Can a virus and viral ideas speed the world’s journey beyond fossil fuels?

Amory B Lovins and Kingsmill Bond

1 Rocky Mountain Institute, 22830 Two Rivers Rd., Basalt, CO 81621, United States of America
2 Carbon Tracker, 40 Bermondsey St., London SE1 3UD, United Kingdom

E-mail: ablovins@rmi.org

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Abstract

Smart investments in pandemic recovery and contagious new tools for deeper, cheaper energy efficiency could speed existing capital flight from fossil fuels. This could help turn pandemic disruptions into durable climate solutions.

Sensitive intervention points, where a small action has a big effect, are well known to amplify change in complex climate systems. They can also abate climate change if exploited in complex socioeconomic systems (Farmer et al 2019). We argue that the COVID-19 pandemic may dramatically speed capital flight from the fossil-fuel industries. That flight could be further sped by (a) reemphasizing energy efficiency in recovery investments, and (b) adding some virally contagious design ideas now absent from most efficiency efforts in industry and mobility.

1. Tipping capital markets—a very sensitive intervention point

Global CO₂ emissions were flat in three of the past 5 y. In 2019, fossil-fuel use rose just 0.7% (falling in 48% of the world) and met only 46% of incremental energy demand (BP 2020). Now the pandemic is speeding the transition to efficient use and renewable supplies by crushing energy demand even as ever-cheaper renewables keep growing. The world’s 2020 primary energy use and CO₂ emissions were respectively forecasted in April 2020 (IEA 2020) to reverse their past 5 and 10 y of growth—both twice the total of all previous drops since World War II—with coal use falling 8%, oil 9%, gas 5%, nuclear 2%, and primary energy 6% while renewables grew 1%, solar 16%, windpower 12%, and total renewable electricity 5%. Six months later, revisions were slight (IEA 2020a). By the time economies recover, renewables could be big enough to provide all the growth in energy demand, condemning fossil fuels to permanent decline.

This substitution has interlocking parts. Three-fourths (BP 2019) or all (BP 2020) of primary energy growth to 2040 makes electricity and waste heat; renewables like solar and windpower profitably displace both. Ever-cleaner electricity plus renewable heat and fuels, all stretched by efficient use, could displace much fossil fuel for heat and mobility. Thus renewables’ total could overtake fossil-fuel recovery, shifting peak fossil-fuel use from perhaps the mid-2020s back to 2019 (Bond 2018).

Similarly, the 2008 financial crisis tipped the unprepared European electricity sector into renewable provision of incremental electricity, shrinking fossil-fueled generation and triggering $150 billion in...
write-offs (Bond 2020a, 2020b). But it is plausible that ‘this time, the peak is global, and it is for the entire [energy] system’ (Bond 2020a): “If the world economy does not rapidly recover from the crisis, and if efforts to curb emissions accelerate moderately, global fossil fuel demand will have peaked in 2019” (Burchardt et al 2020).

This inflection point could speed the energy transformation by sapping fossil fuel suppliers’ financial and political strength. How? When a fast-growing challenger takes all the growth in a slow-growing market, investors flee the incumbents, because investors seek the returns that come from consistent growth, not mere size. Investors rush to sell shares shortly before demand peaks and tips into decline, triggering lower prices, collapsing rents, and stranded assets. History shows that when a fast, scalable challenger reaches just ~2%–3% market share, it can often take all the growth, hence much of the value, from even mighty and venerable incumbents (Bond 2018a).

2. Why global fossil-fuel use probably peaked in 2019

In 2019, renewables added 78% of global net increases in electric generating capacity excluding, or 81% including, big hydro dams (Frankfurt School/UNEP/BNEF 2020). Nonhydro renewable generation grew 14% and total renewables 6%—making 26% of global electricity, outpacing demand growth, and dethroning fossil-fueled generation from its 2018 peak (IRENA 2020, IEA 2020). US renewables surpassed coal for the first time in >135 y. If 2020 is a normal hydro year, renewables should soar from 26% to nearly 30% of global electricity’s reduced use (IEA 2020).

In 2020 globally, only renewables are growing (IEA 2020a). Solar and windpower doubled their share of global electricity production between 2005 and mid-2020. They can grow especially fast because they are granular, modular, mass-producible, fungible, quickly installable by diverse actors with little institutional preparation, nonpolluting, climate-safe, climate-effective (Lovins 2019a, 2019b), job-rich (Hepburn et al 2020, IEA 2020a), and propelled by the powerful feedbacks of increasing returns and learning-by-doing (Haegel et al 2017, Wilson et al 2020, BNEF 2020): in Thomas Friedman’s phrase, the more we buy, the cheaper they get, so we buy more, so they get cheaper. Without subsidies, they are now the cheapest source for 85% of the world’s bulk electricity—soon essentially all; and for storage up to 2 h and rising, batteries’ cost, halved in 2 y, now beats gas-turbine peakers, at least in gas-importing countries (BNEF 2020a).

Before its hazard was found to be small, avoiding crowded public transport spiked short-term driving in some cities, but offsetting trends may prove more durable. Distancing withered office economics, aviation crashed, virtual mobility skyrocketed (send electrons, leave heavy nuclei at home, swap jet-setting for Zoom-sitting). Bicycling surged, >200 cities restricted car traffic, electric two-wheeler services spread, ridehailing strove to revive. Many daily commutes, shopping-mall trips, business flights, and faraway conferences may not resume.

Above all, despite a rising SUV share, automobile sales are shrinking, and oil-fueled auto sales are shrinking faster. Before global passenger-auto sales peaked in 2017, their growth averaged 2.1 million/y, but in 2019, their oil demand probably peaked and 2.2 million battery-electric autos (EVs) were sold. EVs’ 2020 market share remains robust; IEA expects it to rise from 2019’s 2.5% to 3.2%.6 During 2015–19, 13 nations and 30 cities or regions set combustion-vehicle phaseouts; in 2020, so did trendsetting California. In the first half of 2020, Tesla sold 28% of global EVs and became (for now) the world’s most valuable automaker.

Fleets of all kinds will cull idled least-efficient vehicles and buy efficient, oil-free ones, as Lyft and Uber pledge by 2030. EVs use no oil and 3–8× less delivered energy (Lovins 2020b); they win on fleet lifecycle cost today and on sticker price starting in a few years (BNEF (Bloomberg New Energy Finance) 2020, BNEF 2020b). Jet-fuel demand—an astounding 79% of BP’s projected global 2017–40 refined-products growth (BP 2019)—will lag aviation’s recovery as efficient planes start exploiting ~3–5× long-run tank-to-flight efficiency potential (Lovins 2019c). Likewise 3–4× in fueled heavy trucks (Lovins 2020b)—more if electrified, as California, with 14 state partners plus DC, mandates from projects worldwide (IRENA 2020a) confirm ‘how decisively the tables have turned…reinforcing the case to phase-out coal entirely. Next year, up to 1200 gigawatts of existing coal-fired capacity could cost more to operate than new utility-scale [PVs]…costs to install.’ (Bodnar et al 2020) concur and provide attractive phaseout financial solutions for the US, EU, China, and India. Strong EU PV data are parameterized by (Vartiainen et al 2019).

6 (BNEF 2020b) forecasts slightly higher auto sales starting in the late 2020s than in 2017, but agrees oil-fueled car sales peaked in 2017. (IEA 2020c) projects constant or slightly rising 2019–20 EV sales despite ~15% lower total auto sales. Irle (2020) reports 1H20 global sales fell 28% versus 1H2019 for all light-duty vehicles but only 14% for electrics, and projects total 2020 plug-in sales of 2.9 million. Through August 2020, global plug-in new registrations (67% EVs) of 1.44 million were up 58% year-on-year and were 3.8% of the 10%-smaller auto market (Kane 2020), (KPMG 2020) foresee endures drops in US driving.

7 BP’s 2019 mainstream forecast referred to in this paper (BP 2019) was extensively revised a year later (BP 2020).

8 Excluding structural and behavioral shifts (Denning and Sutherland 2020). An attractive example of even more radical (8×) efficiency was recently flight-tested (Otto Aviation 2020), Lovins’s October 2020 overview of heavy transport and process heat savings is currently in peer review for 2021 publication.

This market survey shows recently financed Chinese and Indian PV projects soundly beating existing coal plants. Data from 17 000
2024. Even without adopting such dramatic efficiency
potentials, Shell’s and BP’s CEOs, like Moody’s Ana-
lytics, Boston Consulting Group, Den Norske Veritas,
Bloomberg New Energy Finance, and others (foot-
note 4 supra), warn 2019 oil use might not return,
locking in profit-killing structural overcapacity.
Capital markets avidly sniff out such disruptions:
Investors win by catching the scent early and piv-
oting swiftly. If capital markets think you are in or even
headed for the toaster, they do not wait for the toast
to get done before they disinvest in your old industry
and reinvest in its successor. ‘Reflexivity’ then makes
the cost of capital rise for declining industries and
fall for rising industries,9 further speeding change.
Before the pandemic, investors holding $14 trillion in
assets were fleeing fossil fuels, and the energy sector,
the worst-performing over the past decade, dwindled
7× (then 10×) from its 28% 1980 share of the S&P
500 index, falling behind utilities. Now Pope Francis
urges divestment. Reallocating portfolios’ disinvest-
eted capital to competitors—the energy sector’s fast-
growing renewables, with superior returns at lower
risk (IEA and CCFI 2020), or to EV, ridehailing, and
energy efficiency firms—saves still more fuel, reinfor-
cing disinvestment. Such turbulence will burst some
bubbles, but two decades’ Internet evolution suggests
that superior fundamentals generally prevail.

The coal industry’s value has collapsed and its
cloak shriveled since its 2013 peak. Since 2011, its
market value fell 75% globally (BWCAL index) and
99% in the US (DowJones US coal index). Now oil
and gas show similar dynamics (Buckley and Trivedi
2020). Decapitalizing fossil-fuel incumbents
and reinvesting in insurgents weakens incumbents’
financial and political power. Incumbents become
less able to protect their rents,10 buy lobbyists and
politicians, defend fossil fuels’ $478b/y 2019 sup-
ply and use subsidies,11 and block competitors.12
This self-reinforcing devitalization speeds the talent
exodus that made Saudi Aramco’s CEO in February
2019 decry a ‘crisis of perception’ about falter-
ing demand prospects, endangering recruitment and
finance—not long before lower demand halved oil
prices.

Reinforcing this spiral (Bond Vaughan and Ben-
ham 2020), a 1.5 °C climate trajectory could knock
≥$70 trillion off the fossil-fuel reserve values that
underpin incumbents’ balance sheets and petrostates’
political economy. Another $10 trillion of fixed assets
to supply and $22 trillion to burn fossil fuels also face
disruptive forces. A fourth of global equity and half
of non-financial corporate bonds are in sectors at risk
from clean energy alternatives, with banks exposed
to even larger unlisted debt. Having lost trillions on
European electricity, US coal, autos, turbines, and
oil exploration, investors must now worry about vul-
nerable pipelines, LNG, and plastics. Goldman Sachs
expects more 2021 investments in renewable power
than in oil and gas drilling.

These trends are inexorably underway. In 2012,
when Apple displaced ExxonMobil as the world’s
most valuable public company, four of the top ten
firms were oil companies. By mid–2020, none were,
Apple was worth more than the world’s top 16 listed
hydrocarbon companies combined, and ExxonMobil
was exiting the 30-firm Dow Jones Industrial Average.
By October 2020, ExxonMobil had lost two-thirds of
its nominal value in 7 y—$150b in 2020 alone—and
was worth less than US renewables leader NextEra
Energy.

3. Solving two giant problems at once so
they cancel, not multiply

As oil demand arguably peaked in 2019, skittish
energy investors were eyeing the exits. In 2020 they
have stampeded (Buckley and Trivedi 2020) as accel-
 erating collapse swelled tectonic stresses into ru-
putures, sharpening political choices in the simulta-
 neous pandemic. Using stimulus funds to bail out
the highest-cost fossil-fuel firms—notably frackers
whose business model, says Bloomberg’s Liam Den-
ing, is ‘spending money you don’t have on pro-
ducing energy nobody wants’—would make them
wards of the state, socialize unpayable costs, incin-
erate capital, and prolong futility. By delaying eco-
nomic rationalization, it would leave unsolved the
sector’s structural overcapacity. Yet some govern-
ments in thrall to powerful, desperate incumbents still
favor this self-defeating course.

Building productive recovery on solid competi-
tive foundations requires investing instead in the
market victors—modern renewables plus efficient
energy use, the backbone of the energy savings
that delivered three-fourths of global decarboniza-
tion in 2010–16 (IEA 2017 p 13). Does a post-
pandemic world aspire to restore the old or to enable
the new, ‘build back better,’ and as Denning says,
‘move fast and fix things’? Will emergency economic

9 In 2006–18, the cost of equity capital for the fossil-fuel sector rose
by 3 percentage points while for the renewables sector it fell by 3
percentage points (IEA 2019). Oil and gas investments are paying
up to 20% for capital, versus 3%–5% for renewables (FT Editorial
Board 2020)—the latter range validated by IEA (2020a §6.3.6
and table B.2(a)). ‘Reflexivity’ was popularized by financier George
Soros.
10 ∼2%–3% of GDP (Bond Vaughan and Benham 2020, p 13).
11 OECD/IEA (2020) (finding that outside the road sector, fossil
fuels are taxed at only ∼$38/CO₂), IEA (2020a, 2020c), IRENA
(2020b). In contrast, of $0.4 trillion of G20 energy stimulus fund-
ing from 1 March to 26 October 2020, 54% went to fossil fuels, led
by $72 billion (a 72% share) in the US (Wärtsilä Energy
2020). The President-Elect of the US has vowed to desubsidize US fossil fuels,
specifically oil.
12 (Bond et al 2020) document this paragraph and previous state-
ments about capital flight. Illustrating this trend, in 2020 BP’s au-
ditor challenged its long-run oil price as inconsistent with Paris
Agreement targets, so a 30% price cut plus costlier carbon triggered
a $13.7b writedown. Shell wrote down $22.3b. In nine months,
seven major oil companies wrote down $87b (Ambrose 2020).
rescue and recovery investments to sustain lives and livelihoods—$10 trillion so far, perhaps $20+ trillion ultimately—‘lock us into a fossil system from which it will be nearly impossible to escape’ or set ‘the global economy on a pathway towards net-zero [carbon] emissions’? The latter—a combined solution like Europe’s €1-trillion Green Deal—better serves immediate imperatives too, providing severalfold more jobs, higher economic and job multipliers, and far greater co-benefits, notably in health and security (Hepburn et al. 2020). It especially cuts costs for the ~80% of people whose countries import net fossil fuel. Great stress may now enable great change if stronger governments and weaker fossil-fuel firms can tilt the balance from the few and rich toward the neglected and impatient many and poor.

Expanding energy efficiency needs not only public investment but also new policies and strategies, public and private, including desubsidization, all-resource competition, transparency, internalization, barrier-busting, innovation, financing, marketing, streamlined installation, and retiring or retrofitting inefficient old devices (National Academies 2009, Harvey Orvis and Rissman 2018). Novel policies may add, e.g., fee–bates for more-efficient buildings and vehicles, performance-based design fees, EV smart-charging infrastructure, rewarding utilities for cutting bills not selling more energy, and size-based efficiency metrics to decouple vehicles’ size from their mass.14 ‘Recovery packages that seek synergies between climate and economic goals have better prospects for increasing national wealth, enhancing productive human, social, physical, intangible, and natural capital’ (Hepburn et al. 2020).

Artful energy efficiency typically costs less than supply and modern renewables less than fuels, so both should cut a clean and resilient energy system’s investments and operating costs. A proven agenda (Lovins 2011, Hepburn et al. 2020) ripe for wide adoption emphasizes building retrofits with linked reskilling, natural-capital investments, and clean R&D. Less affluent countries prioritizing energy access and rural development may emphasize rural support for regenerative agriculture, ecosystem restoration, microgrids, and irrigation and household superefficiency (like Berkeley Lab’s 27-W appliance package that halves total capital cost). Saving electricity could displace up to about a fourth of global development capital by cutting power-sector needs (intensity ÷ velocity) by orders of magnitude. And for all countries, making efficiency bigger and faster could hugely increase its climate value.

4. Triggering capital flight sooner by speeding energy savings

Energy demand growth depends on GDP growth minus the drop in energy intensity. Between 2000–09 and 2010–19, this difference between two small numbers nearly halved, from 2.3%/y to 1.2%/y.15 Investor sentiment, hence capital flight’s tipping point, is exquisitely sensitive to the speed of reducing demand. Assets built now can commit huge CO₂ emissions over decades (Tong et al. 2019), so even modestly speeding capital flight from fossil fuels can disproportionately cut cumulative climate risk. Recovery investments in conventional energy efficiency could do that. Might market flips and feedbacks also harness even more-advanced energy efficiency to hasten fossil fuels’ demise? Such an opportunity is now emerging: speeding efficiency by novel design ideas that can save severalfold more energy, cost less, and perhaps spread faster.

For example, making pipes and ducts fat, short, and straight rather than skinny, long, and crooked can cut their friction by ~80–90+% (Stasinopoulos et al. 2009, chapter 6, Chan-Lizardo et al. 2011). Since motors use over half the world’s electricity, half to run pumps and fans, full adoption could in principle save about a fifth of the world’s electricity or half the coal-fired electricity, with typical paybacks <1 y in retrofits and instant in newbuilds. Yet no Integrated Assessment Model (Lovins et al. 2019a),16 government study, industry forecast, or standard engineering textbook includes this option (Lovins 2018), because it is not a technology but a design method, and design is seldom considered a scaling vector.

Such ‘integrative design’ (id.)—optimizing buildings, vehicles, factories, and equipment as whole systems for multiple benefits—can save severalfold more energy than previously supposed, plausibly rivaling all advances in efficiency technologies over the past decade or two. Thus a thermally passive building’s supersurplus, airtightness, etc., eliminate its heating system, saving capital cost that pays for those efficiencies. Yet no official source acknowledges the analogous whole-system design potential (id.) in automobiles (Lovins 2020b), heavy transport,

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13 Hepburn et al. (2020). See also Figueres (2020), Hammer and Hallegatte (2020), Hook (2020), and Andrijevic et al. (2020).
14 As adopted in the US. Using these and many other novel policy options (Lovins and RMi 2011), 2010 state-of-the-shelf technologies, deployed at historically reasonable speed, could support 158% 2010–50 US GDP growth, cut 2050 US CO₂ emissions 82–86%, and save $5t in net-present-valued private internal cost. With today’s lower renewable energy costs, 90%-noncarbon US electricity by 2035 could cost less than now and avoid $1.2t in externalities (Goldman School of Public Policy 2020).
15 Real GDP growth (World Bank, PPP) averaged 2.87%/y in 2000–09 and 3.00%/y in 2010–19, while primary energy intensity’s decline averaged 0.60%/y in 2000–09 and 1.79%/y in 2010–19, shrinking the difference from 2.27 to 1.21%/y. Intensity data, not weather-normalized, are from IEA (2020b) and prior editions.
16 The unexpectedly large practical potential for modern energy efficiency, especially from integrative design, is documented in Lovins (2018, 2020b). Even the pioneering highest-efficiency IAMs (Grübler et al. 2018, van Vuuren et al. 2018) reflect integrative design only in buildings.
or especially industry, where figure 1 illustrates its value in redesigning equipment and processes.

Integrative design generally needs less capital than conventional design. By bandwagon, learning-by-doing, and other established effects (Grübler Wilson and Nemet 2016), it may emulate renewables’ increasing returns (Lovins 2018). It is not yet a mature industry ready to receive much reallocated fossil-fuel capital, but can make all efficiency investments more attractive by saving more energy with less capital. It spreads differently than renewable hardware, and if made contagious by smart scaling vectors, might even spread faster, supercharging climate protection and speeding capital flight. This could help flip demand from post-pandemic growth to decrease, economies from struggling to competitive, and feedback circles from vicious to virtuous.

5. Might integrative design rival solar energy’s speed?

Decades of experience by a growing but still-small band of practitioners prove that integrative design can be taught, learned, and spread (Lovins 2018). Over a dozen scaling vectors—to ‘re-mind’ designers and installers, their software tools’ writers, their managers’ and purchasers’ executives, the rules and institutions that help shape energy demand—now await field-testing to learn rapidly how to shift this practice from rare to common. That requires displacing traditional design assumptions, rules of thumb, pedagogies, tools, and habits in millions of brains. Achievable speed is an empirical question and highly uncertain, but might massless ideas spread faster than scaling physical devices like solar modules?

Spreading potentially at the speed of YouTube and with network and viral mathematics, ideas as contagious as ‘bend minds, not pipes’ can infect by a mere phrase, like engineer Peter Rumsey’s advice to ‘Lay out supply pipes as if they were drains,’ or an image that engineers and installers will find startling and compelling (figure 2).

Changing pedagogy is slow, but virally spreading vernacular ideas that rearrange mental furniture can be nearly irreversible: few installers will readopt the old method, at least without wincing. Such unidirectional progress is emerging in urban and electricity-system design. If spread, it can be buttressed by norms, codes, standards, procurement rules, and performance-based design fees (National Academies 2009, Lovins and RMI 2011, Harvey et al 2018).

The literatures on scaling analysis and theories of diffusion, technology systems, and industry describe how technologies and infrastructures evolve amid complex rules and institutions. Integrative design seems different. German passive buildings spread by systematic design and construction training, component certification, test methods, and supportive financing and policy, but at root they are an idea—a novel way to design a normal-looking building so it needs no heating system, costs about the same to build, and delivers better comfort, health, and satisfaction. Can such ideas also transform big existing buildings? Encouragingly, America’s biggest landlord, the General Services Administration, doubled its retrofit programs’ energy savings in a few years by adopting ‘deep retrofit’ practices and goals. Leadership, demonstrations, internal training, and engaging outside designers to teach other actors triggered competition, making deep retrofit the best-practice norm. Similarly, technical workshops and notable projects quickly spread integrative design in complex but hypercompetitive industries like chipmaking and data centers (Lovins 2018). This suggests that the vital ‘middle-out’ role of professionals (Janda and Parag 2013) in enabling, aggregating, and mediating can
Figure 2. Piping is normally but mistakenly sized to optimize pumping energy without regard to pump/motor sizing and cost, and is laid out orthogonally (all at neat right angles with no diagonals). However, friction falls as nearly the fifth power of pipe diameter, while the cost of latter pipe rises as only about the second power of diameter. Thus big pipes and small pumps (upper image) and laying out pipes before equipment (lower image, eliminating many high-friction 90° elbows by staggering the brown chillers out of their traditionally straight row) can together cut friction and pump/motor sizing by an order of magnitude, with lower total capital cost. The pump on the right side of the upper image looks so small that a traditional engineer might think someone had slipped a decimal point, but it is all that the low-friction piping needs. The pump, too, is raised up on a plinth to meet the pipe, rather than conventionally dipping the pipe down to a pump sitting on the floor. Ducts offer similarly dramatic sizing and layout opportunities. These examples and images are courtesy of Singaporean master engineer Lee Eng Lock (李永禄) and are reproduced with his permission. His and the senior author’s practice confirms that just seeing such images can irreversibly transform how traditional designers and installers think. Once infected by this new thinking, they are free to start practicing and spreading it immediately.
diffuse design learnings rapidly both in and beyond the buildings sector. Conversely, adoption has been slow in ponderous, risk-averse, custom-bound sectors like hydrocarbons, automaking, and aviation that tend to subordinate, fragment, and outsource middle-out roles, but is emerging under competitive pressure.

Changing how design is done and taught is hard, because old habits are entrenched, and much of what spreads design ideas faster is poorly understood. Yet the new design thinking is exciting, memorable, simple, and conveyed by sticky, sweet, bite-sized stories. It is constrained by the effectiveness of its contagion and scaling models but not by physical logistics. Its spreaders can be collaborative, its drivers competitive, and its refinements rapid as it infects millions of ambitious minds. It can spread at the speed not of infrastructure but of social media and software, especially as design software adds coaching to apply it. It transforms existing design processes without needing extra hardware. Rather than adding new capital burdens, it saves investments already slated for disintegrated design—especially in nations like China and India, where fuel import dependence, deadly air pollution, and capital needs for development make it vital to build burgeoning infrastructure right, more easily than fixing it later. Such countries have legions of smart engineers (adding >1 M/y), strong technical training and data networks, most of the world’s growth in energy service needs, and high ambitions to leapfrog.

Hardly any literature directly compares the speed of spreading ideas versus scaling hardware, but a survey of energy-related diffusion (O’Sullivan et al 2015) valuably explores the importance of knowledge creation and application, especially in formative phases. The stigma of novelty can often be offset by the enthusiastic evangelism of ‘re-minded’ designers. Like the key criteria in technology diffusion, integrative design can often be spread by social media and word-of-mouth that network internal and external sources cross-polinated by change agents, exploiting contacts between clustered agents (id., Sprague 2017) to increase virulence. Integrative design often provides striking competitive advantage, and can be quickly tested, measured, and improved. Its generally lower upfront cost, higher profitability, and ability to pervade diverse sectors are the same attributes reportedly conducive to rapid spread of physical technologies (O’Sullivan et al 2015). Thus technology-based evidence that ‘transitions can happen fast when a novel, valued service is provided (high degree of relative advantage), service provision costs fall rapidly due to improved efficiency and economy of scale and learning effects (adoption efforts decline rapidly), and as a result, market response is vigorous’ (id.) implies an urgent need to test if integrative design can do the same thing, then focus policy and business attention on scaling it. The corresponding author aims to pursue such efforts at Stanford University, and invites advice and help.

6. Conclusions

The modern energy transition, especially if strengthened by targeted pandemic-recovery investments, could boost health, wealth, jobs, equity, and security. Its end-use efficiency component might be further sped by contagious integrative design. Other memes and practices, e.g. about keeping carbon where it belongs—in rocks and tilth, not air and oceans—could add contagions of their own. In all these shifts, tipping capital-market dynamics could help unlock a richer, fairer, safer, cooler world.

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ORCID iDs

Amory B Lovins ♦ https://orcid.org/0000-0002-6362-3526
Kingsmill Bond ♦ https://orcid.org/0000-0002-3501-6059

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