# 11 Transportation

*Fission is in Fashion*

Battery electric vehicles

Charging

Two-wheel vehicles

250 GWe demand

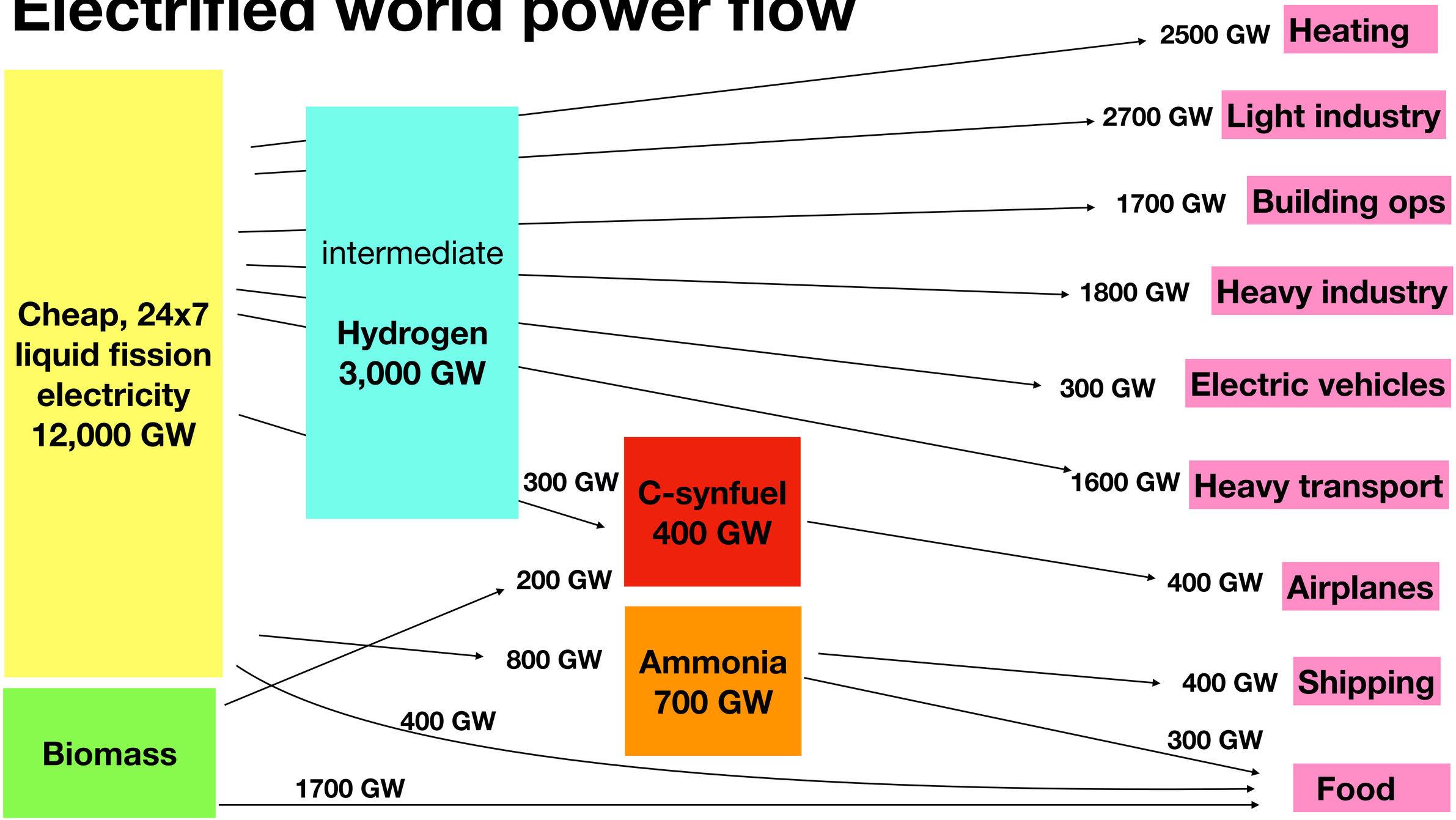
Hydrogen fuel-cell vehicles

Heavy transport, 2100 GWt

Biomass, CCS

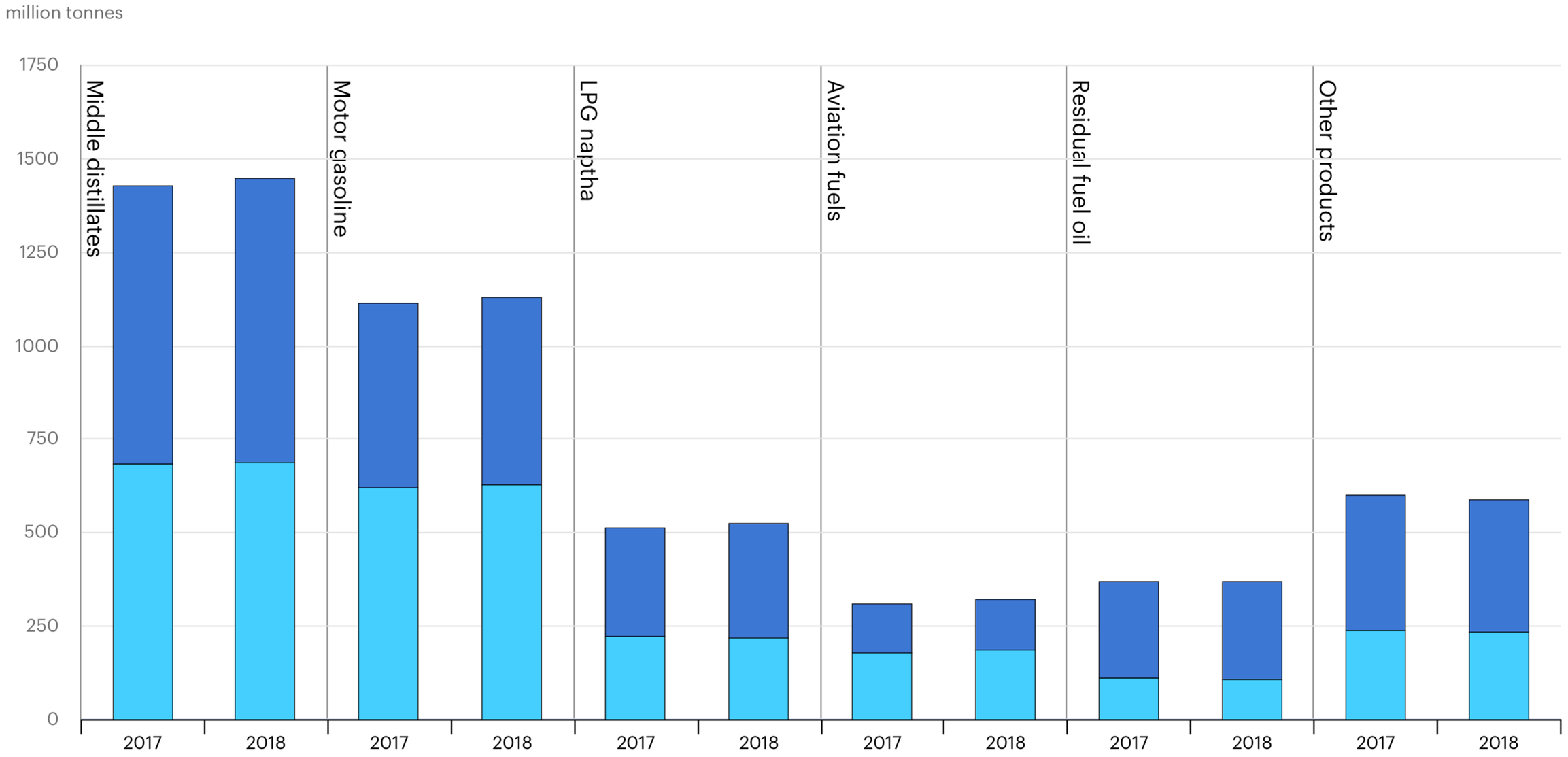
Airplanes

# Electrified world power flow



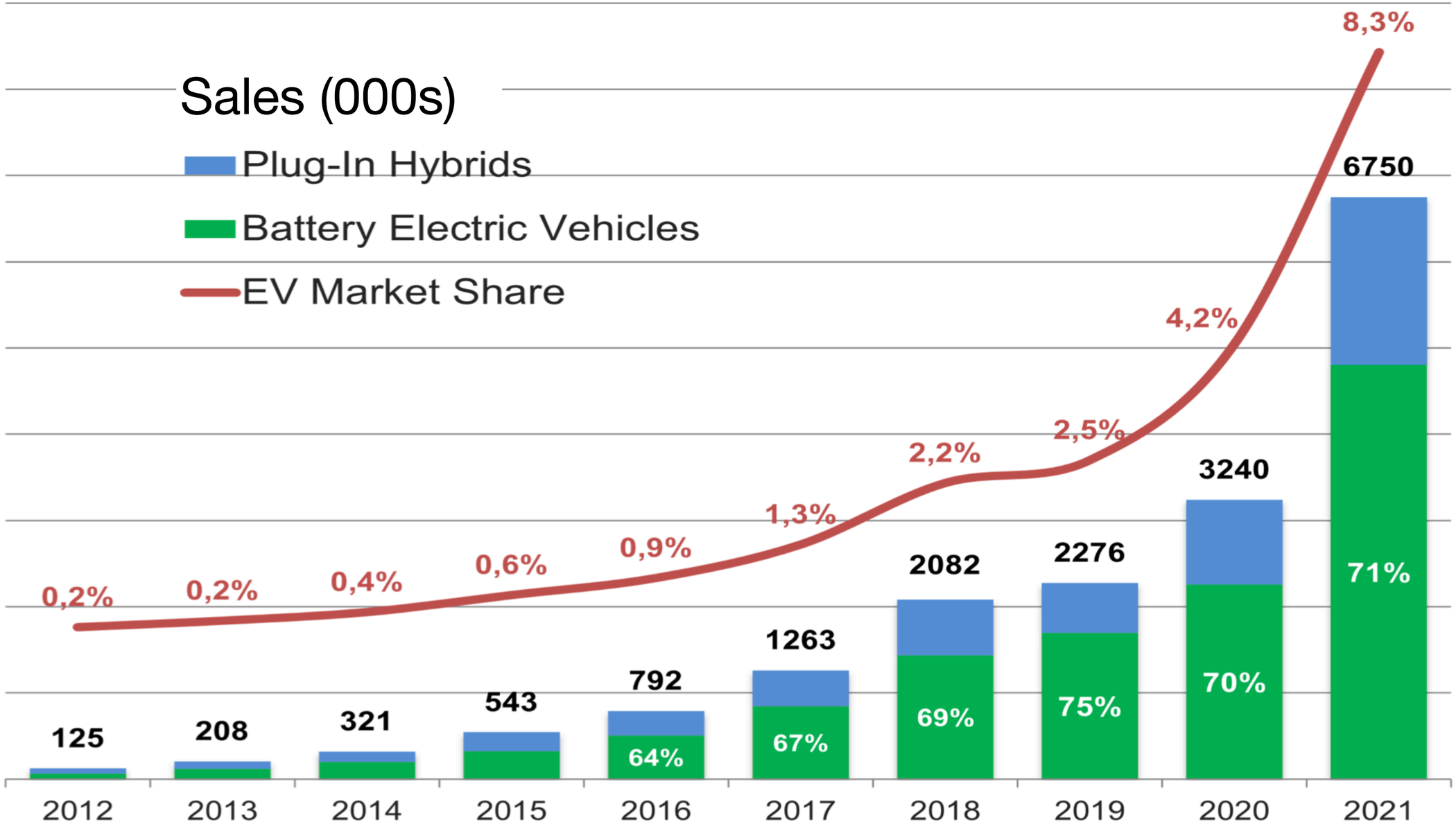
# World gasoline consumption is ~ 1700 GW.

IEA reports 1136 million tonnes for 2018



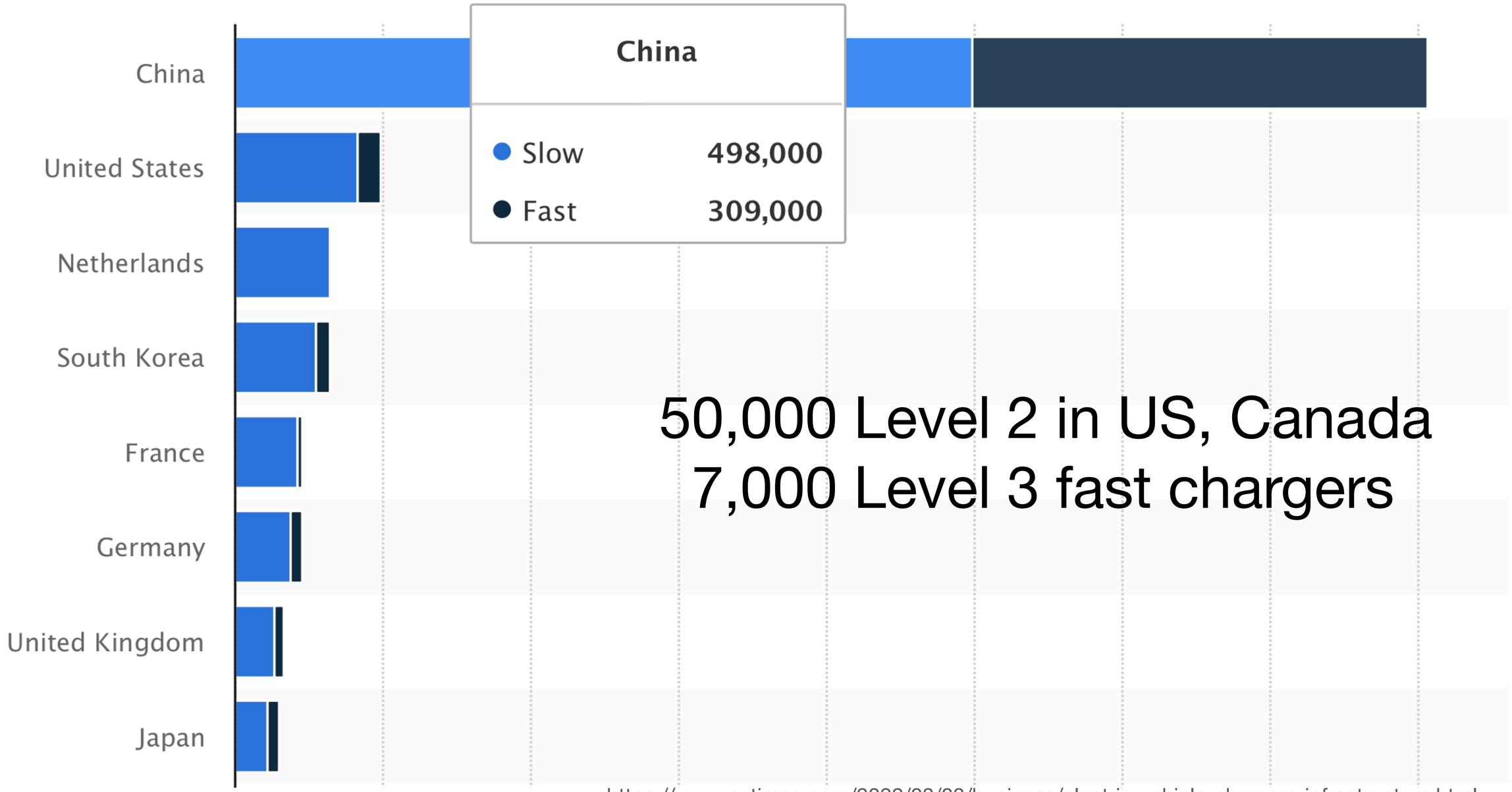

https://www.iea.org/reports/oil-information-overview

# BEV + plug-in hybrid sales, to reach 9.5 million units.




https://www.ev-volumes.com

# 1.3 million public vehicle charging stations worldwide

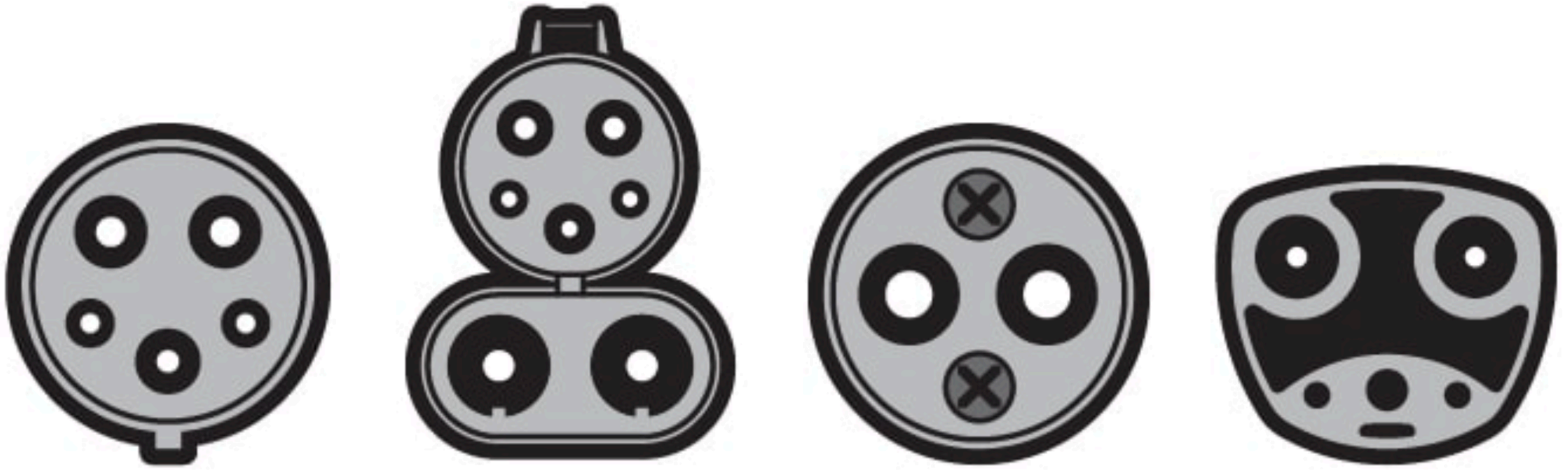



50,000 Level 2 in US, Canada
7,000 Level 3 fast chargers

https://www.nytimes.com/2022/03/03/business/electric-vehicle-chargers-infrastructure.html

https://www.statista.com/statistics/571564/publicly-available-electric-vehicle-chargers-by-country-type/

# 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

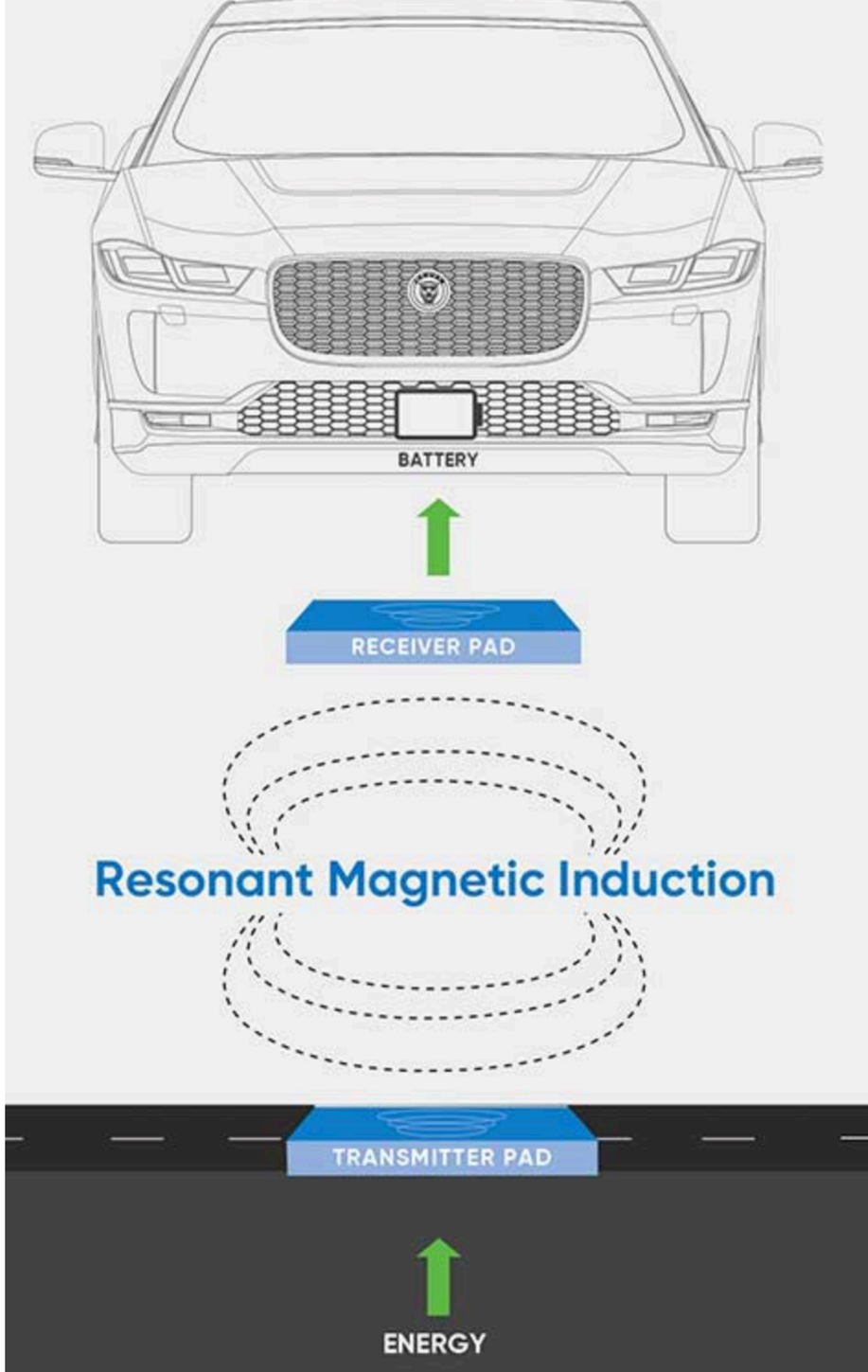
DC Fast Charging CHAdeMO

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.

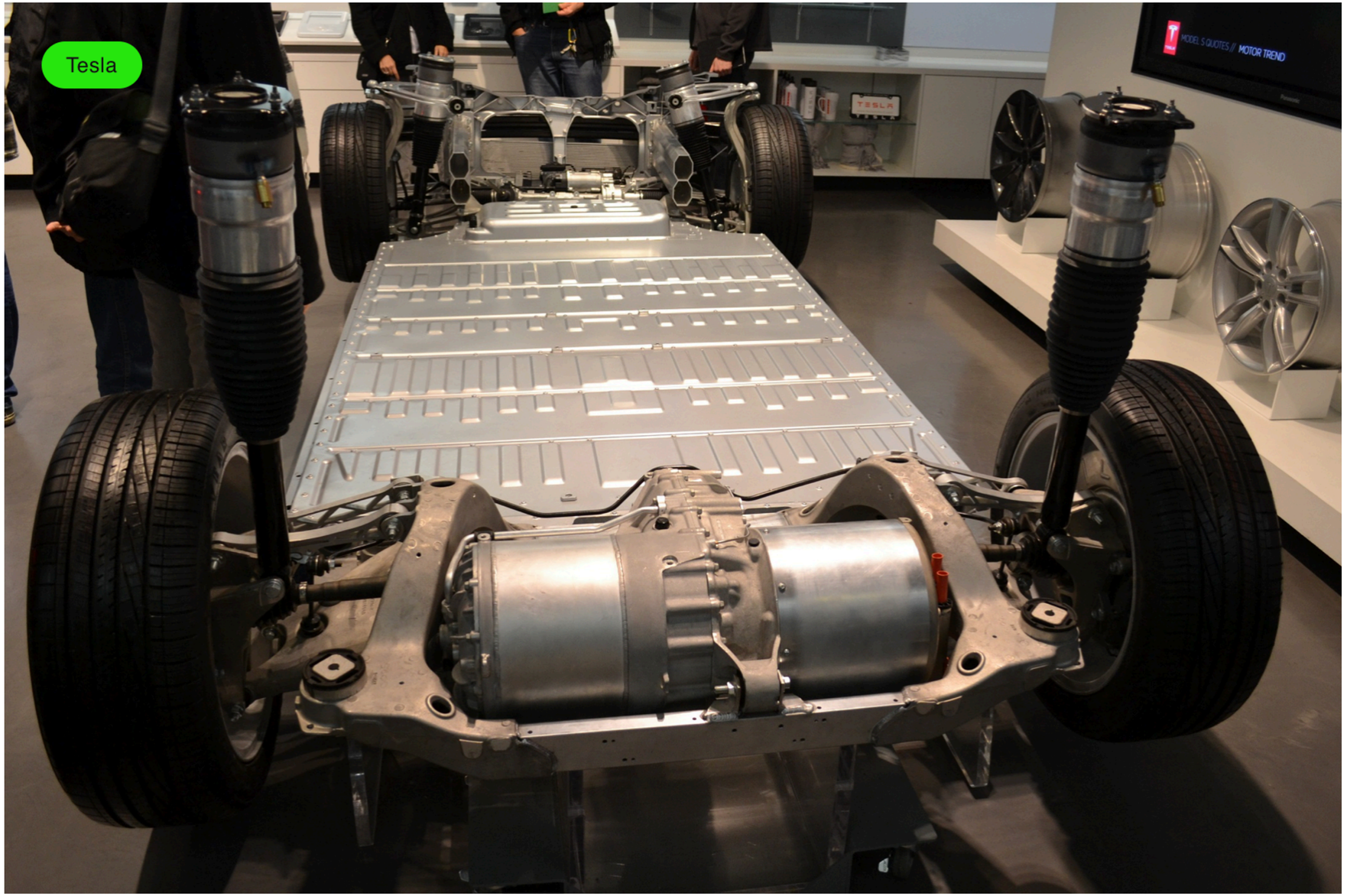

https://spectrum.ieee.org/cars-that-think/transportation/advanced-cars/wireless-charging-tech-to-keep-evs-on-the-go

# 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/

# 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

# Forget Tesla - China's BYD is driving the electric car revolution

Shifting to electric vehicles is an essential part of tackling climate change and China is doing far better than the West

**TECHNOLOGY** 10 July 2019

By **Donna Lu**


**BYD Auto sells more electric cars than any other firm in the world**
Chen Wen/China News Service/VCG/Getty

BYD produced over 1 million EVs in 2018.

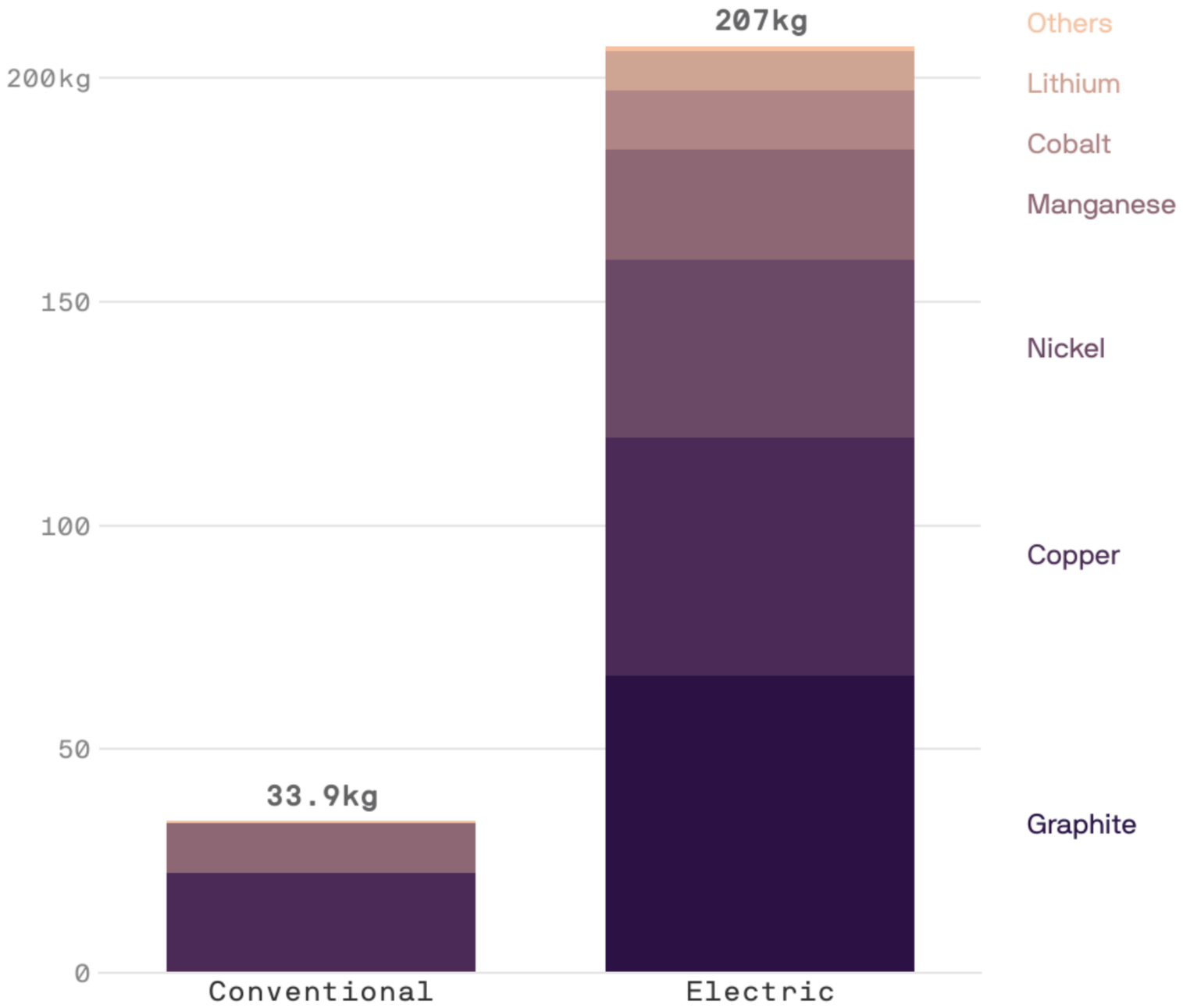
Use **lithium-iron-phosphate batteries, with less cobalt**.

Tesla also using LFP batteries for China Model 3.

2022 available in US.

https://www.newscientist.com/article/mg24332383-100-forget-tesla-chinas-byd-is-driving-the-electric-car-revolution/

# EVs increase demand for more technical metals

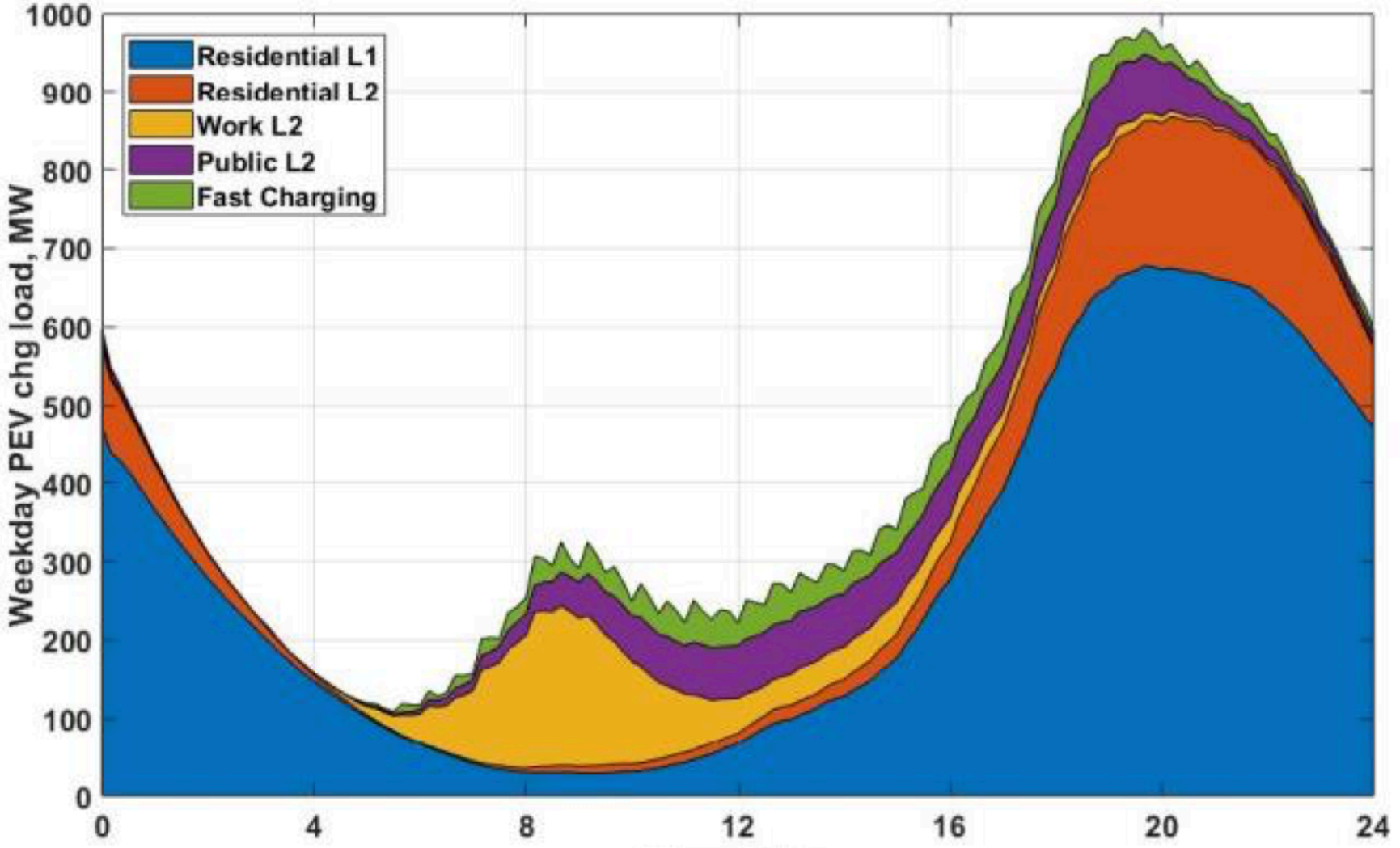



https://www.axios.com/newsletters/axios-generate-441d89bd-0543-45d5-9745-d703a5de0d59.htm

# IEA: ”…looming mismatch between the world’s strengthened climate ambitions and the availability of critical minerals that are essential to realising those ambitions."


https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

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




Smaller, cheaper batteries.

Shaves capital intensive power peaks.

California Energy Commission grid analysis.

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

# 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.

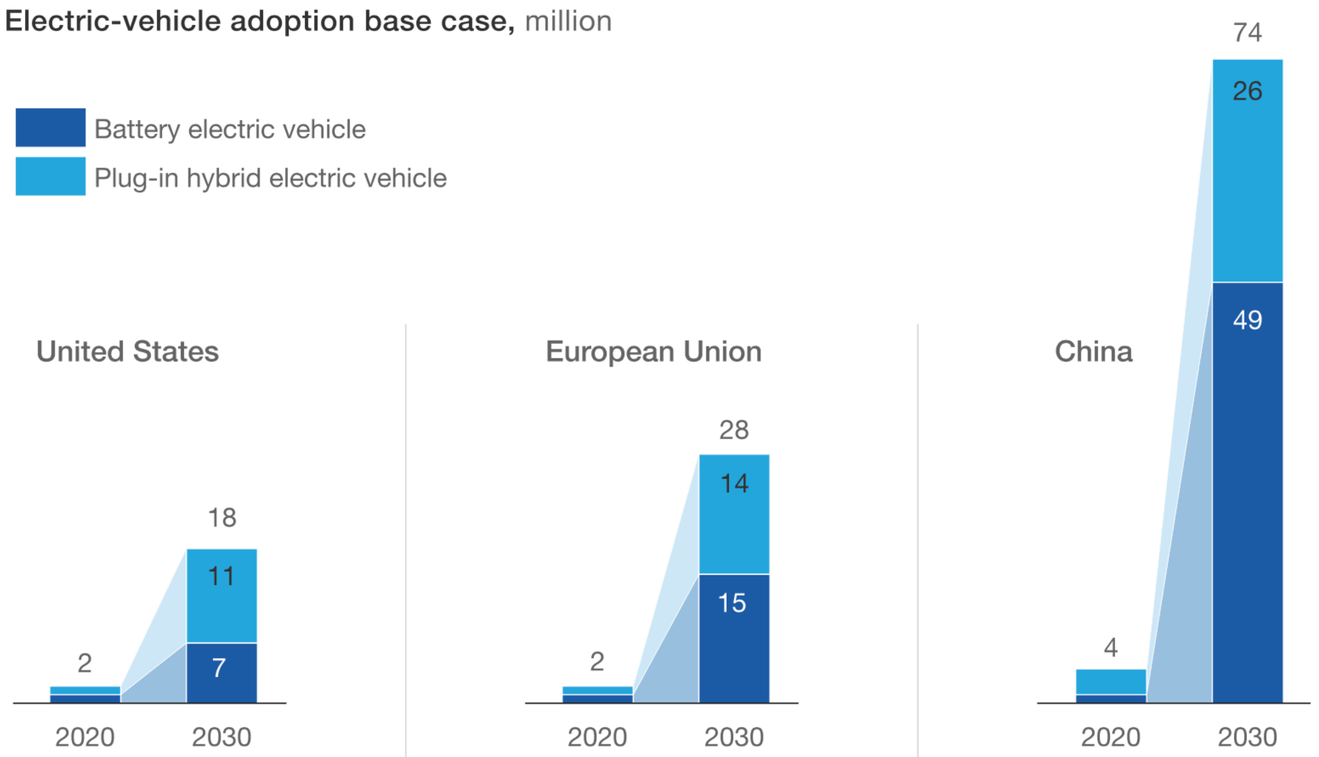
- Gasoline powered two-wheelers are the largest sources of pollution in many cities.
- Gasoline fuel powered ones are prohibited in many China cities.
- Worldwide 350 million electric two/three wheelers in 2019.
- Reduced more pollution than have electric cars.
- India is catching up.

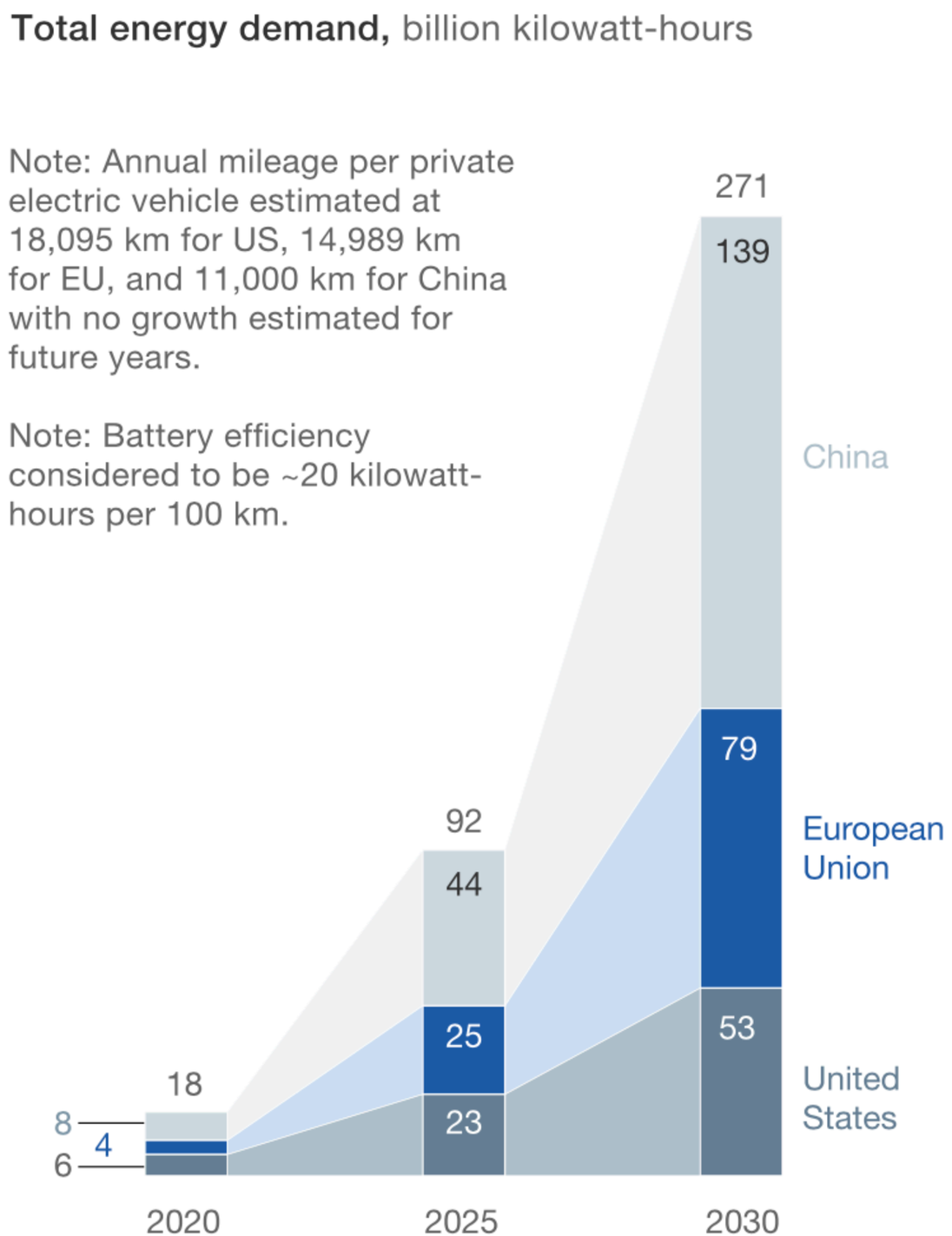
https://www.livemint.com/auto-news/china-is-racing-ahead-of-india-in-adopting-evs-11594740695583.html

# McKinsey suggests ~ 120 million EVs by 2030, consuming 32 GW.

280 billion kWh/year
@ 20 kWh/100 km

250 watts average
power per vehicle




https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/charging-ahead-electric-vehicle-infrastructure-demand

# One billion electric cars averaging 250 watts need 250 GW of electric power.


writes Green Car Reports in 2011

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

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

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

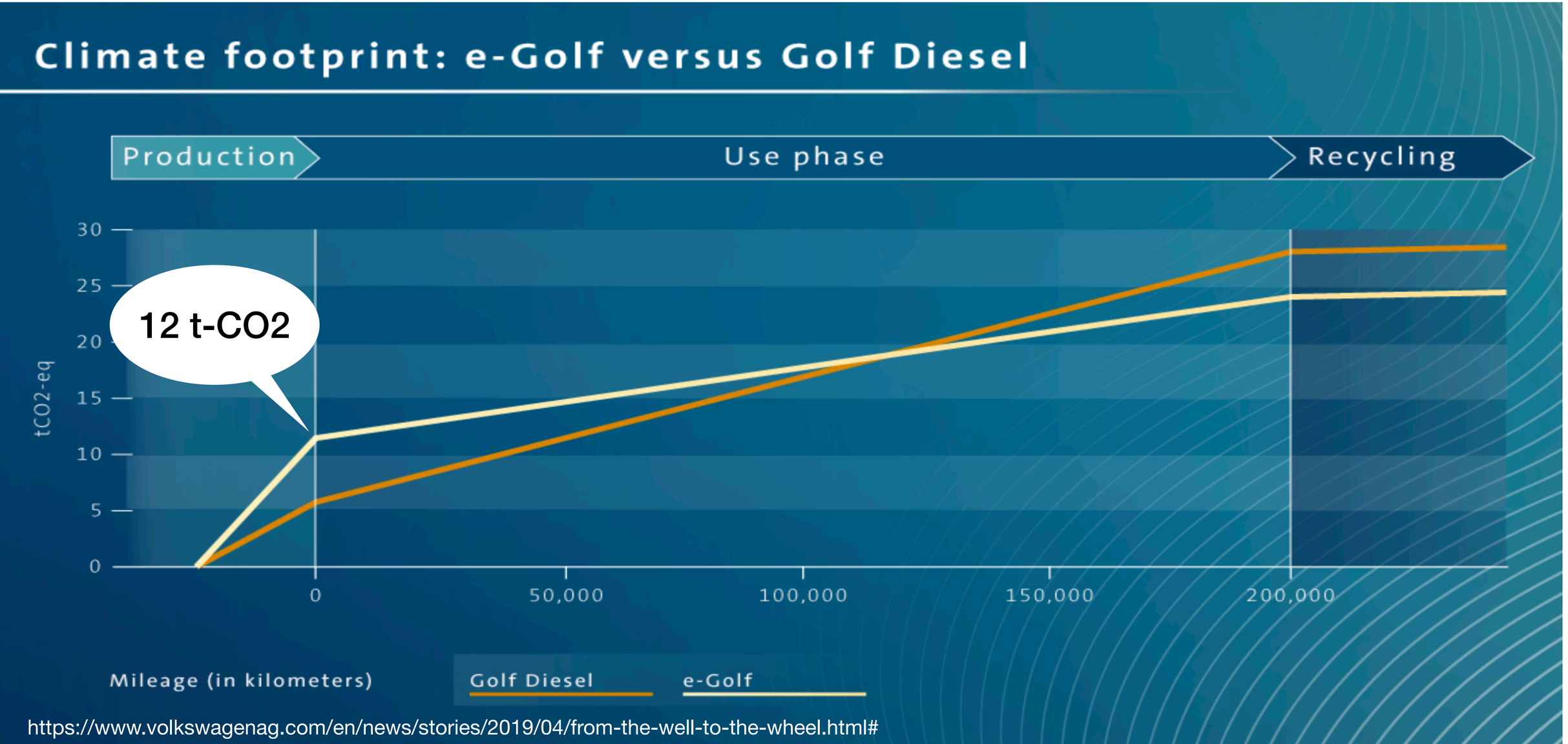
90 kWh(t) per 100 km
25 mpg = 40 km per gal
$10.00 per 100 km @ $4.00/gal

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


20 kWh(e) per 100 km

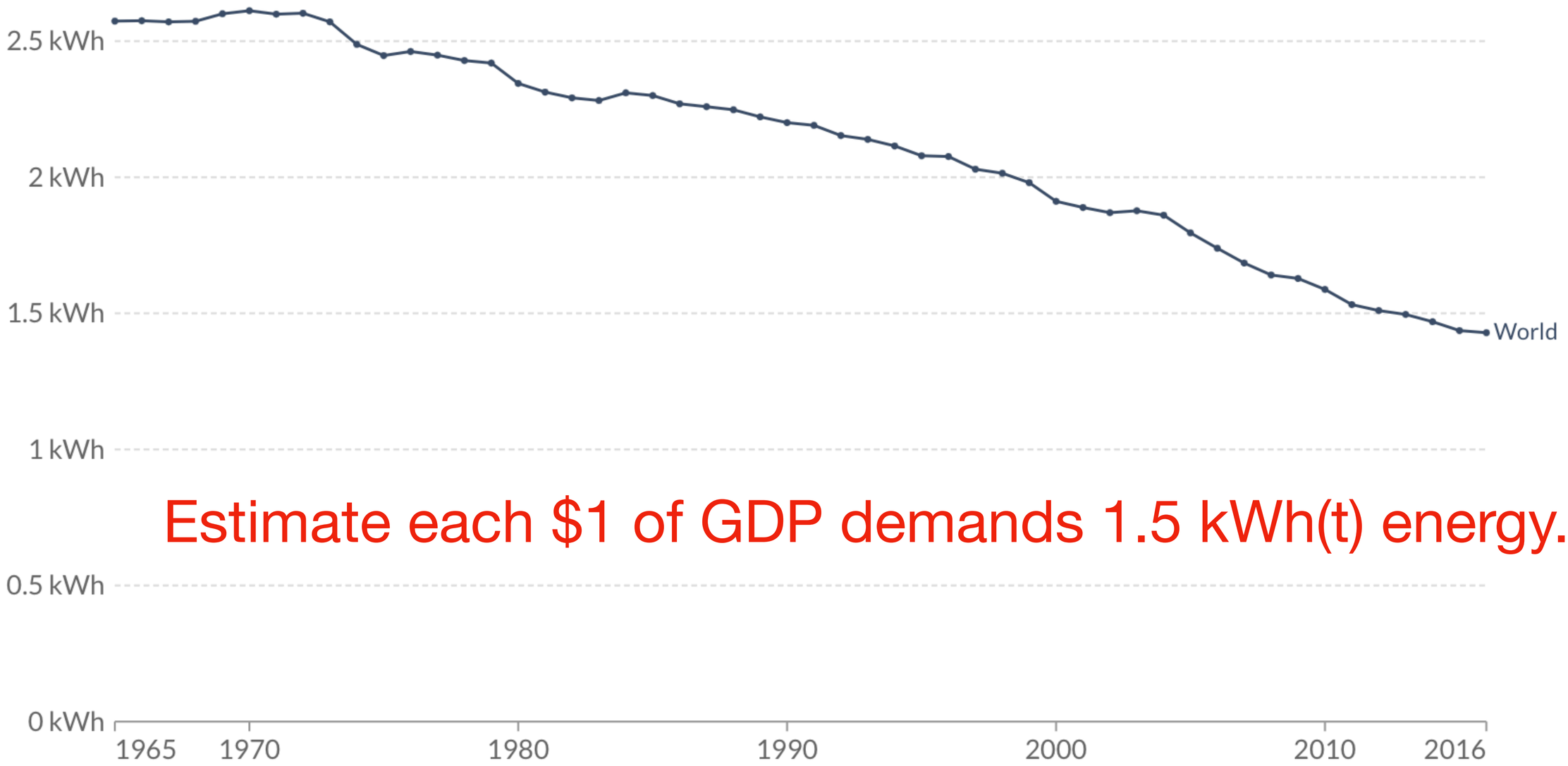
$4.00 per 100 km @ $0.20/kWh

# VW illustrates EV embedded energy (and embedded CO2) is double that of ICE auto.




https://www.volkswagenag.com/en/news/stories/2019/04/from-the-well-to-the-wheel.html#

# Repeat: World energy intensity, kWh/$ ($-2011, PPP)




Estimate each $1 of GDP demands 1.5 kWh(t) energy.

https://ourworldindata.org/grapher/energy-intensity?tab=chart&country=~OWID_WRL

# SWAG: embedded CO2 in ICE, hybrid, plug-in, EV autos.

| | Corolla | Prius | Prius Prime | Tesla 3, LFP |
|---|---|---|---|---|
| $ purchase | $20,075 | $24,025 | $28,220 | $44,990 |
| embedded kWh(t) @ 1.5/$ | 30,000 | 36,000 | 42,000 | 67,000 |
| kg CO2 @ 0.18/kWh(t) | 5,400 | 6,480 | 7,560 | 12,060 |
| | | | | |

CO2 from methane via https://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html

# SWAG matches VW calculated CO2 from Golf autos!

| | Corolla | Prius | Prius Prime | Tesla 3, LFP |
|---|---|---|---|---|
| $ purchase | $20,075 | $24,025 | $28,220 | $44,990 |
| embedded kWh(t) @ 1.5/$ | 30,000 | 36,000 | 42,000 | 67,000 |
| kg CO2 @ 0.18/kWh(t) | 5,400 | 6,480 | 7,560 | 12,060 |
| | | | | |
| VW Golf embedded CO2 | 6,000 | | | |
| VW e-Golf embedded CO2 | | | | 12,000 |

CO2 from energy from natural gas https://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html

# $ cost of driving 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** | |
| | | | | |
| | | | | |

# 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** |
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| **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** |

# Clean power zeros CO2 of driving (not embedded CO2).

| | 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 |
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| **Electricity $/100 km** @$0.20/kWh, 80% eff | | | $5.50 | $3.10 |
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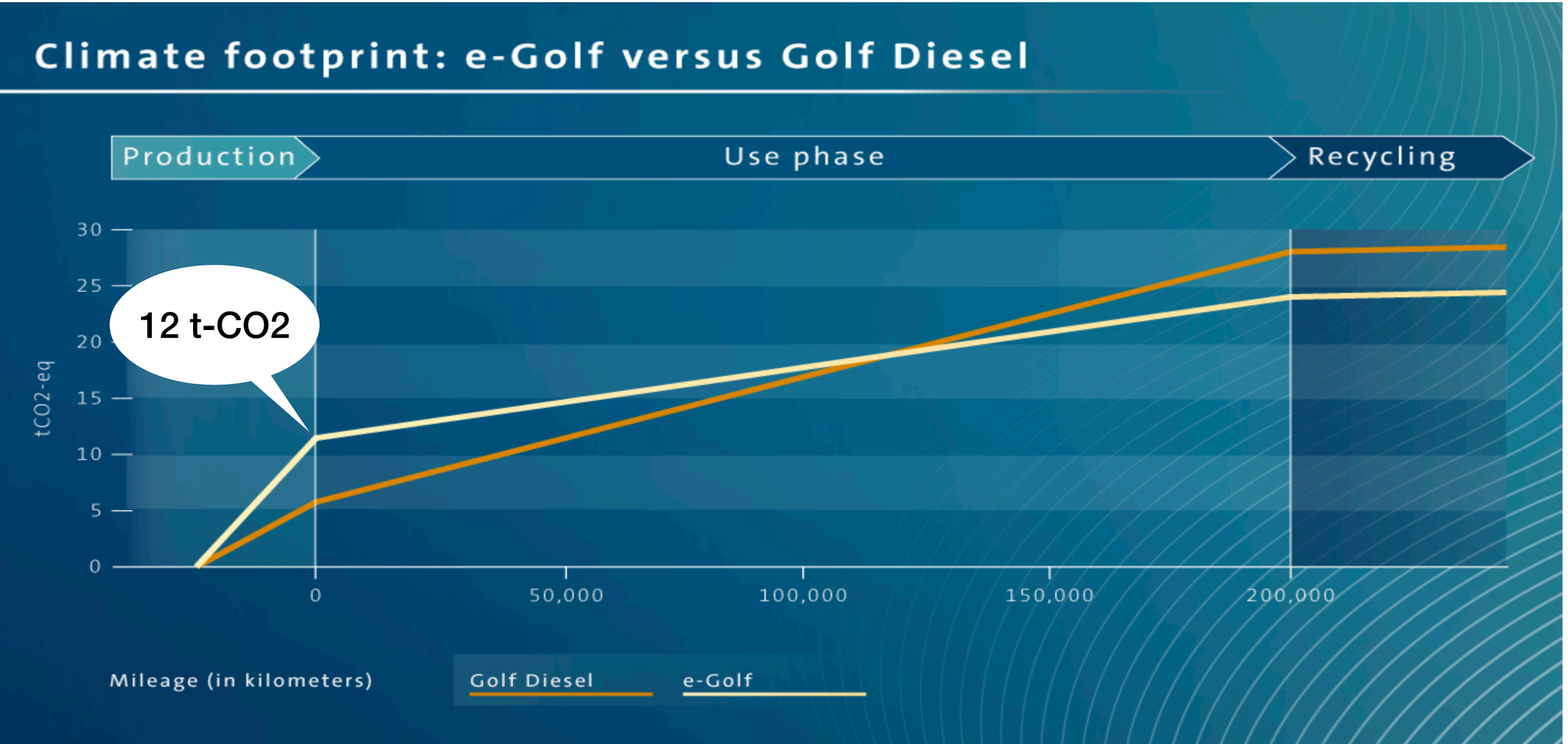
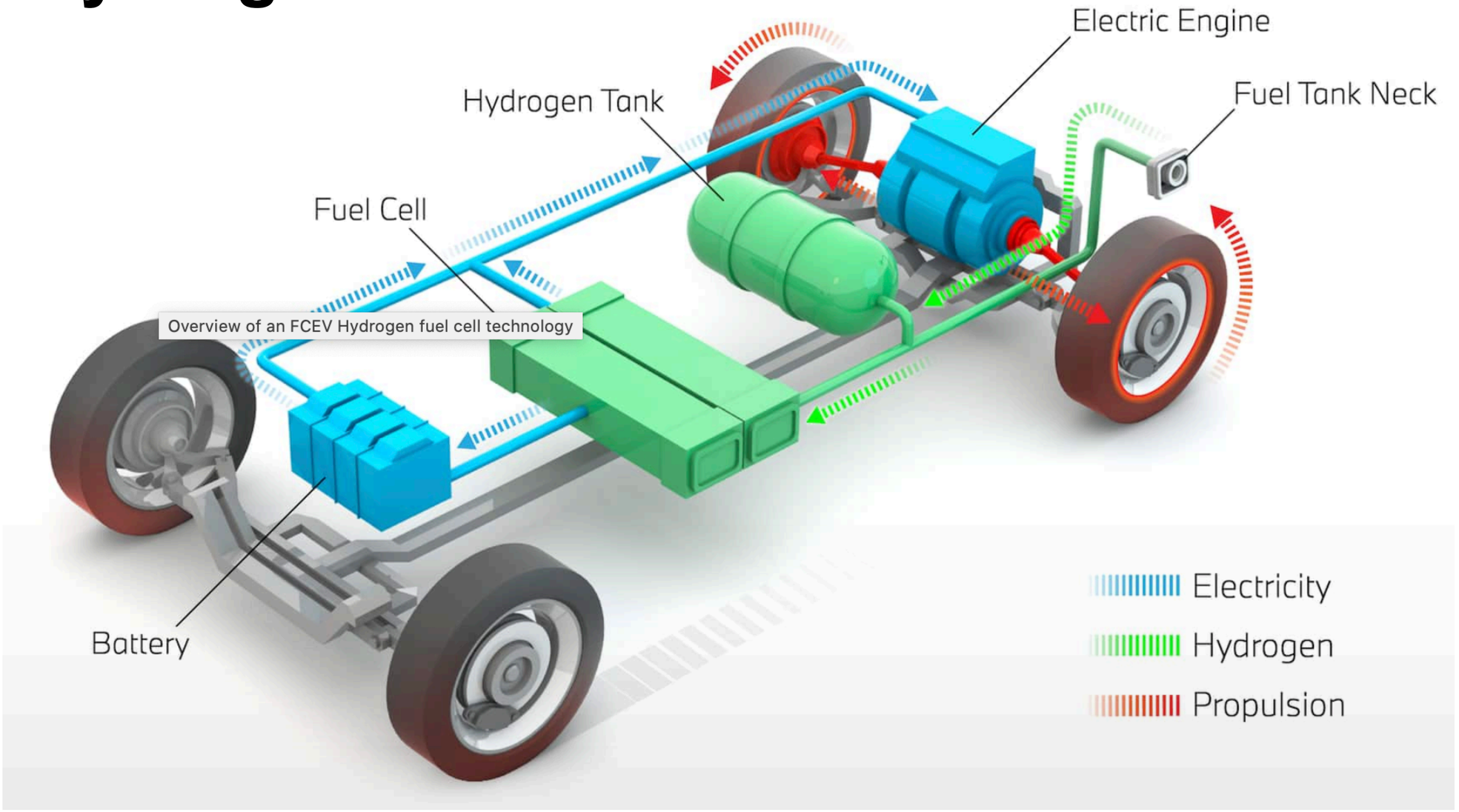
| **Embedded kg CO2/100 km** @200,000 km life | 2.7 | 3 | 3.8 | 6 |
| **Driving kg CO2/100 km** @390 g/kWh, 8.9 kg/gal | **16.91** | **9.5** | **0** | **0** |

# Will EVs save the climate?



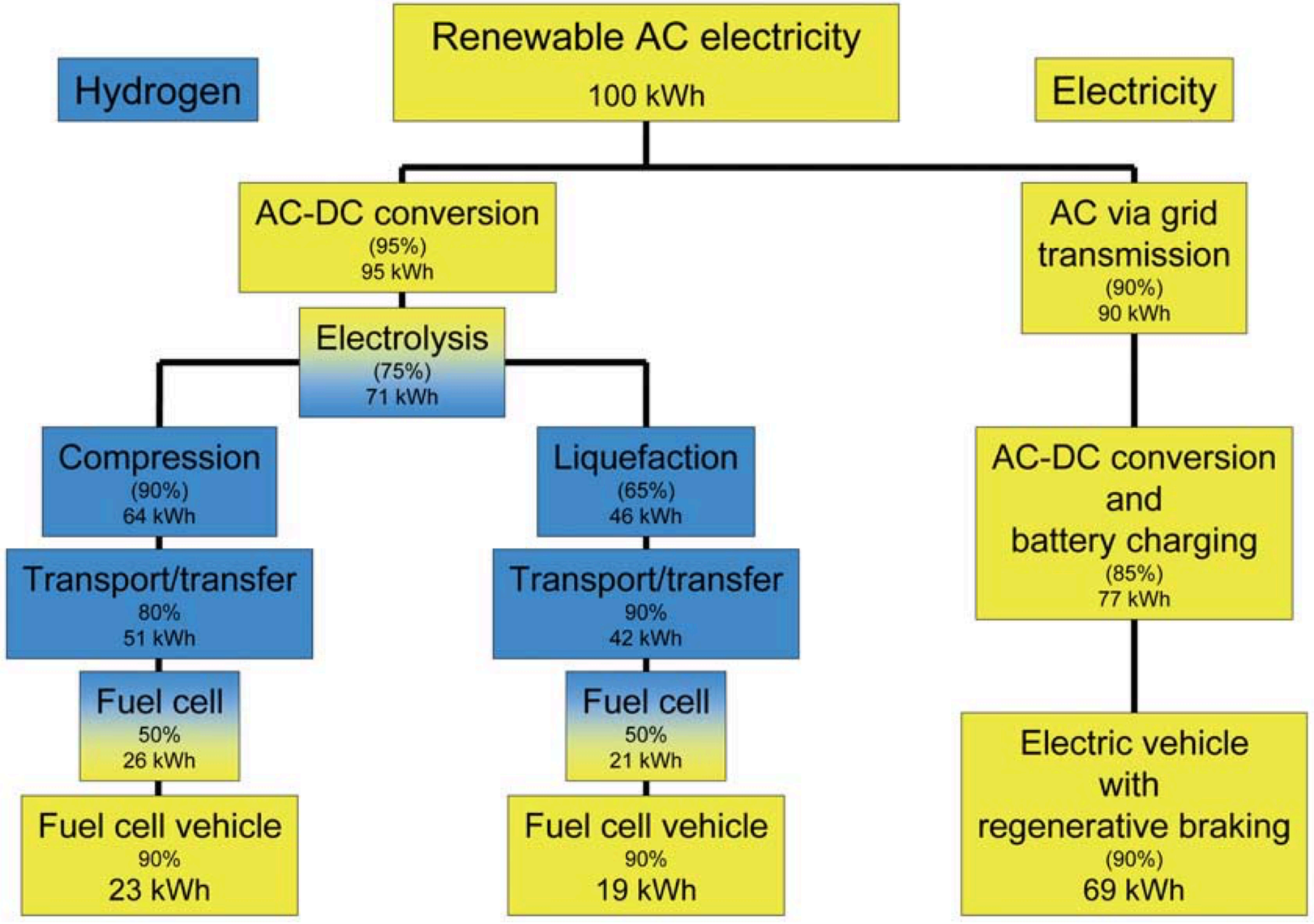
# Honda, Toyota, Hyundai, BMW have provided ~10,000 hydrogen fuel cell cars.




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

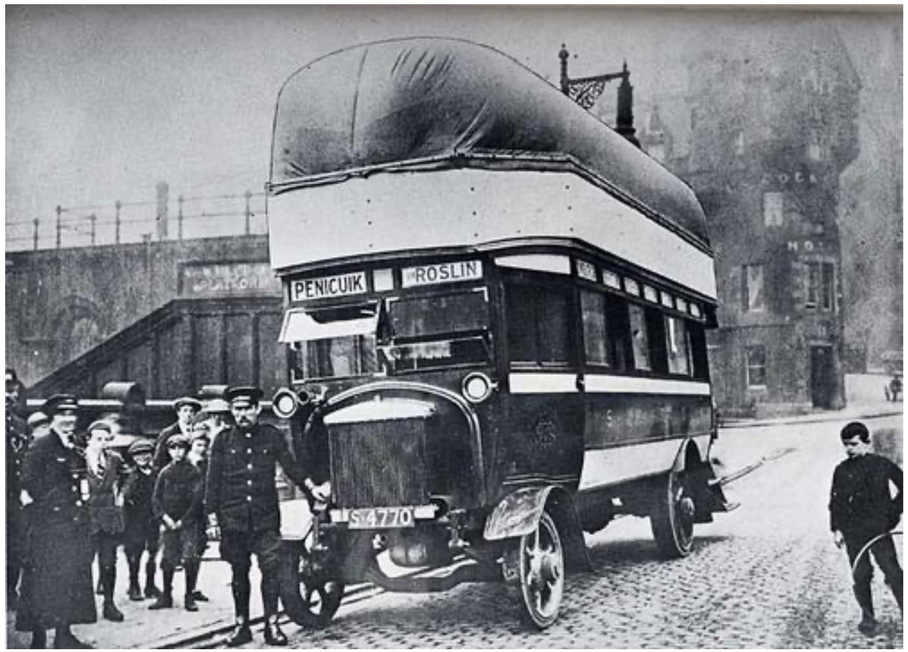
https://www.bmw.com/en/innovation/how-hydrogen-fuel-cell-cars-work.html#

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

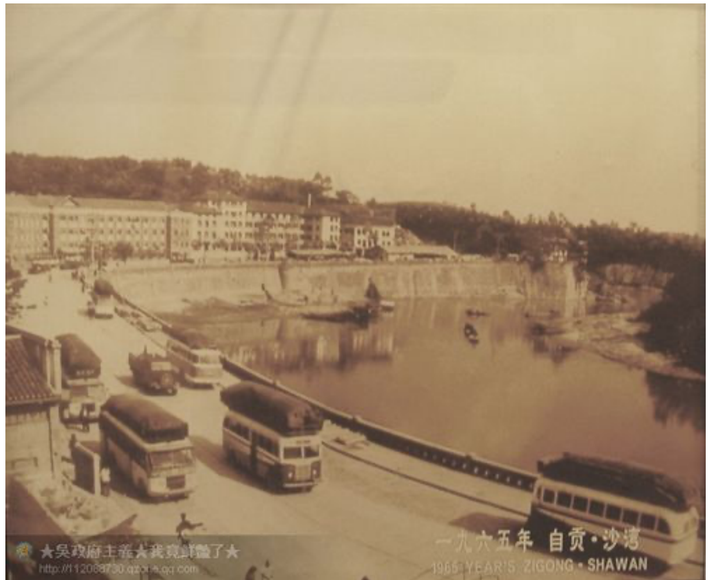



https://www.industrializedcyclist.com/ulf%20bossel.pdf

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



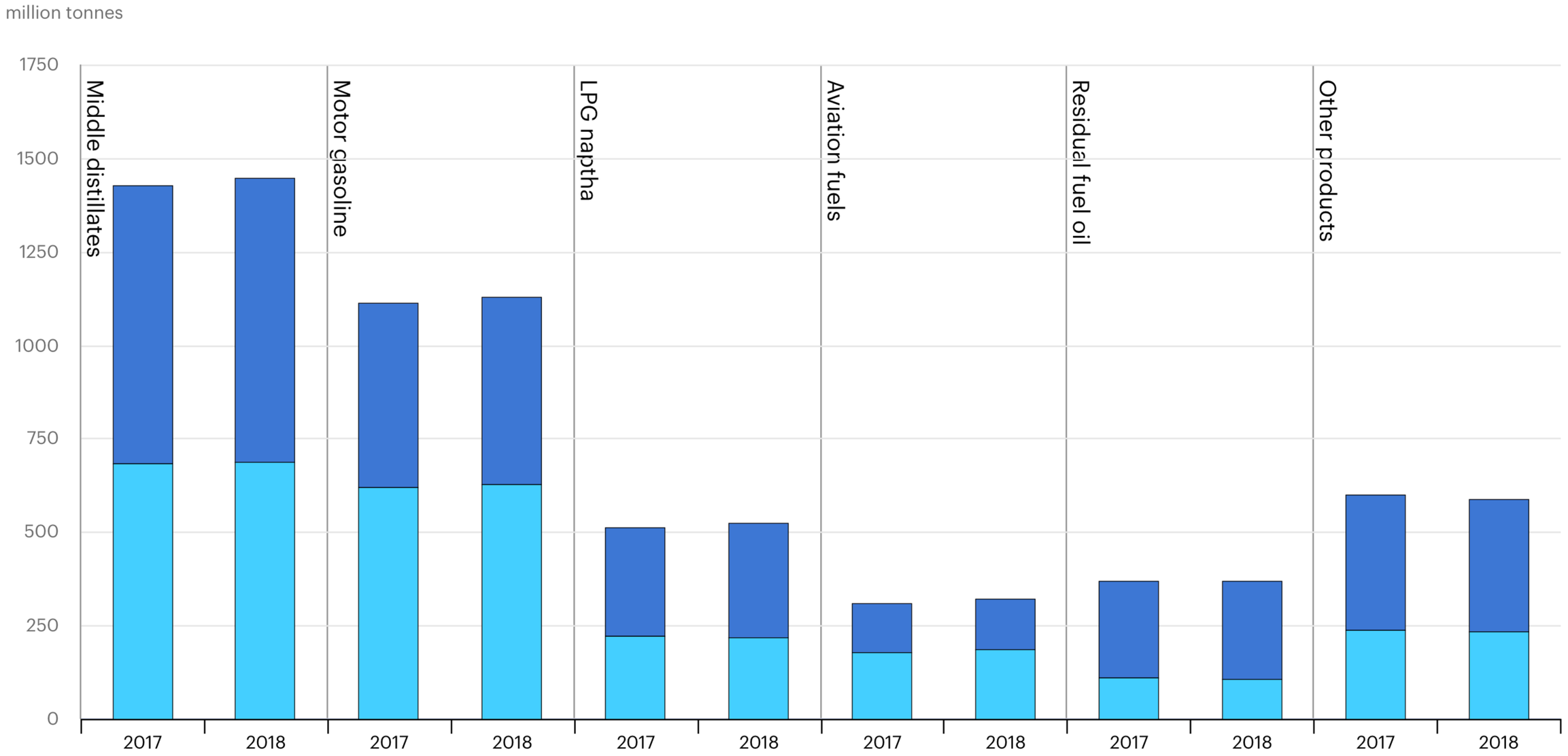





https://www.lowtechmagazine.com/2011/11/gas-bag-vehicles.html

# World diesel fuel consumption is ~ 2100 GW.

IEA reports 1446 million tonnes for 2018




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

# IRENA estimates heavy transport energy use.

## Energy-intensive freight & long-haul transport sectors

**Road freight**

**1000 GW**

In 2017:

- Consumed 32.3 EJ of energy
- Only 1.5% was from renewables
- Emitted 2.3 Gt of $CO_2$

**2 Gt/y**

**Aviation**

**400 GW**

In 2017:

- Consumed 13.5 EJ of energy
- A negligible share was from renewables
- Emitted 0.9 Gt of $CO_2$

**1 Gt/y**

**Shipping**

**400 GW**

In 2017:

- Consumed 11.3 EJ of energy
- A negligible share was from renewables
- Emitted 0.9 Gt of $CO_2$

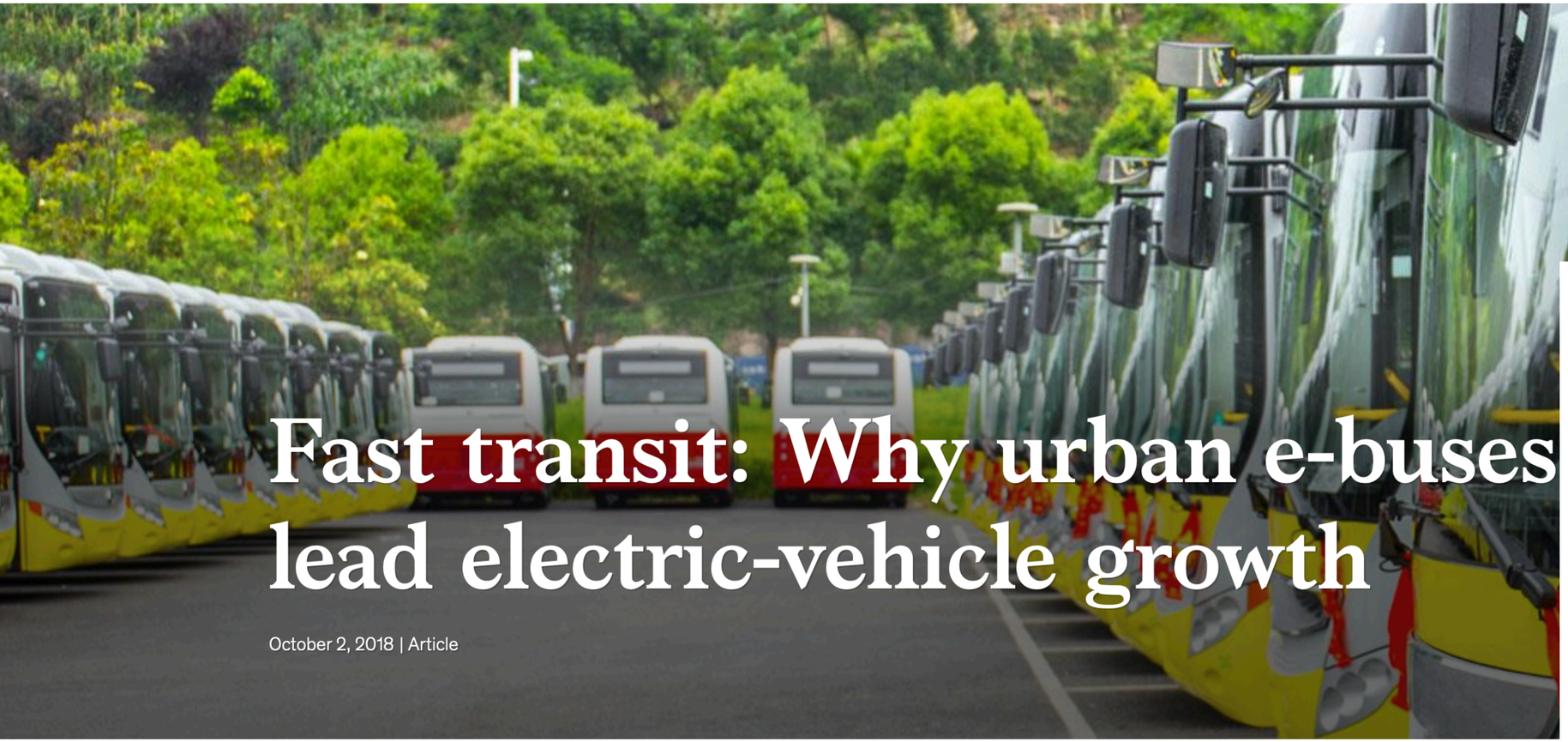
**1 Gt/y**

**CO2 emissions -->**

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

# Largest US refinery produces 40 GW(t).

# McKinsey reported 87,000 of China's 97,000 new bus sales in 2017 were electric.





# IEA reports ~ 100,000 Chinese electric bus registrations each year.

https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/fast-transit-why-urban-e-buses-lead-electric-vehicle-growth

https://www.iea.org/reports/global-ev-outlook-2020

# 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 in 2022.

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/

# Hyundai XCIENT Fuel Cell heavy duty trucks delivered.


- 350 bar, 32 kg H2 tank
- 20 min refueling
- 400 km range
- 7 vehicles in Switzerland
- 50 by end 2020
  1600 by end 2025

https://www.axios.com/hyundai-hydrogen-fuel-cell-trucks-2021-ecebcdfa-cfde-479e-aba8-71882cbc2d58.html?utm_source=newsletter&utm_medium=email&utm_campaign=newsletter_axiosgenerate&stream=top

# Kenworth, Toyota T680 Hydrogen Fuel Cell Truck

10 hydrogen fuel cell electric trucks for Port of Los Angeles

300 mile range per fill

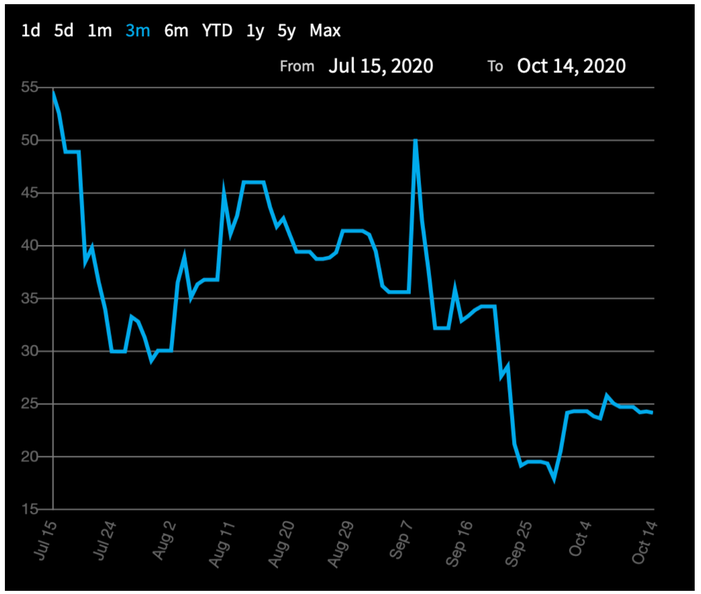

https://www.truckinginfo.com/330270/toyota-and-kenworth-unveil-jointly-developed-hydrogen-fuel-cell-truck

# 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/

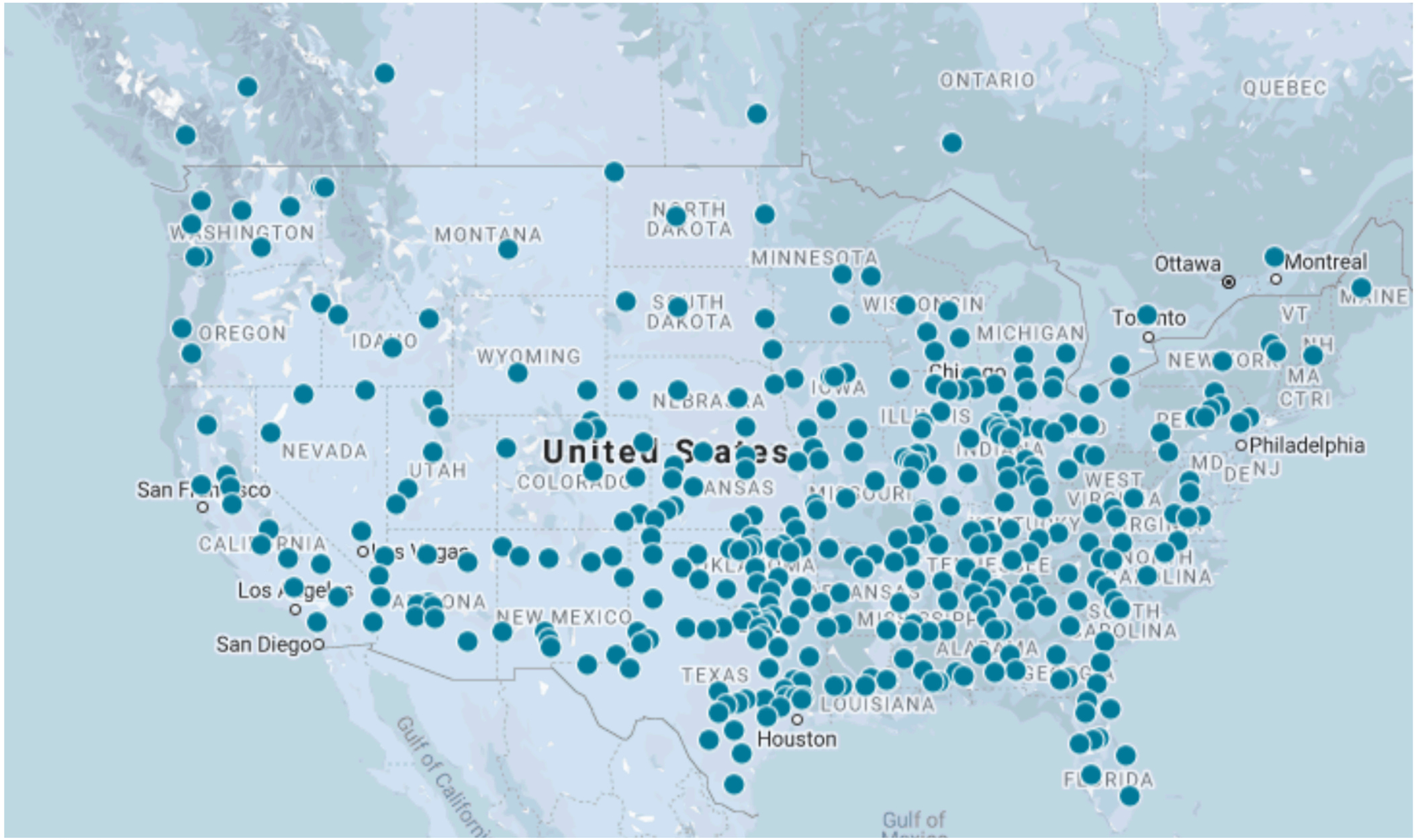
# Nikola strategy is hydrogen-powered trucks and H2 fueling station network.

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





# Proposed Nikola H2 stations are on major trucking routes.




https://nikolamotor.com/hydrogen

# Onsite electrolysis obviates need for H2 transport.

Issues?

1. Cost of electricity, transmission.
2. Electrolysis efficiency with intermittent duty cycle from lulls, clouds.
3. Refueling station draws ~**14 MW(e)** @ 95% electrolysis efficiency, H2 compression.

## 8T/DAY H2 STATION CONCEPT: 70 MPA HEAVY DUTY & LIGHT DUTY

8,000 kg-H2/day
700 bar, ~10,000 psi


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

# Nikola TWO FCEV ALPHA PROTOTYPE

## DUAL STACK FUEL CELL

**Generates Electricity**

- 240 kW Fuel Cell (Gross)
- Heavy-Duty Application
- Custom Build

## POWER ELECTRONICS / DISTRIBUTION UNIT

**Distributes energy to axles and vehicle**

- Energy Flow & Conversion

## E-AXLES / ELECTRIC MOTORS

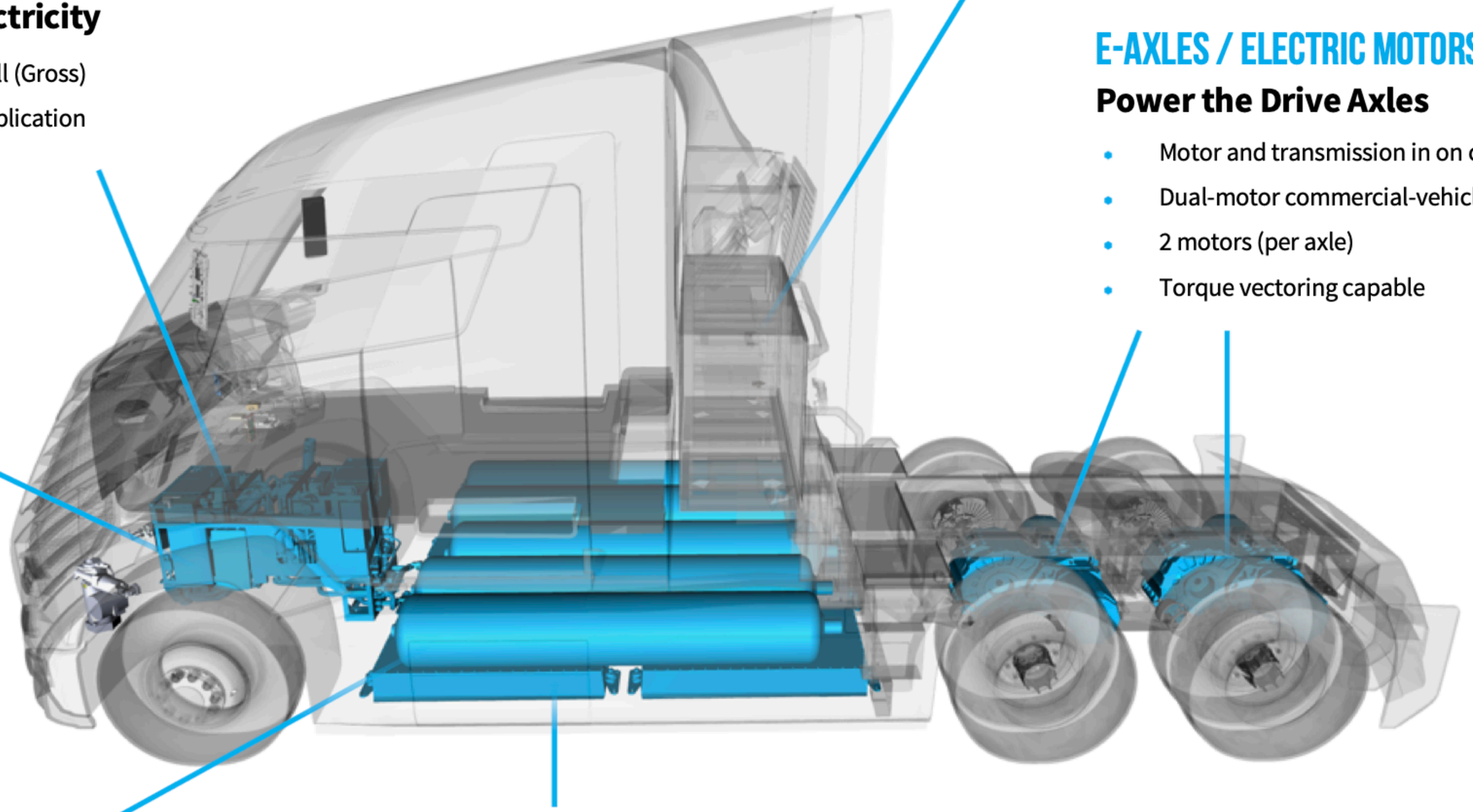
**Power the Drive Axles**

- 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

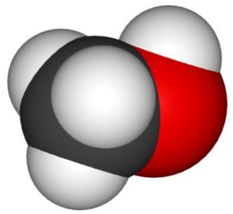
https://d32st474bx6q5f.cloudfront.net/nikolamotor/uploads/investor/presentation/presentation_file/19/Nikola_Mission_Hydrogen_Presentation2.pdf

# 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 |

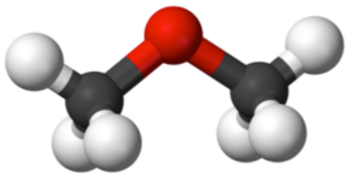
https://en.wikipedia.org/wiki/Energy_density

# Where to get carbon to make carbonaceous synfuels?



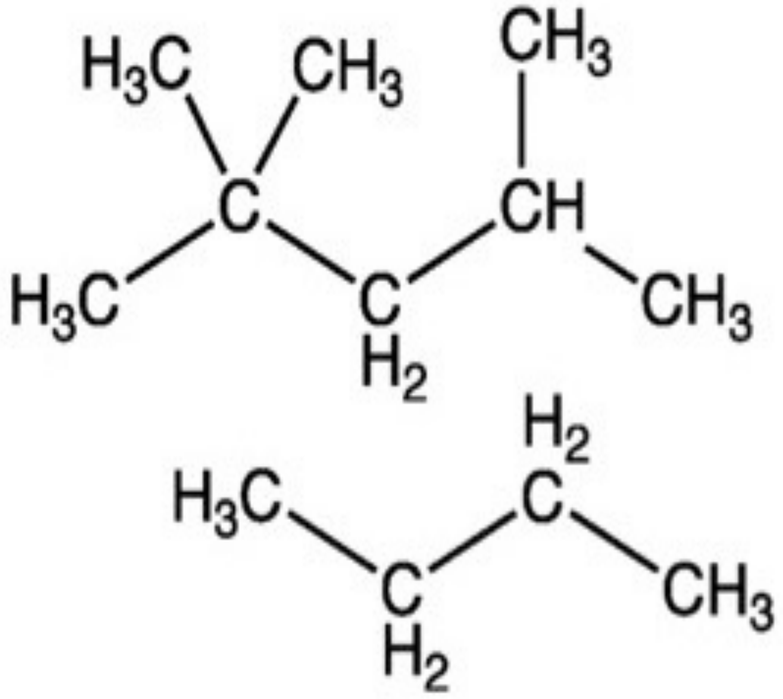
Methanol

$CH_3OH$

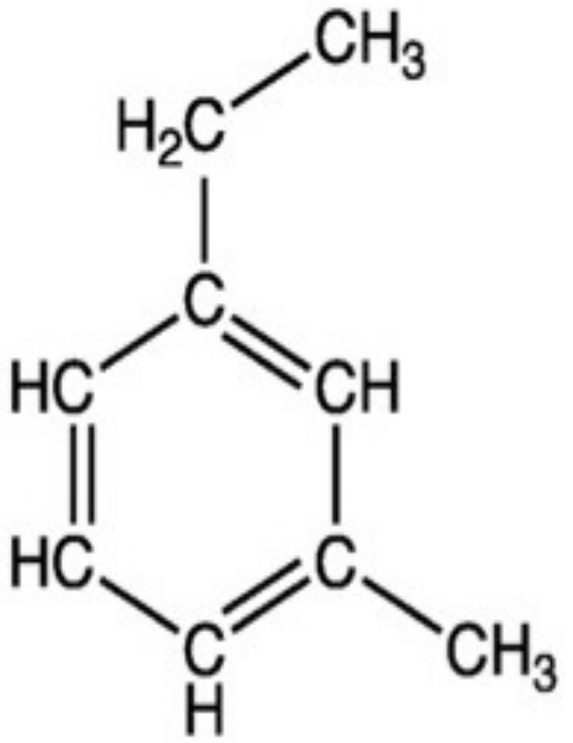


Dimethyl ether

$H_3COCH_3$




Gasoline




**CO2 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/

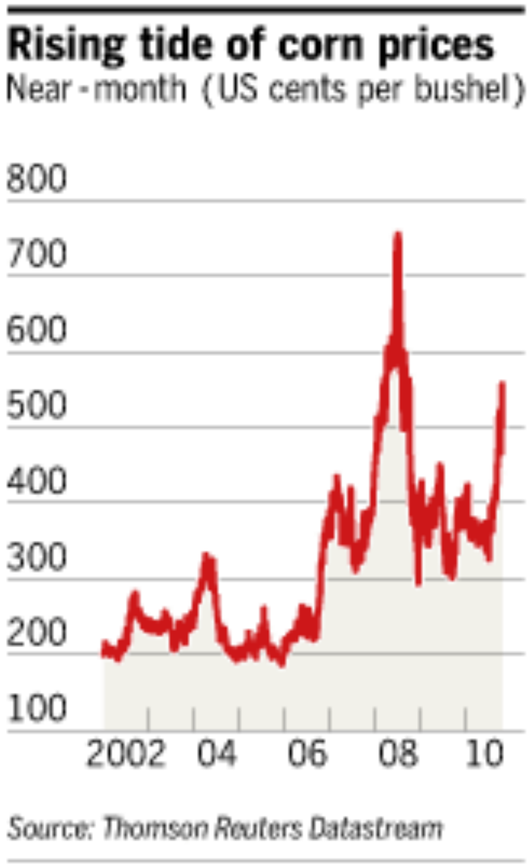
# Food and ethanol compete for corn.

## *Thousands in Mexico City Protest Rising Food Prices*

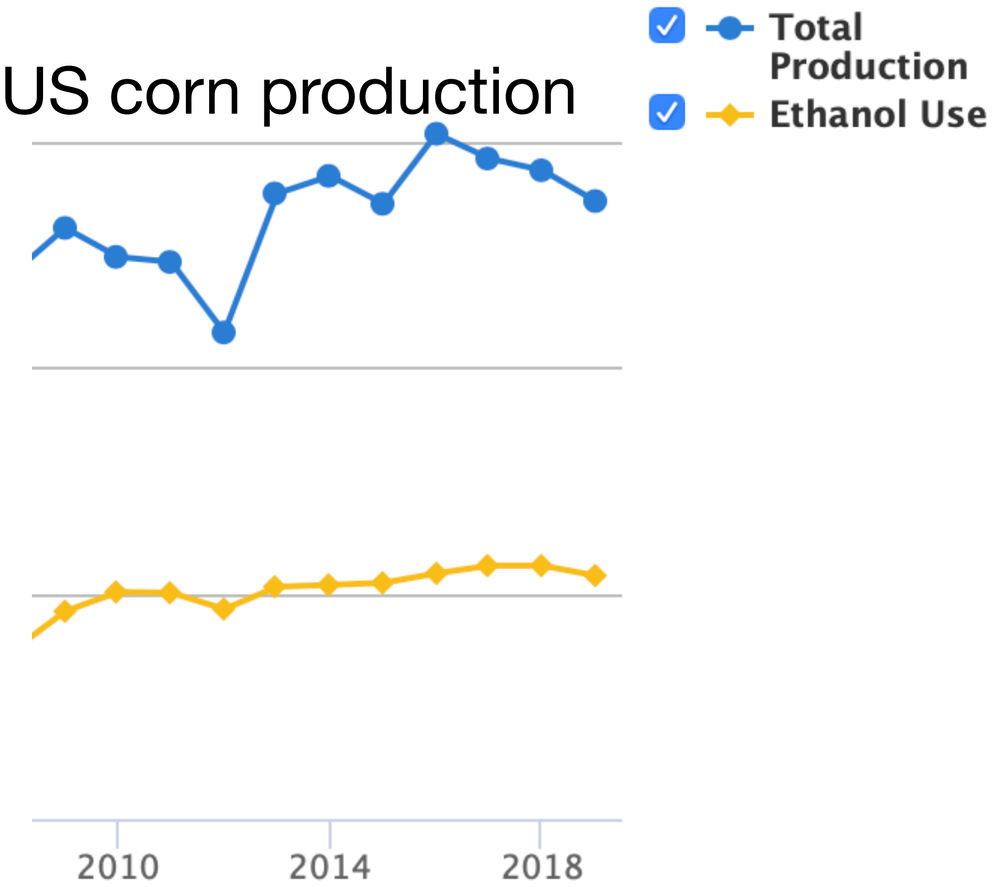
**By Elisabeth Malkin**

Feb. 1, 2007

Corn tortilla prices doubled.




US corn production




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

# Land impact of 2008 Renewable Fuel Standard

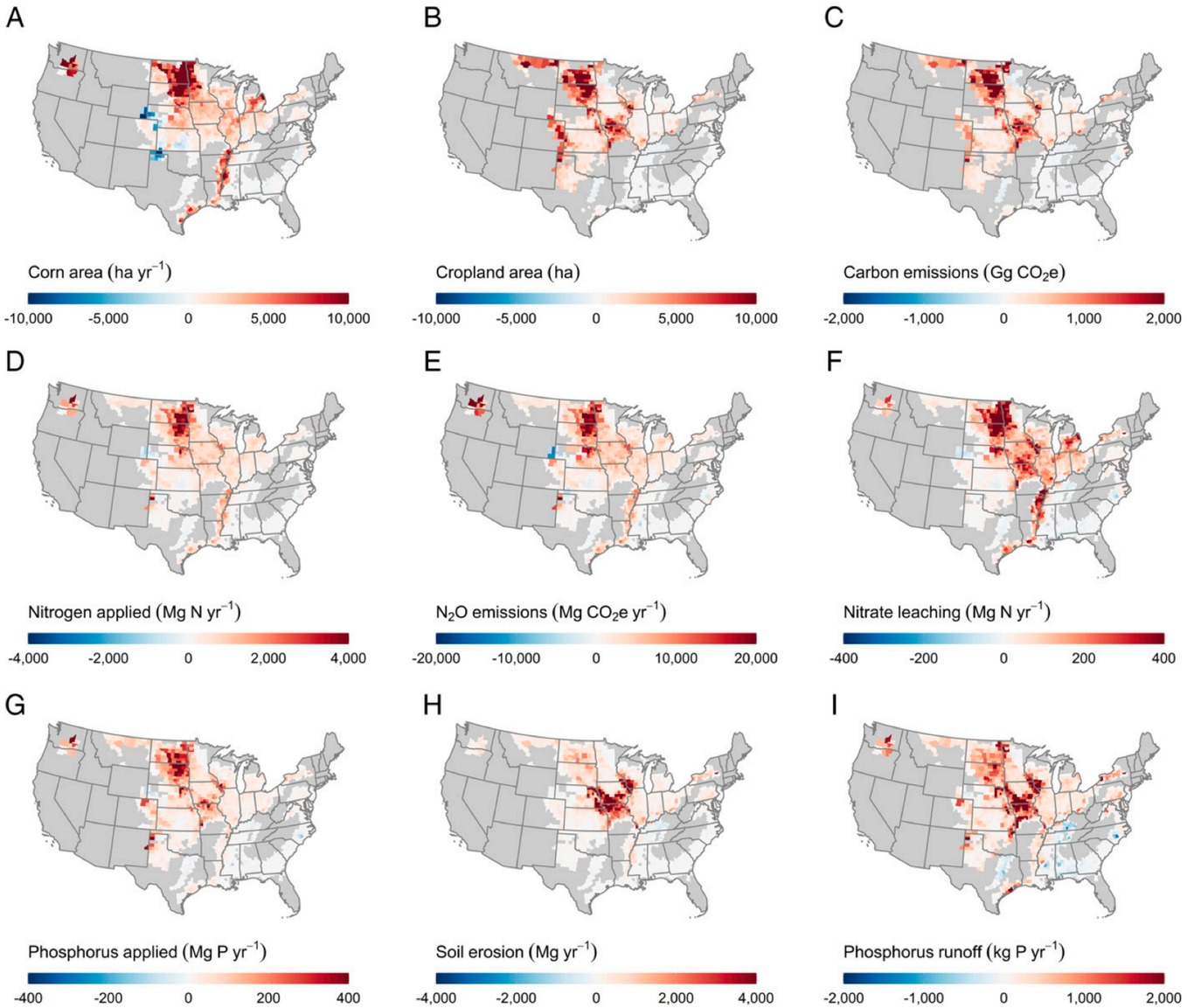



**Fig. 2.** Changes due to the RFS. (*A*) Corn planted area. (*B*) Cropland area. (*C*) Carbon emissions. (*D*) Nitrogen applications. (*E*) Nitrous oxide emissions. (*F*) Nitrate leaching. (*G*) Phosphorus applications. (*H*) Soil erosion. (*I*) Phosphorus runoff. Positive numbers indicate an increase due to the RFS. Field-level results were aggregated to the county level for enumeration and visualization.

Negative cropland impacts:

CO2 emissions, N2O emissions, nitrate leaching, soil erosion, P runoff

Corn prices +30%

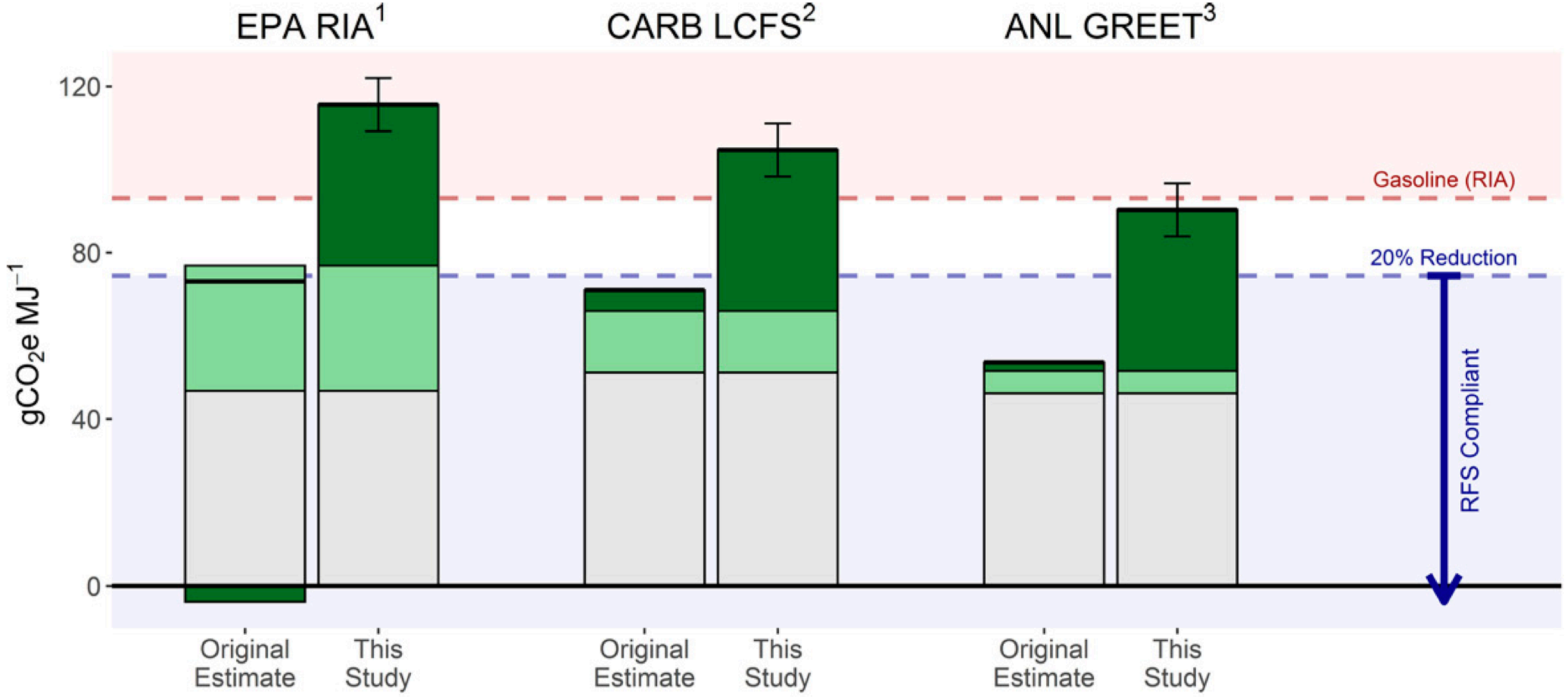
Other crop prices +20%

Corn farming area +8%

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

# **RFS goal to reduce CO2 by 20% not met.**

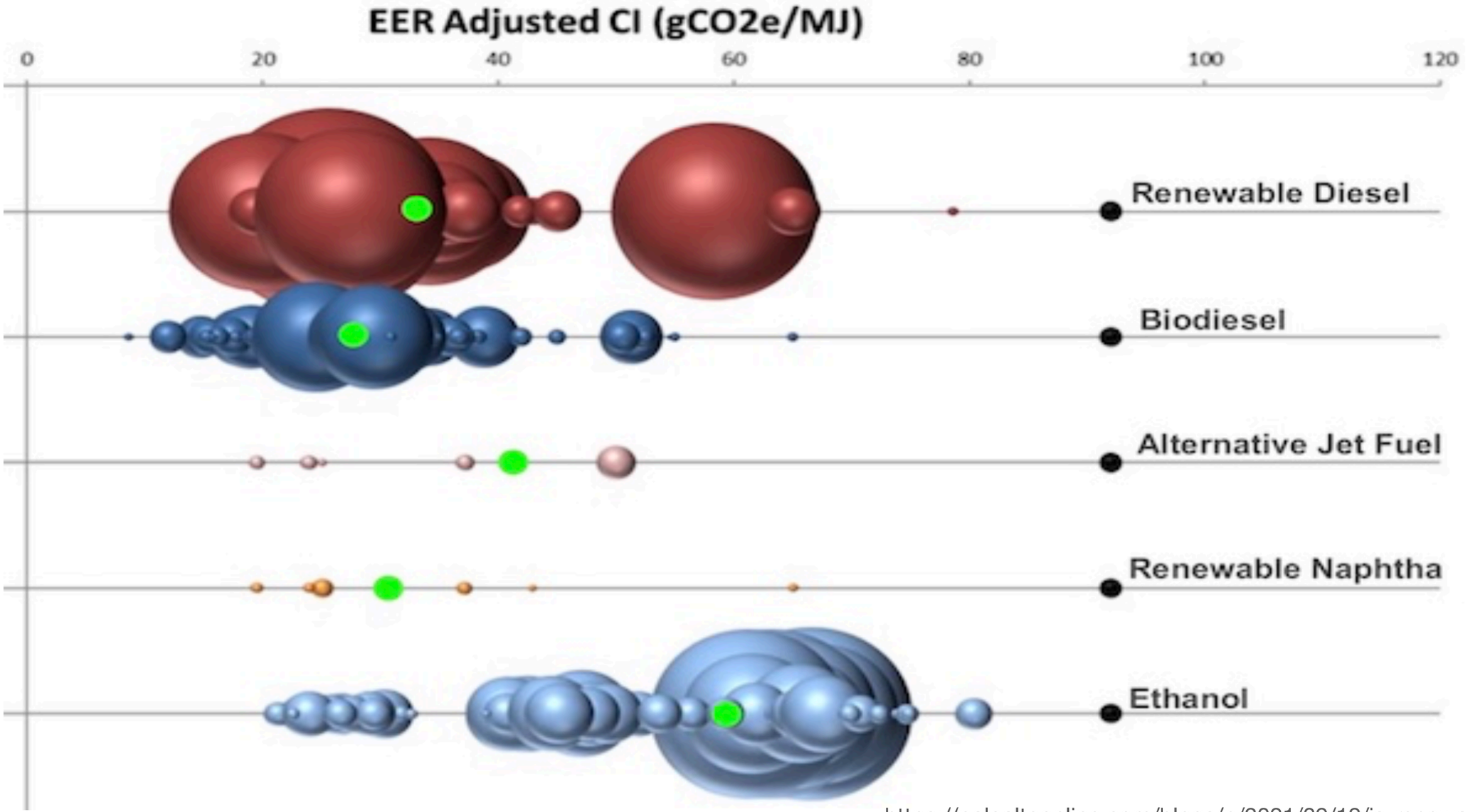
2 of 3 studies: RFS CO2 emissions exceed gasoline's.




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

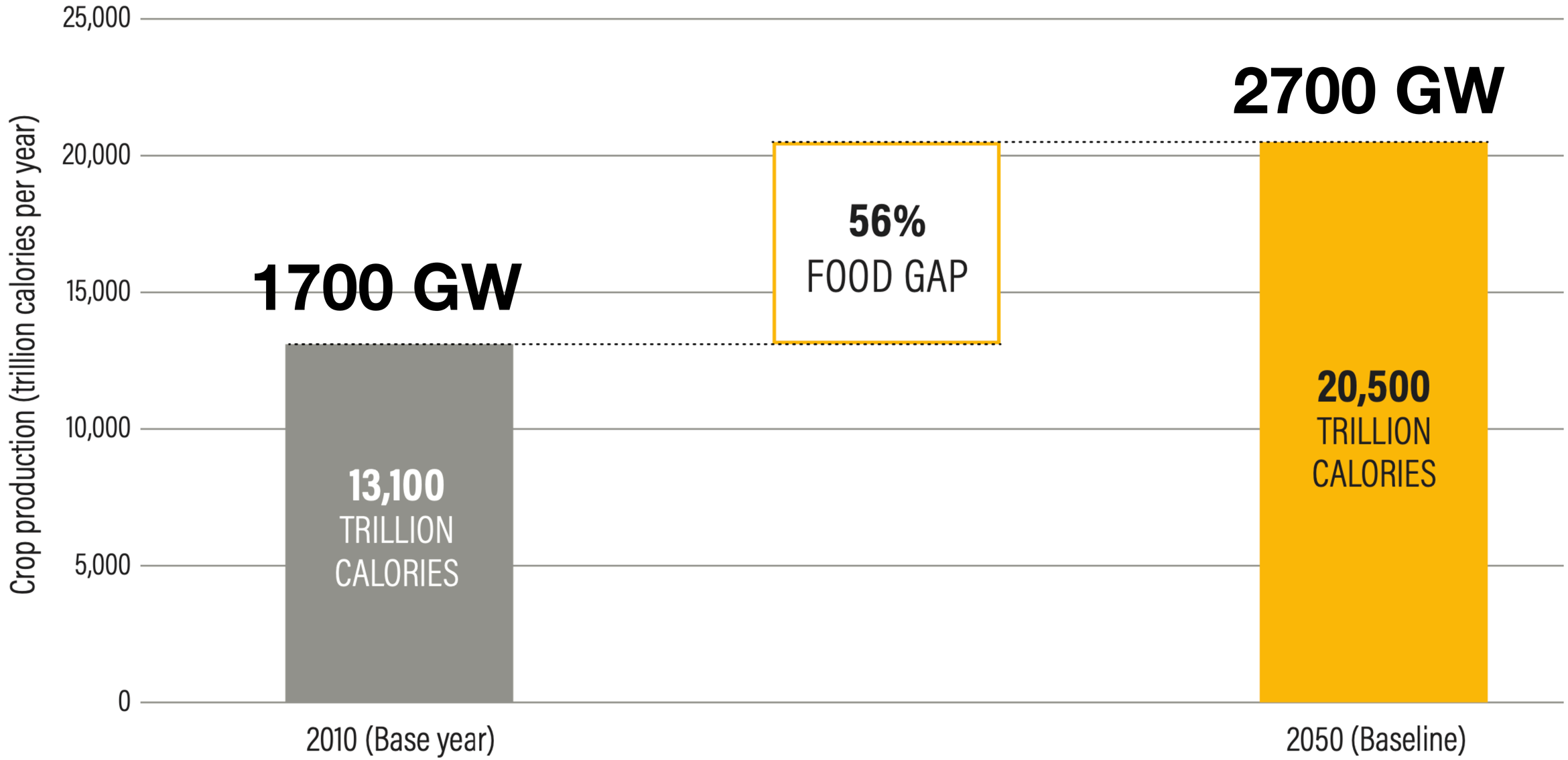
# **Renewable diesel is replacement for petro diesel.**

Not your father's biodiesel. ~$1.30/gal subsidy in Ca.




https://paloaltoonline.com/blogs/p/2021/09/19/is-renewable-diesel-the-real-deal

# 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

# Per capita energy flow from food crops

**Total crop supply:** 3,938 Kcal/capita/day of crops (2009)

# Per capita energy flow from food crops

**Total crop supply:** 3,938 Kcal/capita/day of crops (2009)

# 1400 GW power from food crops feeding 7 billion people

**Total crop supply:** 3,938 Kcal/capita/day of crops (2009)

## 66% HUMAN FOOD

2,609 Kcal/capita/day

**900 GW**

## 27% ANIMAL FEED

1,072 Kcal/capita/day

**400 GW**

## 3% SEED

122 Kcal/capita/day

**40 GW**

## 3% BIOFUELS AND OTHER

**50 GW**

# IEA proposed 4,600 GW from burning biomass by 2060 !

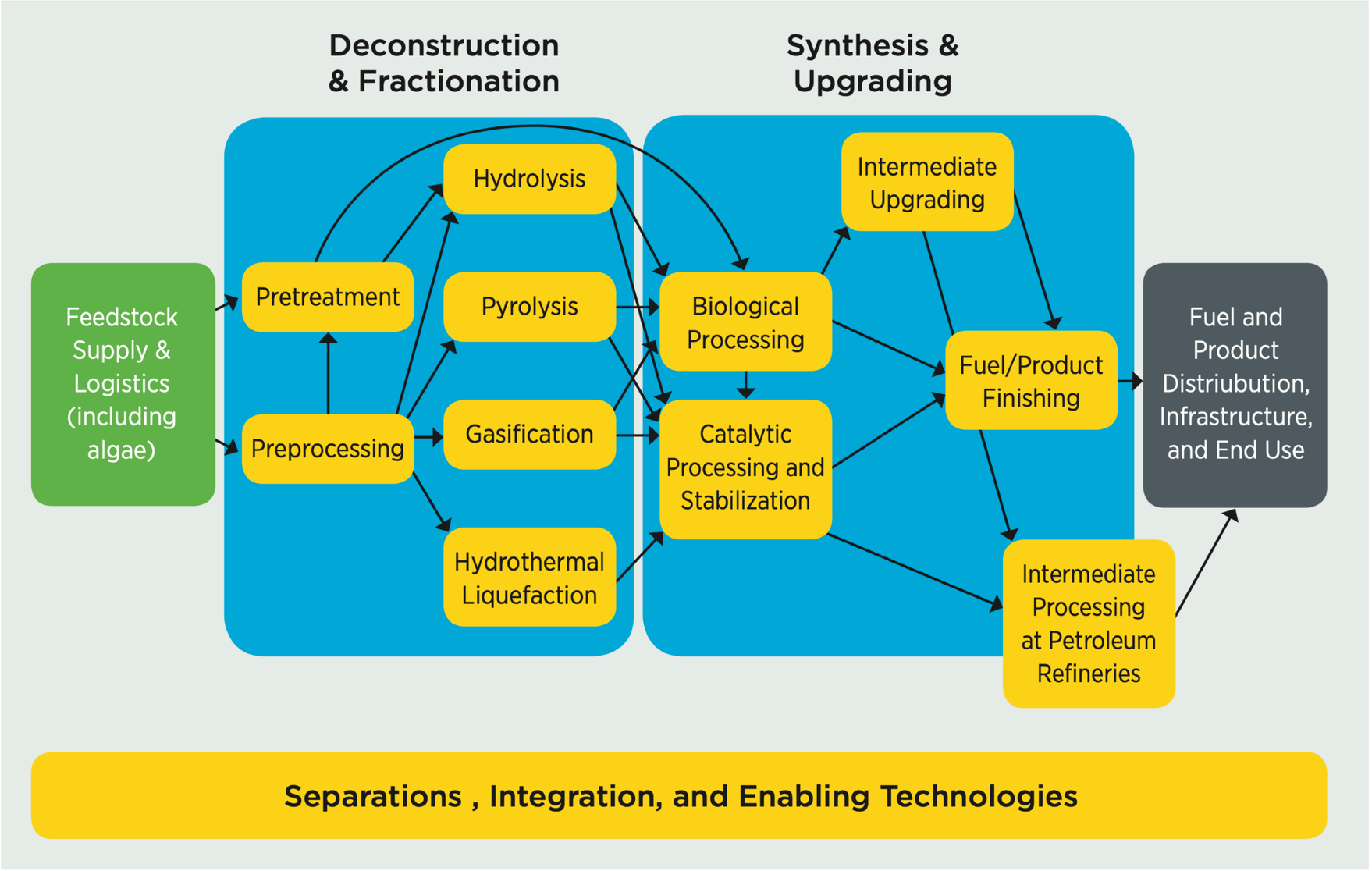
**Total crop supply:** 3,938 Kcal/capita/day of crops (2009)

# Hydrocarbon fuels can be synthesized from H2 and almost any carbon source.

- World cattle dung of 2.5 Gt/yr is ancient, labor-intensive fuel.
- Sewers collect 100 g hydrocarbons /person/day.
- 5 billion urban people generate enough biomass for ~ 1 GW of diesel fuel.
- Not enough, Bob.

http://ecen.com/eee57/eee57e/carbon_content_in_biomass_fuel.htm

# 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

# Don’t burn biomass! Hydrogenate it!

## Hydrogenation and hydrodeoxygenation of biomass-derived oxygenates to liquid alkanes for transportation fuels

Shaohui Sun, Ruishu Yang, Xin Wang, Shaokang Yan

Research Center of Heterogeneous Catalysis & Engineering Science, School of Chemical Engineering and Energy, Zhengzhou University, Zhengzhou City, China

Received 10 June 2017, Revised 17 January 2018, Accepted 22 January 2018, Available online 31 January 2018.

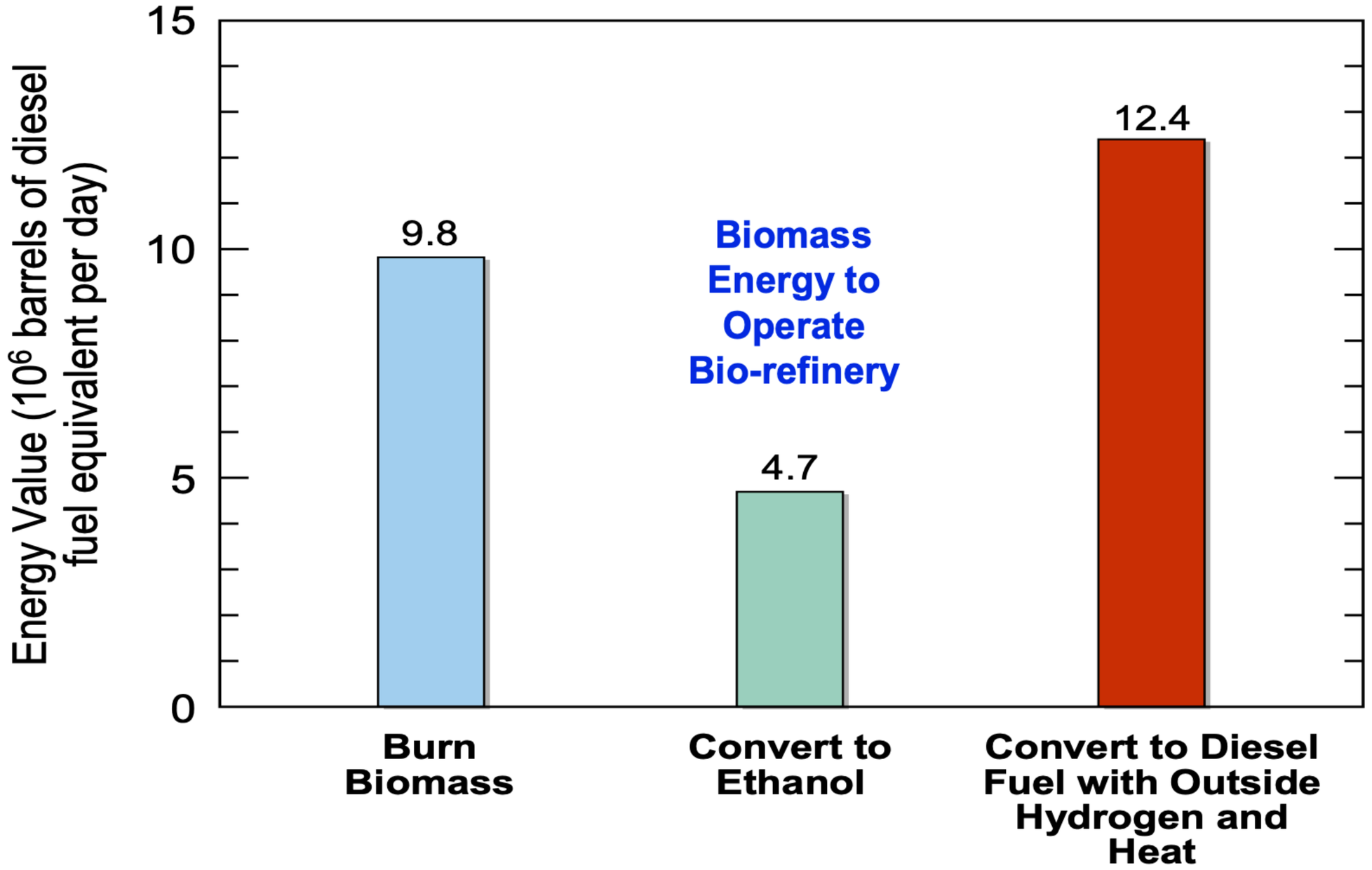
Farming produces ~ 2-5 tonnes of dry biomass per hectare-yr.

Half the content of dry biomass is carbon.
1.7 t biomass + H2 can produce 1 t hydrocarbon fuel.

https://www.sciencedirect.com/science/article/pii/S2352340918300726

https://www.sciencedirect.com/science/article/abs/pii/S0360319908009385?via%3Dihub

# Hydrogen and heat triple fuel yield from biomass.




**3X**

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

# Powering just airplanes with hydrogenated biofuel would use 5% of world agricultural land


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**

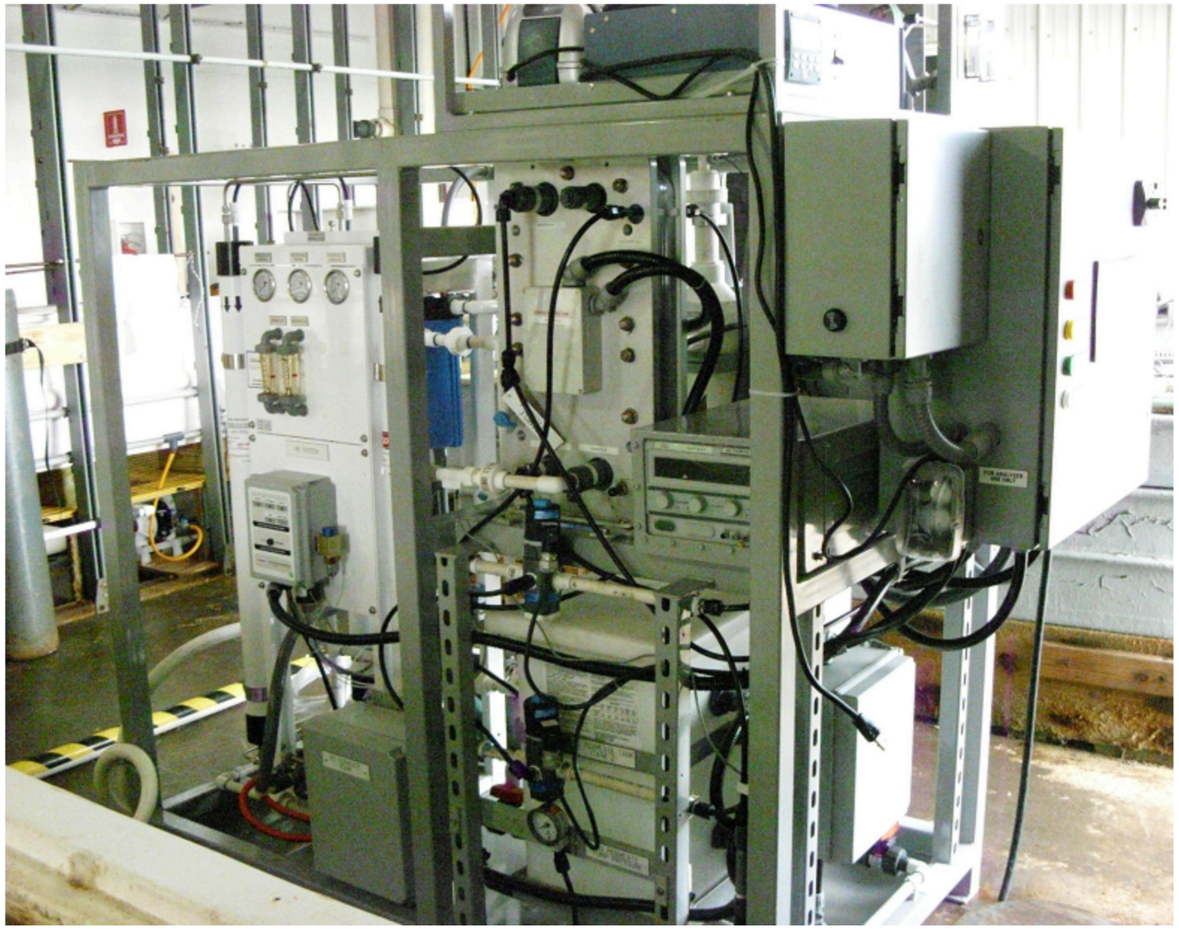
# We might limit use of biofuels to airplanes.

**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

**Limit use of biofuels just to airplanes?**

# US Navy Research Labs demonstrated capturing $CO_2$ from seawater 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

# NRL demonstrated capturing $CO_2$ from seawater to make $5/gallon jet fuel.


http://www.nrl.navy.mil/media/news-releases/2014/scale-model-wwii-craft-takes-flight-with-fuel-from-the-sea-concept
http://www.nrl.navy.mil/media/news-releases/2012/fueling-the-fleet-navy-looks-to-the-seas

# 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 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

# 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

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

# The Tupolev-155 was retrofitted to use LNG. 😢


https://i.redd.it/yvopv26zs4p31.jpg

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


**Typical TGV**

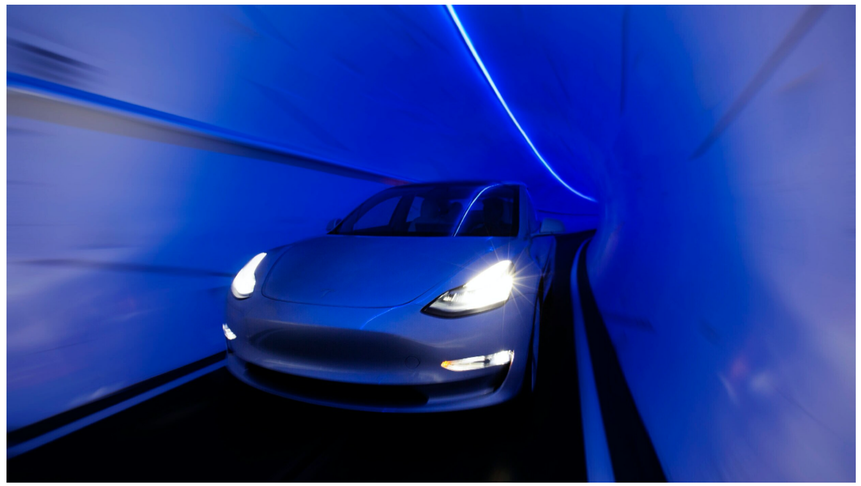
- 10 MW
- 25 kV
- **300 km/hr**
- 400 passengers
- 400 tonnes

| 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

# Elon Musk's Boring Company might overcome right-of-way barriers to transportation and power.

- $10 million per mile
- build 1 mile/week
- goal: 7 miles/day

https://www.boringcompany.com

# 11 Transportation

*Fission is in Fashion*

Battery electric vehicles

Charging

Two-wheel vehicles

250 GW demand

Hydrogen fuel-cell vehicles

Heavy transport

Biomass, CCS

Airplanes