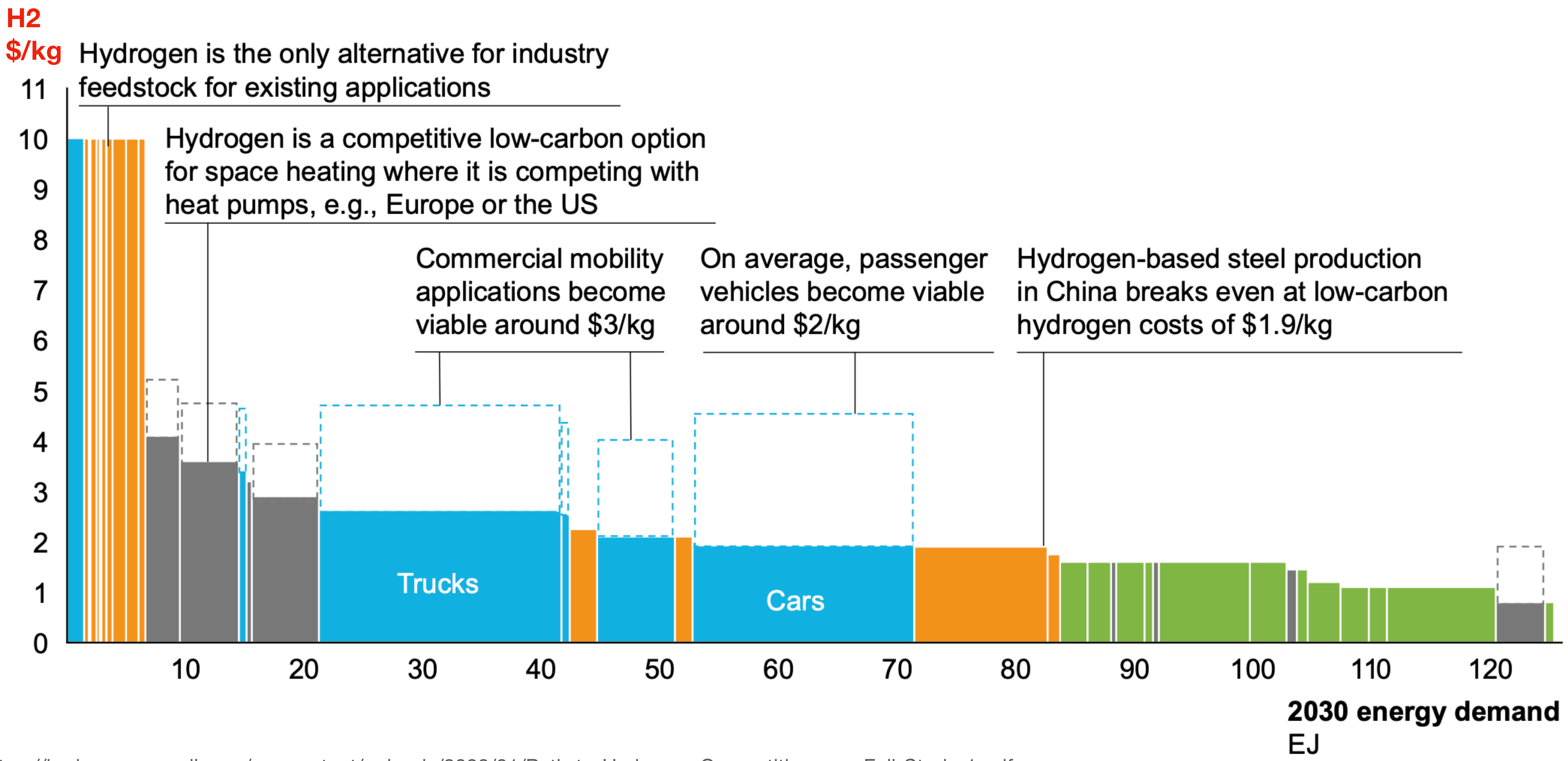


Figure 5.1—Steel process map[9]

http://www.withbotheyesopen.com/read.php

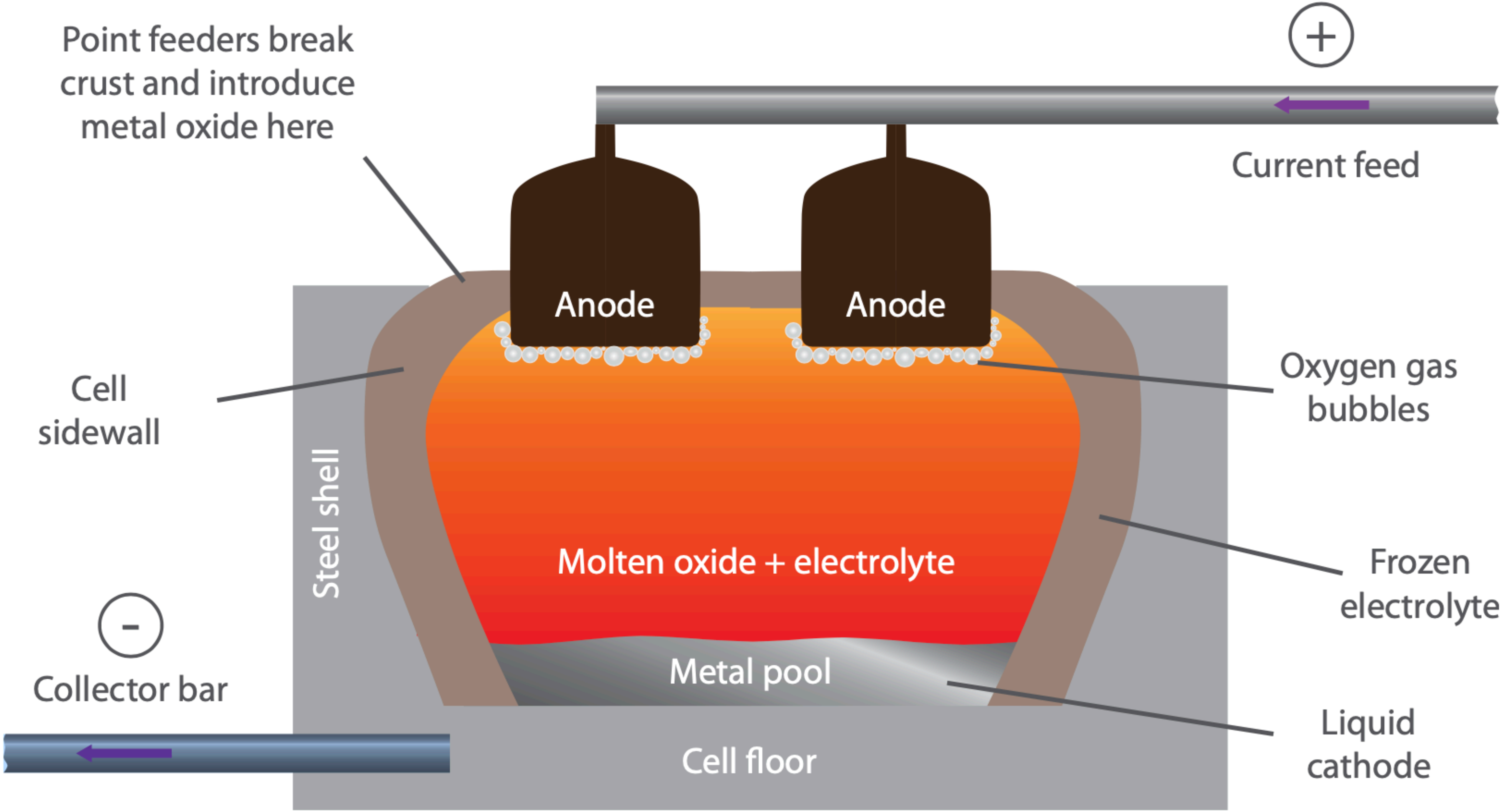
Hydrogen based steel production may be viable at $1.9/kg-H2.
(Hydrogen Council)



https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf

Iron may be freed from oxide ore by electrolysis.

Sustainable Materials
with Both Eyes Open



http://www.withbotheyesopen.com/read.php

45 Mt of aluminum are used each year.

Aluminium product catalogue

Transport

Cars
8 Mt
18 %

An average car contains 120 kg of aluminium. 35 % is in the cast engine, requiring high strength and wear resistance. 15 % is in the cast transmission casing, providing stiffness for gear teeth alignment and thermal conductivity for dissipation of frictional heat. 15 % is in the cast wheels, giving a lightweight aesthetic design. The remaining aluminium is mainly in the heat exchanger (requiring high thermal conductivity) and forgings in the chassis and suspension. Aluminium is increasingly used in car engines and bodies to save weight.

Trucks
3 Mt
7 %

Many of the basic aluminium components described for the car also apply to trucks, with the exception that aluminium cast engines are rare. Aluminium is used in trucks for corrosion resistance and weight saving. Applications include the cab structure and outer skin, chassis and suspension parts, tipping bodies and sliding side doors.

Other
1 Mt
2 %

Aluminium, used extensively in the aerospace industry for its high specific strength, fracture toughness and good formability, typically makes up 80 % of the airframe. Common alloys are AA2024 and 7xxx. Rail carriages are made from aluminium welded extrusion frames (AA5083/6061) and sheet sidewalls (5xxx/AA6061), giving light, non-corroding vehicles.

Industrial equipment

Electrical equipment
2 Mt
4 %

Electrical equipment includes conduits (often AA6063) and sheathing (Alclad 5056) to strengthen and protect electrical wiring. Other applications include wide strip aluminium in bus bars (1xxx) to conduct electricity around switchboards.

Electrical cable
4 Mt
9 %

Cables are made from concentrically stranded aluminium wire (typically AA1350-H19) wound in multiple layers around a steel core. The aluminium has conductivity around 60 % that of copper, but is cheaper and lighter.

Mechanical equipment
3 Mt
7 %

Mechanical equipment includes products such as heating and ventilation systems. Aluminium is widely use in heat exchangers for its high thermal conductivity, good corrosion resistance and low cost. Drawn or extruded tubes are either brazed or mechanically fastened to sheet (both 1xxx or 3xxx alloy).

Packaging
6 Mt
13 %

Aluminium is used in packaging, and provides an attractive outer package and inert inner surface. Half of this aluminium is used in light-weight drinks cans (14 grams each), where rolled (AA3104) aluminium strip is drawn to form the can body, the lid attached (AA5182) and inside sprayed with an epoxy-based lacquer. The other half is thin aluminium foil used in household foil, food and drink pouches and semi-rigid containers to provide an inert and flexible package.

Construction

Buildings
11 Mt
24 %

Most aluminium in construction is made from extrusions or sheet. 45 % of it is used for extruded frames in windows, doors and curtain walls (projected, non-load bearing façades on commercial buildings). Another 40 % is used in corrosion resistant roofing and cladding, for which aluminium strip is cold formed to a profile.

Metal products

Other
4 Mt
9 %

Approximately half of this is powdered aluminium used in powder metallurgy, paints and pigments. Other applications are the deoxidation of steel: aluminium has a high affinity for oxygen, so is used to reduce formation of gas bubbles in steel casting. Lithographic plate (1xxx and 3xxx series) is another significant use, for which aluminium is chosen because of the criteria for flatness and high surface quality.

Appliances
3 Mt
7 %

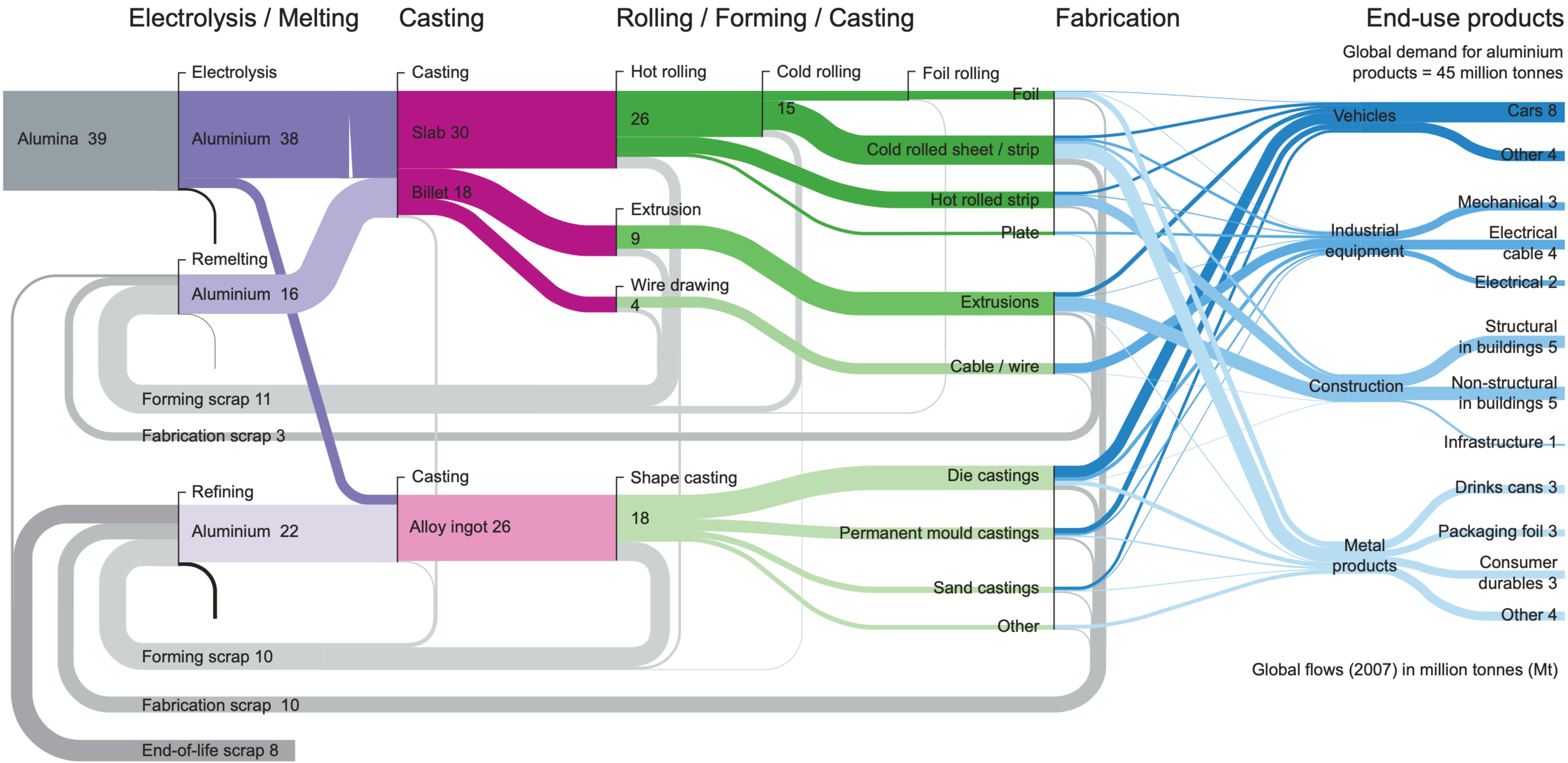
The main use of aluminium in consumer durables is in household white goods. Most aluminium in white goods is in fridges/freezers and washing machines. AA5754 is a common sheet alloy of medium strength used for appliance bodywork, and AA3003 and AA3103 are common sheet materials used as fridge/freezer linings. Fridge/freezers also require heat exchangers where the fins, and sometimes tubes, are aluminium.

Figure 3.2—Aluminium product catalogue

We make approximately 45 Mt of aluminium products every year. We have shown the uses of global aluminium production divided into 4 sectors and 10 categories of end-use products. The amount of aluminium in each category is given in millions of tonnes Mt and the fraction of global aluminium as a percentage %, with the images sized to reflect this fraction. The end-use of aluminium is more evenly spread across the 4 sectors than for steel. These numbers are derived from data from 2008. (Aluminium alloy codes, e.g. 1xxx are described at the end of this chapter).

Sankey aluminum flow

Sustainable Materials
with Both Eyes Open



http://www.withbotheyesopen.com/read.php

Shipbuilding technology for whole new factories.

Shell's natural gas liquifaction plant larger than 5 aircraft carriers.

https://www.abc.net.au/news/2020-08-21/worlds-largest-floating-lng-factory-remains-in-shutdown/12565490

Recommended energy policies

#1 **Education**

#2 **Technologies**

#3 **Regulations**

#4 **Cost**

#5 **Taxes and mandates**

#1 <u>Educate</u> people and politicians about fission energy.

Problems

1. Unawareness of costs of **intermittent** wind/solar/battery energy.
2. Even most French people think their fission power plants **emit CO_2**.
3. Many fear fission power plants might **blow up** like a bomb.
4. People (even doctors) are taught all radiation is **carcinogenic**.
5. Pompous advisory organs substitute **fear and doubt** for evidence and science.

Solutions

1. Science education; young people are more **open minded**.
2. Public **communications**: ample, cheap, clean energy for health and prosperity.
3. **Rebranding** as "fission" avoids nuclear weapons mindset.
4. Political leaders **endorse** fission and blame all who continued the ALARA fraud.
5. Frame fission energy as the **feedstock** for a clean, prosperous economy.

#2 Technologies deserving of public and private investment.

1. Liquid fission electricity, cheap, 24x7
2. Hydrogen electrolysis
3. Vehicle batteries
4. Fuel cells, SOEC/SOFC
5. Ammonia synthesis
6. Ammonia combustion engines
7. Hydrogen fueled trucks, buses
8. Resonant inductive highway charging
9. Hydrogen enhanced biofuels
10. CO2 from seawater or air to jet fuel
11. High speed trains, public transportation
12. Buildings, codes, cooling, heating
13. Iron ore electrolysis, H2 reduction
14. Cement production, alternatives
15. Shipping
16. Building factories with shipyards

#3 Lift regulatory roadblocks.

1. End **ALARA/LNT** policy, which keeps fission energy costs high. Government agencies now appease activists, accede to politicians, ignore science.

2. Base **environmental protection** on science, not the precautionary principle.

3. **Permits** take decades and billions. Fund and speed up reviews.

4. Speed up obtaining **rights of way** for power lines, pipe lines, rail lines.

5. Overhaul fractured responsibility for electric power **grid** regulation (in US).

6. Limit activist, special-interest **intervenor**, stakeholder delays.

#4 Prioritize low energy costs through free competition.

1. Sunset all stimulus **subsidies**.
2. End directive **technology** preferences.
3. Open **competition** beyond 'certified' suppliers.
4. End tariffs; enable imports from **all international** suppliers.
5. Use multiple, diverse suppliers for energy **security**.
6. Remove selective **taxes** on assets, revenues, and income.

#5 Proffer low cost energy first, use mandates and taxes last.

Imposing global CO_2 taxes is not feasible; noncompliance creates economic benefits. Developing nations need energy, have highest, growing CO_2 emissions.

1. Deploy fission electricity cheaper than from coal or LNG.
   - ***eliminate over 1/3 of energy CO_2 emissions, without mandates or taxes.***

2. Electrified transportation can be cheaper than petroleum fueled transportation.
   - ***eliminate almost 1/3 of energy CO_2 emissions, with few mandates or taxes.***

3. For buildings, market energy cost savings; support district heating; mandate building codes.

4. Industry. Assist, subsidize, cajole, bully, threaten, tax; then mandate.

Our Burning Economy, Siren Song, and Fission Promise

Hydrogen, Transportation, Buildings, Industry, Policy

Osher @ Dartmouth

Robert Hargraves

Jan 25, 2023