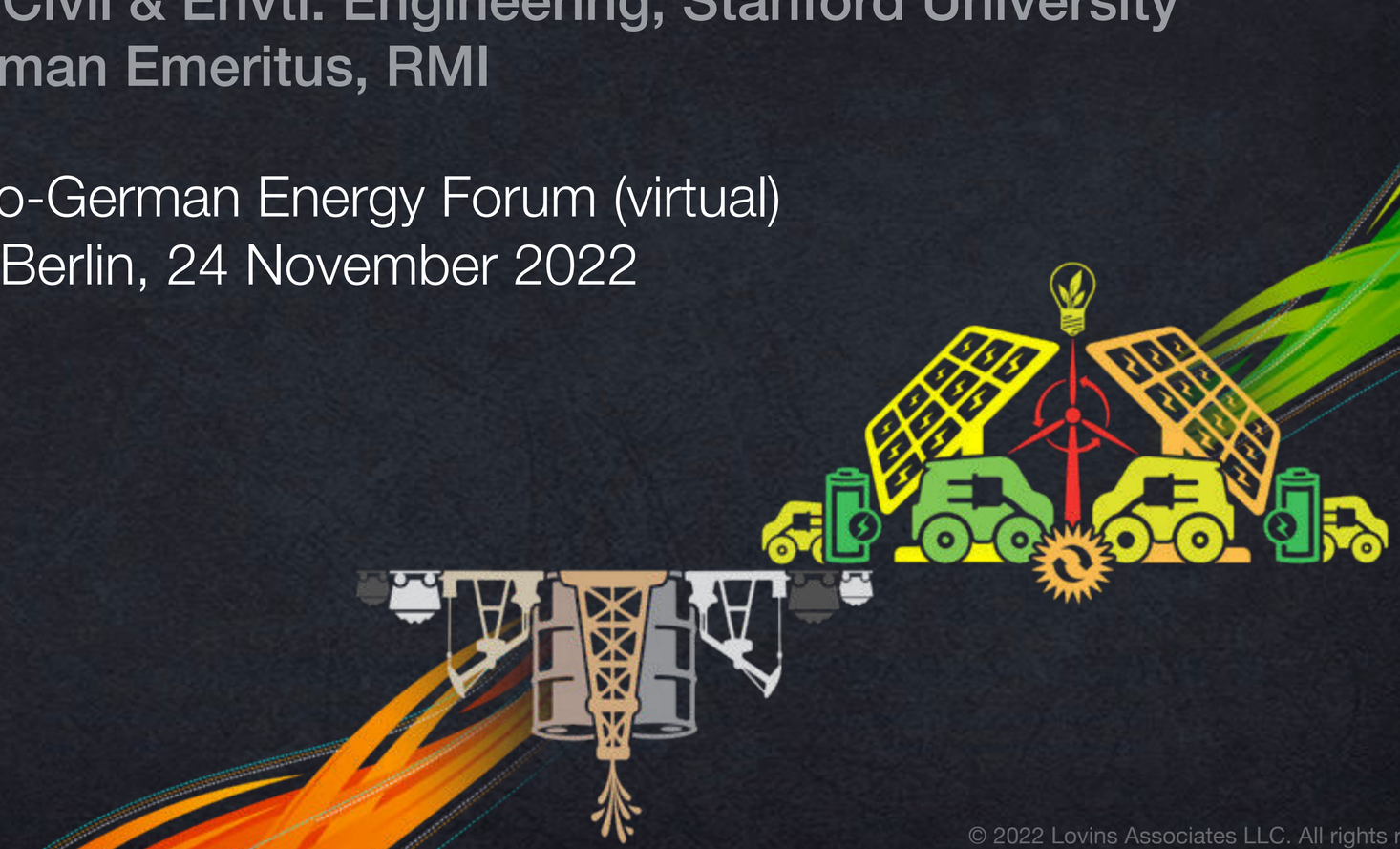
ROCKY MOUNTAIN
INSTITUTE

Overlooked climate change mitigations

Amory B. Lovins
Adjunct Professor of Civil & Envtl. Engineering, Stanford University
Cofounder and Chairman Emeritus, RMI

Franco-German Energy Forum (virtual)
Berlin, 24 November 2022

RMI
ENERGY. TRANSFORMED.

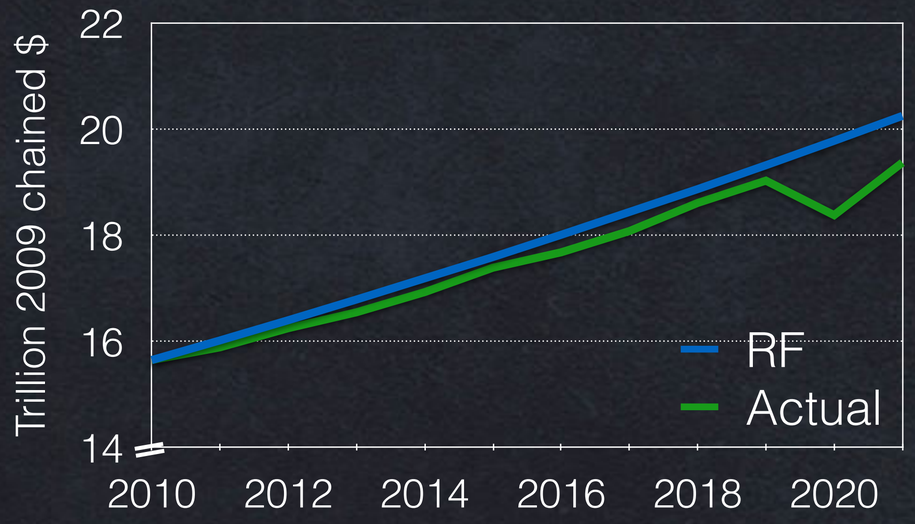


© 2022 Lovins Associates LLC. All rights reserved.

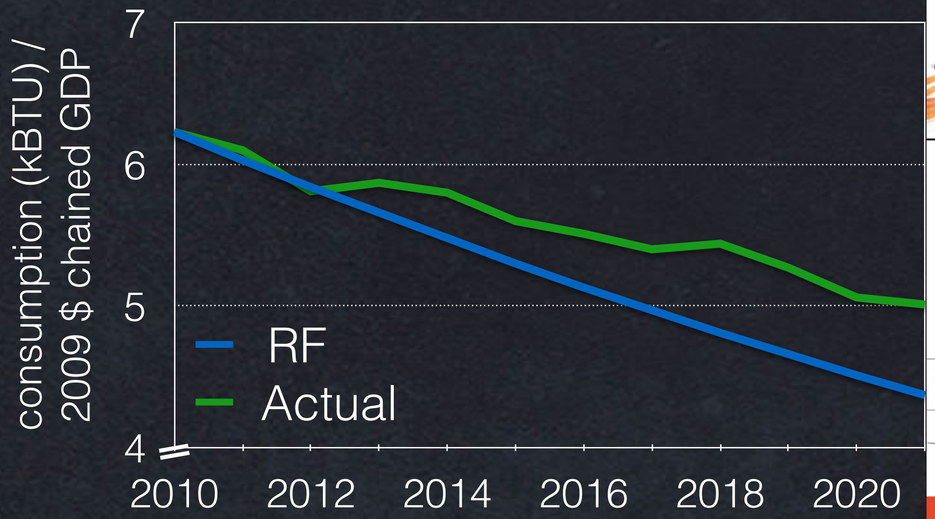
2010–2021 US progress toward *Reinventing Fire's* 2050 goals

Actuals (USEIA) are not weather-adjusted. *Reinventing Fire* progression based on constant exponential growth rate.

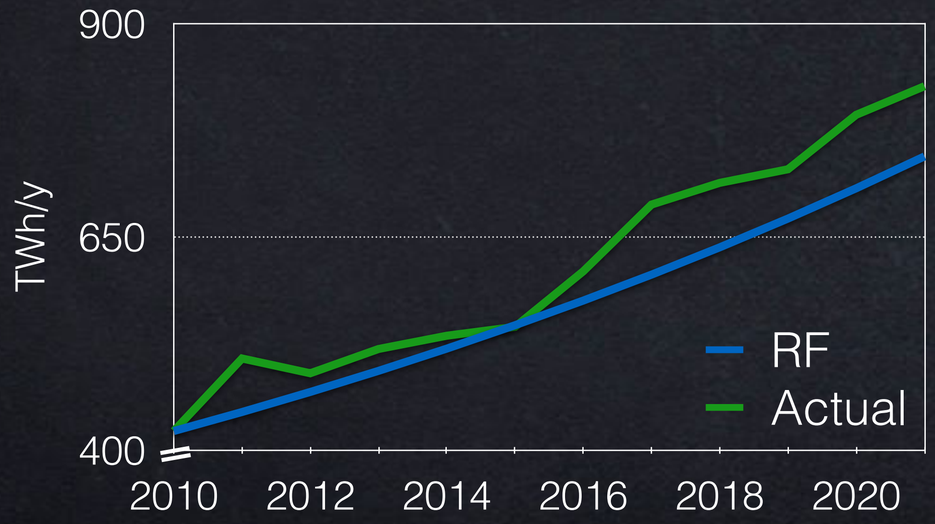
GDP



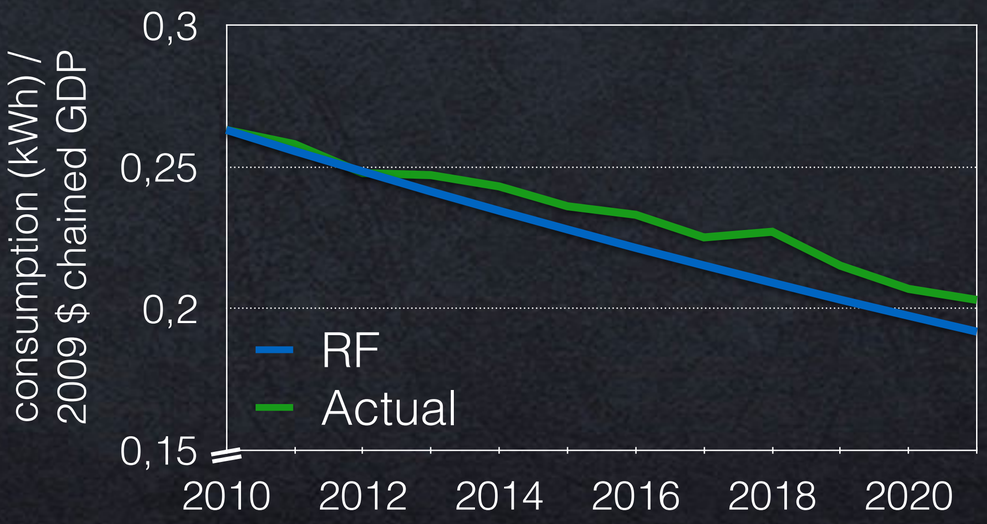
Primary energy intensity



Renewable electricity generation

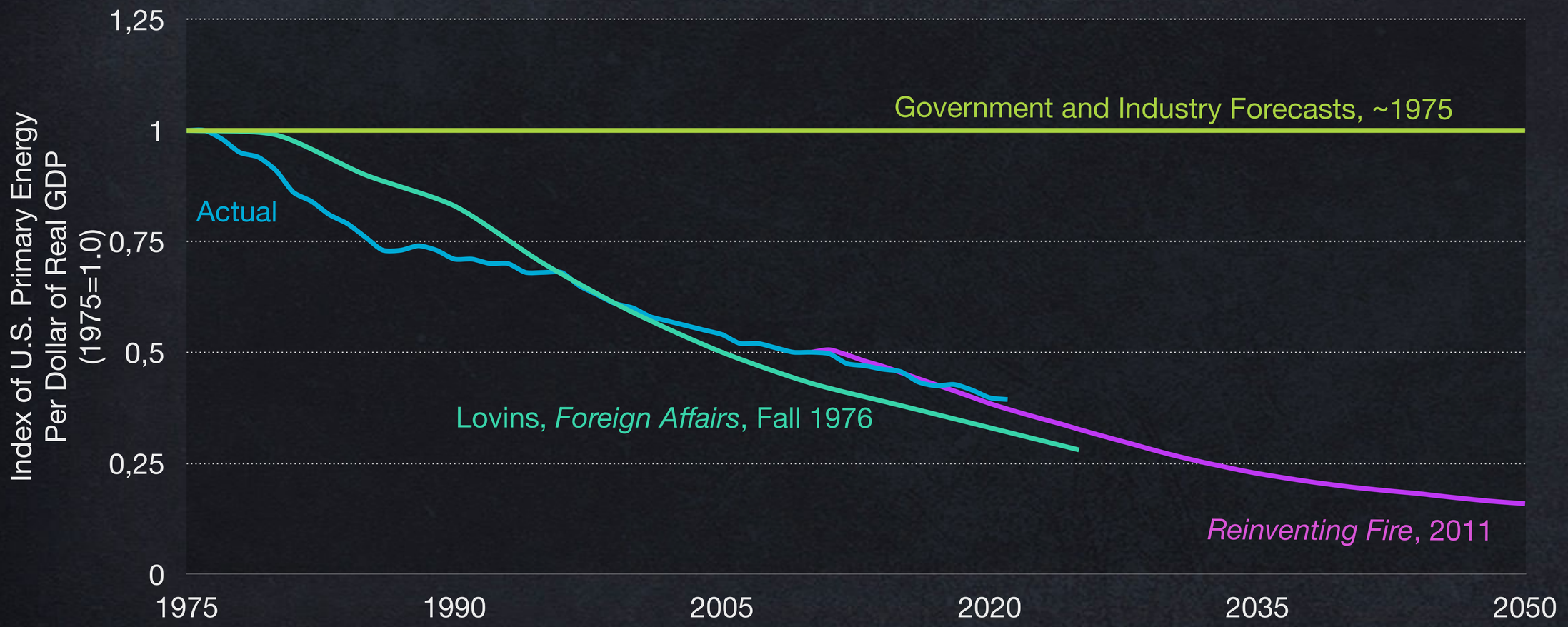


Electric intensity



Heresy Happens

US primary energy intensity, 1975–2021



See “How big is the energy efficiency resource?”, *Environ. Res. Ltrs.* **13** (2018) 090401, https://doi.org/10.1088/1748-9326/aad965

What can integrative design do? (η ≡ end-use efficiency)

buildings: ~4–≥10η
automobiles: ~4–8η
trucks: ~3–4η
airplanes: ~3–8η
factories: ~2–3η old, ~2–10η new
use of steel, cement,…: >2η

so…world economy: ~5η?

See “How big is the energy efficiency resource?”, *Environ. Res. Ltrs.* **13** (2018) 090401, https://doi.org/10.1088/1748-9326/aad965

US office buildings: 2–5× best-efficiency gains in 5 years

(site energy intensities in kWh/m²-y; US office median ~367)

~277➡173 (–38%)

2010 retrofit

284➡85 (–70%)

2013 retrofit

...➡108 (–63%)

2010–11 new

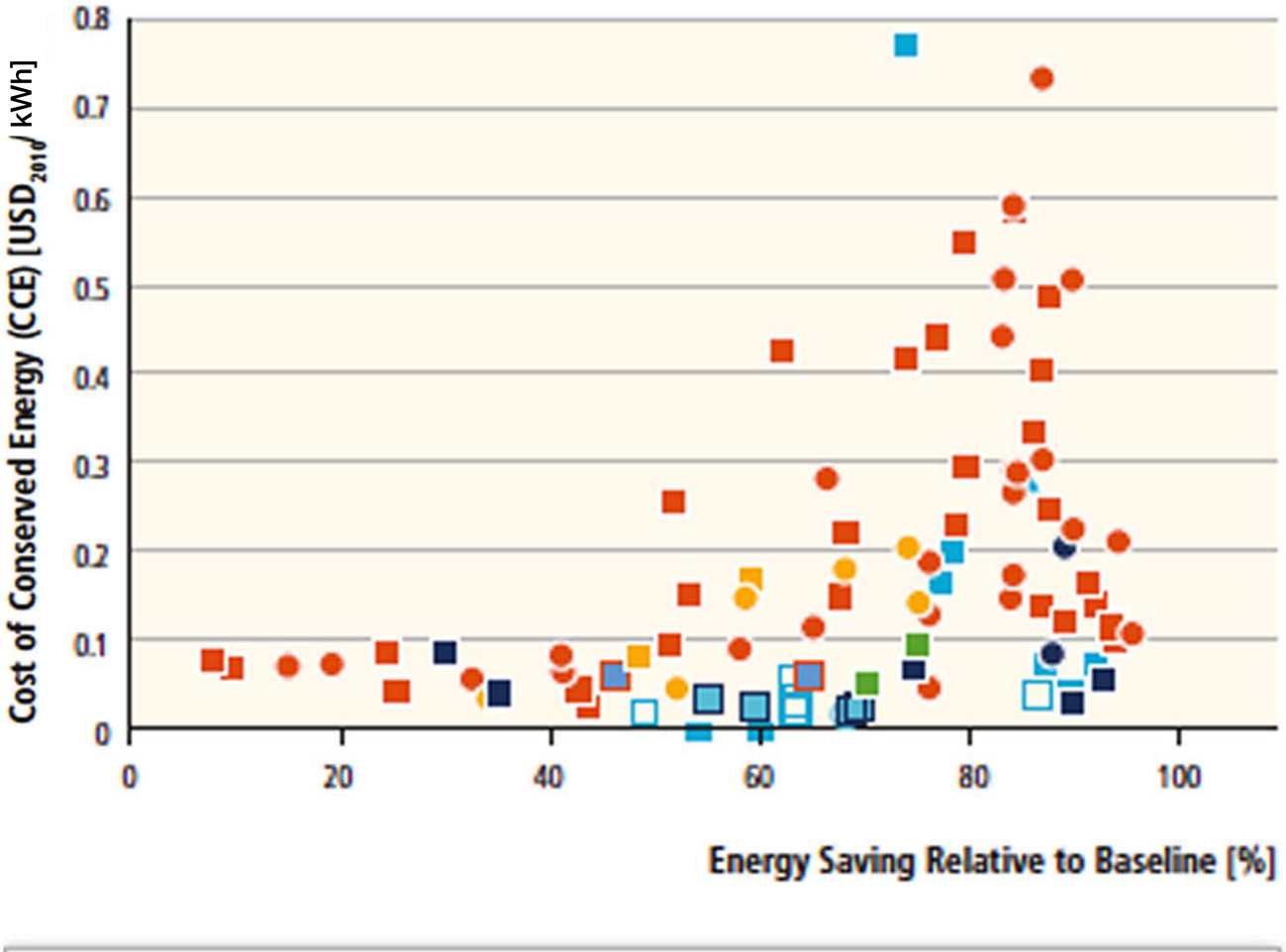
...36 (–88%)

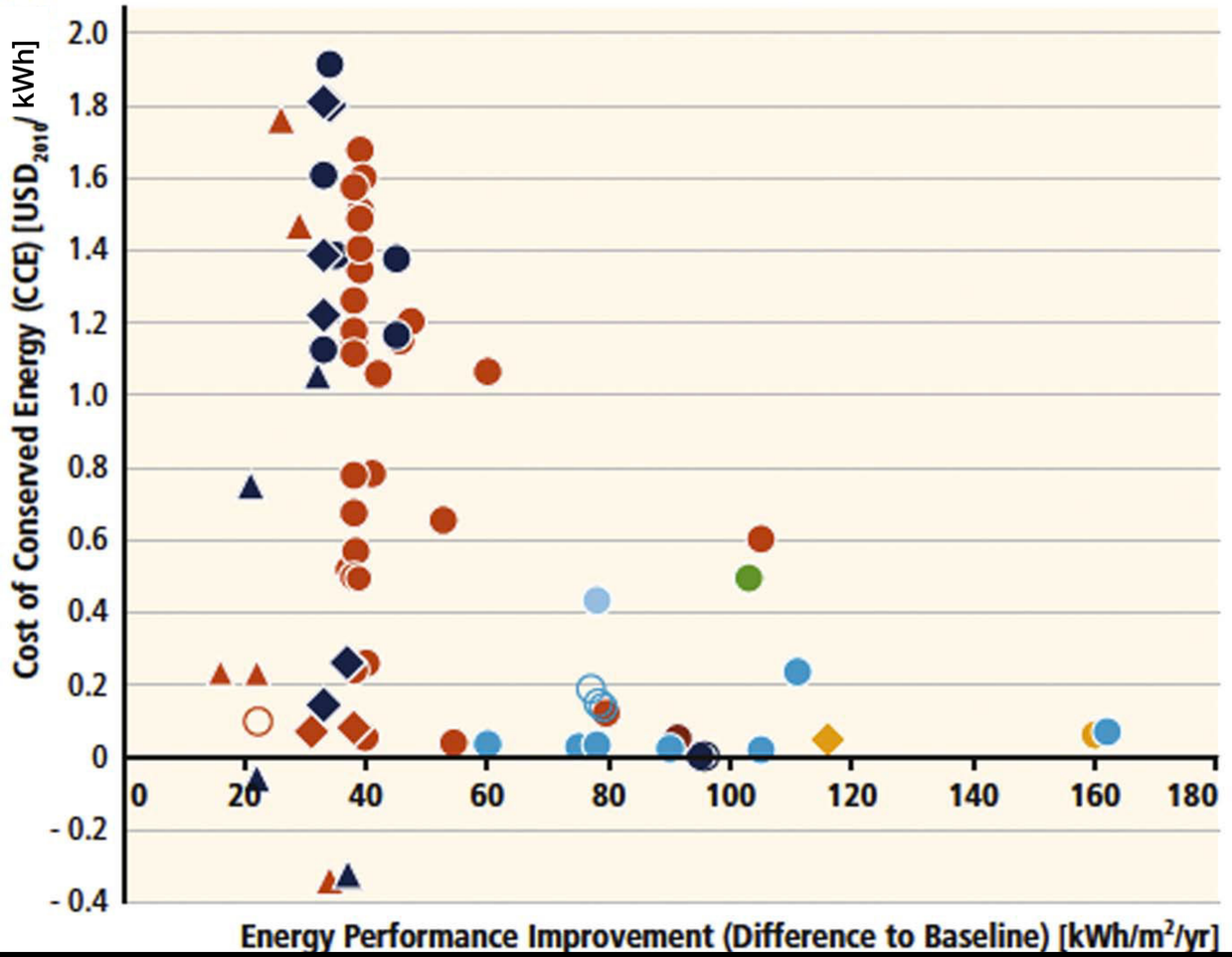
2015 new

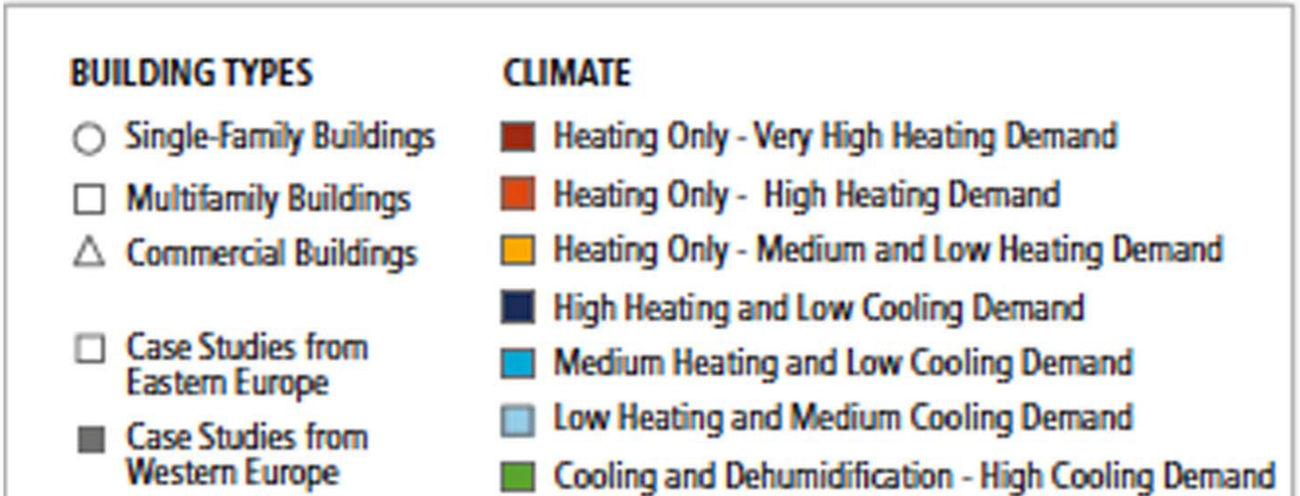
...21 (–93%)

…and in Germany,
2013 new
(office and flat)

Yet all the technologies in the 2015 example existed well before 2005!







IPCC AR5 WG3 pp 702–704 (2014) reports that high-ambition European new (left) and retrofit (right) buildings show no significant increase in the cost of saved energy up to ≥90% savings. Some examples do show higher costs, but they needn't: whatever exists is possible.

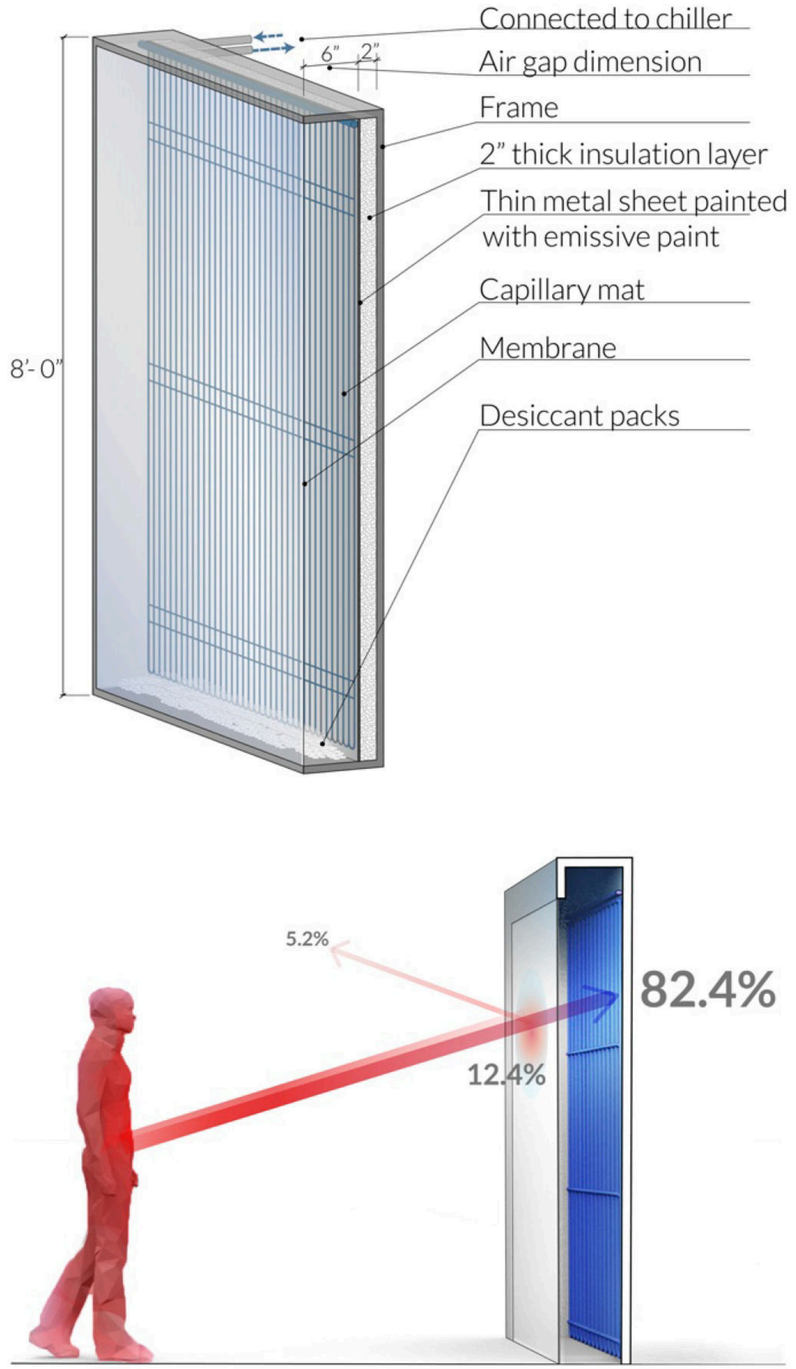
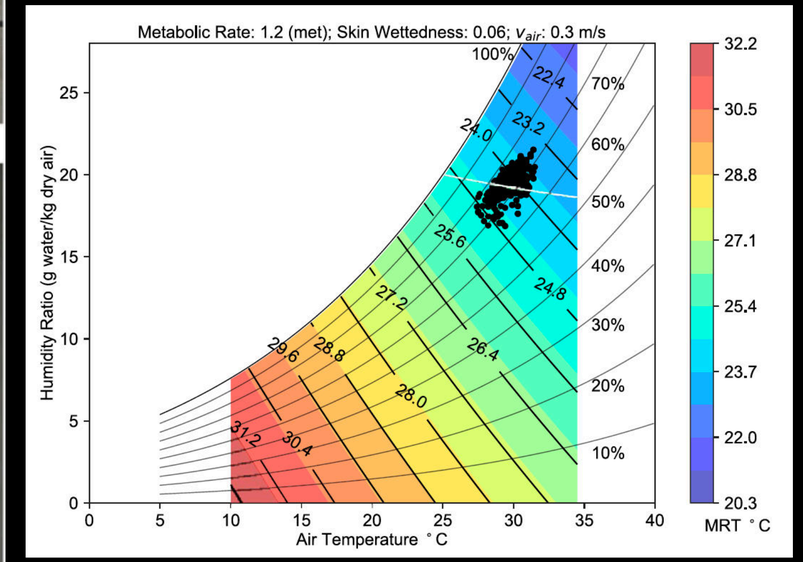


Fig. 1. Schematic of a Cold Tube radiant cooling panel (*Upper*) and radiant heat transfer through the IR-transparent membrane (*Lower*).

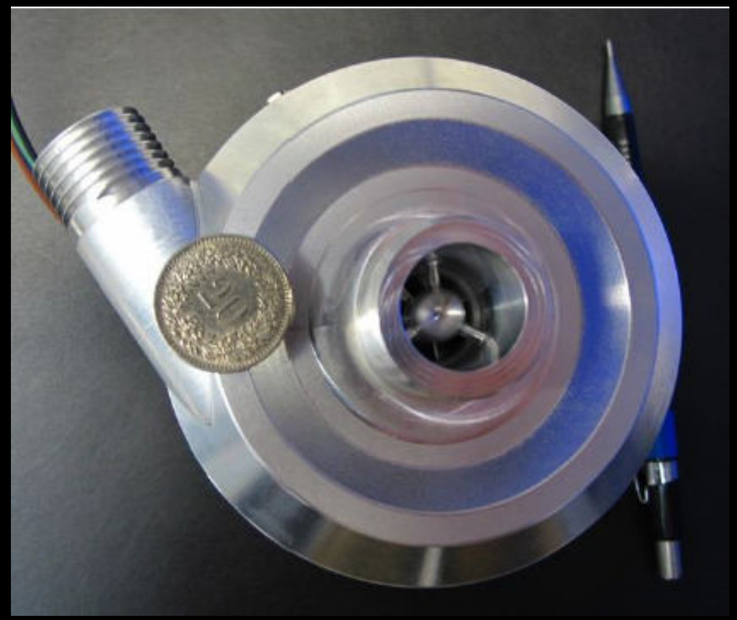
Fig. 2. The completed Cold Tube.

Pure-radiant-cooling 2019 breakthrough: outdoor comfort in the Singapore summer with shading but no chiller, no fan, no latent load, and no condensation!



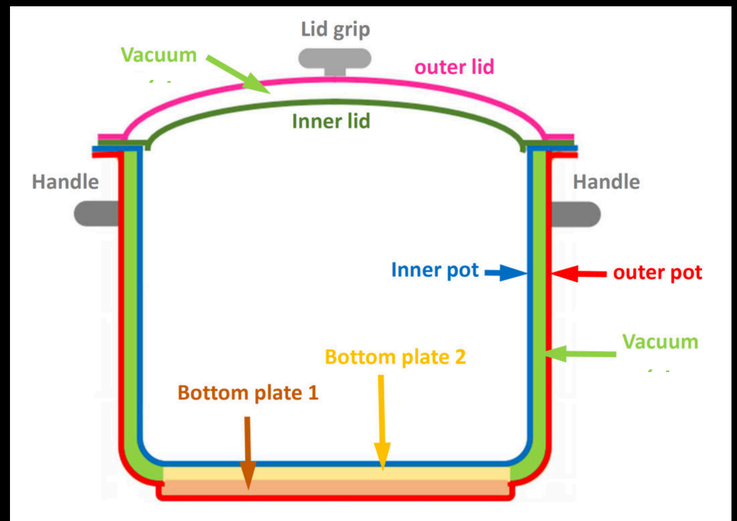
E. Teitelbaum *et al.*, *PNAS* **117**(35):21162–21169, 1 Sep 2020, www.pnas.org/cgi/doi/10.1073/pnas.2001678117

Two Swiss examples of state-of-the-art home appliances to save electricity and replace gas



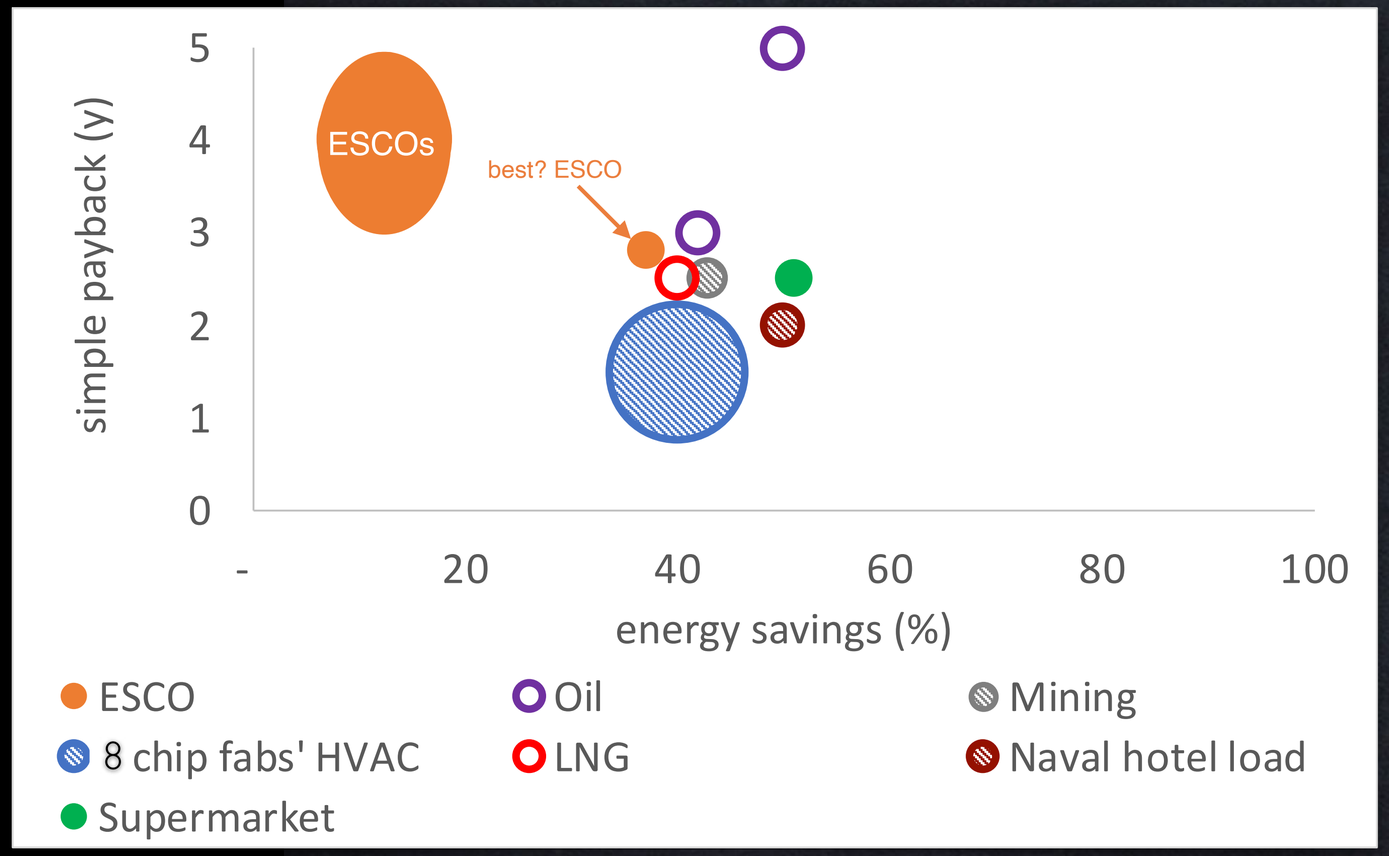
9–20 kW_t, 200 krpm heat pump for domestic hot water, ~8 cm diameter, >60% of Carnot efficiency, COP=6–15 for △T=23–56F˚, e.g. heating to the needed 111˚F from 55–88˚F

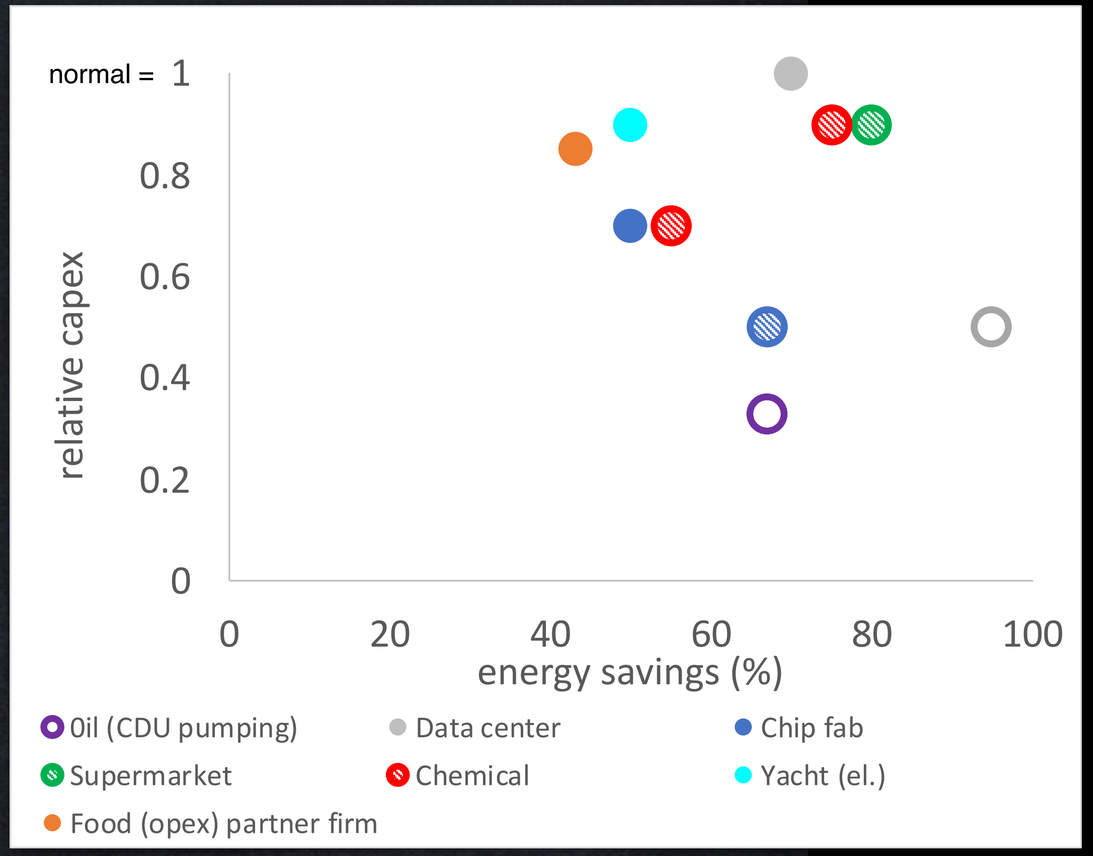
A superior electric-*con*duction cooking system
2–4½× more efficient than *in*duction; vacuum pots



RMI's latest >$60b worth of integrative design in diverse industrial projects—retrofits and newbuilds

(solid = built, shaded = incomplete data, circle = not yet built)





Retrofits

Newbuilds

Designing to save ~80–90% of pipe and duct friction—equivalent to about half the world's coal-fired electricity

thin, long, crooked

fat, short, straight

Typical paybacks ≤1 y retrofit, ≤0 new-build
But not yet in any textbook, official study, or industry forecast

Designing to save ~80–90% of pipe and duct friction—by making them fat, short, and straight

Big pipes, small pumps

Nonorthogonal layout, 3D diagonals, few & sweet bends

Decarbonize industrial process heat *indirectly*… by elegantly frugal structural design

A. Lovins, “Profitably decarbonizing heavy transport and industrial heat,” RMI, July 2021, www.rmi.org/profitable-decarb/, and “Decarbonizing our toughest sectors—profitably,” *MIT Sloan Mgt Rev*, Aug 2021, https://sloanreview.mit.edu/article/decarbonizing-our-toughest-sectors-profitably/

Tension structures—~80–90% less material

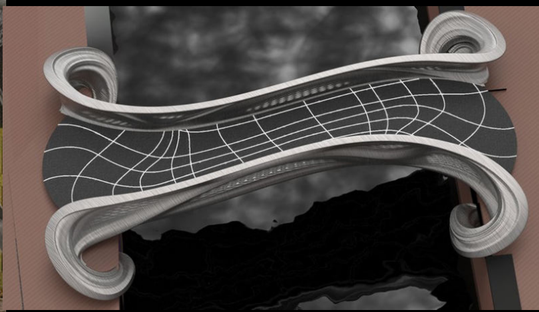
Schlaich Bergermann—see the remarkable book *Leicht Weit*

Fabric forms—≥50% less material

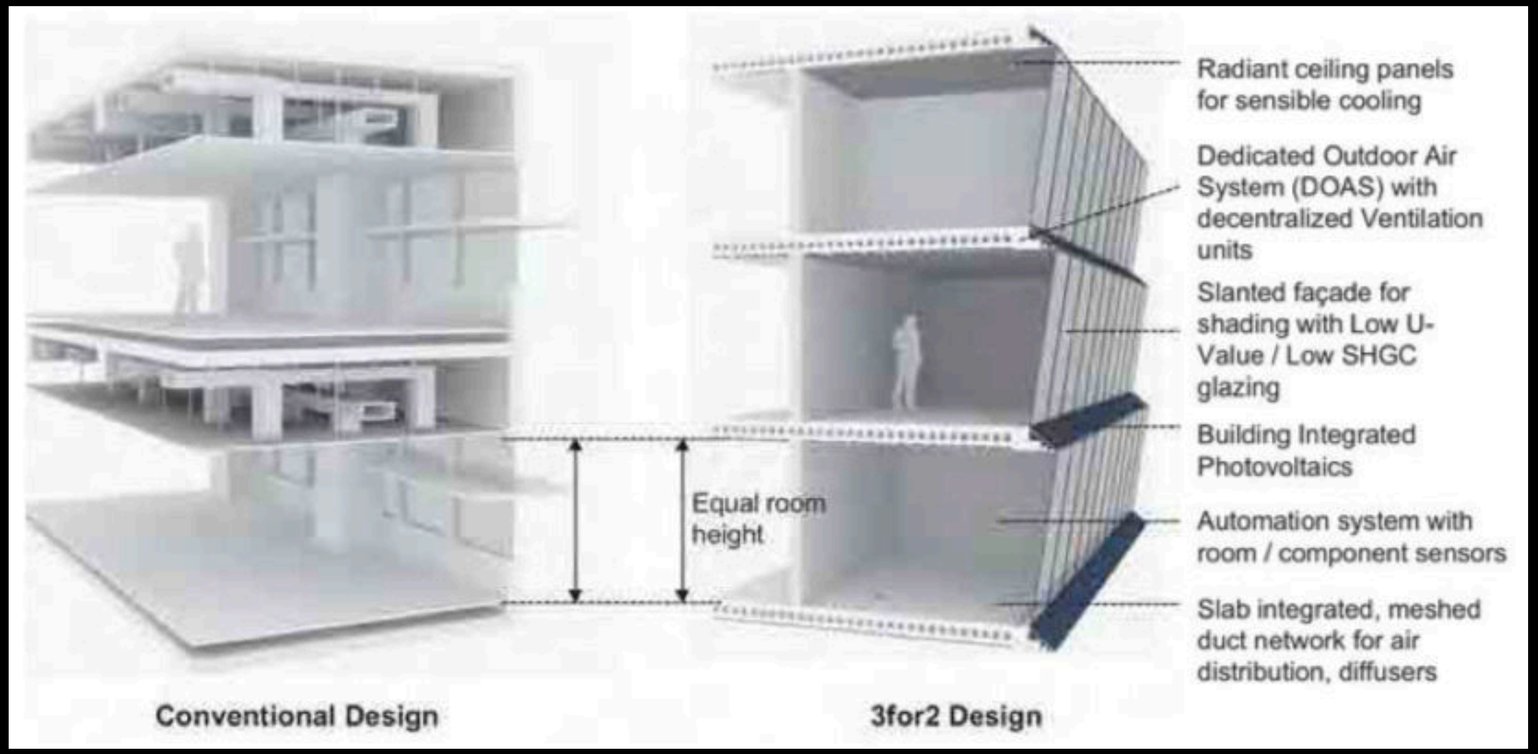
Mark West, *The Fabric Formwork Book*, Routledge, 2016; CAST (Centre for Architectural Structures and Technology), University of Manitoba, Winnipeg. See Hawkins *et al*’s 172-reference 2016 review, doi:10.1002/suco.201600117

https://www.shapeways.com/blog/archives/35854-3d-printed-bridges-now.html (Joris Laarman Lab, MX3D)

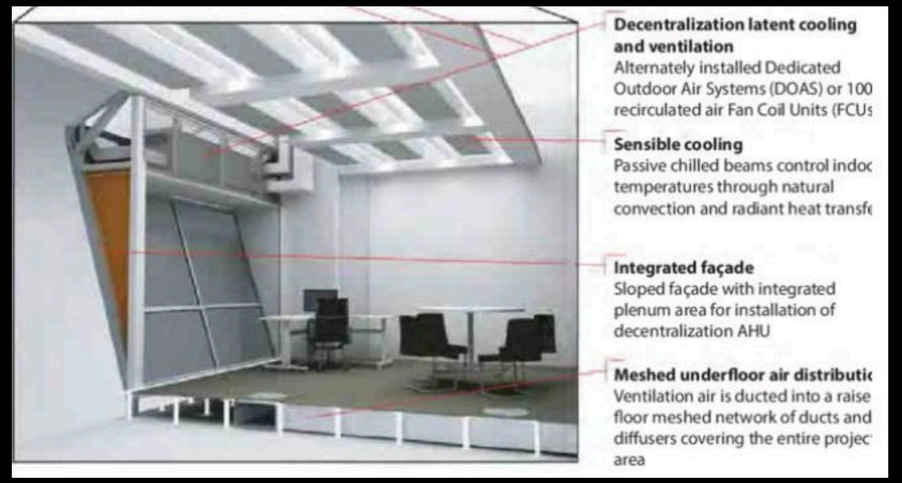
The artistic 3D-printed 12.5m stainless-steel bridge over Amsterdam’s Oudezijds Achterburgwal canal



Three stories in the height of two: the magic of the negaplenum



UCWSEA pilot installation, Singapore, 2015



A. Schlueter *et al.*, “3for2: Realizing Spatial, Material, and Energy Savings through Integrated Design,” *CTBUH J.* **2016**(2):40–45, Council on Tall Buildings and Urban Habitat

A competitive carbon-fiber electric car, 2013–22

2013 BMW *i3*, http://www.superstreetonline.com/features/news/epcp-1303-bmw-i3-concept-coupe/

BMW MY2013's ~120–150-kg carbon-fiber-composite passenger cell; m_c 1,250 kg

sgl-carbon.com

https://www.autocar.co.uk/car-news/industry/bmw-set-make-more-extensive-use-carbon-fibre

BMW's sporty, 1250-kg 4x-efficiency *i3* was profitable from the first unit, because it:

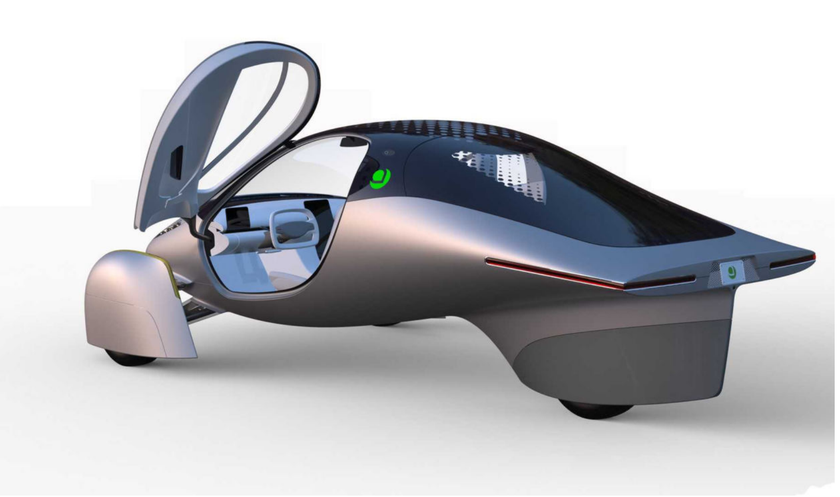
- pays for the carbon fiber by needing fewer batteries (which recharge faster)
- saves ~2.5–3.5 kg total for each kg of direct mass saved (Detroit says <1.3–1.5)
- needs two-thirds less capital, ~70% less water, ~50% less energy, space, time
- requires no conventional body shop or paint shop (automaking's two hardest steps)
- ensures safe, clean, quiet, superior working conditions

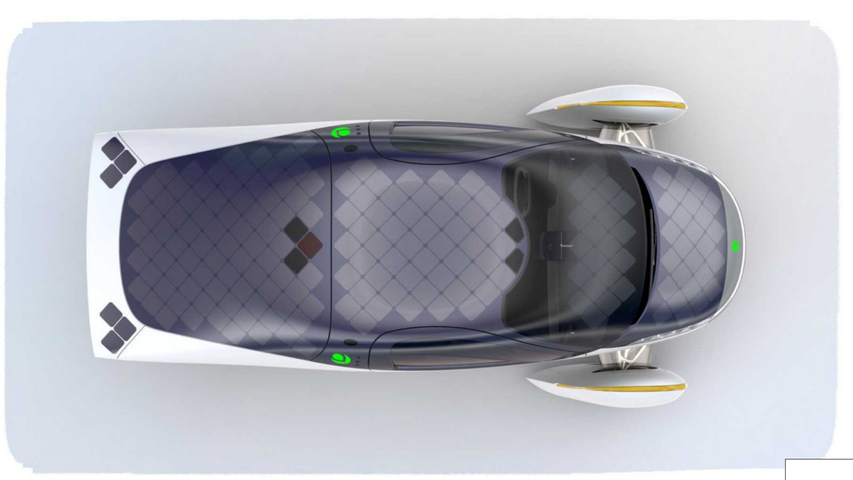
A. Lovins, SAE *J-STEEP,* 2020, https://doi/org/10.4271/13-01-01-0004

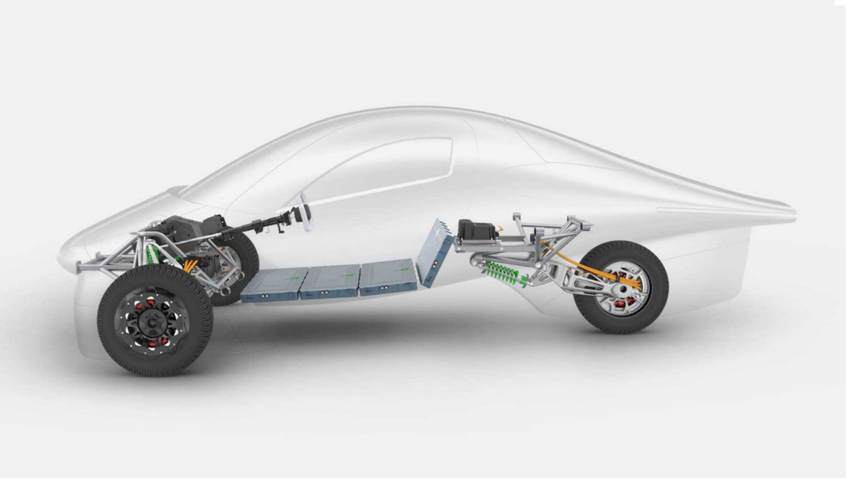
- delivers 1.9 L_{equiv}/100 km (124 mpge) on US 5-cycle test, 1.7 Ger., ~1.6 old US cycle
- provides exceptional visibility, agility, traction, and crash safety; halved turn radius

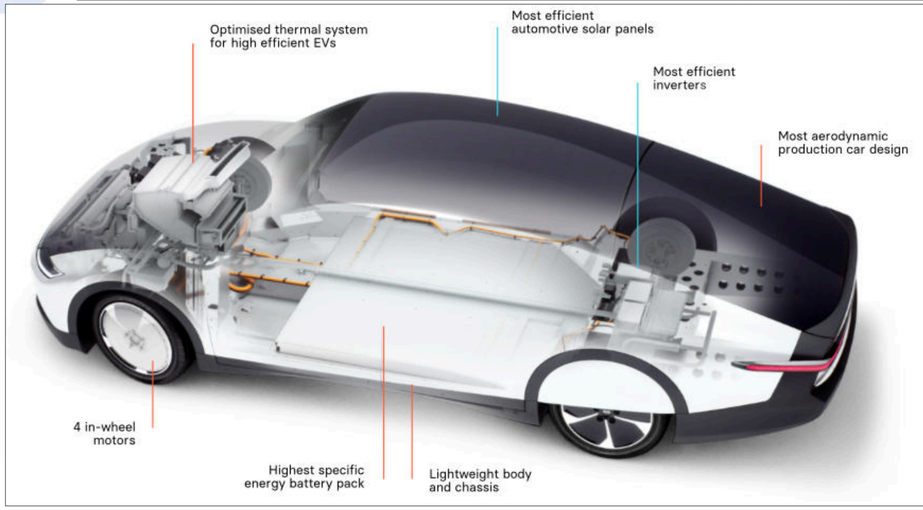
Efficiency can save most of the battery minerals

A. Lovins, 2022, https://rmi.org/insight/six-solutions-to-battery-mineral-challenges/







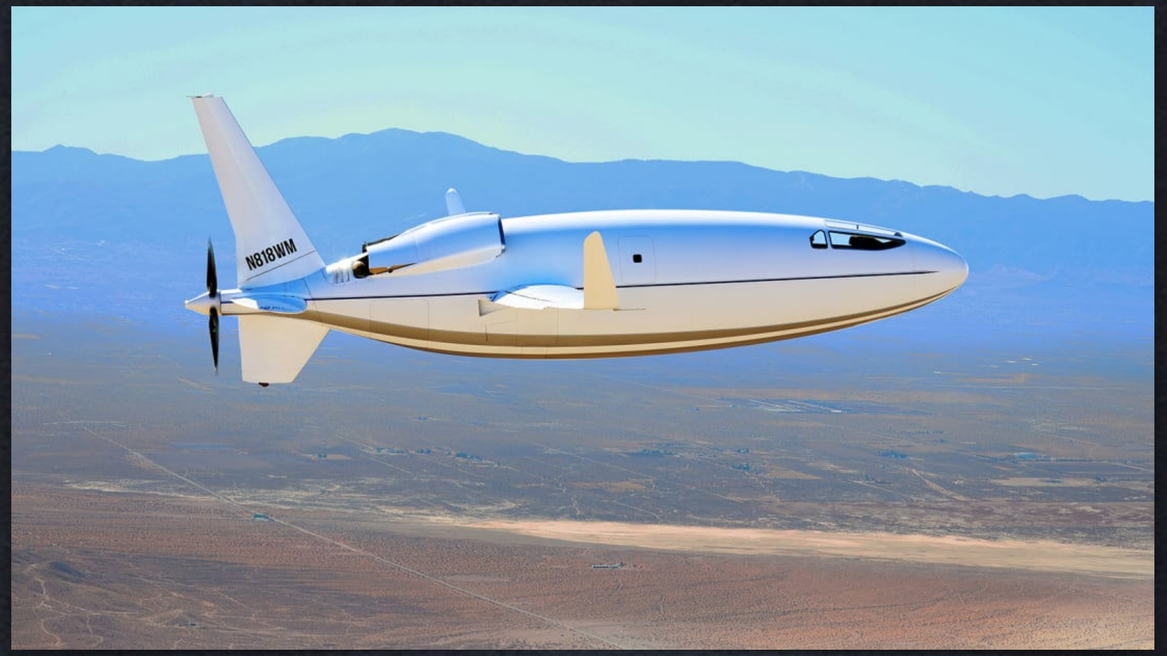


“NeverCharge” solar-powered Hypercar®-class 2-seat el. vehicle: up to 1,600-km range, but most drivers *will need no recharging*, because it’s so efficient (**<0.7 L_{equiv}/100 km**) that its solar cells capture enough energy for ~18,000 km/y. It has half a Tesla’s mass, and less air drag (at C_d 0.13) than the side mirrors of a US pickup truck! 2022/3 release (aptera.us); US$26–45k, varying with range.

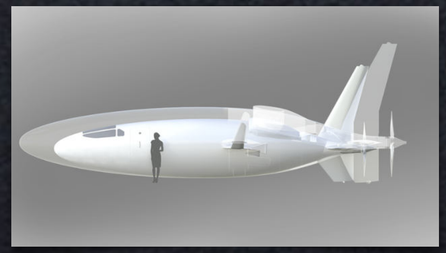
“Lightyear One” mostly/all solar-powered (5 m^2, 21.5%-efficient PV, ~12 km charge/h) 5-seat 4-wheel sedan, 0.8–1.7 m^3 cargo, C_d 0.175, **0.9 L_{equiv}/100 km**, 725-km range, 2022/3 release (lightyear.one).

The revolution accelerates…

Tesla *Semi* Class 8 battery-electric truck (2023), 500-mile full-load range (+ ~400 mi w/30-minute recharge), 2-y pay-back (could be 0 in this decade), million-mile warranty, 3–5× faster acceleration, 1/3-faster hill-climbing (5%)



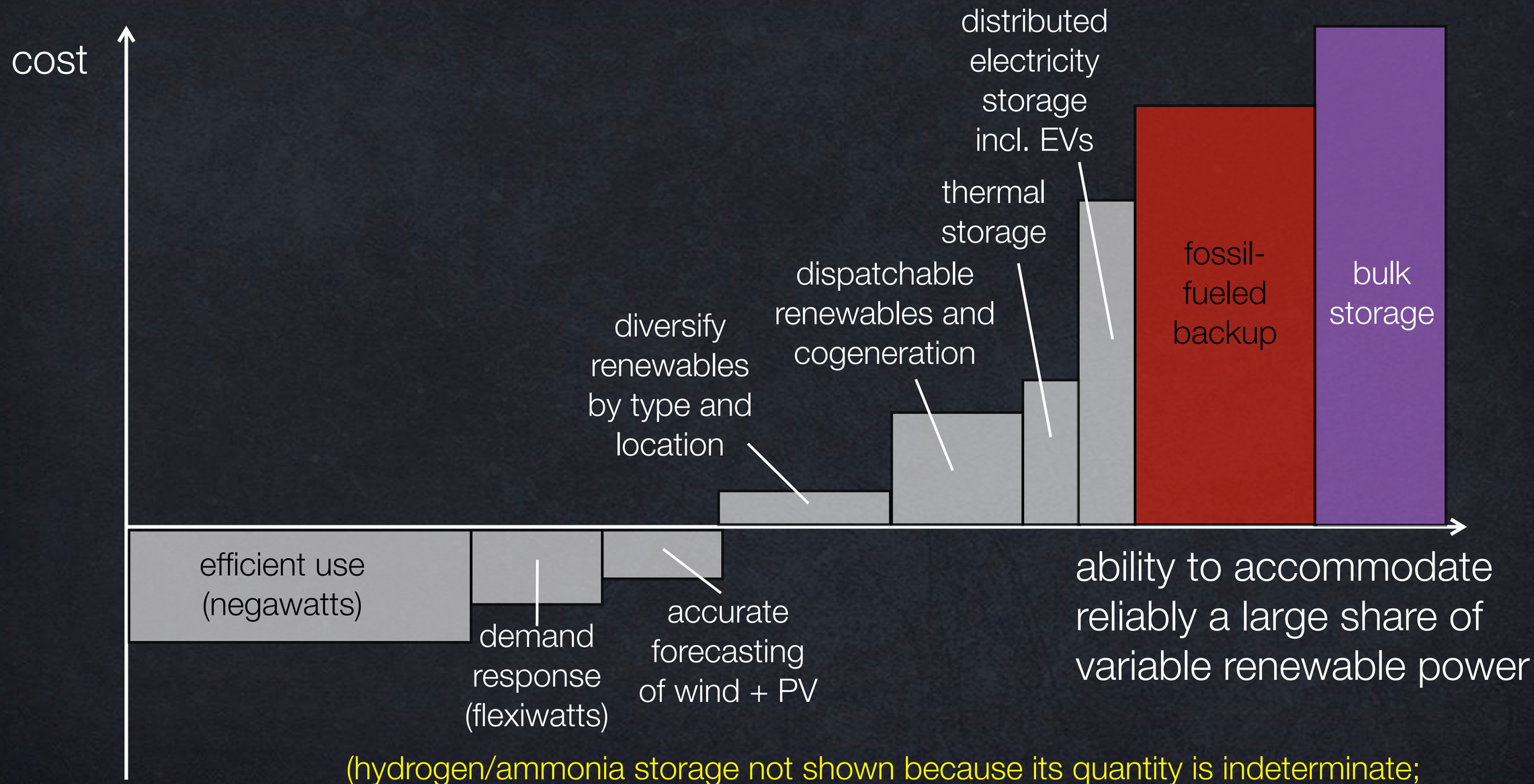
Celera *500L* (Otto Aviation 2020 prototype—the commercial version will add windows), *8× efficiency* (18–25 mpg *vs* ~2–3), >460 mph, 4500-nm range, 6× lower opex ($328/h); 6-seater can scale up to >20; good candidate for electrification



with more to come…

Grid flexibility resources

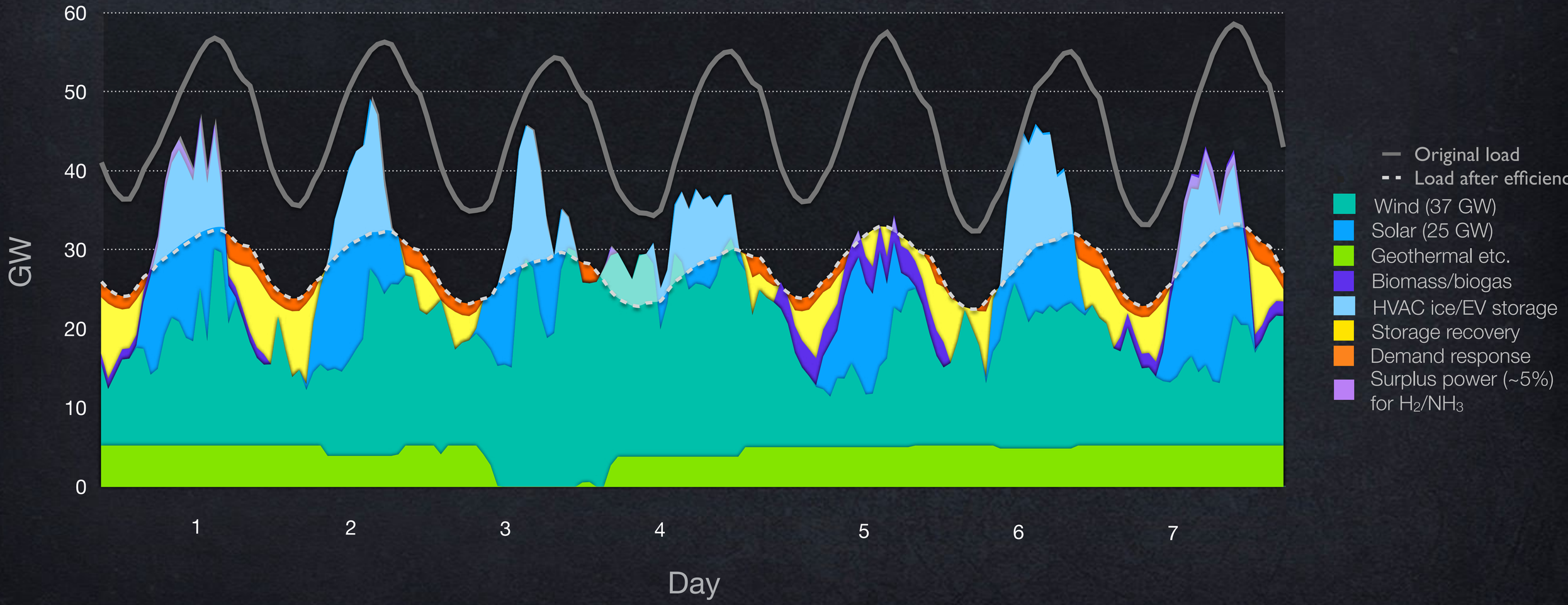
(all values shown are conceptual and illustrative)



(hydrogen/ammonia storage not shown because its quantity is indeterminate;
“bulk storage” combines batteries with pumped hydro, compressed air, gravity,…)

Choreographing Variable Renewable Generation

ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation, 2004 renewables data)



An EU analysis finds no structural seasonal deficit in a 2050 net-zero power system: 70% el. use growth to 2050 needs only 240–400 dispatchable GW for 1–2 *weeks*/y

A WELL-BALANCED RES MIX DOES NOT CAUSE A STRUCTURAL SEASONAL MISMATCH BETWEEN DEMAND AND RES SUPPLY

Complementarity of wind and solar power

The generation patterns of wind and solar energy in Europe are complementary: wind energy production is most abundant in winter, whilst around 40% of solar energy is produced between June and August. Figure 4 shows the long-term fluctuations (over a time scale of 1 to 12 months) in the BAUx3 RES supply in Europe in 2050, and of the direct electricity demand (ELEC-pathway). Achieving the right balance between wind and solar production in the energy mix avoids a structural seasonal mismatch between supply and demand in summer (e.g. oversupply of solar energy) and winter (e.g. undersupply because of low solar infeed).

No need for large-scale volumes of green molecules to cope with seasonality in the power sector

The BAUx3 RES expansion scenario does not reveal a structural seasonal mismatch between supply and demand on a European level under the ELEC-pathway in 2050. This means that there is no need in the power system for large-scale seasonal storage via green molecules. The role of green molecules will be limited to covering periods of 1 up to 2 weeks with exceptionally low RES infeed. Belgium and Germany can achieve a balanced RES mix by building interconnectors with countries with a complementary RES mix.

FIGURE 4: SEASONAL PATTERN OF ELECTRICITY GENERATION AND DEMAND (FLUCTUATIONS 1 TO 12 MONTHS). THE RIGHT MIX OF WIND AND SOLAR POWER AVOIDS A SEASON-LONG MISMATCH BETWEEN ELECTRICITY DEMAND AND SUPPLY IN EUROPE IN 2050 (BAUX3 RES, ELEC-PATHWAY)

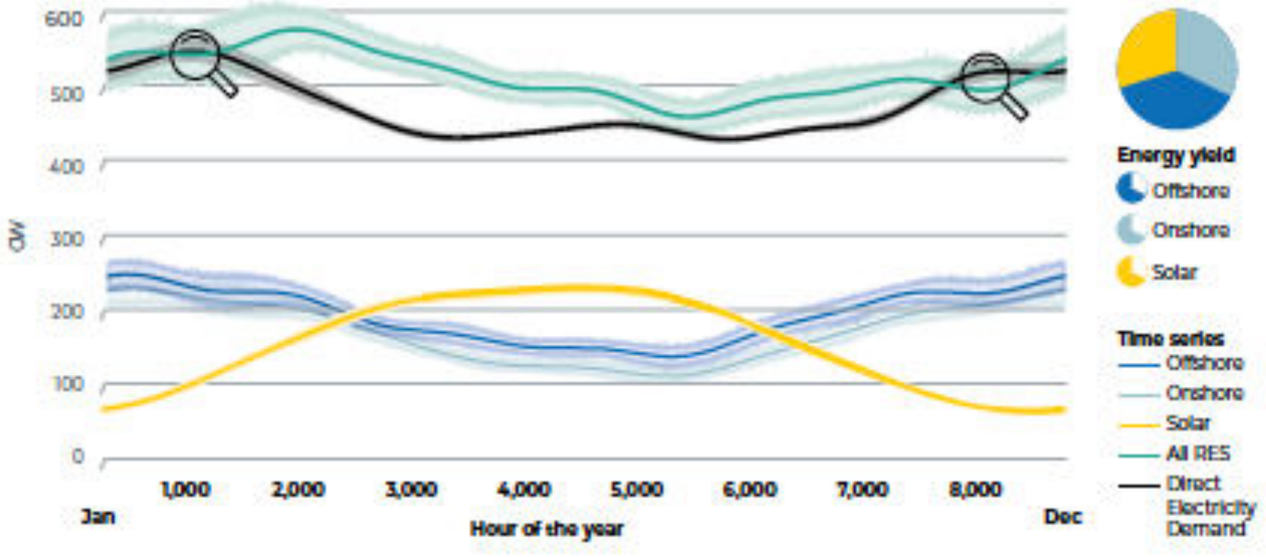
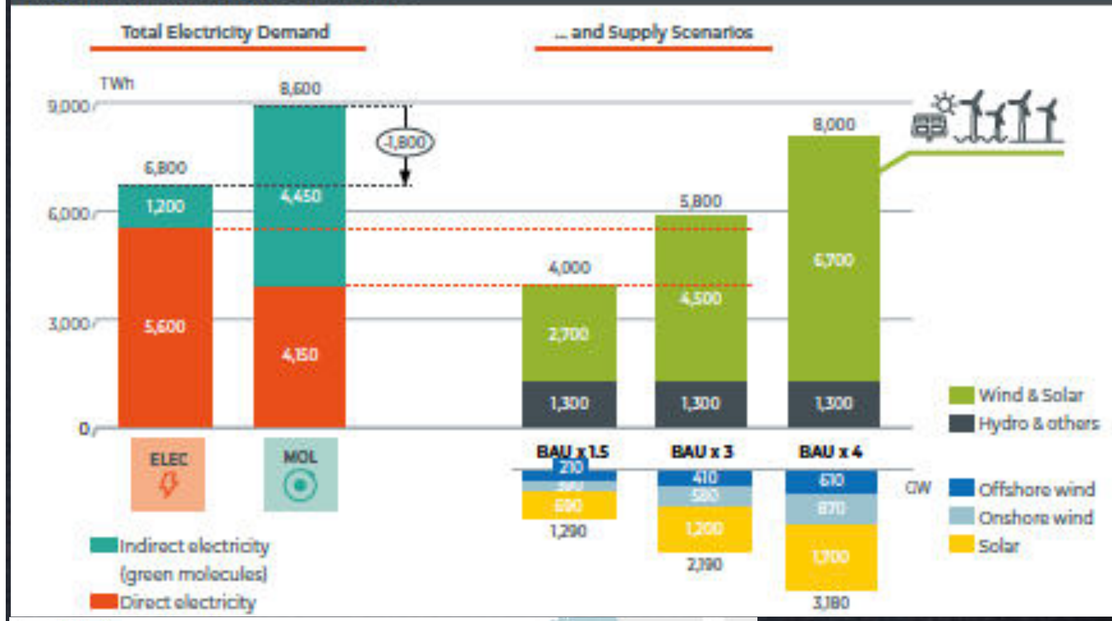
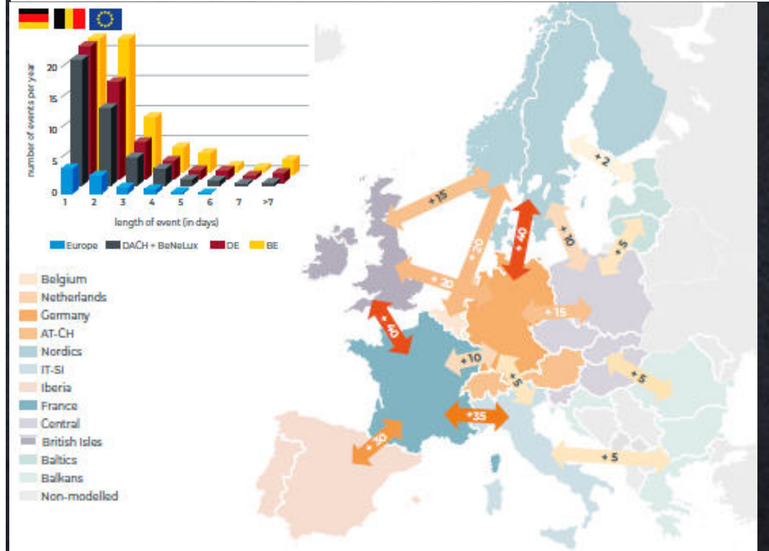


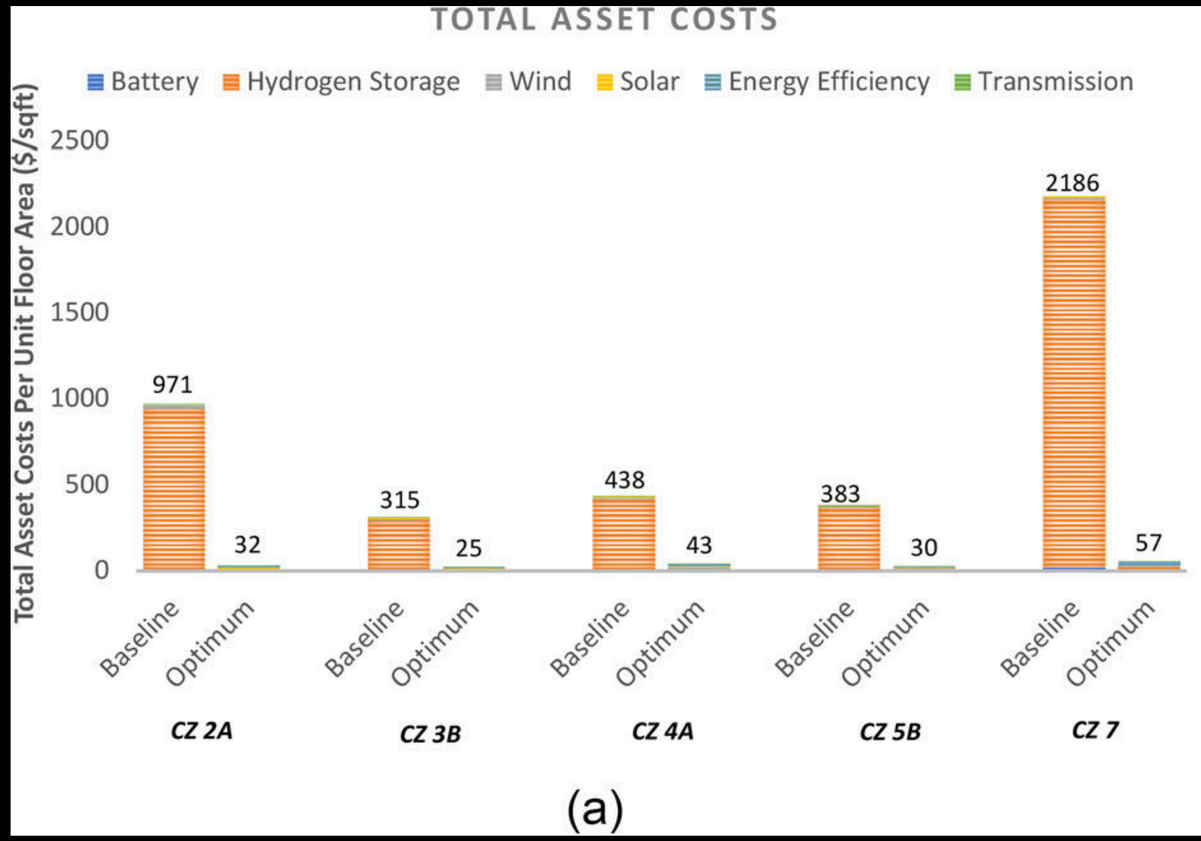
FIGURE 2: STRONG ELECTRIFICATION OF END USE (AS UNDER THE ELEC-PATHWAY) SAVES UP TO 1,800 TWH AT THE EUROPEAN LEVEL COMPARED TO THE MOL-PATHWAY. DIRECT ELECTRICITY DEMAND UNDER THE ELEC-PATHWAY INCREASES BY 70% COMPARED TO TODAY'S DEMAND. A TRIPLING OF TODAY'S RES EXPANSION RATE IS NEEDED TO MEET THIS DIRECT ELECTRICITY DEMAND

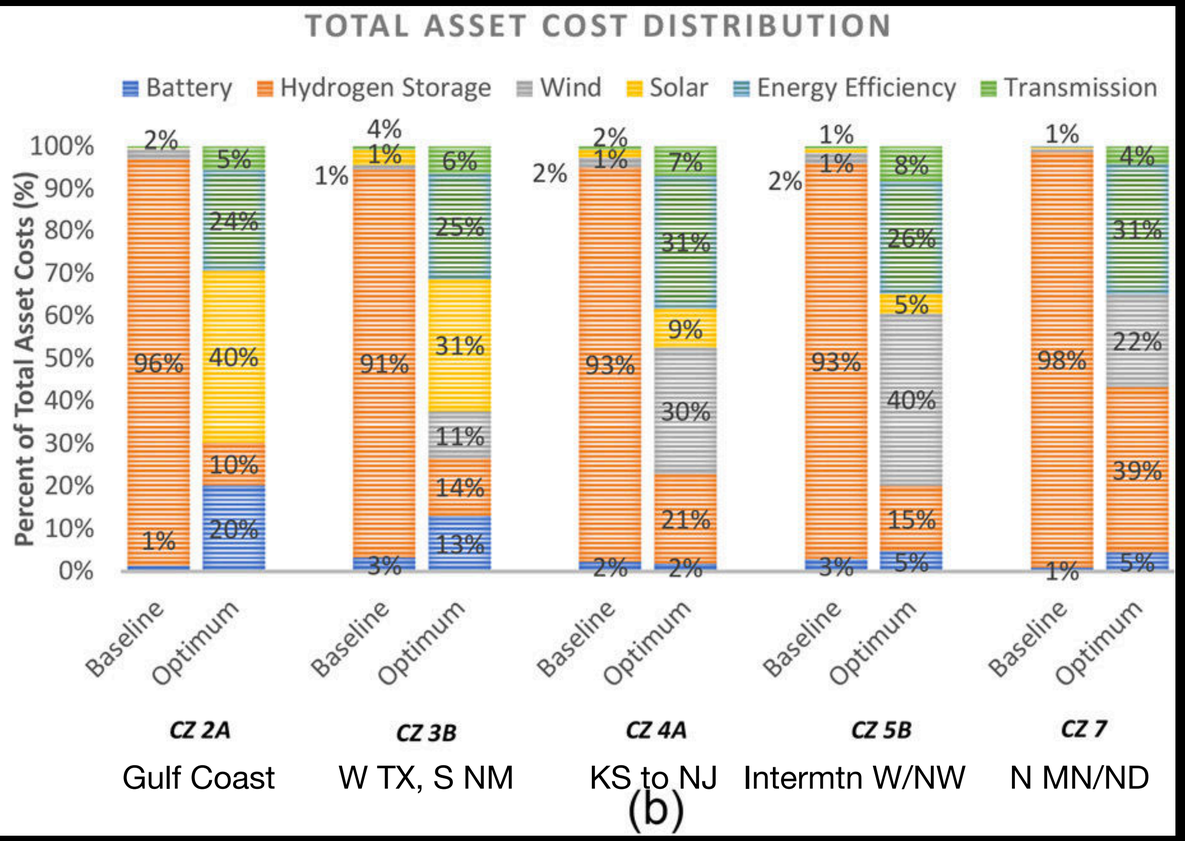




Elia Group/50Hertz, *Roadmap to Net Zero*, 19 Nov 2021, p 7, https://www.50hertz.com/en/News/FullarticleNewsof50Hertz/11597/elia-group-publishes-roadmap-to-net-zero-our-vision-on-building-a-climate-neutral-european-energy-system-by-2050. "RES" ≡ renewable energy supply.

Energy-efficient buildings displace and outcompete electricity storage

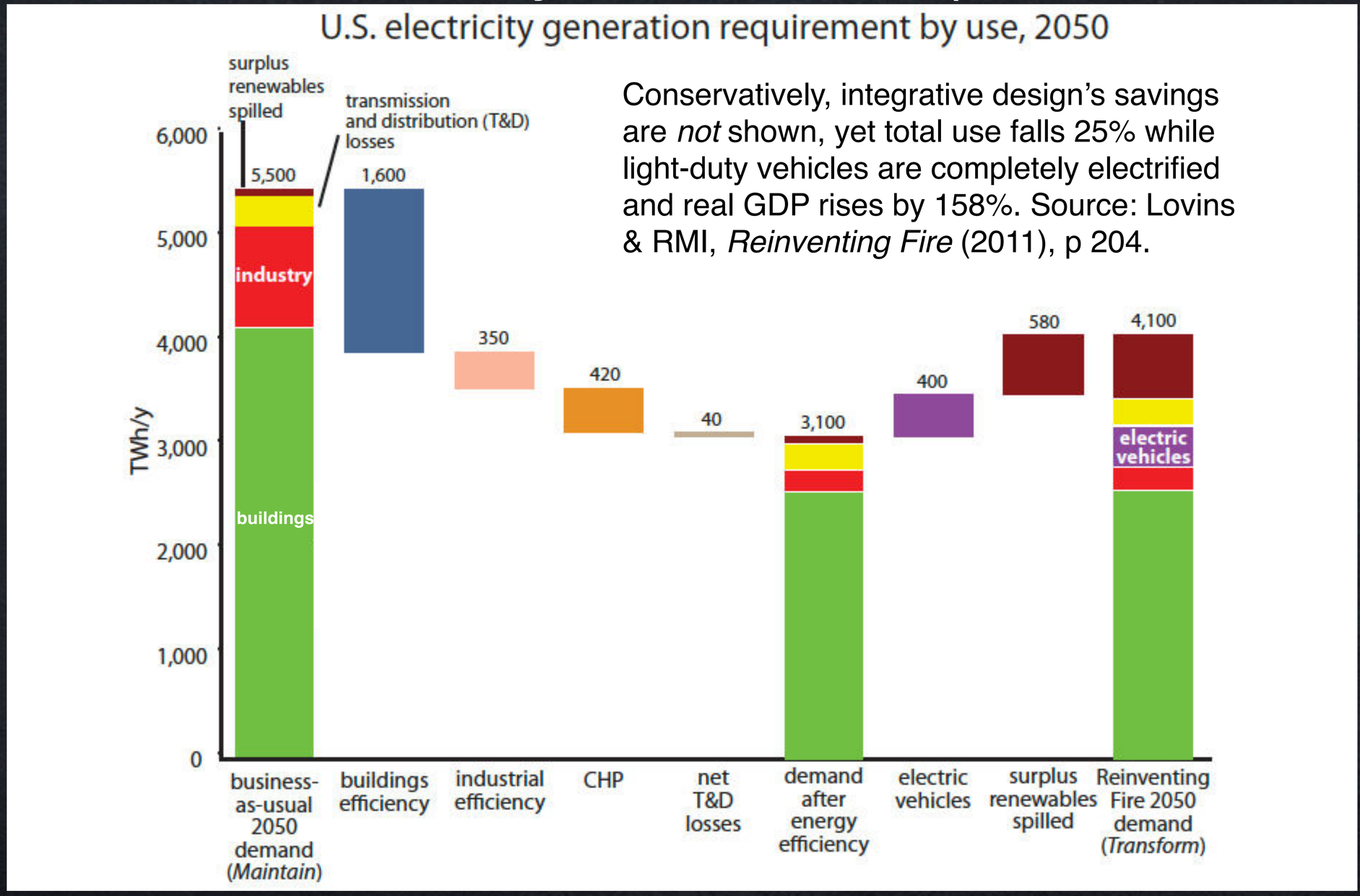




Retrofitting conventional building efficiency, plus extra renewables in an optimal mix, largely displaces H_2 long-term storage, *cutting investment by ≥1 order of magnitude*. This "can eliminate the need for long-duration energy storage for U.S. regions" defined by" the Gulf Coast, the desert Southwest, and the Intermountain W & NW.

S. Hussainey & W. Livingood, "Optimal strategies for a cost-effective and reliable 100% renewable electric grid," *j. Ren. Sust. En.* **13**, 066301 (2021), https://doi.org/10.1063/5.0064570, 2 Nov 2021

U.S. Electric Productivity Can Quadruple in 2010–50



Conservatively, integrative design's savings are *not* shown, yet total use falls 25% while light-duty vehicles are completely electrified and real GDP rises by 158%. Source: Lovins & RMI, *Reinventing Fire* (2011), p 204.

Profitable Climate Protection for Development and Security

www.rmi.org | ablovins@stanford.edu