

10 Ammonia



Green revolution

Feeds nearly half the world

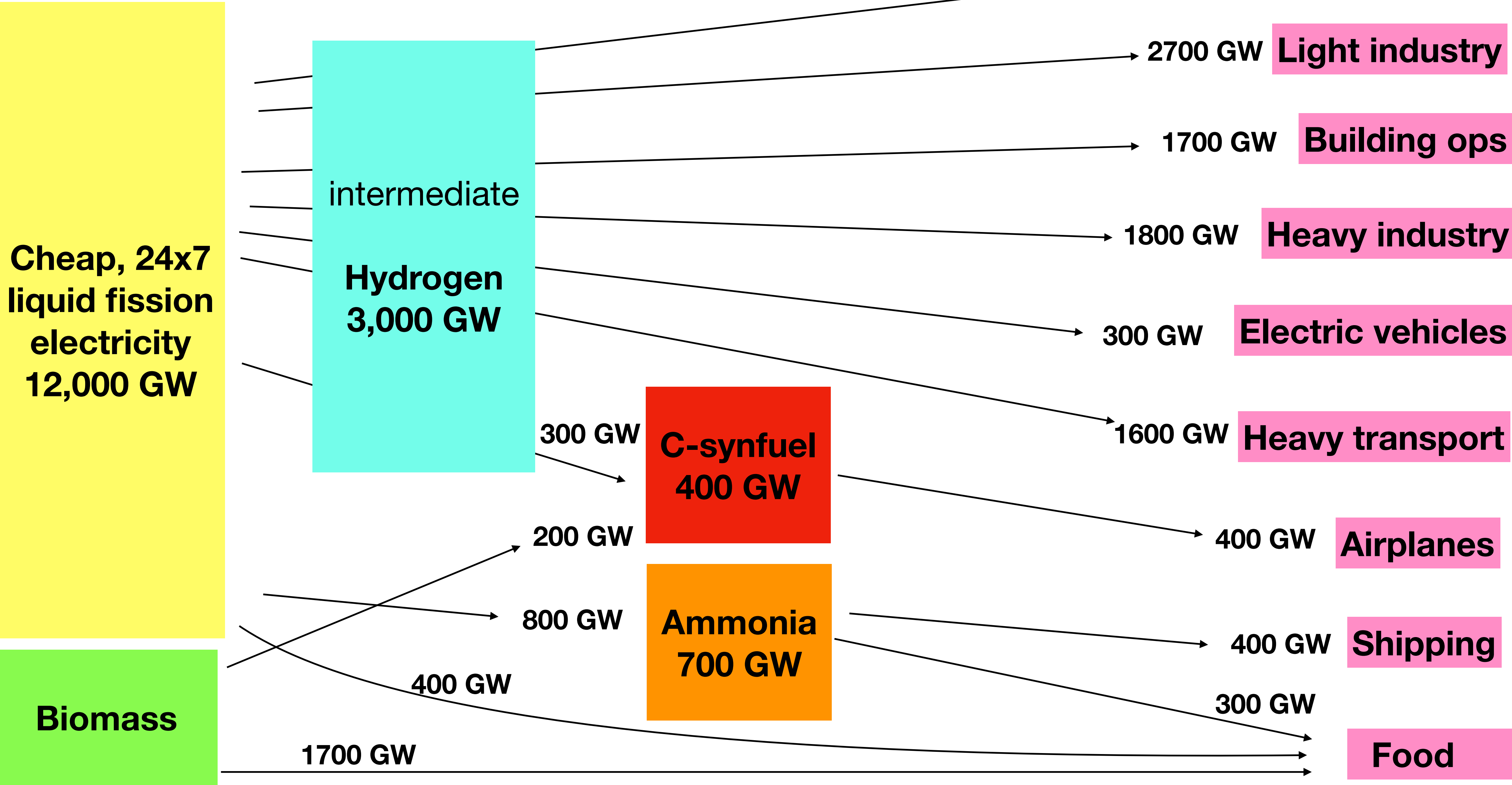
Shipping use 7% of oil

Ammonia combustion engines

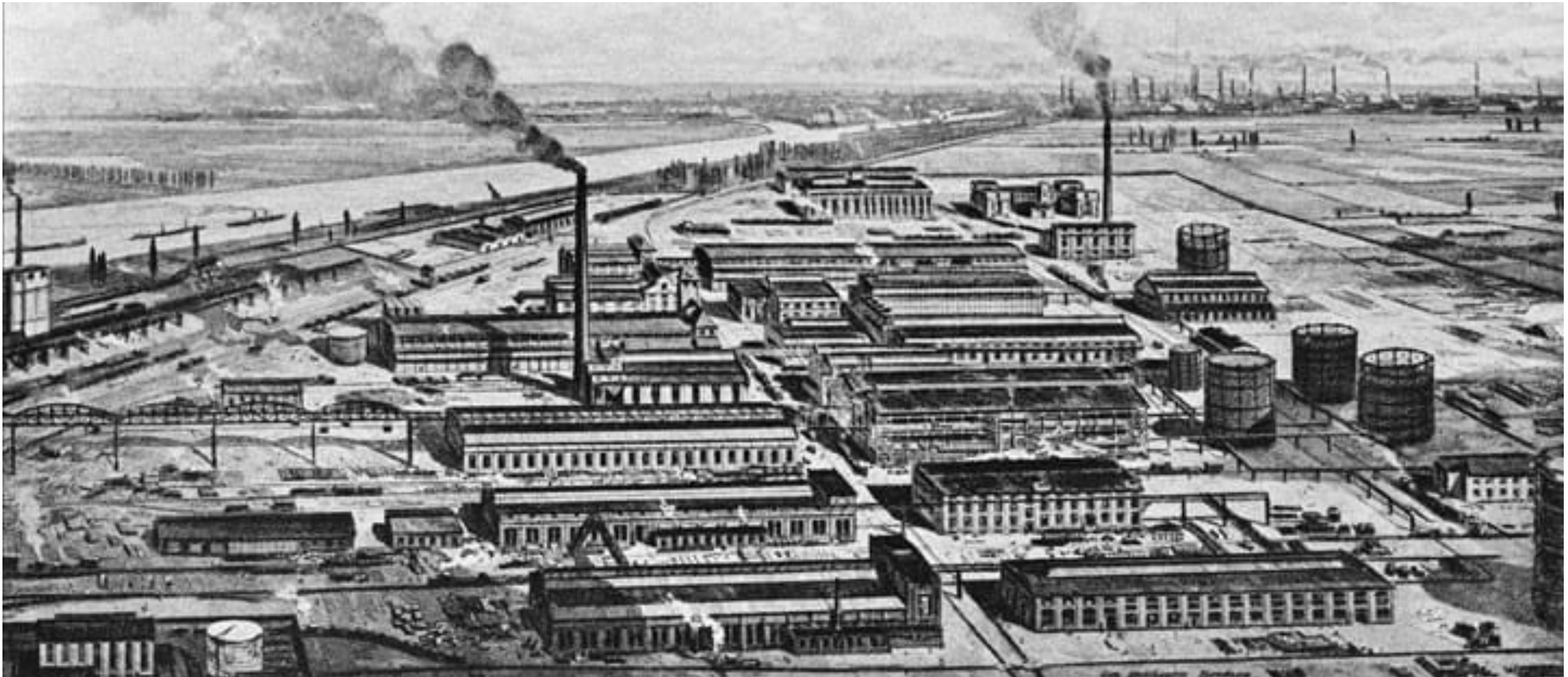
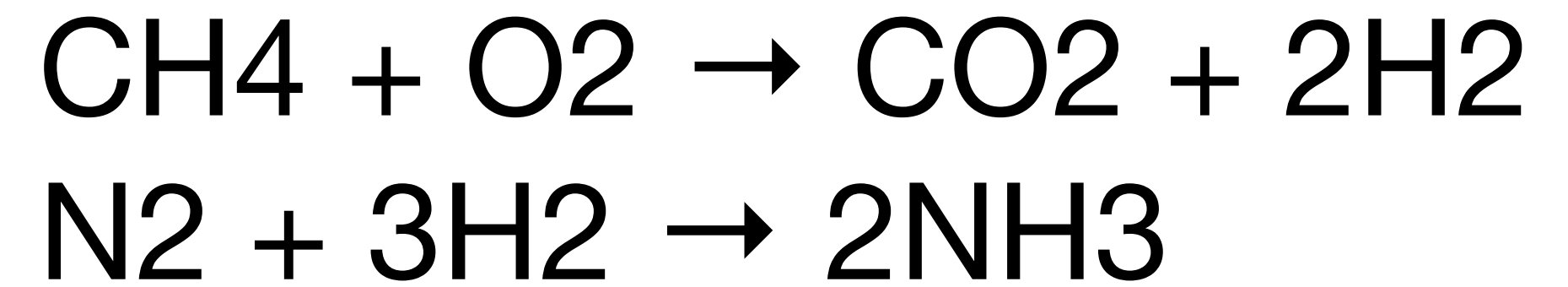
Solid oxide synthesis cells

Fission is in Fashion

Ammonia for fertilizer and for fuel



Century-old Haber-Bosch process makes NH₃ (ammonia) from CH₄ (natural gas).

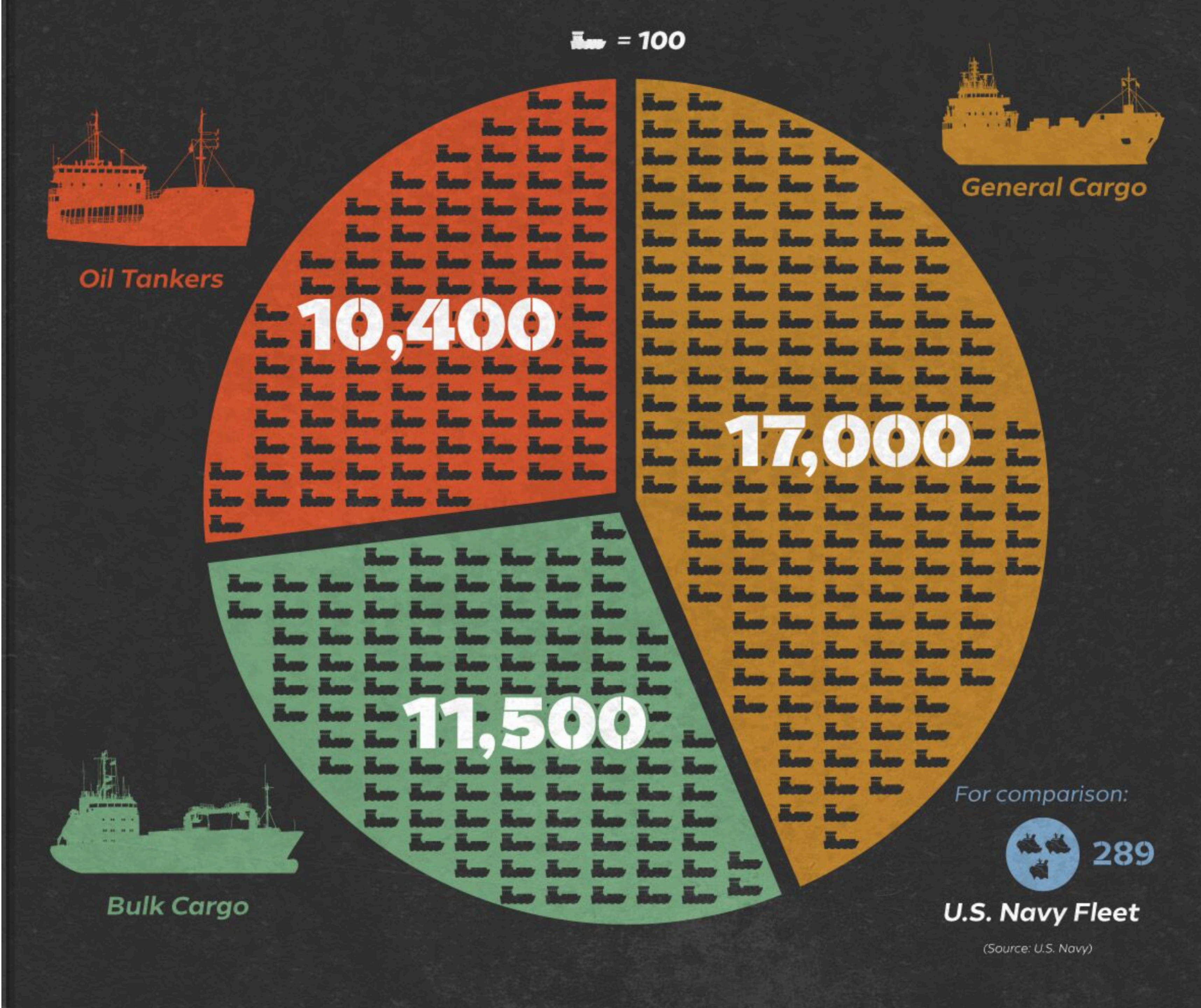


Ammonia fertilizer: basis of the Green Revolution, feeds nearly half the world.



- 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.

Global trade depends on this massive fleet of commercial ships.



**Shipping uses 7% of oil production, emitting SOx.
2020 IMO changed SOx cap from 3.5% to 0.5%.**



More nuclear reactors in ships than power plants in 1990 !

US built just one nuclear powered merchant ship.



SCIENCE PHOTO LIBRARY

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

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



Mirai, Japan



Otto Hahn, Germany



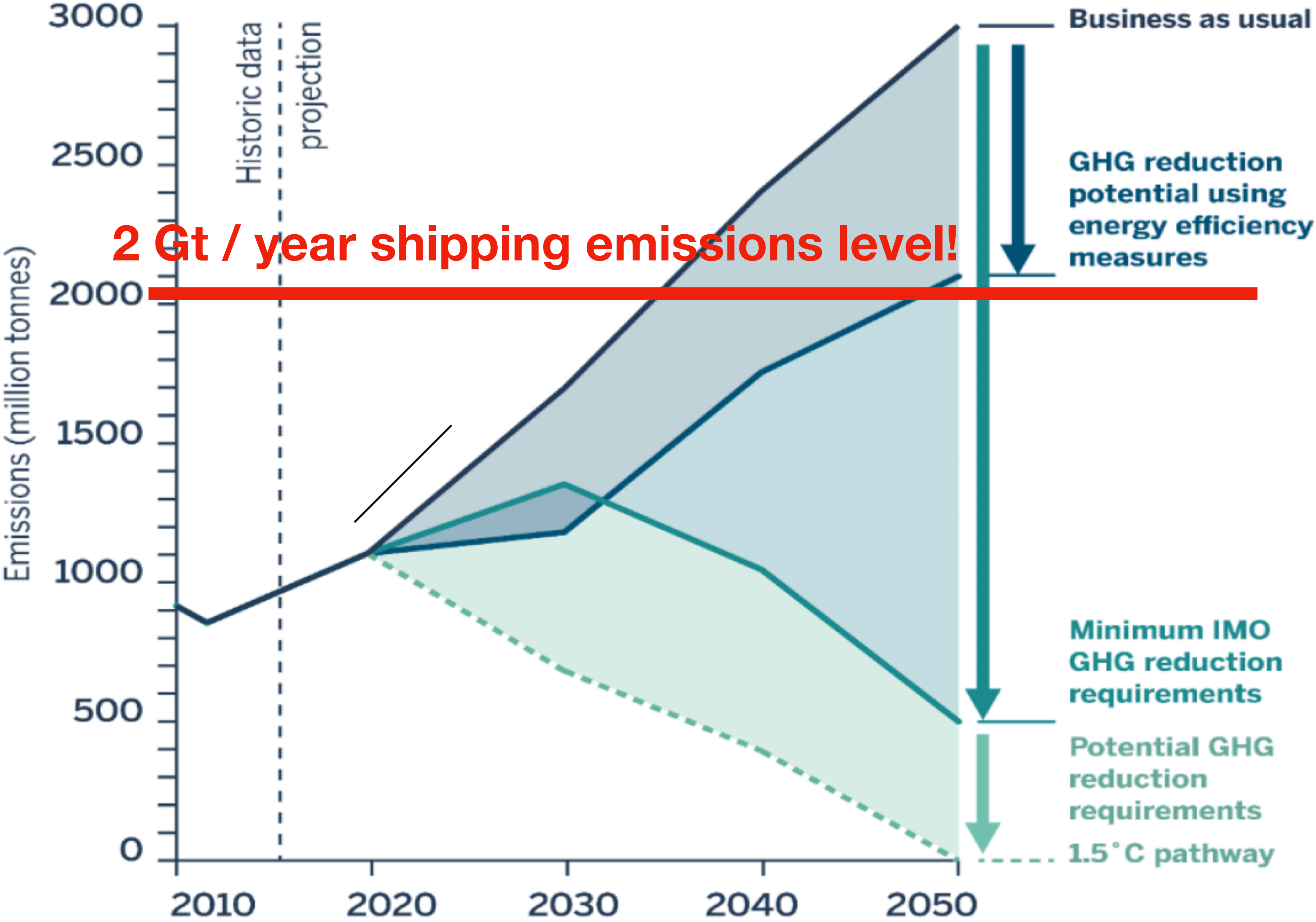
Dozen icebreakers,
Russia



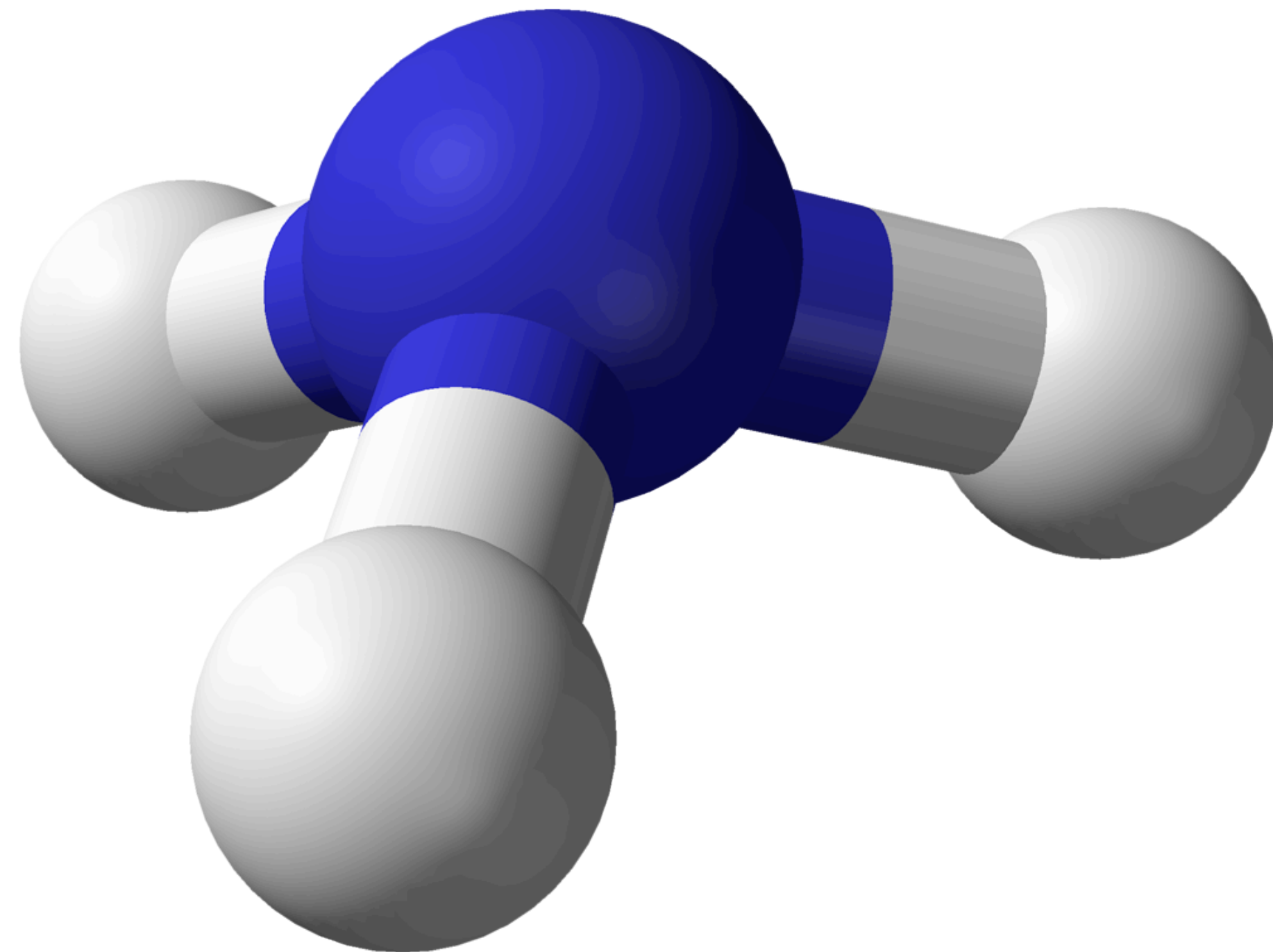
11 carriers, 100+
submarines, US

Fission powered shipping is a good emissions solution, ignored.

Clean Air Task Force recommends NH3 ammonia fuel for shipping.



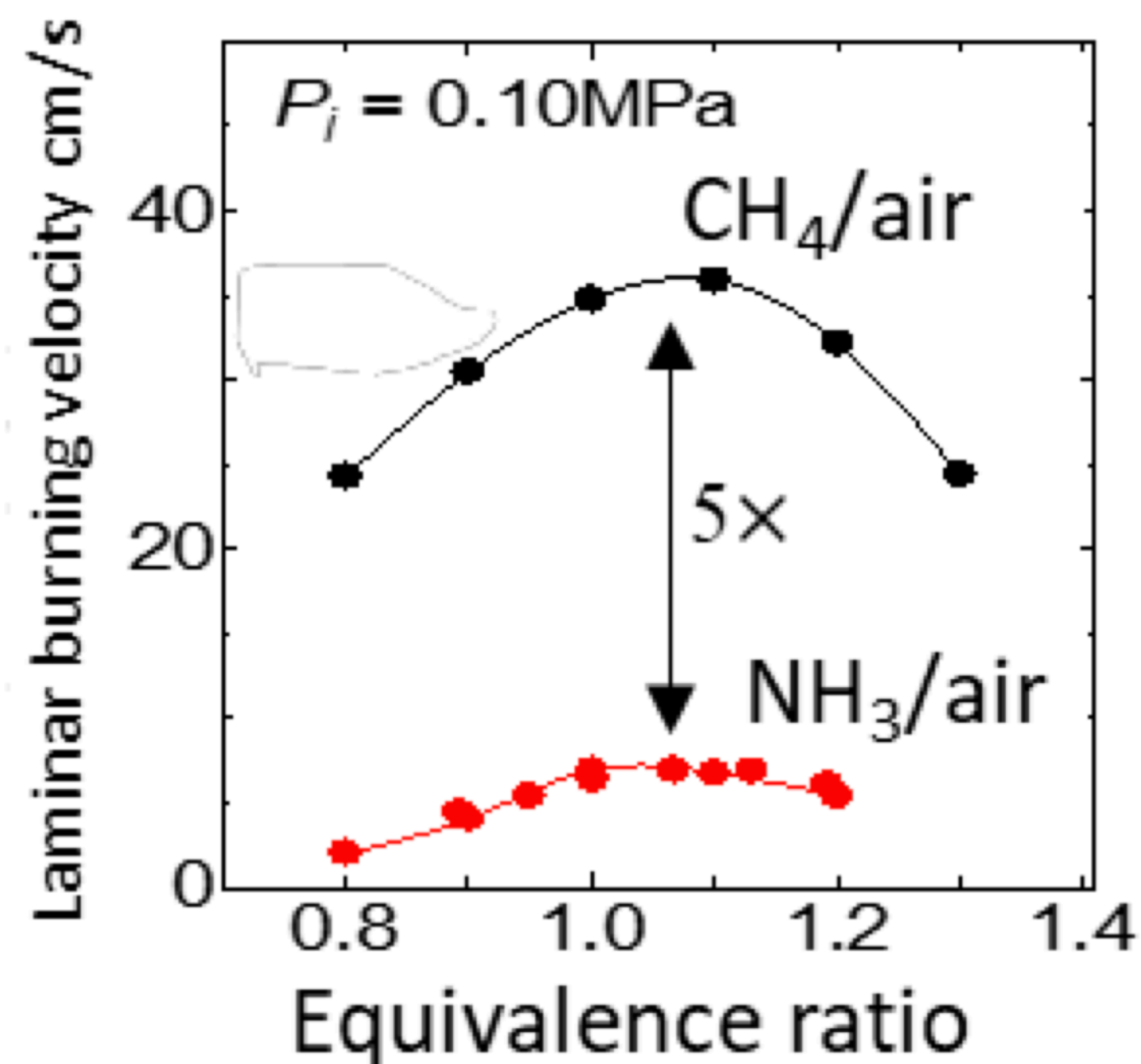
Ammonia, NH₃



- Nitrogen is 78% of the atmosphere.
- Ammonia stored in pressurized tanks, ~15 bar, like propane.
- 11.5 MJ/liter energy density, 1/3 that of diesel.
- High octane, low flame temperature can enable high-compression ICE with little NO_x emissions.
- Household ammonia is NH₃ in H₂O.

NYK ammonia tanker will use ammonia in its fuel mix.

NH₃ speed of combustion is low, compared to C_xH_y fuels.



H2 might be a combustion accelerator for a ship's ammonia engine.

Cracking (heating) NH_3 yields H_2 accelerant.

25:1 compression ratio allows NH_3 compression ignition.

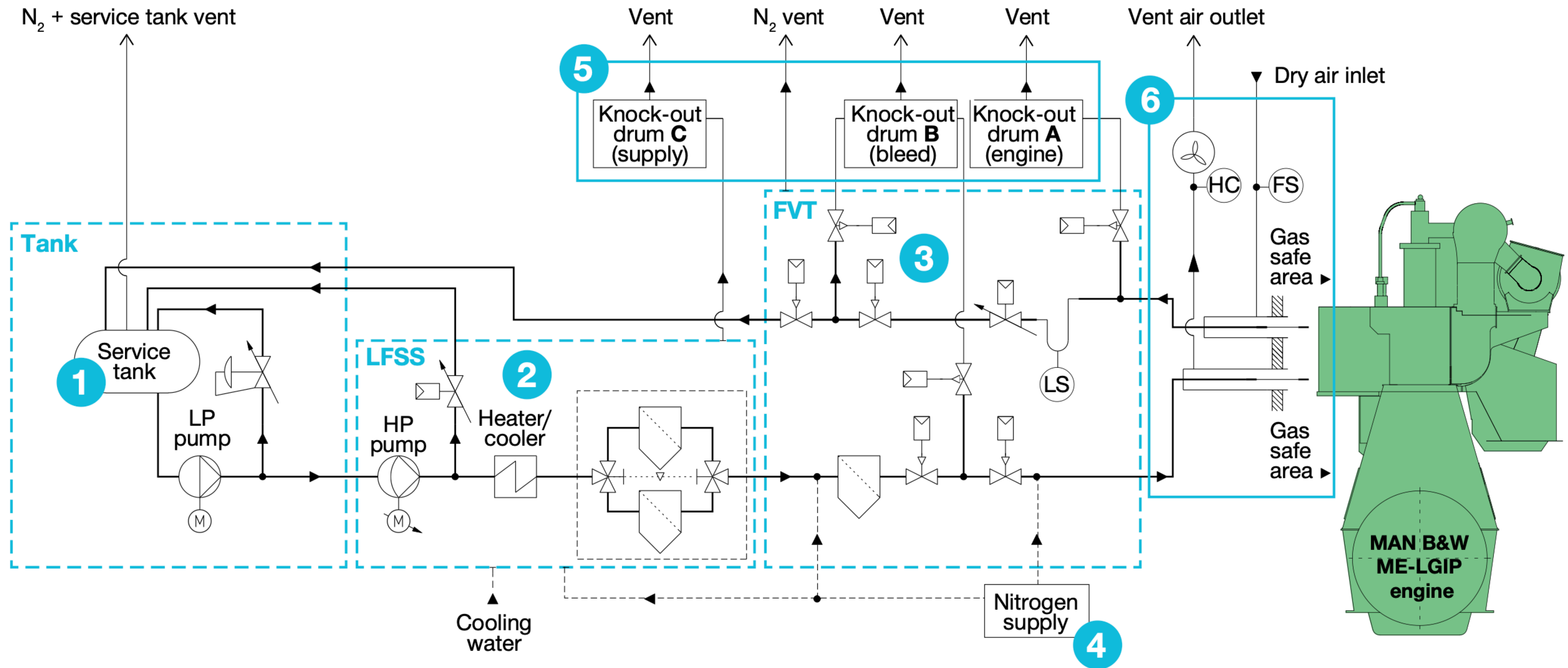
Emerging technology

Big (diesel) engine example

- 80 MW power (100,000 hp)
- < 120 rpm



MAN ES expects to deliver its first marine ammonia engine in 2024, retrofits in 2026.



Ammonia fueled Belgium motor-buses.



The X-15 used ammonia fuel to set speed and altitude records in the 1960s.



Trucks can run on ammonia fuel.



Internal combustion engines can run on ammonia fuel.



Marangoni Toyota G86 Eco Explorer
180 km on 30 litres NH₃ @ \$0.20 ~19 miles/\$

Experience with producing, transporting, using ammonia.

- 2nd most common chemical in use
- 130 Mt/year
- 3000 miles of US pipelines
- No corrosion or embrittlement problems
- 4.5 Mt of large-tank ammonia storage



Ammonia can be handled safely.

Vehicle pressure tanks

ammonia 14 bar

propane 12 bar

natural gas 200 bar

Spill danger

alerting odor

lighter than air

difficult to ignite; ignition temperature 650° C

fire extinguished with plain water

Toxicity

safety experience: 2nd most common industrial chemical

inhalation of 500 ppm is dangerous

humans and mammals process NH₃ in urea cycle (but not fish)



About as dangerous as gasoline

Limit use to trained truck drivers and ship crews?

Solid state ammonia synthesis can make NH₃ from H₂O, N₂, and electricity.

Like a solid oxide fuel cell, in reverse

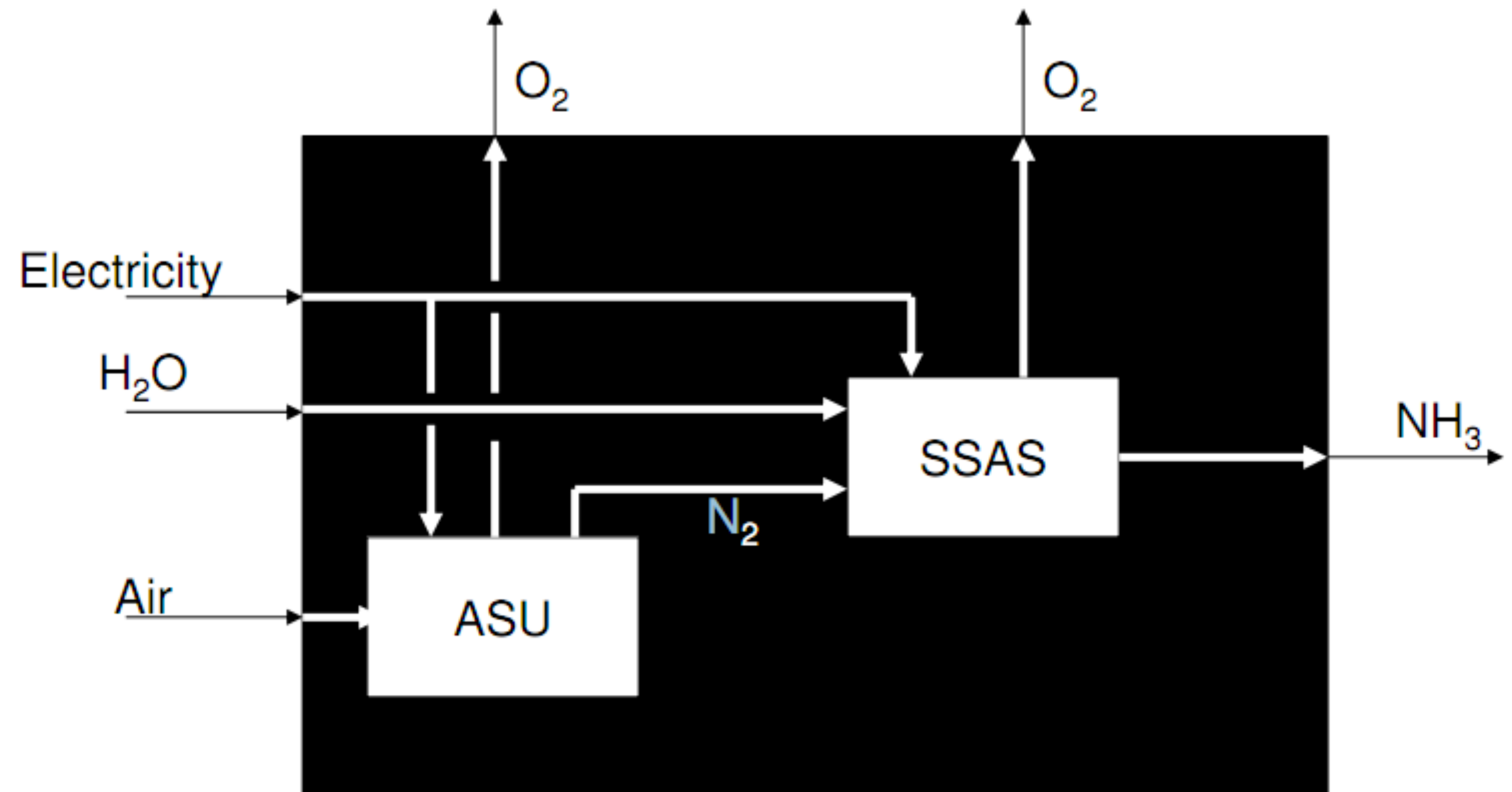
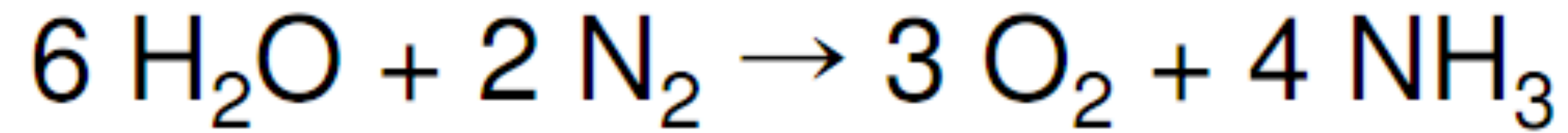
Proton conducting ceramic membrane

Advantages

- Never any H₂ gas
- Low pressure
- Modular scale-up

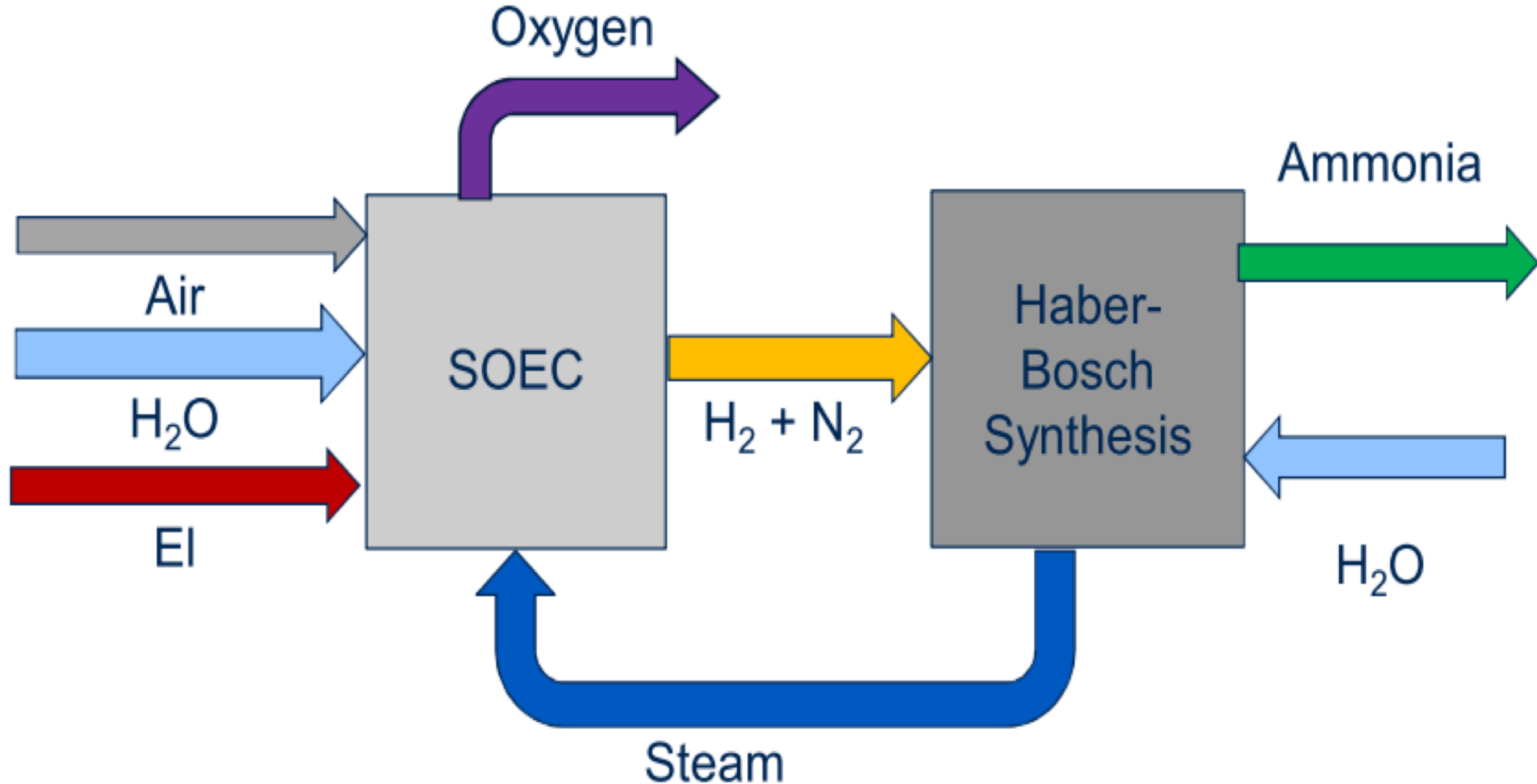
550° steam from liquid fission reheated to 650°

Safer, cheaper than Haber-Bosch



~6800 kWh / ton

Haldor Topsoe solid oxide NH₃ synthesis



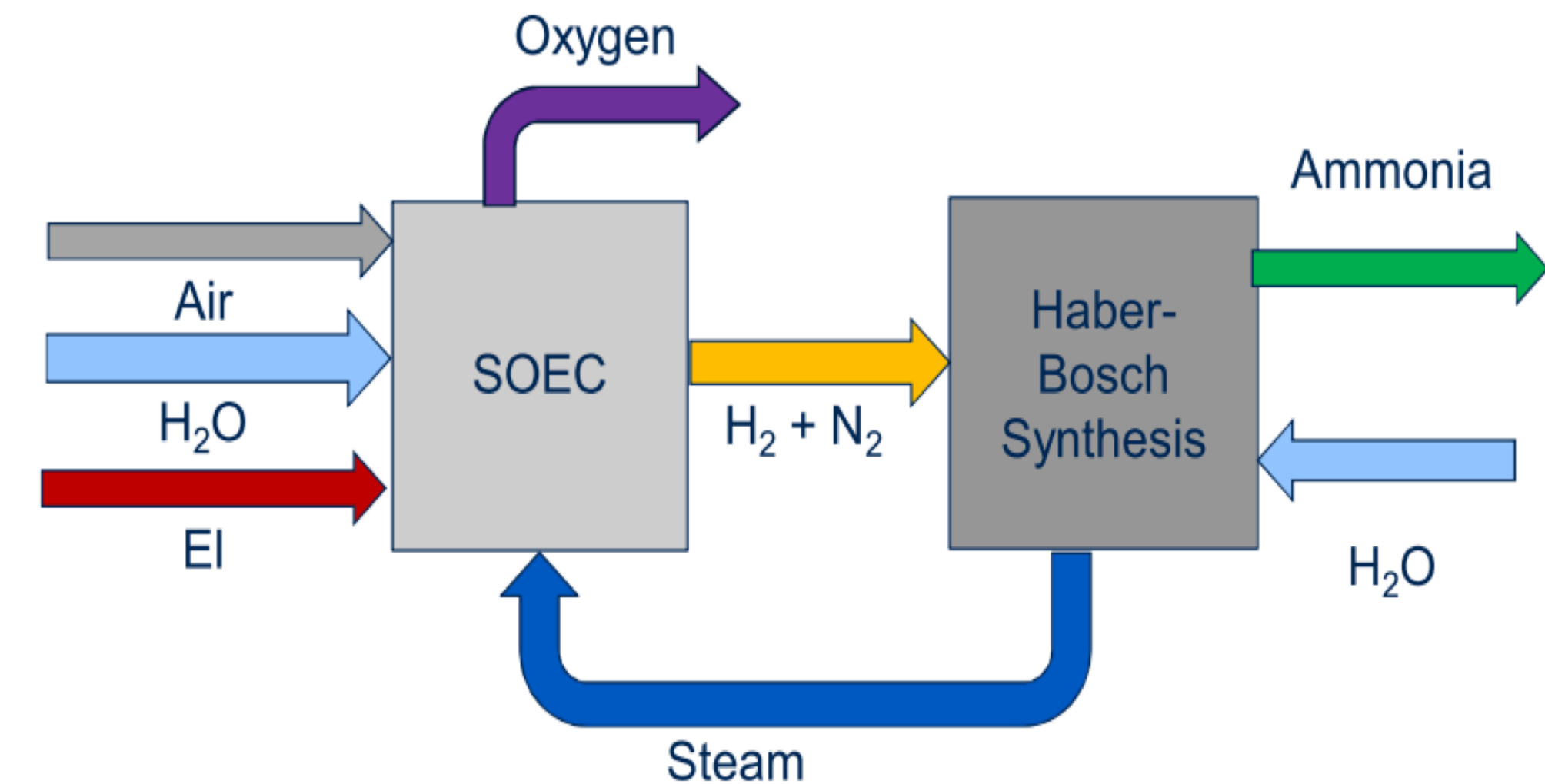
NH₃ solid oxide fuel cell synthesis benefits:

New Solid Oxide Electrolysis based synthesis gas process

1. Synergy with HB using steam from synthesis reaction
2. Eliminates air separation unit due SOC built-in oxygen separation
3. Utilize heat of air combustion to split steam
4. High efficiency

Ammonia is the perfect fuel for Solid Oxide Fuel Cells

1. No fuel processing
2. No carbon problems => no need for steam addition
3. Cooling by ammonia cracking



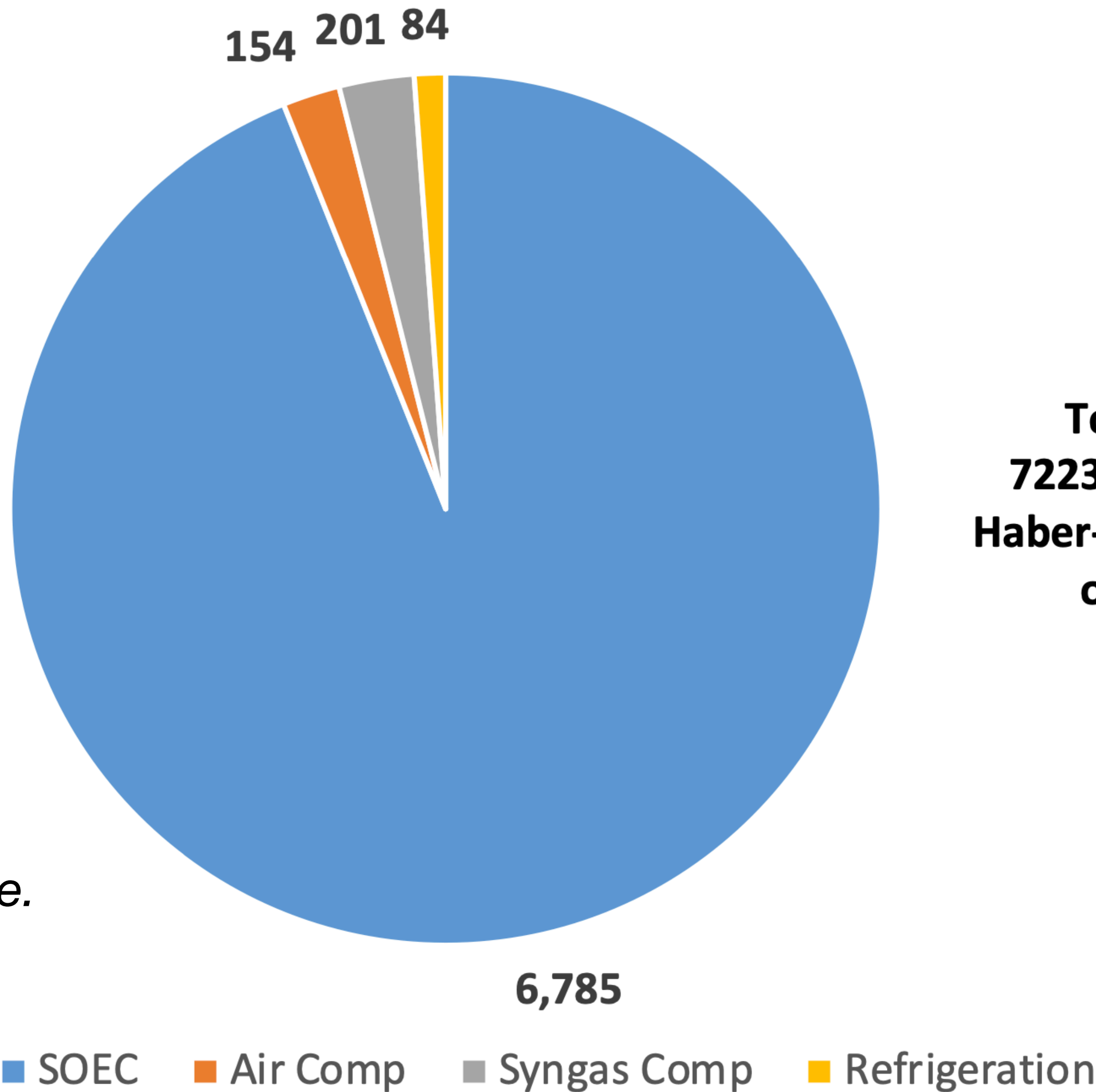
The Future is Here for Solid Oxide Electrolysis Cells

(Oct 22, 2020, Ammonia Energy Association, Science)

1. “the initial electrochemical performance of state-of-the-art SOEC single cells has more than doubled, while long-term durability has been improved by a factor of ~ 100 . Similar improvements in performance and durability have been achieved on the stack level.”
2. “unrivalled conversion efficiencies — a result of favorable thermodynamics and kinetics at higher operating temperatures.”
3. ability to be “operated in reverse, [so that] an SOEC functions as a solid oxide fuel cell (SOFC),”
4. solid oxide cells providing **1000 GW** of power in fuel cell mode would require just 1 month’s worth of global ZrO_2 production and 21 months’ worth of Y_2O_3 , compared to...
5. 1000 GW-hours from Li-ion batteries requires ~ 160 years of Li production (2012), and 1000 GW-days from a PEM fuel cell system requires 53 months’ global Pt production.

Haldor Topsoe NH3 synthesis process: 7.2 kWh/kg

At \$0.03/kWh
electricity
ammonia costs
22 cents/kg



Total energy:
7223 kWh/MT NH₃
Haber-Bosch Synthesis
only 6.0 % !

Confirming Darryl Siemer's decade-old estimate.

Green Energy Oman proposes wind and sun to power hydrogen-ammonia production.



25 GW(e)

wind at night, sun in day

70% capacity factor

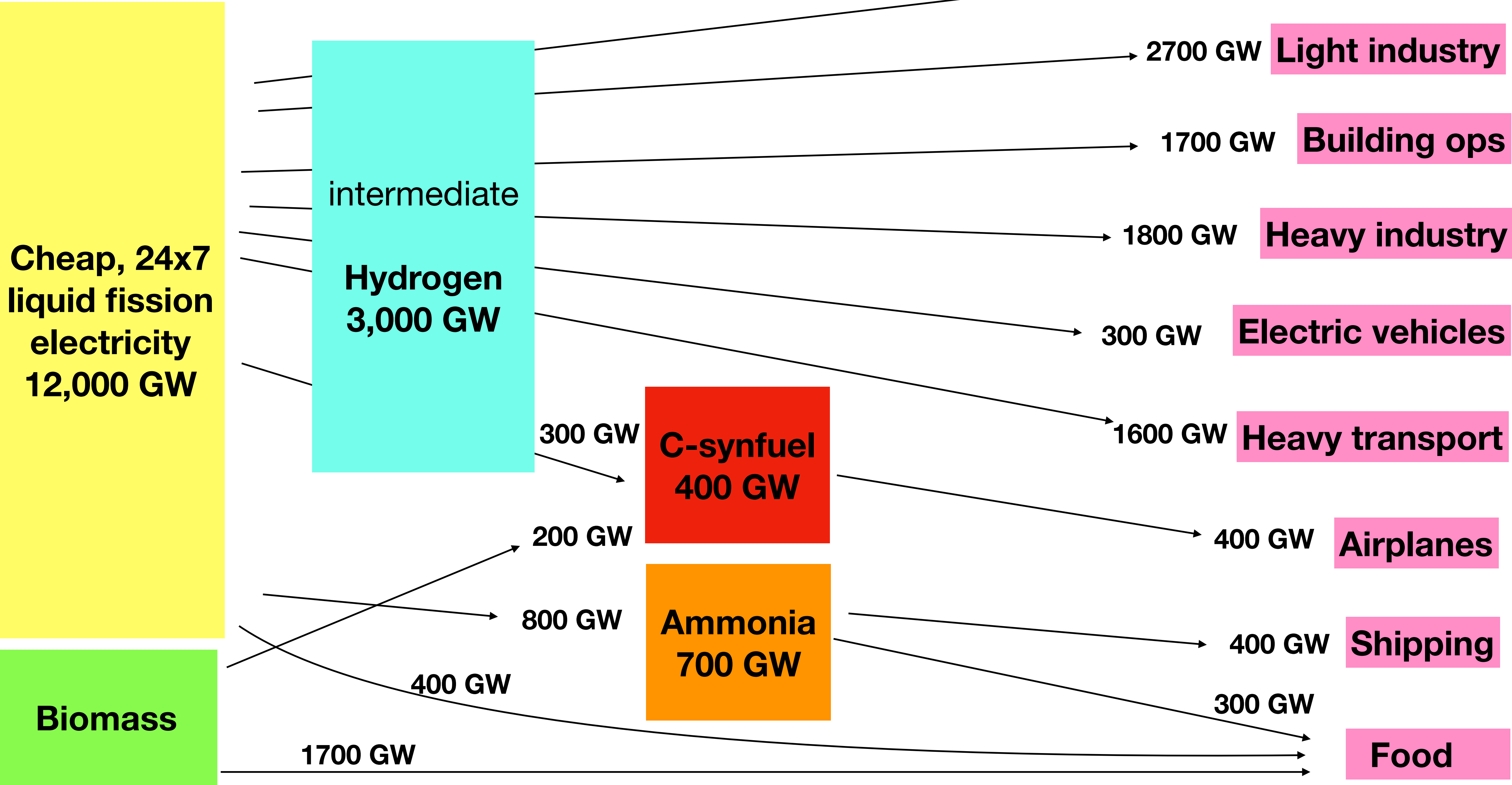
\$30 billion

6,500 km²

10 MT/year ammonia

= 5.7 GW(t)

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