Welcome to this week's presentation & conversation hosted by the **Canadian Association for the Club of Rome**, a Club dedicated to intelligent debate & action on global issues.

The views and opinions expressed in this presentation are those of the speaker & do not necessarily reflect the views or positions of CACOR.

Part 2: GHG Trends and Reasons for Hope and Rapid Progress on the Climate Front.

Our speaker today is Raymond Leury, who has always been interested in science & environmental issues. Ten years ago he bought his first EV, which led him to become President of the Electric Vehicle Council of Ottawa (EVCO). Now retired from a long IT career, Raymond spends much of his time researching and advocating for EVs of all sizes from light duty to medium and heavy-duty vehicles. This led to a successful campaign to get OC Transpo to transition to e-buses.

DESCRIPTION: Climate change is an existential threat. Temperature records keep falling, climate emergencies are declared, yet we don't seem to be making much progress in addressing the threat. How much progress have we made? There is no doubt that we are going to continue to see average temperatures increase for some time. What are our prospects for keeping those increases low enough so that we can avoid total societal collapse and a return to the stone age? Are we too late? The most recent data coupled with some analysis and careful forecasting shows that there are some paths that would substantially limit temperature increases and create conditions for a "soft landing." For those paths to be realized, we need all hands on deck and unprecedented cooperation because there is not a minute to waste.

The presentation will be followed by a conversation, questions, & observations from the participants.

CACOR acknowledges that we all benefit from sharing the traditional territories of local Indigenous peoples (First Nations, Métis, & Inuit in Canada) and their descendants.

Website: canadiancor.com
Twitter: @cacor1968
YouTube: Canadian Association for the Club of Rome
2024 Feb 07 Zoom #183

Hope or reality?

Part 2: GHG Trends and Reasons for Hope and Rapid Progress on the Climate Front – Part 2

Raymond J Leury, MBA

February 7th, 2024

My background

- **Science and business training**
  - Understand technology
  - Understand what business drivers will make an organization choose a technology
  - Many decisions that look illogical are based on business constraints
- **Every project implemented change**
  - Change is hard, risky and uncertain
    - What if I lose my job?
  - *Always* opposition – some winners think they will lose
  - What is hard we will have done by tomorrow and what's impossible will take a bit longer
  - Problem? We need to find a solution – "that's what I'm paid for"
- **My "superpower"**
  - Aggregate a large set of disparate data and distill it into viable solutions
    - Find a viable path from within a very messy reality
  - Involves understanding technology and the business/human impacts
  - Get the impossible done, make things happen
  - *No, can't, impossible* is a challenge, not a roadblock
    - Hard stuff is hard (Katherine McKenna)

Never say never

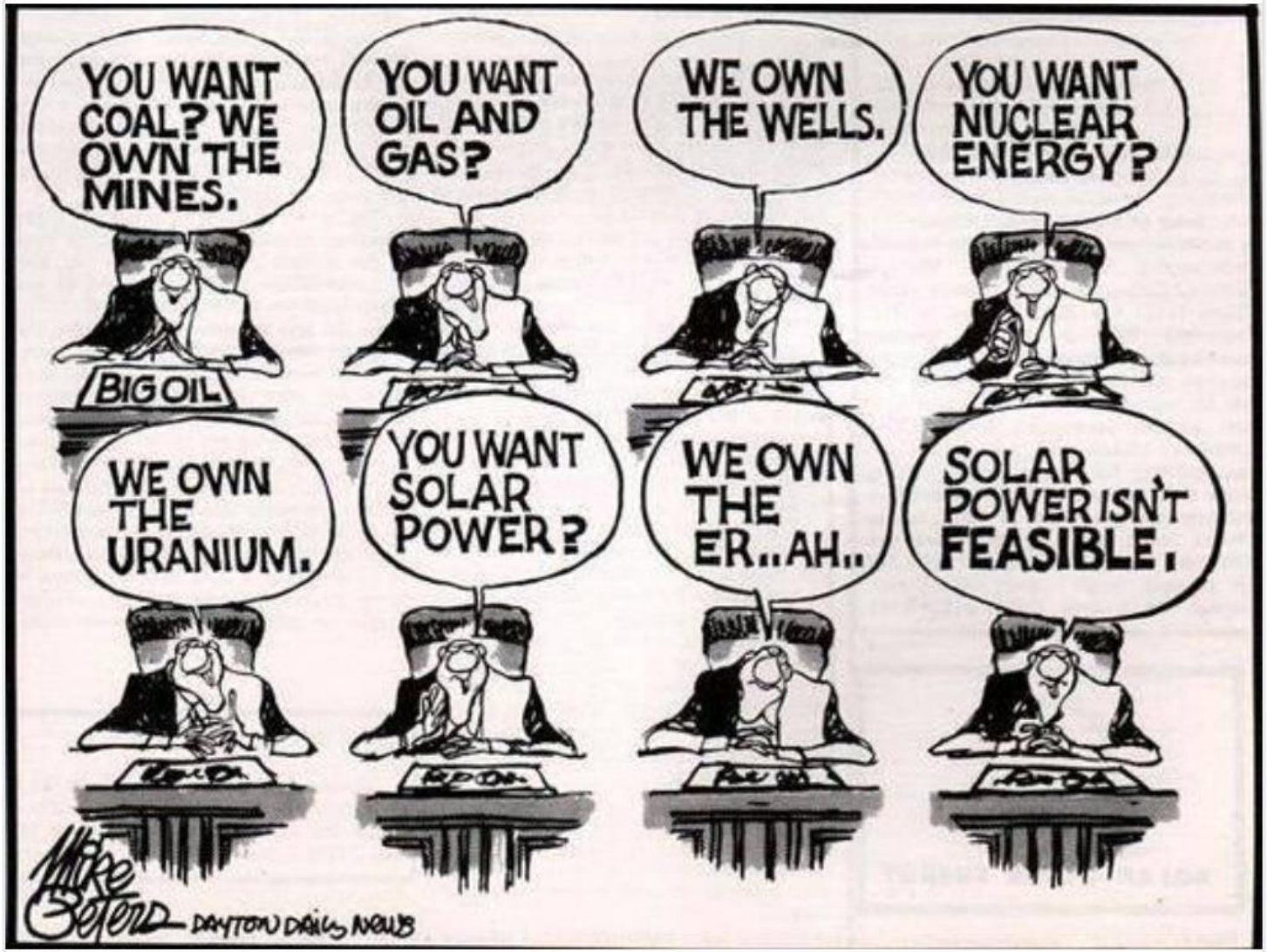
- Must, will, always, never, don't, impossible, etc. are all extreme positions
  - Closes possibility of being wrong
- Never is a long time!
- Laws of nature are fixed, technology is not
- True or False – "it depends"
  - Technology answers change as technology evolves
  - **What was false in 1990 might be true in 2023**
    - Can you squeeze all the processing power required for a smart phone into a portable device? False became true
    - **Note Moore's law forecasted this**
- If you have extreme position, you should check if it's still correct
    - **The answer may have changed!**
- **"We can't make windmills without fossil fuels"**
  - **Hold my beer!**

What can we conclude from Part 1?

- **Green washing is real** – and very well funded!
  - not everything is green washing
- Need to call out green washing
- Must understand difference
  - Not always obvious
- **IEA woefully understates pace of change**
- **Solar, wind, batteries and EVs**
  - **Rapid adoption**
  - **Much faster than IEA forecasts**
- https://decarbconnect.com/

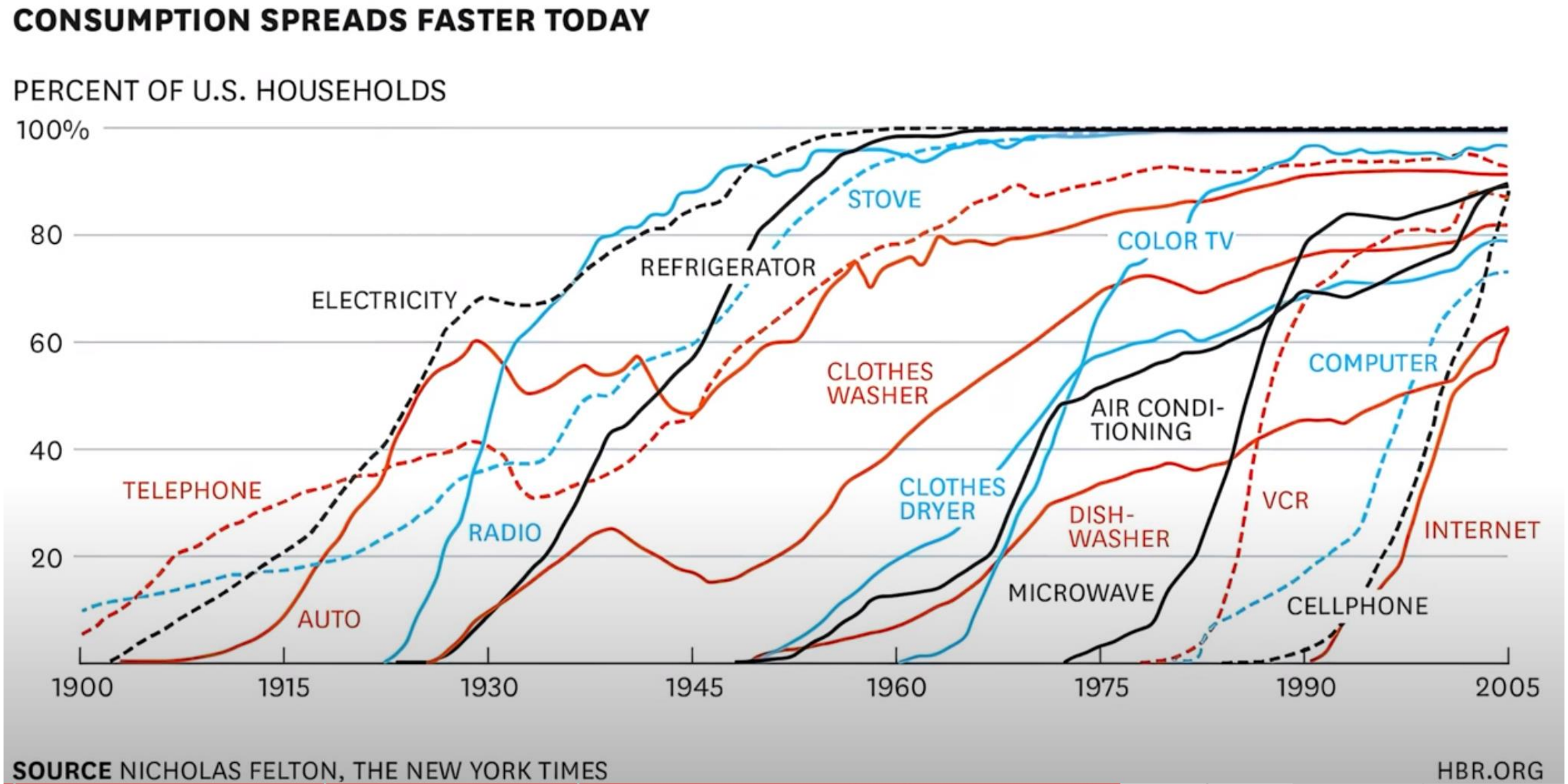
Fossil Fuel Incumbants

- Writing is on the wall
- Trying to hold on to their markets
- Using all means to slow the transition
- Lots of misinformation
  - What is the truth?
- Ex: “softening EV sales”
- Think of cigarette companies…
- “Never ask a barber if you need a haircut” (Warren Buffett)



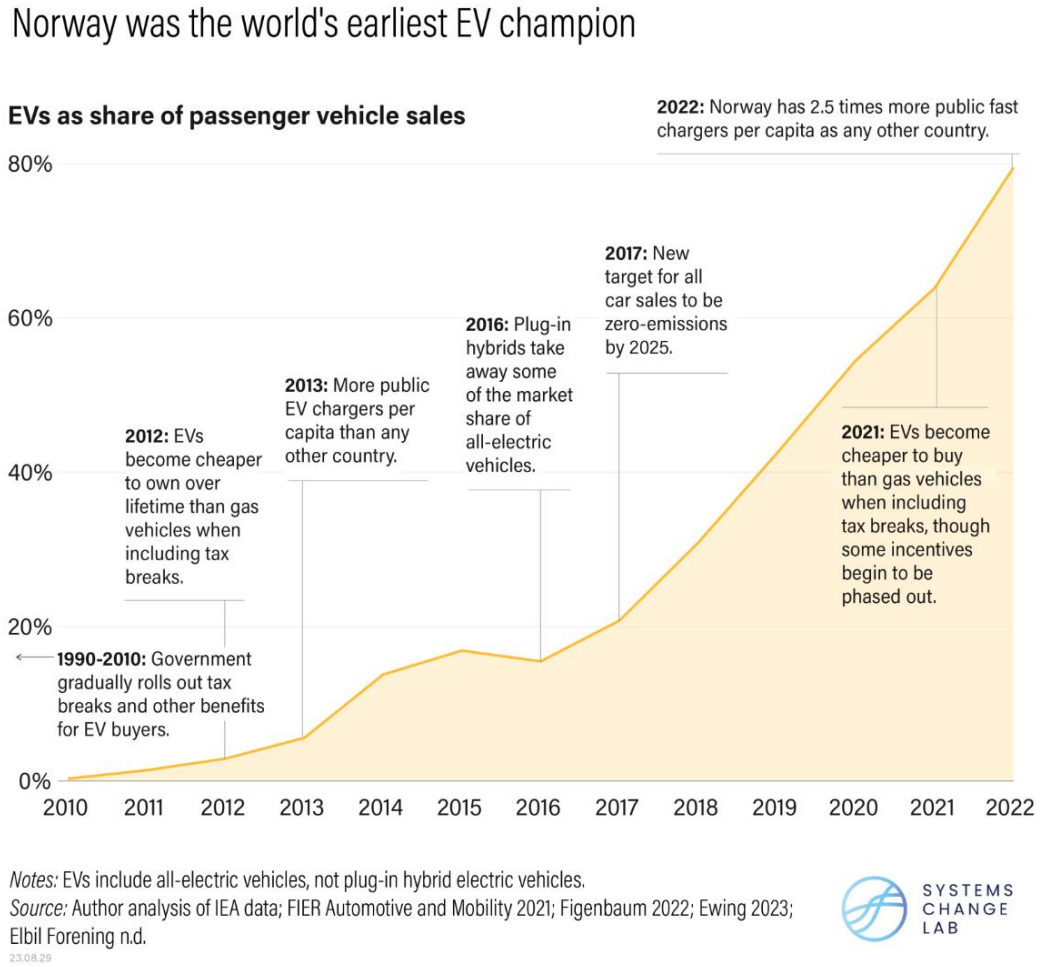
IEA Forecasts Are Linear
Should be S-curves

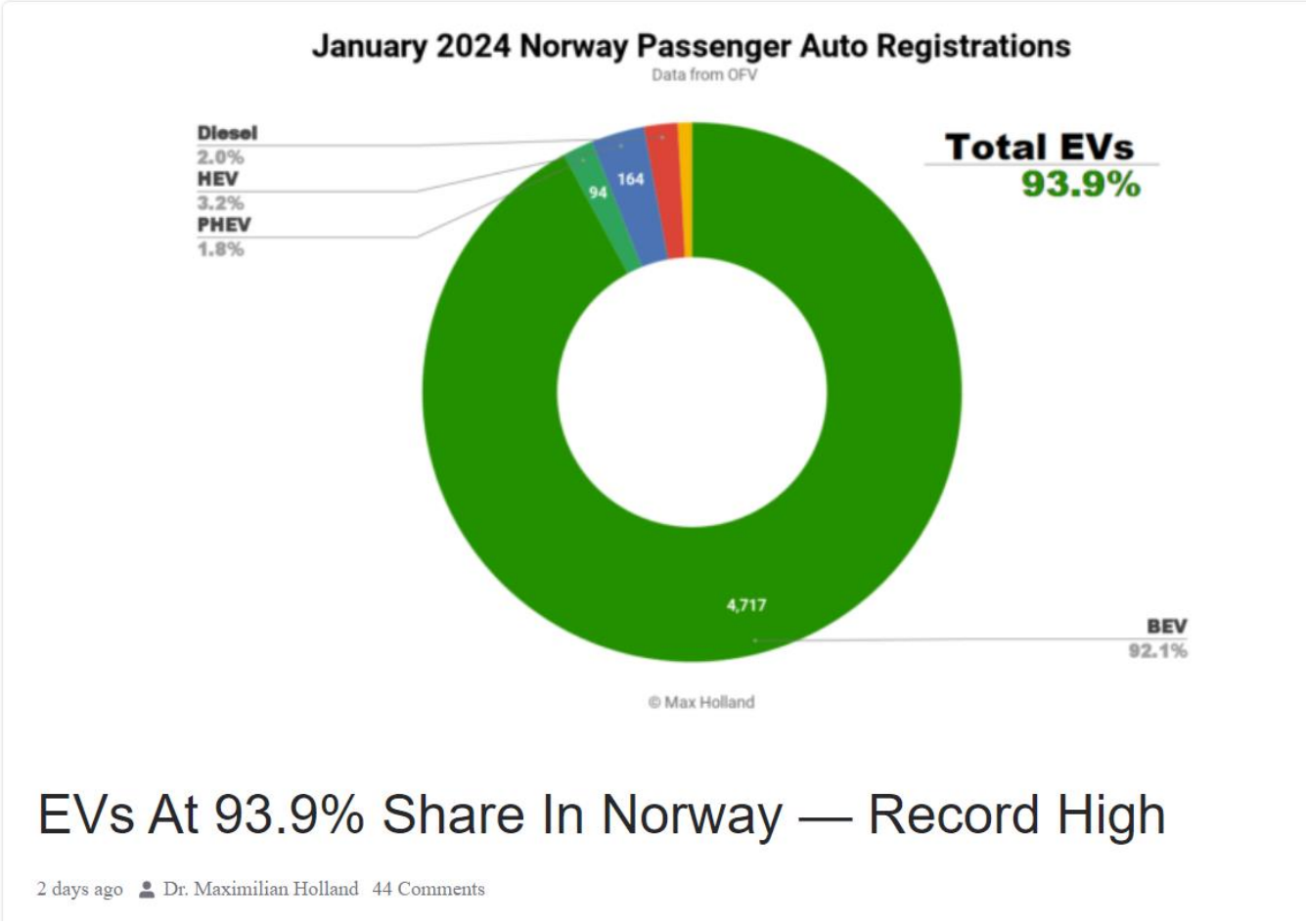
Constantly under-estimates pace of change



How fast can it be?

- Canada likely to be there around 2030
- Canada, US, Australia - laggards





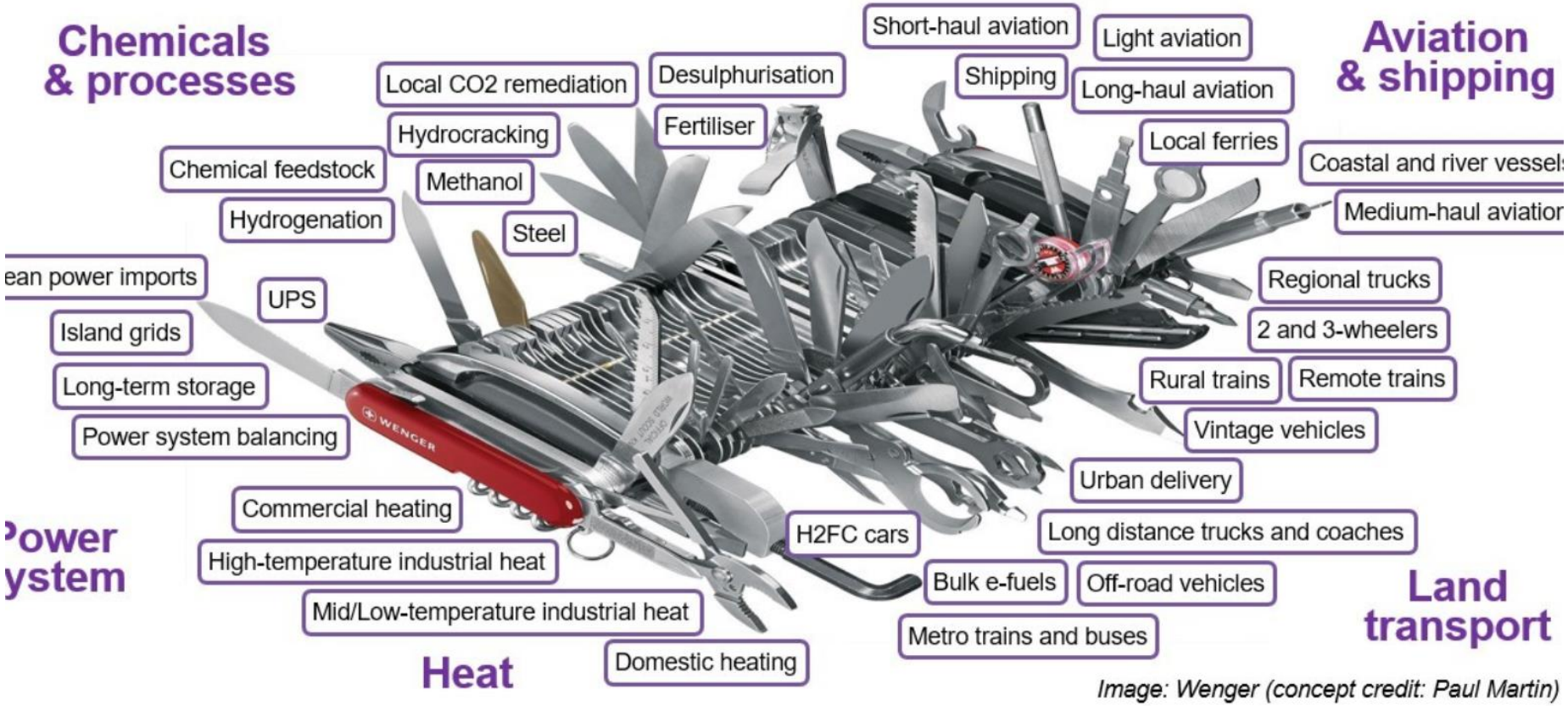
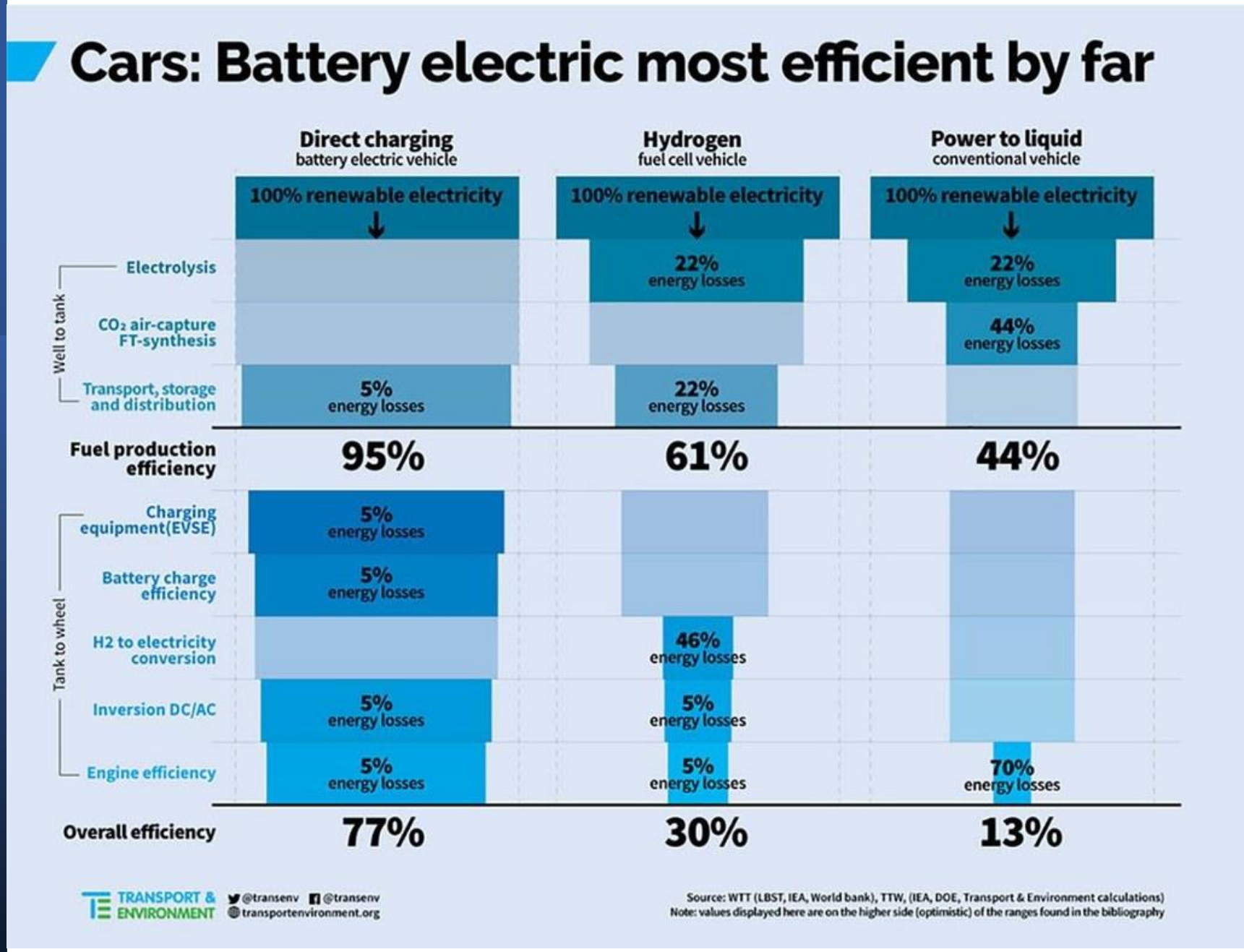


Image: Wenger (concept credit: Paul Martin)

Hydrogen – the Swiss Army Knife

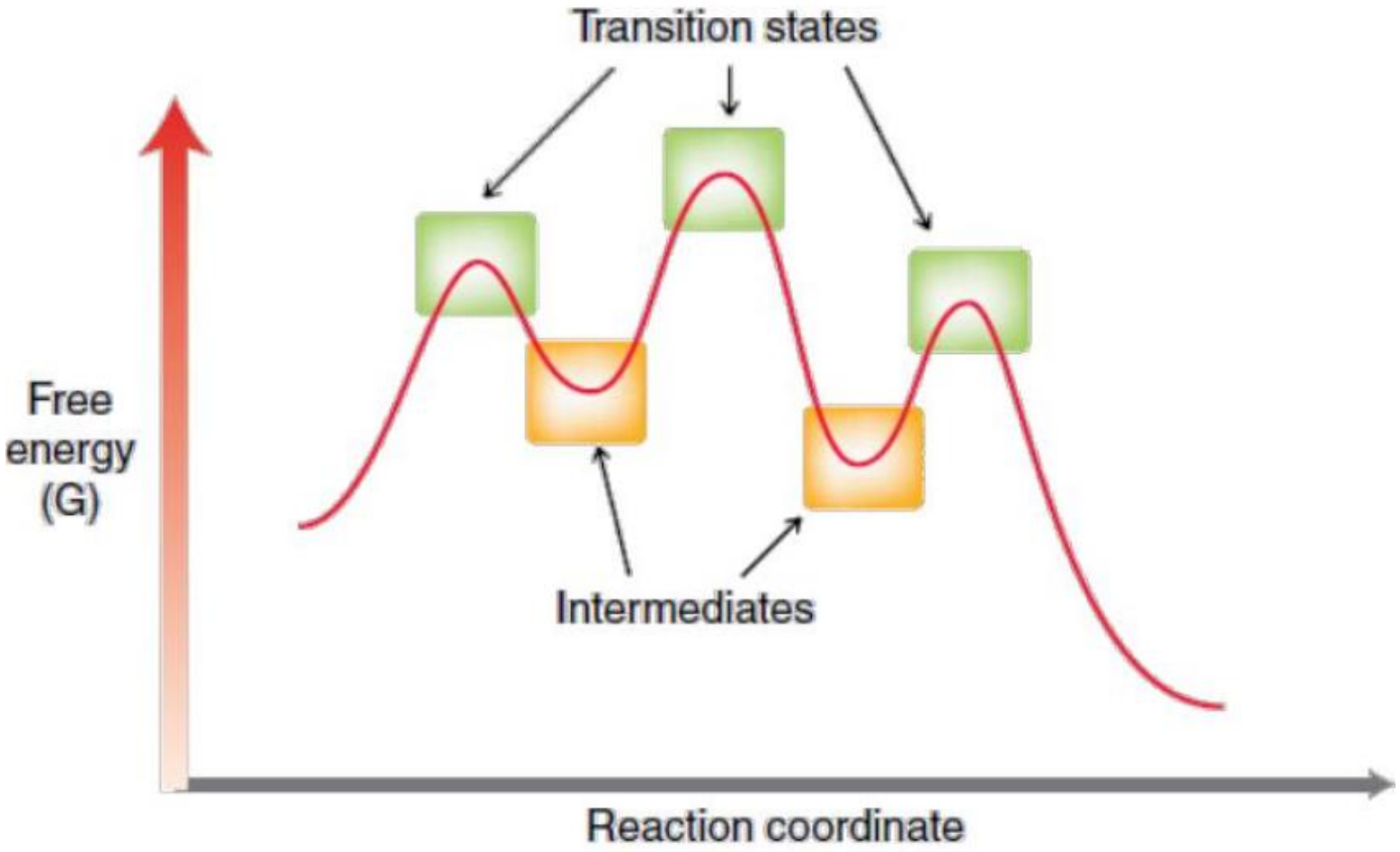
Paul Martin – will present in June

Hydrogen *Works* – Is it a good solution?

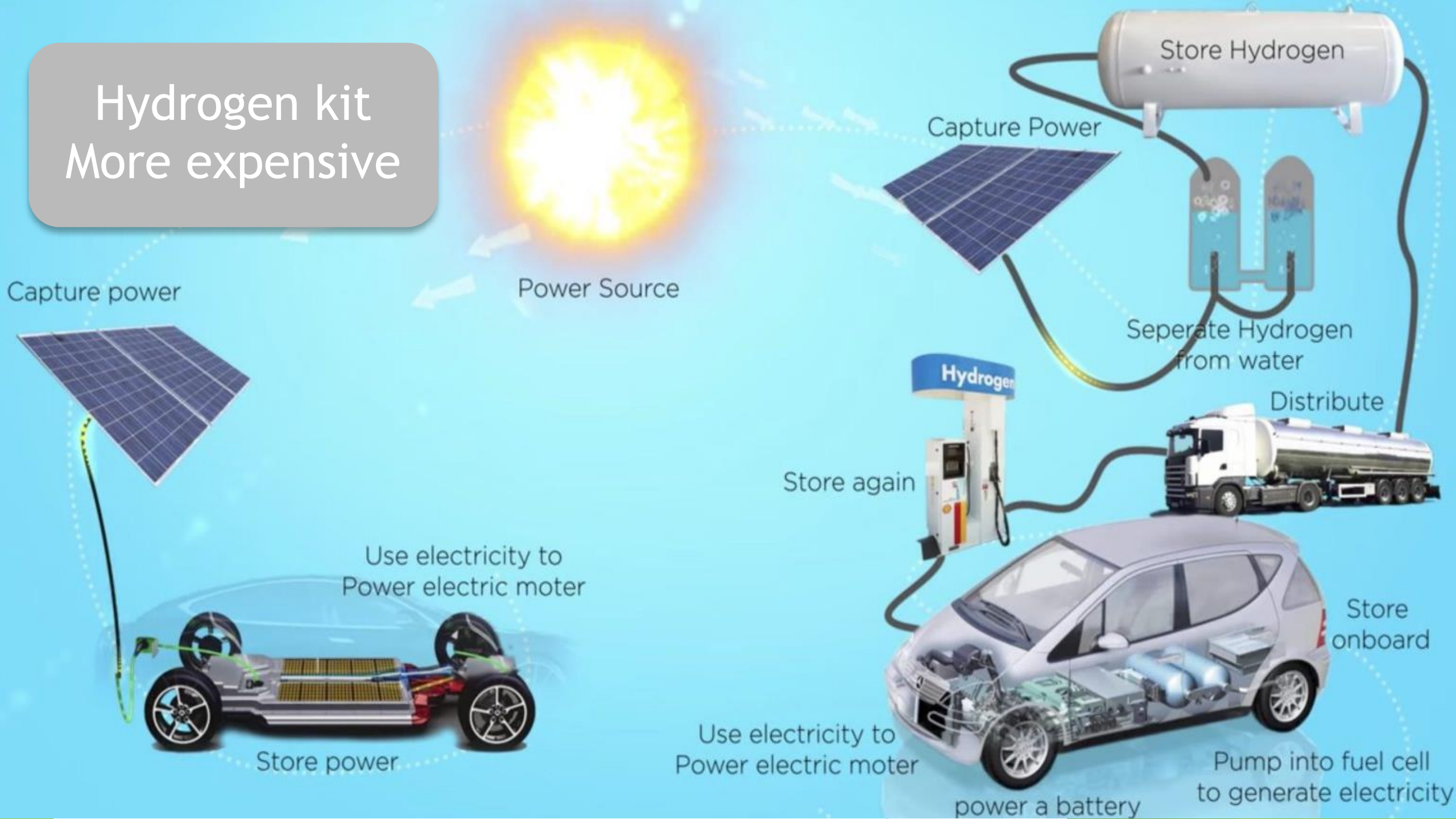


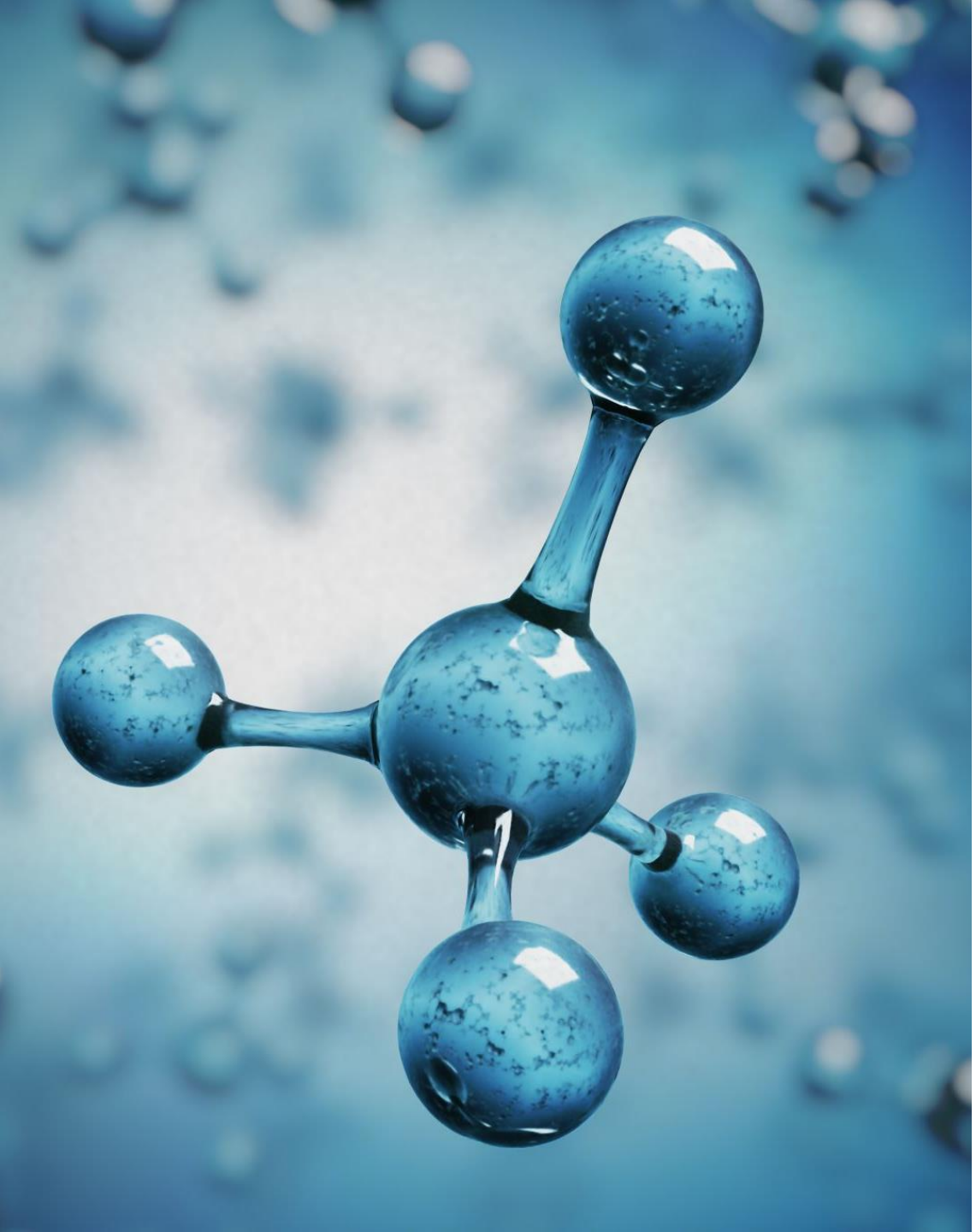
Physics and Chemistry

- Hydrogen requires 3x the energy
  - Huge cost disadvantage
- Laws of nature get in the way
- Energy is “wasted” as heat
- ICE - 70-80% loss
- Storage
  - 5000-10000 PSI
  - 23 ° K (−250.2 °C)
- Convert to NH3 – ammonia
  - Haber-Bosch process
  - More heat loses
- No free lunch



Hydrogen kit
More expensive





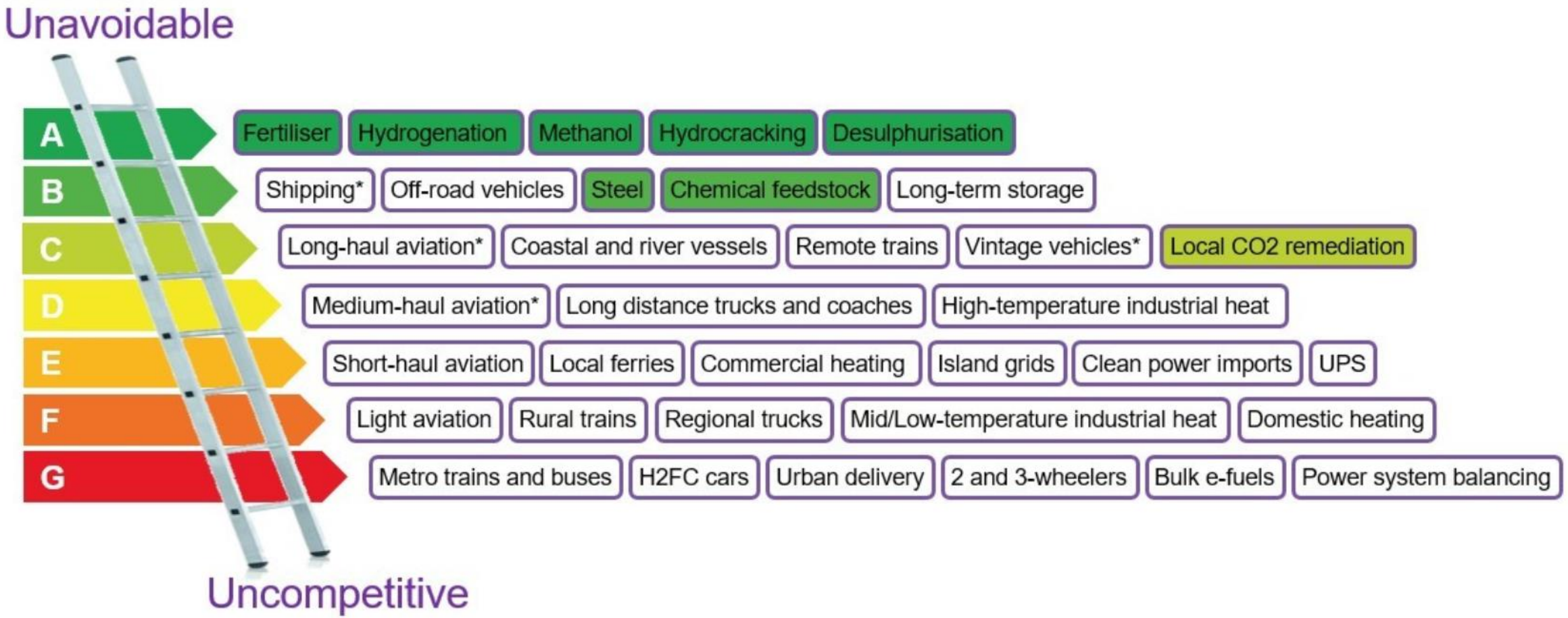
Electric more efficient than Hydrogen

- Transport – 3x (hydrogen ICE much worse)
- Heating – burning H_2 vs air source heat pump 6x
  - Heat pumps good to 200^{o}C
- **NOT a good solution for transport or energy applications**
- Many other issues
  - Safety
  - Transporting H_2 is challenging
  - Density is much lower than alternatives
- **Hydrogen has other uses**

- For more see **Prof David** Cebon from Cambridge - https://www.youtube.com/watch?v=JlOCS95Jvjc
- **Michael Liebreich** Keynote to Hydrogen Congress 2022 - https://www.youtube.com/watch?v=Xj900aBPkiY&t=1s
- **Paul Martin** - Distilled Thoughts on Hydrogen | LinkedIn

Clean Hydrogen Ladder: Chemicals & processes

Liebreich Associates



** Via ammonia or e-fuel rather than H2 gas or liquid*

Source: Liebreich Associates (concept credit: Adrian Hiel/Energy Cities)

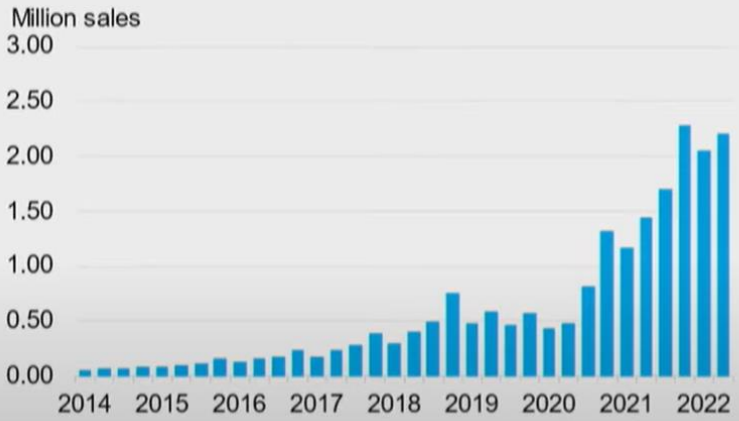
- All good uses have to do with chemistry – replace gray/black hydrogen
- Source: https://www.liebreich.com/the-clean-hydrogen-ladder-now-updated-to-v4-1/
- Mission Hydrogen: https://mission-hydrogen.com/

FCV sales are booming?

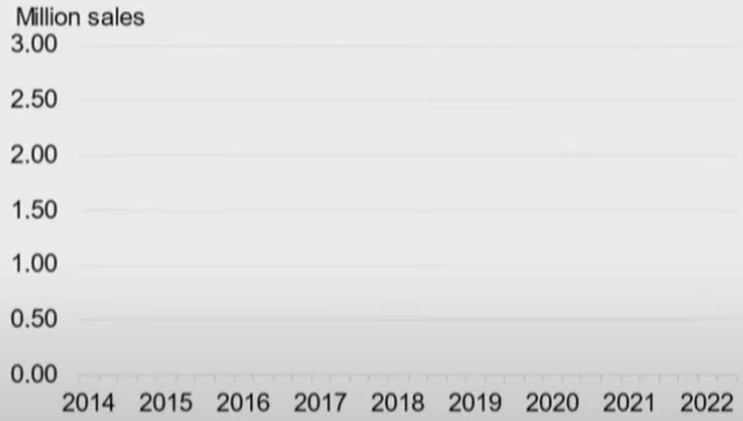
Global BEV vs. FCV sales quarterly

Liebreich Associates

Battery electric vehicles

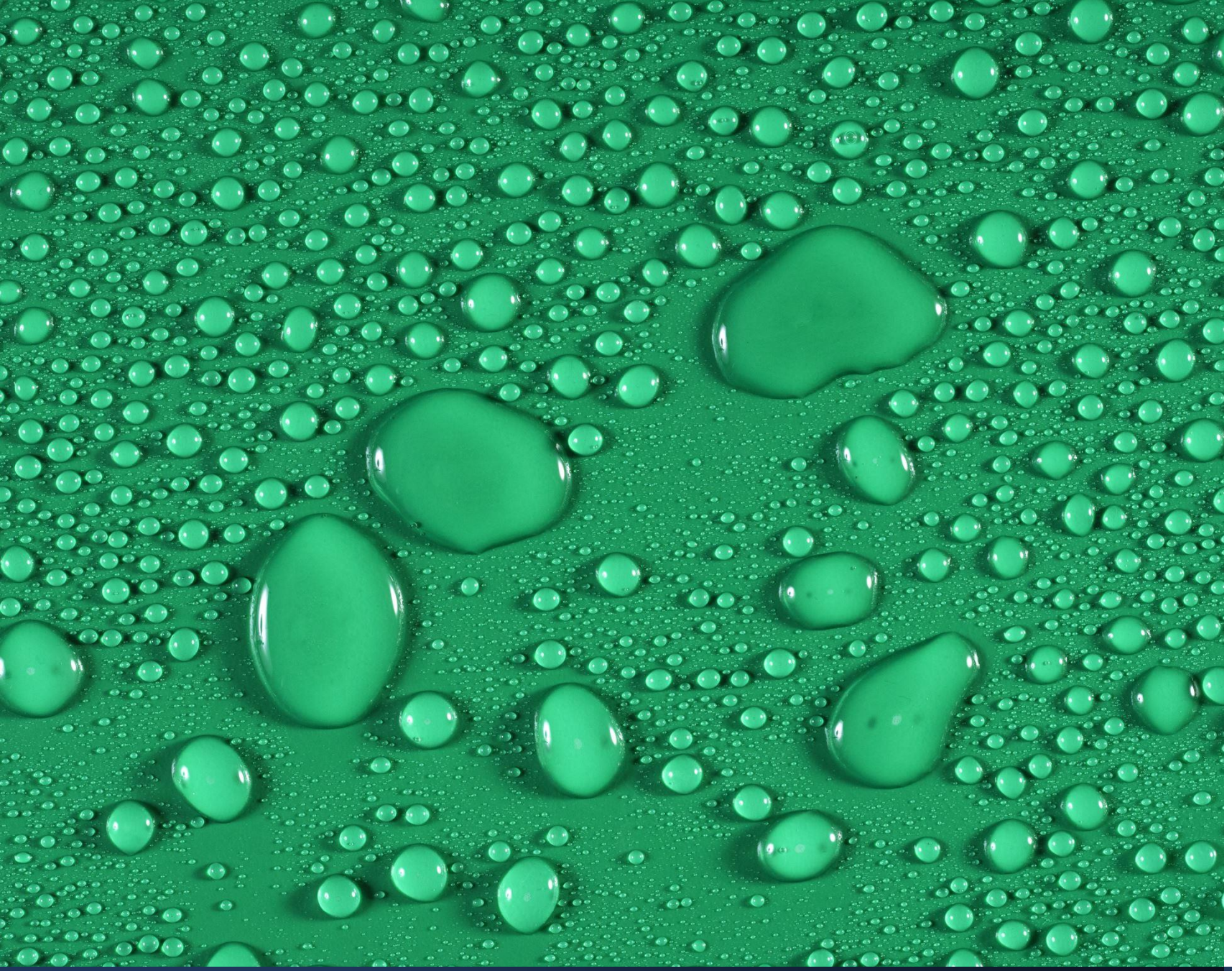


Fuel cell vehicles



Note: Includes PHEVs

Source: BloombergNEF



Lots of Green Washing!

- Who benefits from hydrogen?
- $Green H2 > $gray H2
  - ~$8 vs $2
- FF industry produces 120M tons/year
  - 700M tons GHG/year
- Need to replace gray/black hydrogen
- Forget about other uses for now

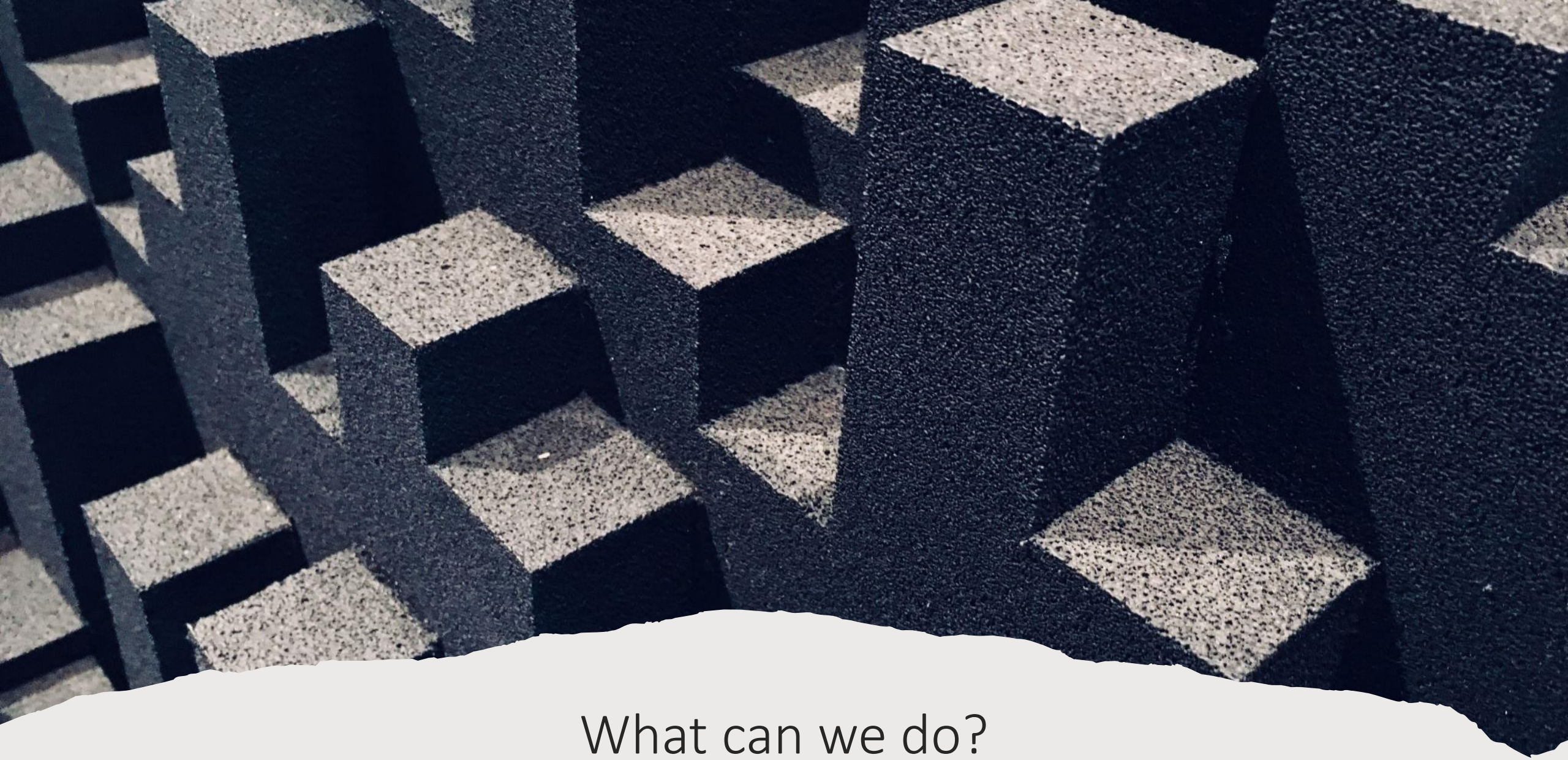
What choices do we have?

What options do we have? Option 3

- **Use technology to decarbonize and eliminate GHGs**
  - **“Electrify everything”**
- Consequences:
  - Less warming than option 1 or 2, eventual reversal
  - Less famines, less migration
  - Sacrifice of less than 7 B people (assumes we can support 1B)
- Risk is that we don’t/won’t have the technology
- **Humans will choose this willingly – no/low sacrifice**
- **ONLY ACCEPTABLE OPTION** in my view
- Any other option condemns 7 B people to famine and death - unacceptable

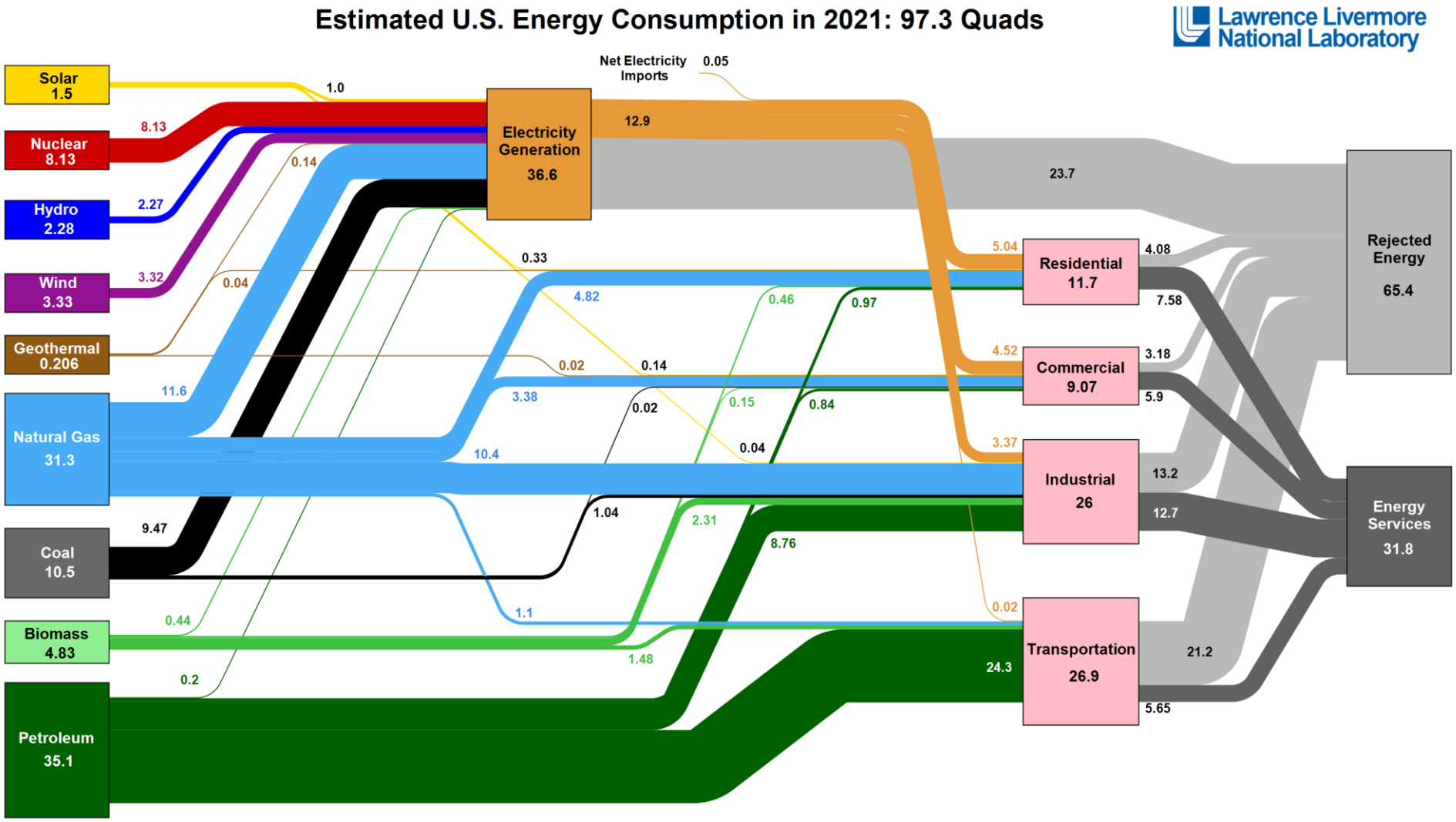
Implementing Option 3

- Want to avoid revolutions and bloodshed
- That means:
  - A capitalist system
    - **Strong monetary incentives**
    - Note: China is most capitalist country on the planet
  - Democratic or authoritarian governments
    - Hope is that all are democratic, but not required
- Figure out how to **use capitalism**
  - **Drive the right changes**
  - Decarbonize



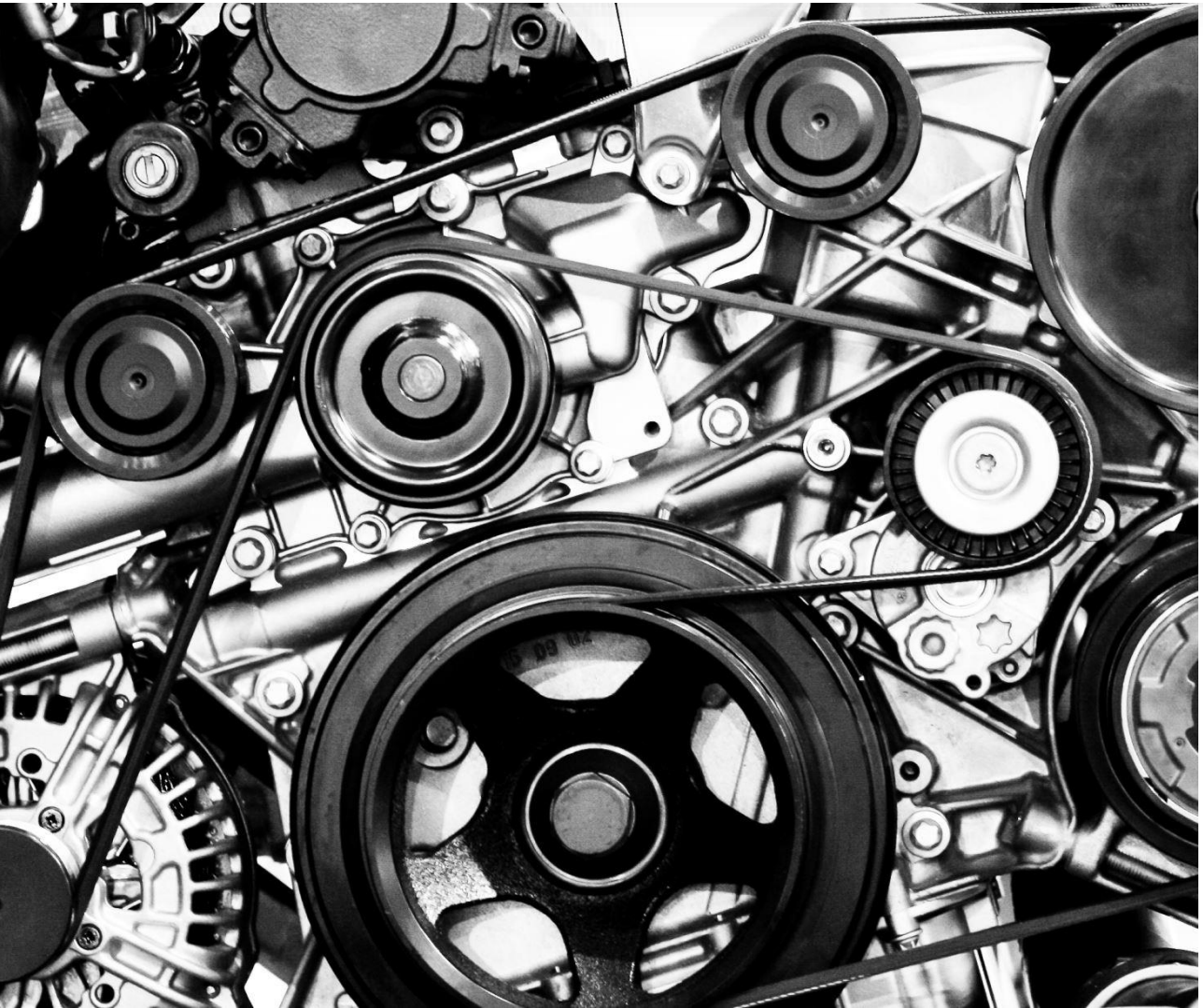
What can we do?

How big is the problem?



Source: LLNL March, 2022. Data is based on DOE/EIA MER (2021). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector and 49% for the industrial sector, which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

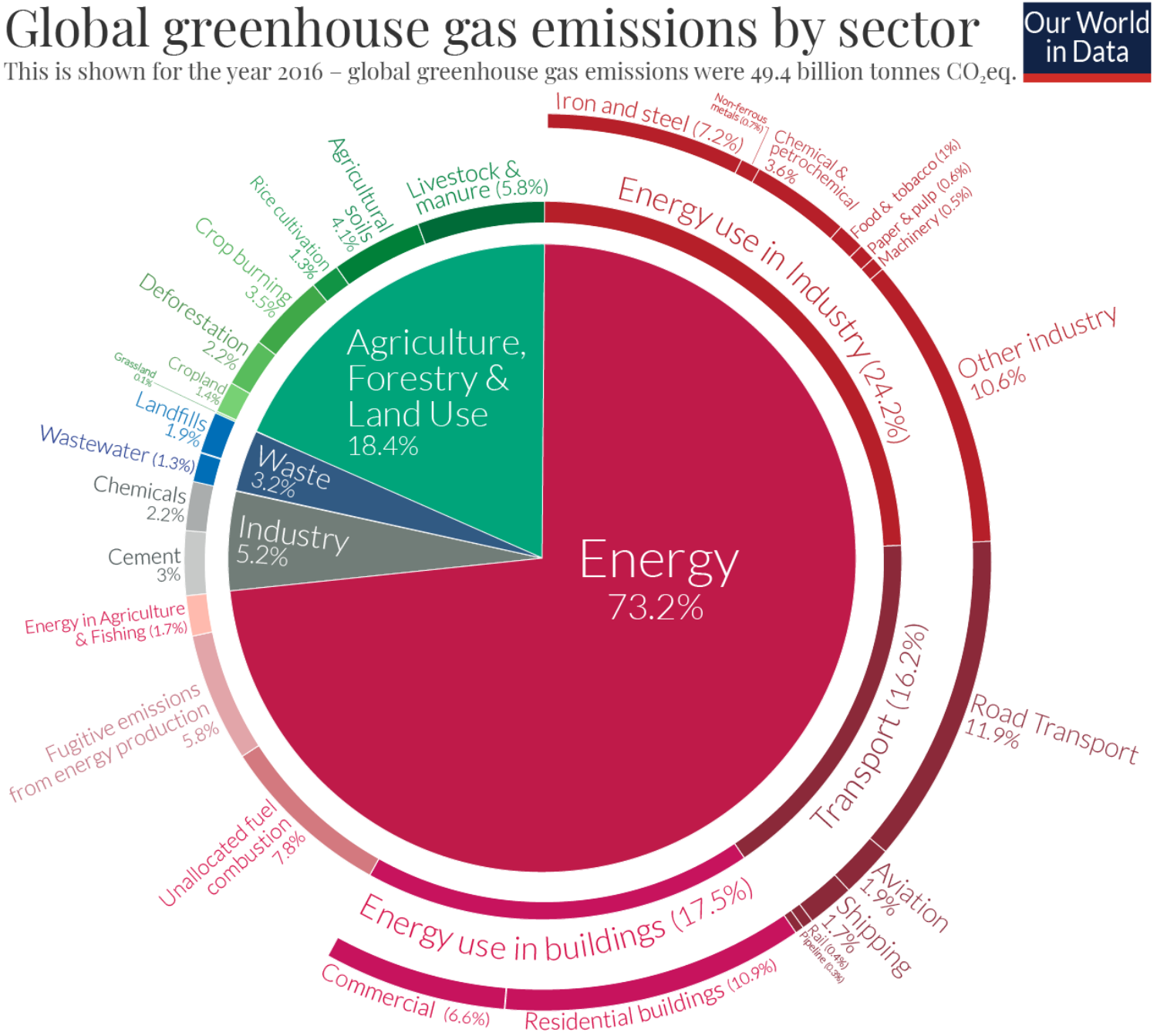
FF Efficiency is a Problem



- Internal Combustion Engines (ICE) are 20% efficient
- Electric is 75% efficient
  - 3x less energy required
- Fossil gas heating is near 100% efficient – sounds good!
- Air Source pumps are 300-400% efficient
  - 3-4x less energy required
  - Ground source can exceed that efficiency

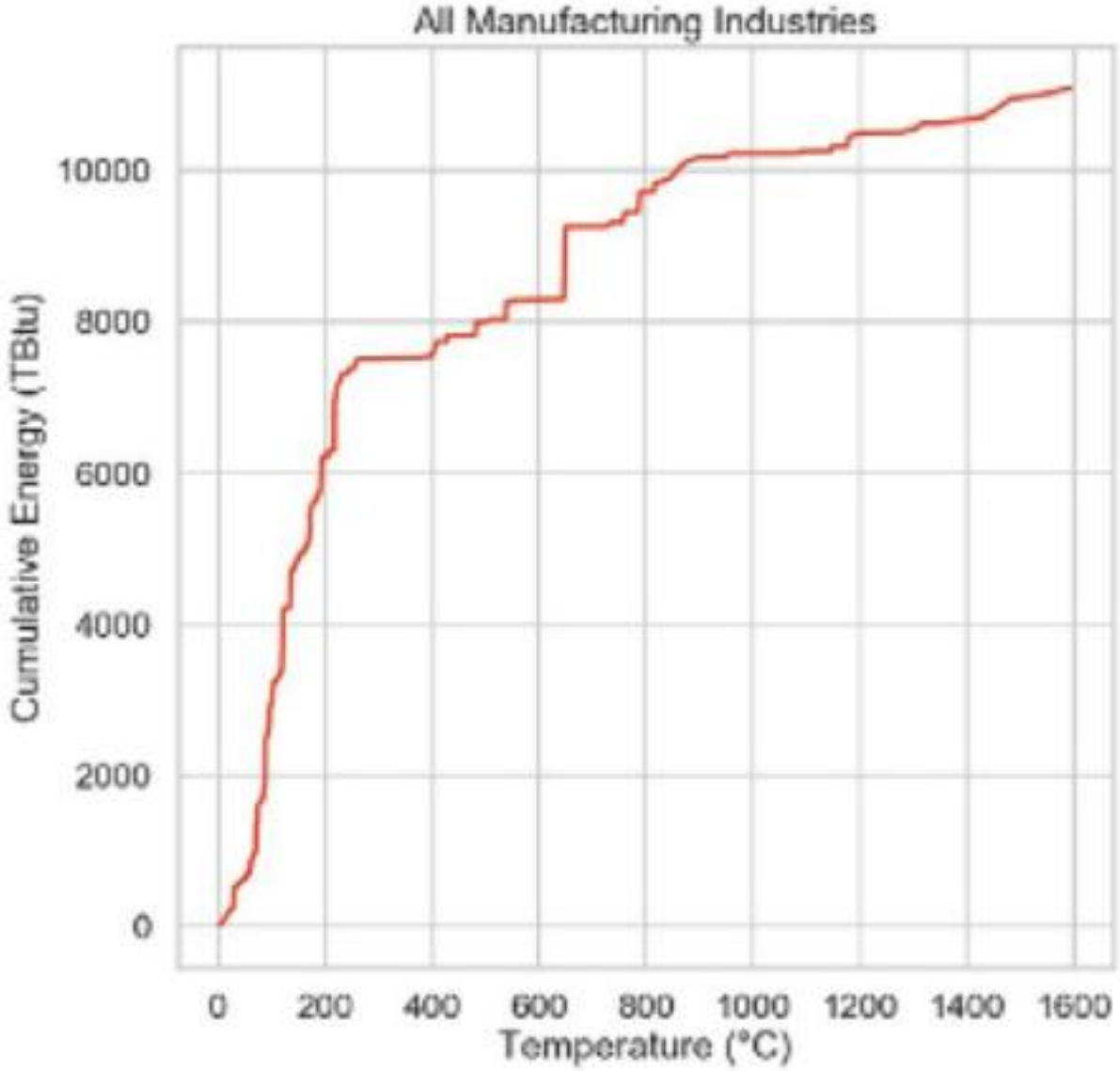
- Electric solutions much more efficient that fossil fuel equivalents
- We (mostly) need to replace useful energy, not rejected energy
  - We don’t need to triple electricity production
- Reduction in energy use per capita!

Where do Emissions come from?



Heating

- Heat pumps
  - Space and water
- Heat pumps are feasible up to 200°C
- Resistive heating can be used above that
  - Electric arc furnace
  - Recycled steel



ndustrial heating vs temperature, 2014, from McMillar

Transport

- Light duty
- Medium-Heavy duty
  - Trucks, buses
- Ships
- Planes
- Trains
- Note: some of the largest motors are electric/diesel-electric
  - Azipod (ships), Mining trucks, locomotives

Transport – Light Duty

EXXONMOBIL AT THE CROSSROADS

Every new passenger car sold in the world will be electric by 2040, says Exxon Mobil CEO Darren Woods

PUBLISHED SAT, JUN 25 2022•7:05 AM EDT

Lindsey Jacobson
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@LINDSEYTWEETED

SHARE

- He is arguing against his self-interest…likely true statement
- I rest my case…actually, it's likely to happen before 2035

Transport Medium and Heavy Duty

Every truck OEM in North America and Europe (except Western Star)
- EV in market or announced

Transport - Ships

- Short haul – battery electric
  - Ferry
- Long haul
  - 30% carry fossil fuels
  - 40% of emissions
    - No longer needed…
  - Biofuels
  - Efficiency – lower speed
  - Sail
  - Shore power
- Cruise ships
  - Shore power
  - Batteries?

The new Wolfe Island ferry has a capacity of 399 passengers and 75 vehicles, nearly double the size of the existing vessel. **CKWS TV**

Transport - Trains

CN has purchased Wabtec's heavy-haul battery-electric locomotive, shown above, for testing. (Wabtec)

- Electrification
  - Already widespread outside North America
- Battery Electric
  - Re-use part of diesel/electric
  - Weight is not significant problem
  - Battery cars can be swapped easily
  - Recoup range downhill

The E9X concept, designed by the Dutch company Elysian, is a battery-powered plane that can theor
fly up to 500 miles (800 kilometers) on a single charge. (Image credit: Elysian)

Eviation

Transport – Aviation Short/Medium haul

- Electric
- Need higher gravimetric power density
  - Over 400 Wh/kg
- Trainers available now

Transport – Aviation – Long haul

- Hydrogen is not the answer
- SAF – synthetic aviation fuel
- All of aviation is 2%

	Jet A1, SAF or liquid eFuel	Liquid hydrogen
Gravimetric density	44 MJ/kg	120 MJ/kg
747 fuel load (weight)	200 tonnes	[73 Tonnes] 150 - 300 Tonnes* ✓ ✗
Volumetric density	34.7 MJ/litre	8.5 MJ/litre
747 fuel load (volume)	250,000 litres	1,020,600 litres ✗

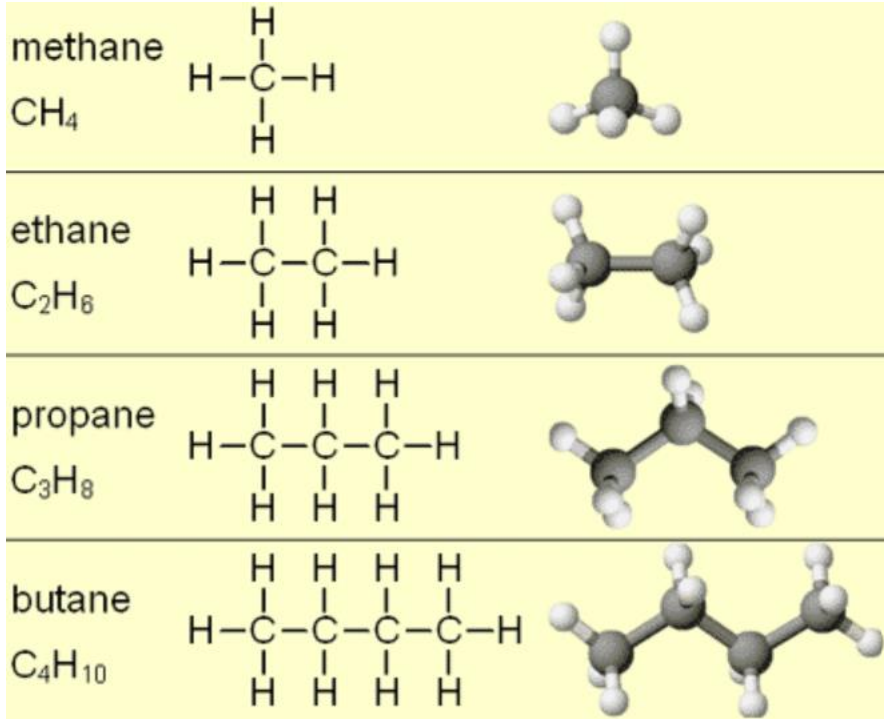
* Hydrogen weight would be 73 tonnes; potential cryogenic system fuel mass fraction 25-50%

Source: Boeing; Liebreich Associates

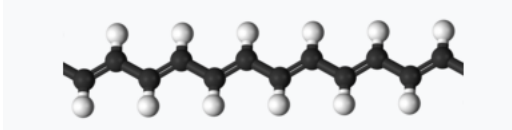
“Refineries will produce gasoline regardless of demand”

- Speaks to myth that oil refineries output proportions are fixed
  - “If we don’t burn the gas, then we’ll have to dump it”
  - Quite a coincidence that refineries are producing exactly the mix we need…
  - Bollocks!
- Refineries
  - Separating compounds out of crude oil – “refining”, Fractioning
  - Petrochemicals – cracking, etc.
    - Cracking - process whereby **complex organic molecules** such as kerogens or long-chain hydrocarbons are **broken down into simpler molecules** such as light hydrocarbons, by the breaking of carbon-carbon bonds in the precursors
    - All sorts of transformations

Carbon (Organic) Chemistry

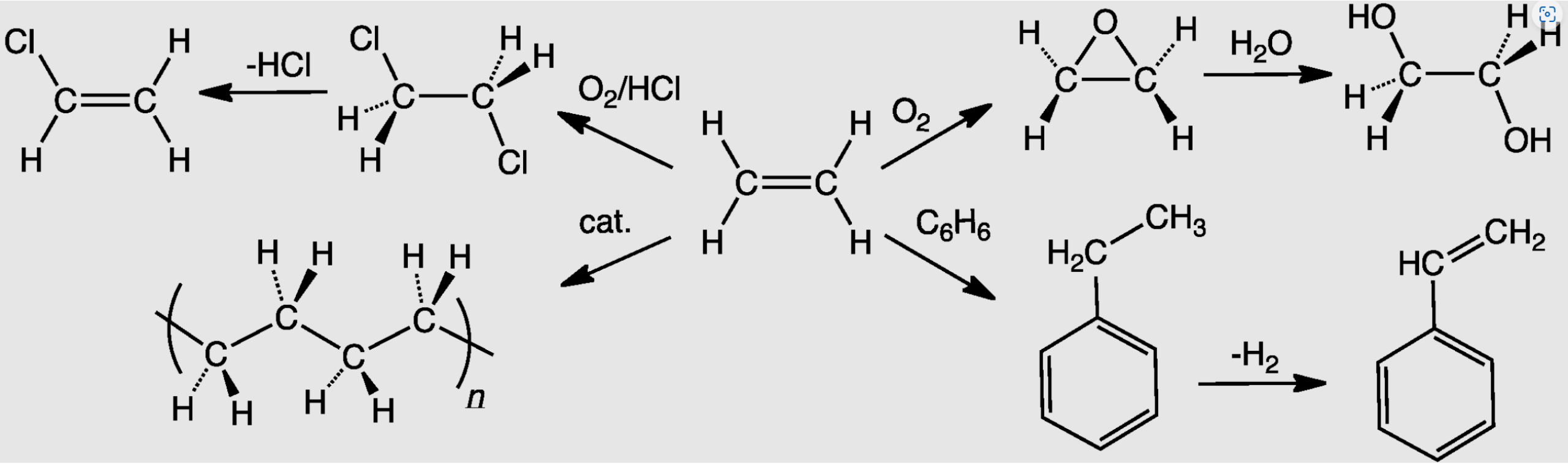


- Lots of variability
  - Larger molecule
    - Higher melting and boiling point
- Can be combined in many ways
  - Many industrial applications
  - Polymers – Plastics
- About 40 precursor chemicals
  - Most/all available from non-fossil sources



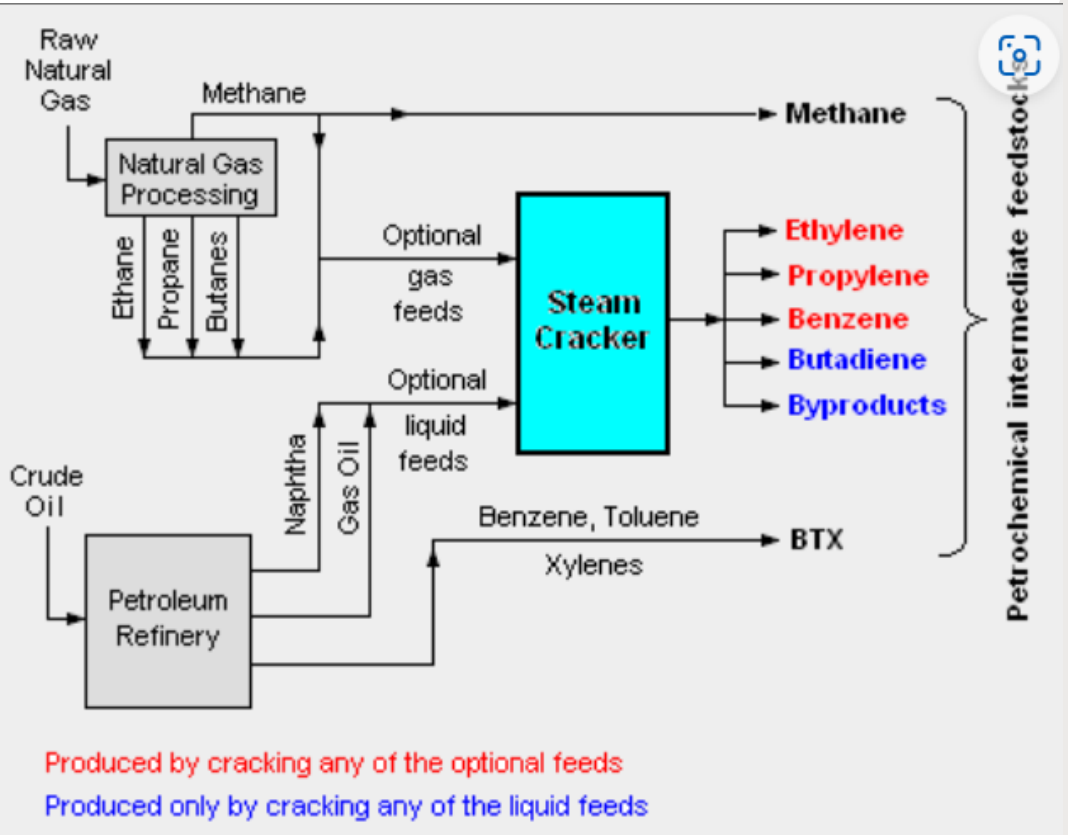
- Keep in mind that for petrochemicals were are not intending to burn products

Ethylene



Main industrial uses of ethylene. Clockwise from the upper right: its conversions to ethylene oxide, precursor to ethylene glycol; to ethylbenzene, precursor to styrene; to various kinds of polyethylene; to ethylene dichloride, precursor to vinyl chloride.

- Ethylene can be synthesized from renewal natural gas - methane
- Most reactions require heat…cost – no free lunch



Petrochemicals

- Oil refineries produce **olefins** and **aromatics** by **fluid catalytic cracking** of petroleum fractions.
- Chemical plants produce **olefins** by **steam cracking** of natural gas liquids like ethane and propane.
- **Aromatics** are produced by **catalytic reforming** of naphtha.
- **Olefins** and **aromatics** are the **building-blocks** for a wide range of materials such as solvents, detergents, and adhesives. Olefins are the basis for polymers and oligomers used in plastics, resins, fibers, elastomers, lubricants, and gels.
- You can make any molecule from other organic molecules
- **Bio sources** exist for most, if not all, precursors
- We don’t need fossil oil for petrochemicals
- Source: https://en.wikipedia.org/wiki/Petrochemical

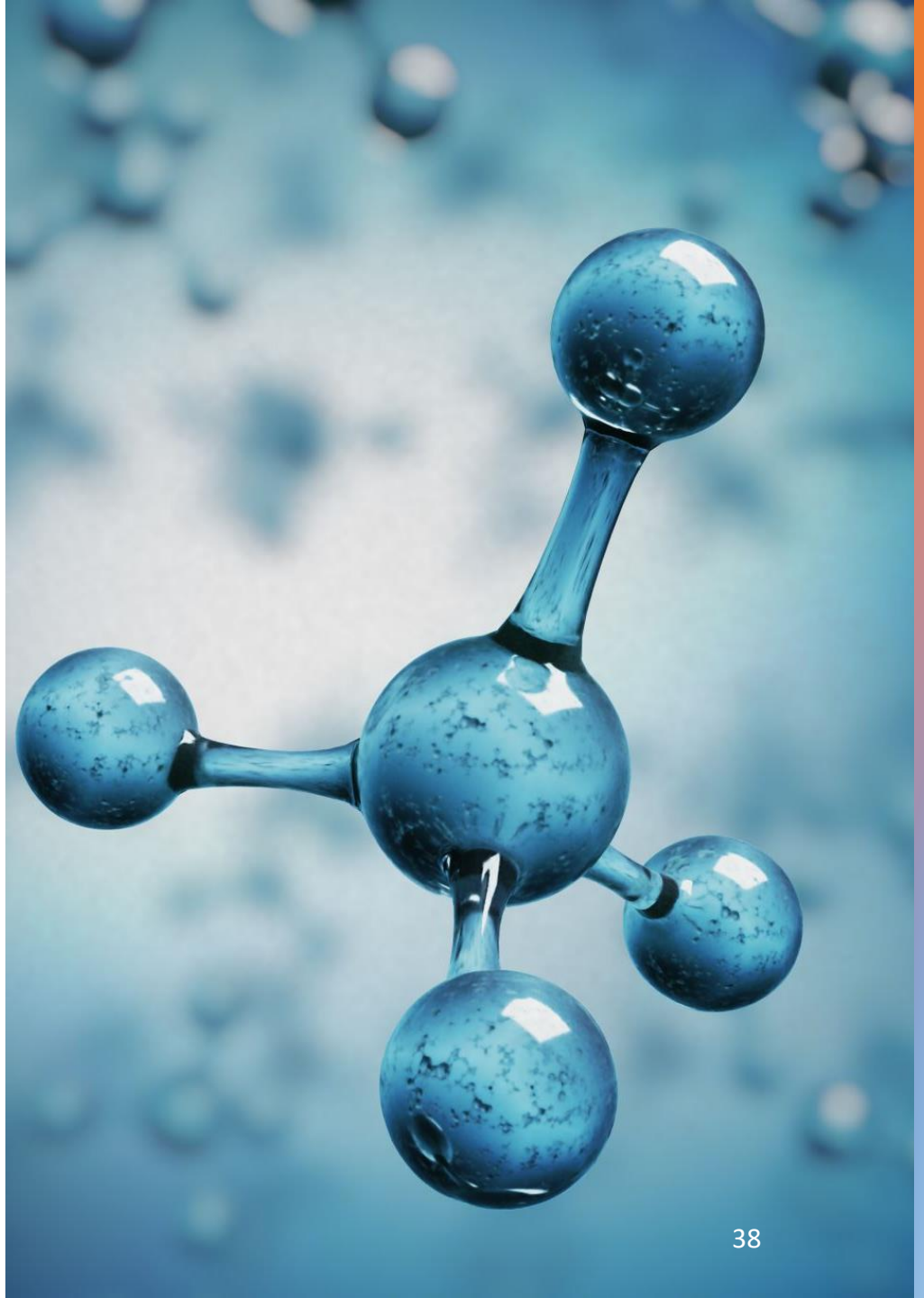
Organic chemistry is fascinating!

Steel – Conventional Smelting

- Iron Ore mixed with coke (or methane)
  - Coke is “pure” carbon
  - Iron ore is Fe_xO_y
  - $Fe_xO_y + C_x$ -> $Fe + CO_2$
  - Coke provides heat, chemical reduction and carbon
- “Steel” is iron + carbon
  - We need a bit carbon in there
  - Up to 2% of steel content
  - Carbon is “sequestered” in the steel
- 1.9 tons CO_2 /ton of steel produced
  - 7-8% of global emissions!

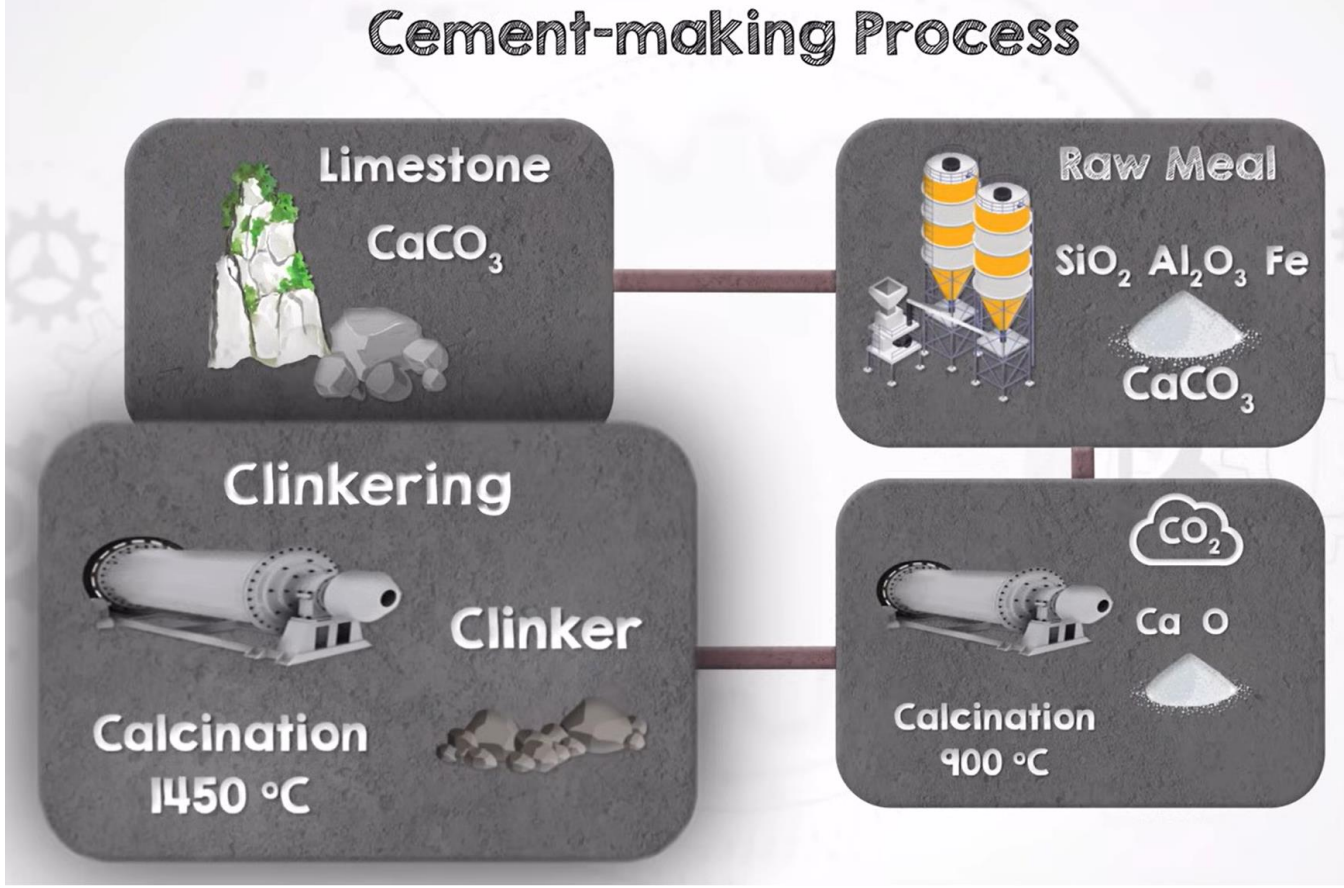
Green Steel

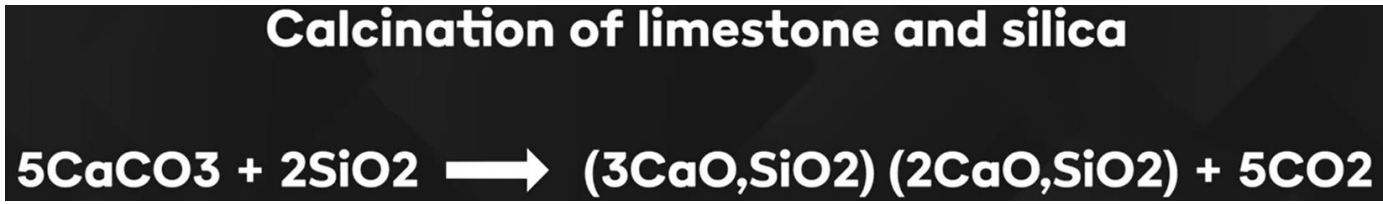
- Hydrogen reduction
  - Iron ore processed with Hydrogen instead of coke
  - Hydrogen or electricity provides heat
  - $Fe_xO_y + H_2 \rightarrow Fe + H_2O$
  - Re-use existing infrastructure (blast furnace)
- “Steel” is iron + carbon
  - We need a bit of carbon in there
- Isn’t electricity more efficient?
  - Thermo Electrolysis 1400-1500^oC - Boston Metal
  - Low temperature electrolysis 60-150^oC



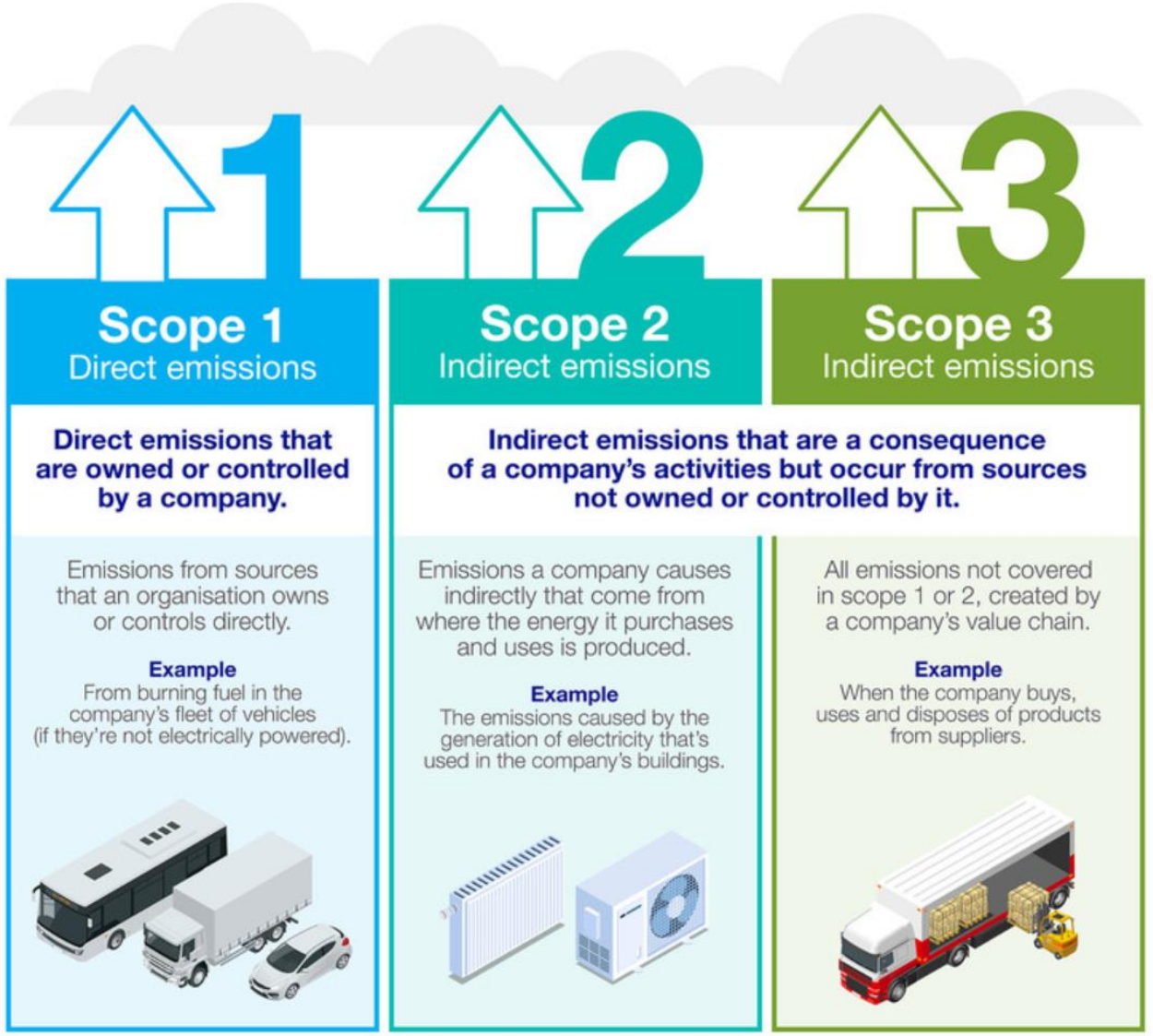
Cement 7-8% of world emissions

- About 10% of concrete is cement
- Emissions from
  - Heating using FF - electrify
  - Chemical reaction
  - ~1 ton CO_2/ton of concrete
- Companies working on this
  - Carbon Cure
  - Carbicrete
  - Sublime Systems
  - Brimstone

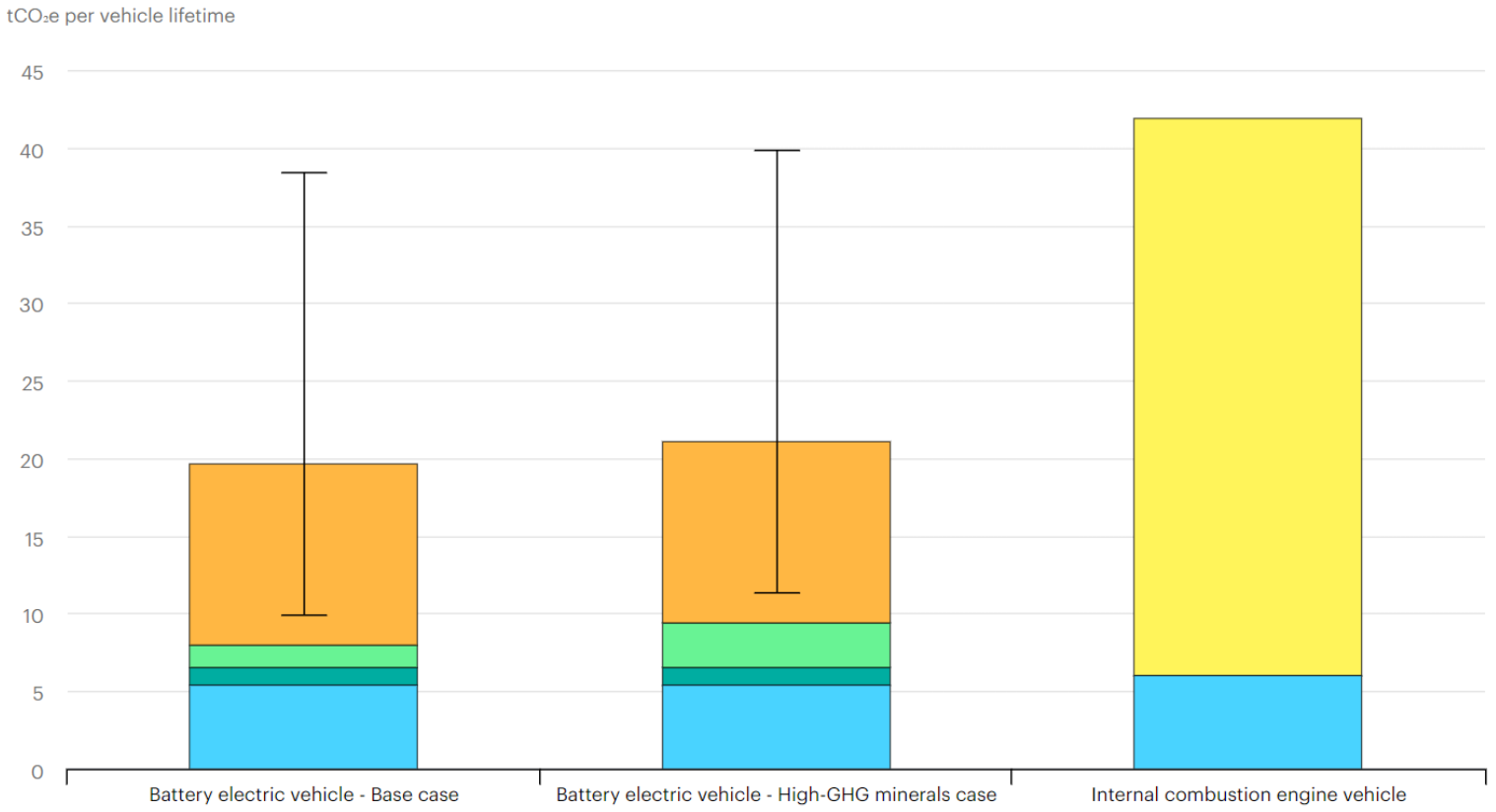




Emission during product lifecycle



Decarbonizing a Tesla



Sources

- IEA analysis based on IEA (2020c); Kelly et al. (2020); Argonne National Laboratory (2020).
- Notes
- The "High-GHG minerals" case assumes double the GHG emission intensity for battery minerals (70 kgCO2-eq/kWh compared to 35 kgCO2-eq/kWh in the base case; other assumptions are the same). The values are for a vehicle manufactured from today's manufacturing lines assuming dynamic global average grid carbon intensity in the SDS (including transmissions, distribution and charging losses, weighted for mileage decay over a 20-year lifetime). The ranges shown for BEV represent cases for charging with a static low-carbon (50 gCO2-eq/kWh) and high-carbon electricity mix (800 gCO2-eq/kWh). Vehicle assumptions: **200 000 km lifetime mileage**; ICE **fuel economy 6.8 Lge/100 km**; BEV **fuel economy 0.19 kWh/km**; BEV battery 40 kWh NMC622. NMC622 = nickel manganese cobalt in a 6:2:2 ratio. Lge = litre of gasoline-equivalent.
- IEA, Comparative life-cycle greenhouse gas emissions of a mid-size BEV and ICE vehicle, IEA, Paris https://www.iea.org/data-and-statistics/charts/comparative-life-cycle-greenhouse-gas-emissions-of-a-mid-size-bev-and-ice-vehicle, IEA. Licence: CC BY 4.0

Decarbonizing a Tesla
4 Sources of GHGs

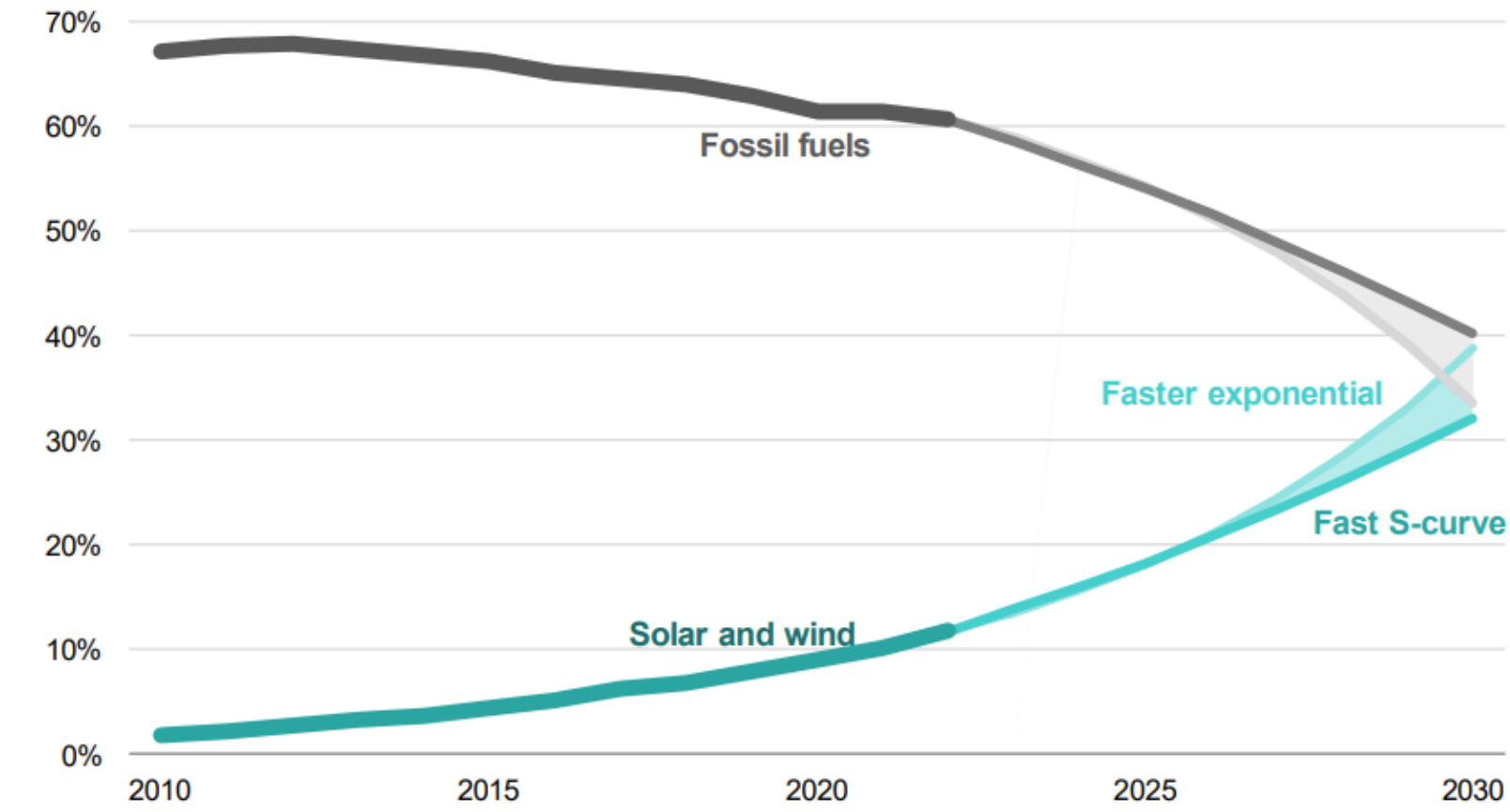
- Vehicle Manufacturing
  - H2/Electric processing (steel or aluminium)
  - Heat pumps for water and space
  - Green electricity
  - Electric trucks, mining
  - Paint – “cooking” and VOC (volatile organic compounds)
  - Green steel, green concrete
  - Glass
- Batteries assembly and “other”
  - Green electricity
  - Adhesives, fillers
- Battery minerals
  - Local sourcing (avoids shipping)
  - Electric mining and processing
- Electricity (to power the vehicle)
  - Green electricity - Art

Decarbonizing a Tesla North America

- Green energy at plant Nevada (batteries, power train)
- Green energy at Freemont and Austin (assembly)
- Electric trucks to transport batteries from Nevada
  - Same with other raw materials
- Paint – cook with electricity, capture VOCs
- Raw materials
  - Lithium
    - Sourced in Nevada
    - Processed in Corpus Christi
  - Electric mining and processing using green electricity
- Every part has a supply chain that can be decarbonized

Global Share of Electricity by source

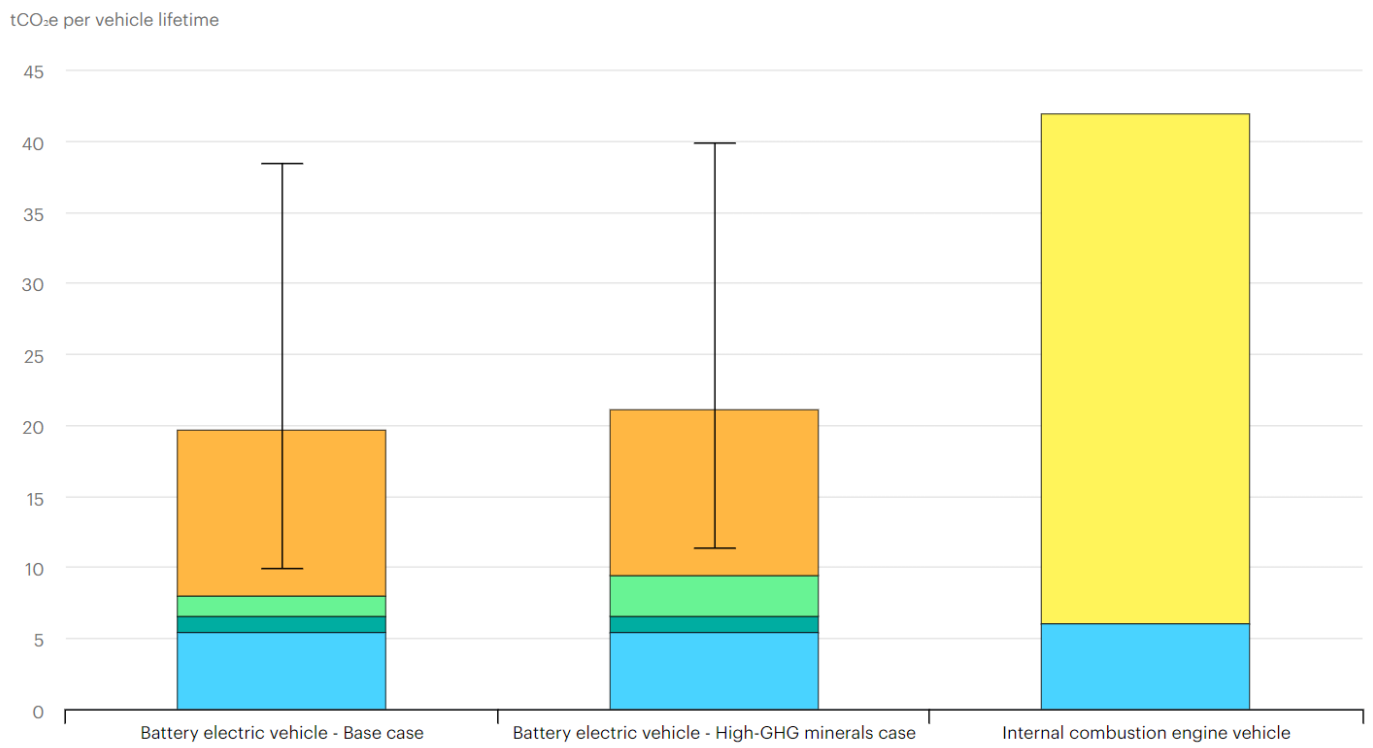
Figure 15: Global share of electricity generation by source



Source: Energy Institute (past),[76] RMI forward

Source: https://rmi.org/insight/x-change-electricity/

Decarbonizing a Tesla



IEA. Licence: CC BY 4.0

Vehicle manufacturing | Batteries-assembly and other | Batteries-minerals | Electricity | Fuel cycle (well-to-wheel)

Sources

- IEA analysis based on IEA (2020c); Kelly et al. (2020); Argonne National Laboratory (2020).
- Notes
- The "High-GHG minerals" case assumes double the GHG emission intensity for battery minerals (70 kgCO2-eq/kWh compared to 35 kgCO2-eq/kWh in the base case; other assumptions are the same). The values are for a vehicle manufactured from today's manufacturing lines assuming dynamic global average grid carbon intensity in the SDS (including transmissions, distribution and charging losses, weighted for mileage decay over a 20-year lifetime). The ranges shown for BEV represent cases for charging with a static low-carbon (50 gCO2-eq/kWh) and high-carbon electricity mix (800 gCO2-eq/kWh). Vehicle assumptions: **200 000 km lifetime mileage**; ICE fuel economy 6.8 Lge/100 km; BEV fuel economy 0.19 kWh/km; BEV battery 40 kWh NMC622. NMC622 = nickel manganese cobalt in a 6:2:2 ratio. Lge = litre of gasoline-equivalent.
- IEA, Comparative life-cycle greenhouse gas emissions of a mid-size BEV and ICE vehicle, IEA, Paris https://www.iea.org/data-and-statistics/charts/comparative-life-cycle-greenhouse-gas-emissions-of-a-mid-size-bev-and-ice-vehicle, IEA. Licence: CC BY 4.0
- ICE 42 tCOe
- BEV 0-3, tending towards 0

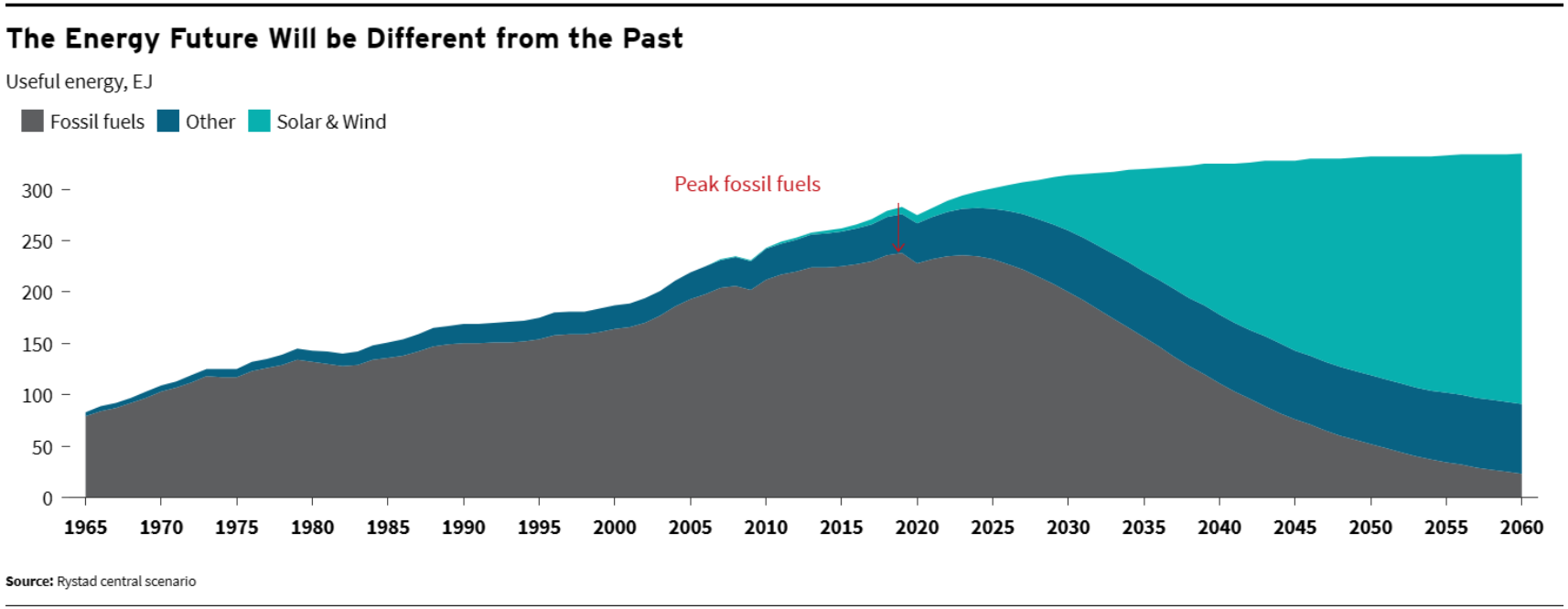
What Does that mean for FF?

Note: Useful (not total) energy

Oil demand will crash

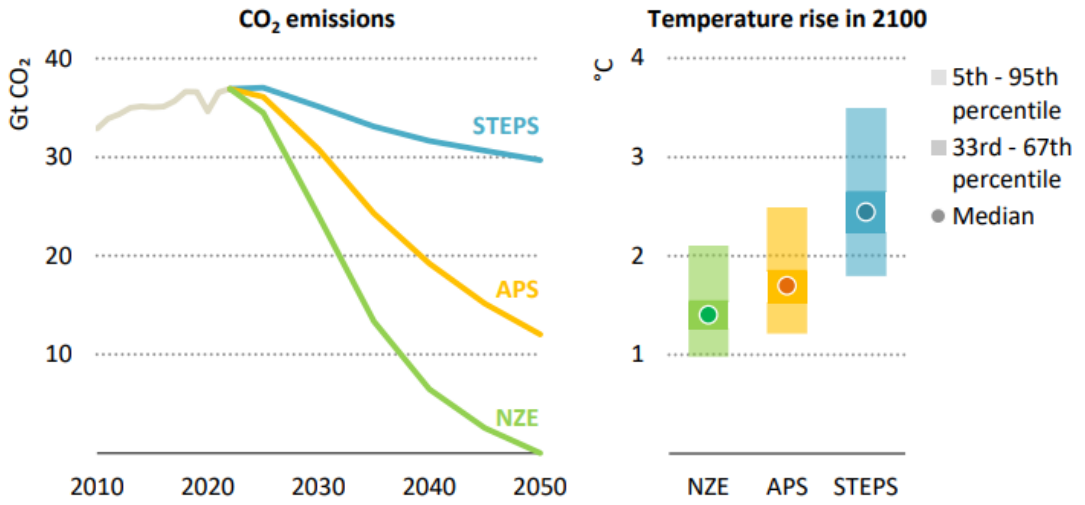
Tar sands emissions

- High price energy
- Crash even faster
- 3 mbpd
- ~20% of GHG in Cdn



Source: https://rmi.org/peaking-the-series/, Rystad

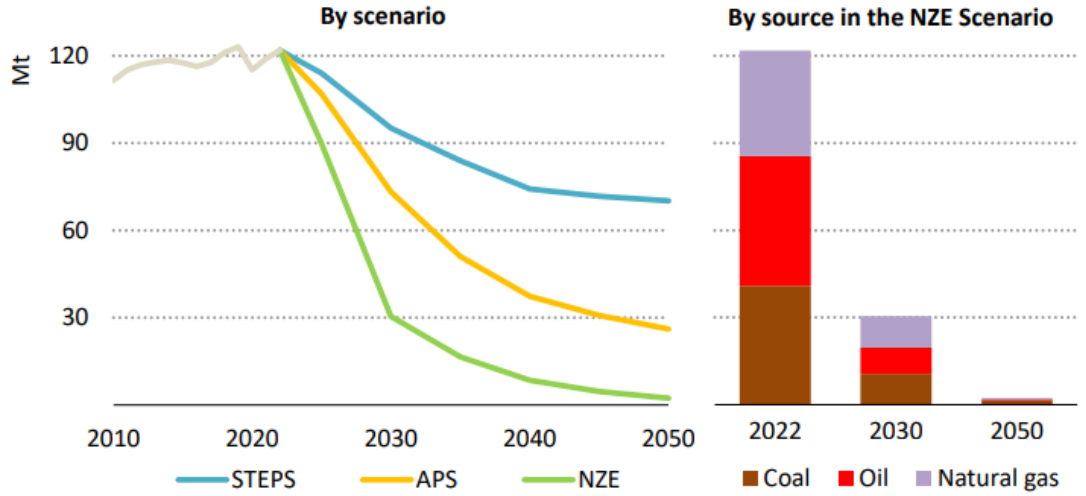
Figure 4.1 ▷ Global energy-related and industrial process CO_2 emissions by scenario and temperature rise above pre-industrial levels in 2100



IEA. CC BY 4.0.

Temperature rise in 2100 is 2.4 °C in the STEPS and 1.7 °C in the APS: it peaks at just under 1.6 °C around 2040 in the NZE Scenario and then declines to about 1.4 °C by 2100

Figure 4.4 ▷ Methane emissions from fossil fuel operations



IEA. CC BY 4.0.

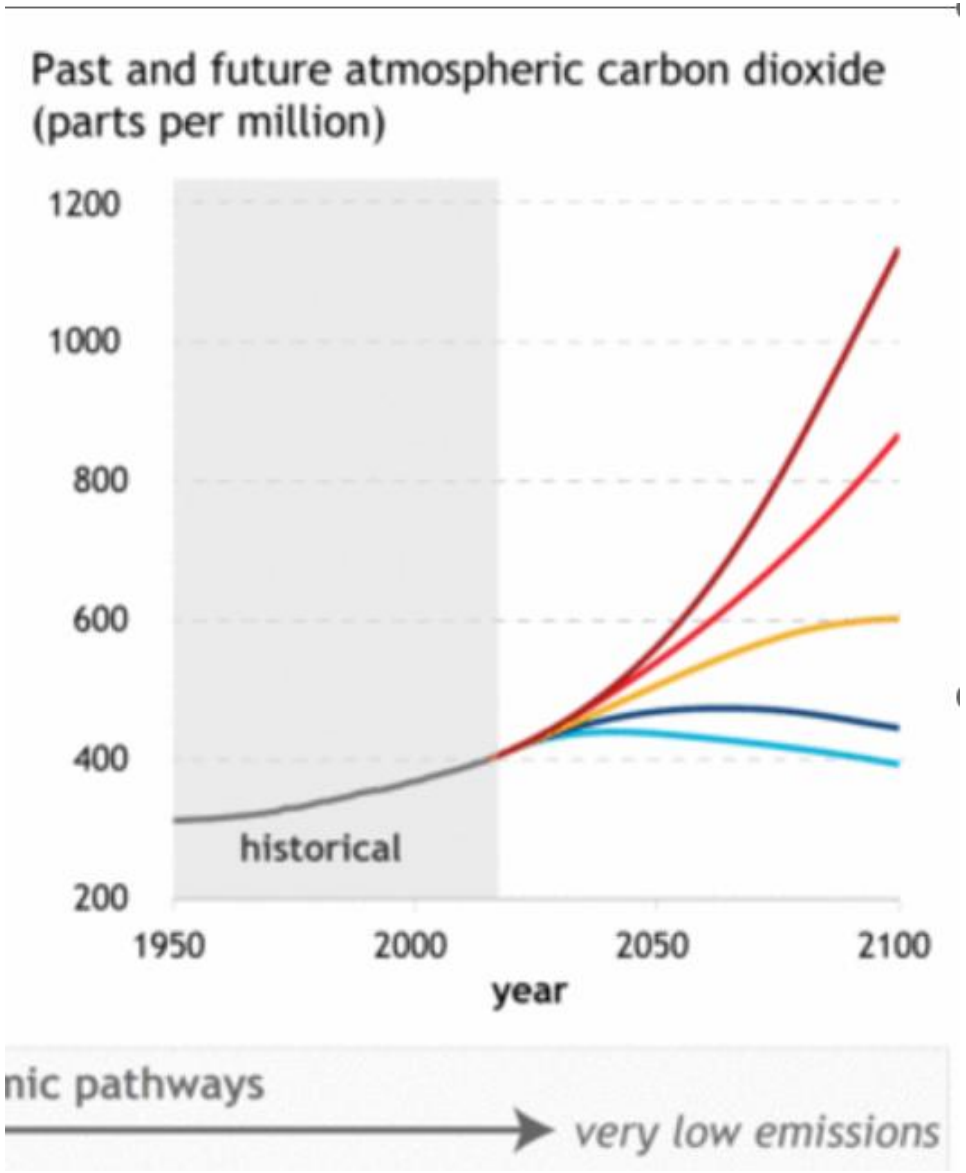
If countries make good on their pledges, methane emissions will fall by around 50 Mt to 2030; they fall an additional 45 Mt in the NZE Scenario

GHG Emissions

- CO2 biggest contributor
- CH4 30%, degrades into CO2

GHG Concentrations

- Will continue to rise for another decade or two +/-
- Lags emissions
- Ultimate numbers depend on
  - Emissions
  - Natural absorption rates
    - Weathering
    - Ocean absorption – 25-30%
- Don’t need net-zero for drop?

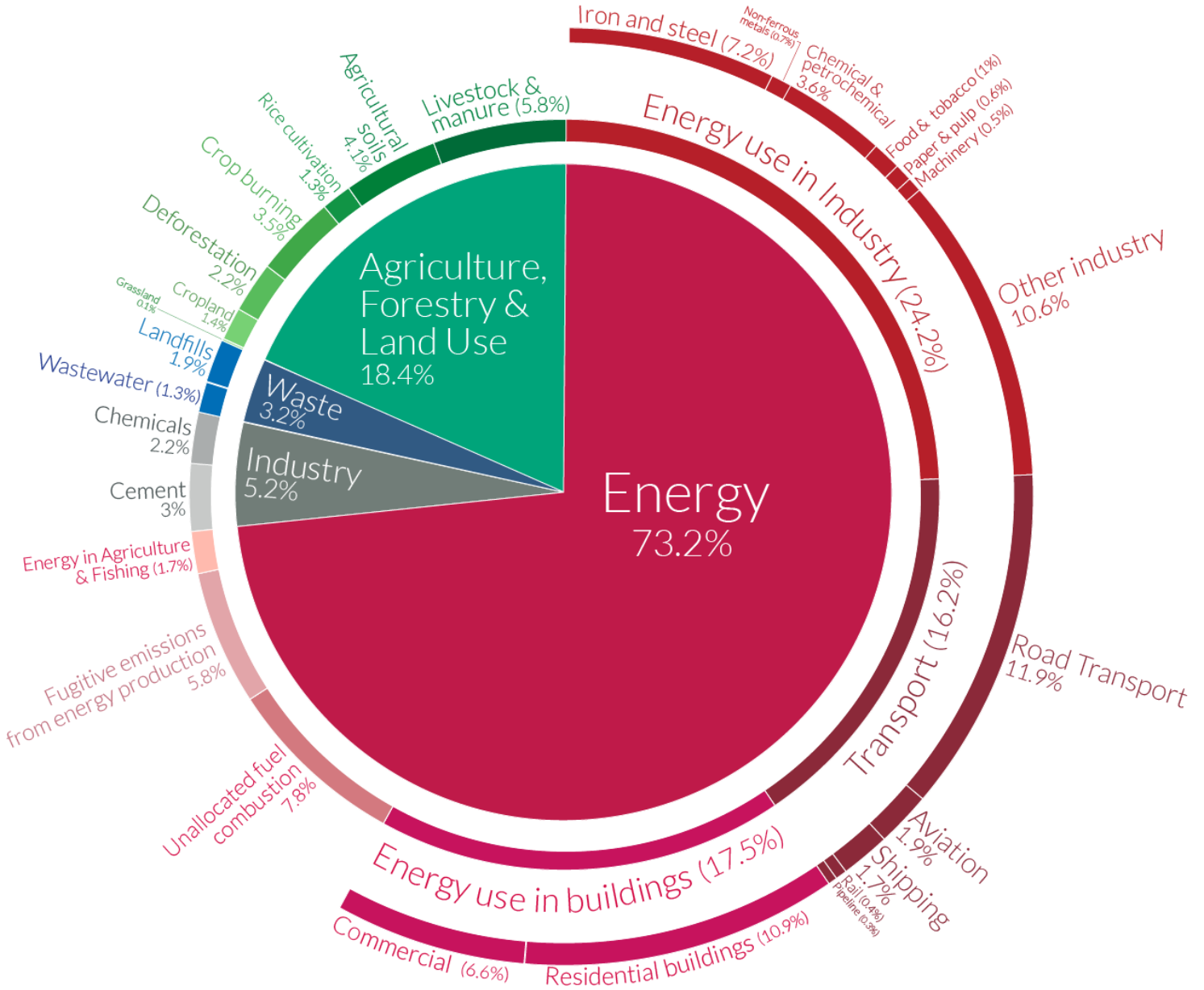


Need to eliminate all GHG sources

Global greenhouse gas emissions by sector

This is shown for the year 2016 – global greenhouse gas emissions were 49.4 billion tonnes CO_2eq.

Our World in Data

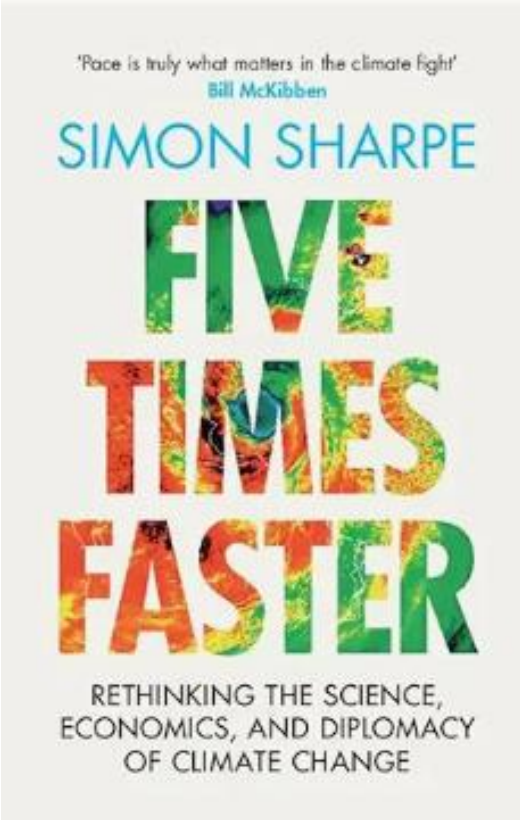


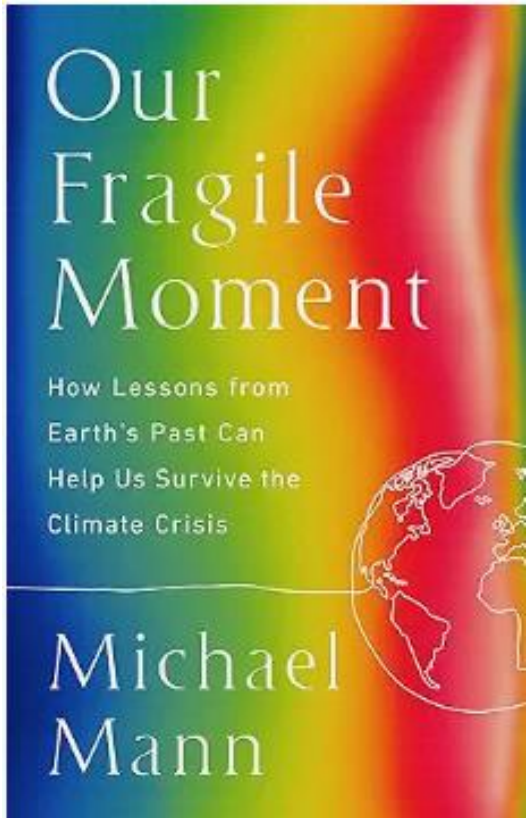
CHINA ENERGY | 13 November 2023 0:01

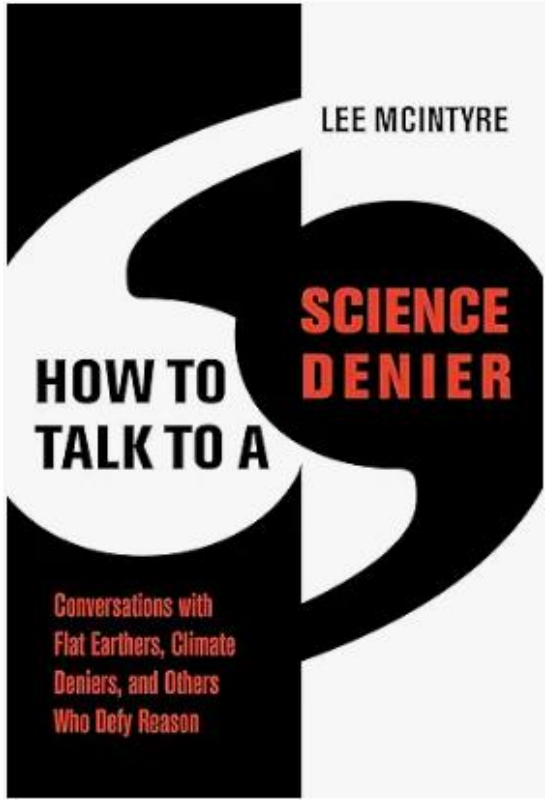
Analysis: China's emissions set to fall in 2024 after record growth in clean energy

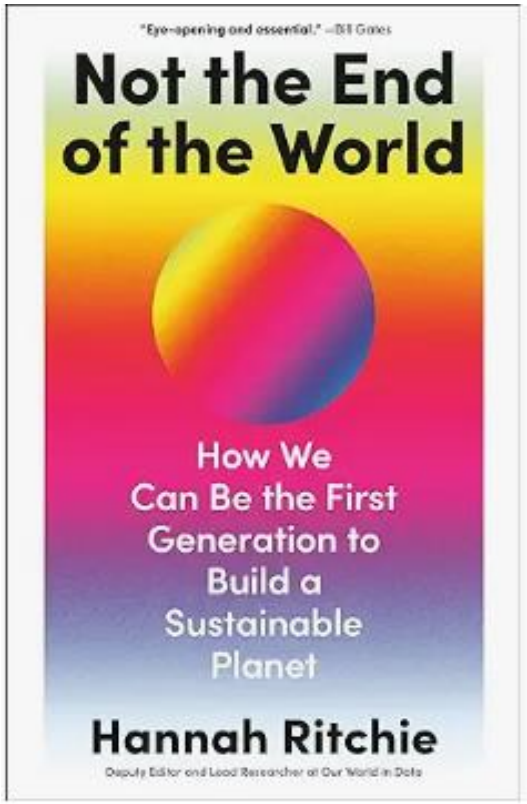
Workers speed up installation of photovoltaic panels at the construction site of the solar power generation project in Zhangye, China. Contributor: Cynthia Lee / Alamy Stock Photo

Books









"Accepting defeat on climate change is an indefensibly selfish position to take" Hannah Ritchie
Hans Rosling (200 years in 4 minutes) on YouTube: https://www.youtube.com/watch?v=jbkSRLYSojo