CCS: SITTING ON THE WRONG SIDE OF INNOVATION

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Proponents of carbon capture and storage tout the innovation and economic benefits that its deployment and diffusion would offer. In the U.K., the government is prepared to spend £1 billion in public funds toward a CCS demonstration project to show leadership in what it believes will be a critical feature in the world's collective carbon mitigation response, and therefore a strong money-earner for the country's scientists, engineers and technicians. In fact, the Department of Energy and Climate Change (DECC) forecasts an industry that employs 100,000 people and generates £6.5 billion in economic value by 2030 if all goes as planned. The recent history of CCS, though, shows that very little has gone as planned.

The promise to ride fossil fuel combustion from centralised energy plants - minus the carbon - far into the future hasn't come close to the reality. It's not for a lack of trying or public subsidy. The Zero Emissions Platform (ZEP), a European consortium of CCS well-wishers, states that over $26 billion in funding has been proposed by governments globally for large-scale projects. Yet for all these pledges, not a single utility-scale CCS plant is operating anywhere on the planet, though plenty have been cancelled or postponed. The U.K.'s signature large-scale project, Longannet in Scotland, met its demise this past autumn. In the United States, what was supposed to be the largest CCS demo in the world, was shelved last summer. The lead partner, American Electric Power, cited economics and regulatory uncertainty as the justification – even though the federal government planned to pick up half the tab. FutureGen, another U.S. government CCS programme that has gone in fits and starts for nearly a decade, hopes to have a project up and running by 2015. Mind-boggingly slow considering the government is fronting 75% of the capital cost.

There are many reasons why CCS has been slow to move from concept to application to maturity. In this, it bears resemblance to countless other technologies that struggle for early stage adoption. But as government has chosen to be highly vested in its outcome, it must be considered whether CCS bears the markings of an innovative technology or sector that justifies the push from the public sector (and resource allocation from the private). Governments, after all, uniformly cite innovation as one of the main drivers behind subsidy and partnership activities with business and technology. But if it's innovation that governments seek, they ought to look elsewhere. CCS' lack of progress and still distant timeframes to maturity stand in stark contrast to cost, efficiency and penetration figures from renewables. Looking at historical precedence in other sectors dulls the shine from CCS even further.

Finding the perfect innovation analogy to the energy sector generally and CCS in particular is hard, but transport might be a useful proxy. Like energy, the infrastructure that supports mobility is long-lived and delivered through a combination of public and private resources. Arguably, decisions by private end-users have been greater determinants in pushing new technology to the fore in transport. Perhaps this helps explain the relative constancy of the centralised fossil-fuel paradigm and few discernible changes bar efficiency improvements in generation over the past century – with nuclear as the one major exception. But if these end-user decisions are of such relevance, distributed renewable energy, coupled with various efficiency and demand-side measures, can usher similar transformative changes that have occurred in mobility and logistics.

A 1990 book by Arnulf Grubler, *The Rise and Fall of Infrastructures: Dynamics of Evolution and Technological Change in Transport*, traces the remarkable historical similarities and consistencies for technology and system substitution, irrespective of the transport system or whether at play in planned or market economies. Grubler shows that new technologies gain initial traction for reasons other than price, for example speed or efficiency improvements, or added functionality with reduced complexity. Gaining share initially in premium (less price sensitive) markets gives new technologies an opening to improve costs while supportive institutional arrangements relevant to its diffusion can take shape. The subsequent technological shifts, where a previous innovation is replaced by a newer one, follow certain dynamics. One is that the incumbent technology or system tends to reach a saturation stage (i.e. 90% of its total system size or market share) before being superseded. Whereas not all countries reach saturation within the same expansion cycle, the apparent congruence of the saturation periods of infrastructure growth and technological substitution in the transport sector is striking. The diffusion time for an emerging technology to go from early stage (i.e. 10%, the point at which its economic impact in terms of jobs and clusters is significant and that the technology is visible and clearly implement-able) to saturation was shown to be remarkably consistent whether the country was an early adopter or a laggard. For example, the timeframe was 47 to 57 years for railways in the countries sampled. Early adopters reach their saturation point sooner, but the overall time period in which the technology and system substitution occur remains reasonably constant.

Grubler's findings also suggest that being the lowest cost system, or producing in-system technological innovation, is not sufficient to maintain primacy. New technology innovation and changeover can still prevail. For example, for long-distance travel, railways continued to have lower passenger mile costs than the private automobile well into the 1970s, but this could not arrest the loss of market share since the railway system reached saturation in the 1930s. The personal convenience of end-to-end mobility and speed and comfort variables propelled private auto growth at railway's expense. Or similarly, the replacement of steam by diesel and electric locomotives after 1930 (a process that ranged between 12 and 16 years on countries assessed) showed that technological innovation within the system was not a sufficient brake against saturation and decline.

The pervasiveness of the centralised fossil-fuel infrastructure and penetration of new technologies, particularly in advanced economies, suggests that a saturation point may be at hand. If the threshold of ten percent cited in the Grubler book as the point where the push of new technologies forces old technologies to recede is assumed, the fossil fuel energy regime could soon peak. The U.S. Department of Energy reports that in 2009, 3.8% of global electricity generation came from non-hydropower renewable energy. If hydropower is included, the figure exceeds 20%. The view from individual countries – the leader or first-tier innovators, as per Grubler's analysis – shows where the peak may have happened. Wind energy as a percentage of domestic electricity supply has exceeded 10% in Denmark since 1999, reaching 22% in 2010[1]. In Germany, 2010 production from solar and wind combined met 8.2% of all domestic generation[2]. Solar itself is forecast to provide 10% of supply in Germany by 2020[3].

To draw further from the transport analogy, CCS might be commensurate with the railway's switch from steam to diesel / electric locomotion: beneficial, but insufficient to reverse the trend. But the analogy is ultimately less favourable to the energy sector. Diesel and electric locomotives still delivered cost and reliability efficiencies. CCS, however, layers cost and complexity in its purported innovation.

One of the biggest inhibitors to CCS deployment is its fuel penalty. It takes more energy input to create a commensurate output with non-CCS plants; estimates range from a 15 to 40 percent add-on. Therefore, costs are invariably higher, a fact that CCS proponents do not dispute. System complexity, too, is a weakness. Adding the pre- or post-combustion carbon separation technology to existing fossil fuel stations or new builds means more capital investment and operating functions at the plant. And still there's much more required to make CCS fulfil its purpose. Once separated, the carbon dioxide needs to be transported and injected to its end repository. True, there's some limited infrastructure available to move CO_2 for industrial purposes, and injection for enhanced oil recovery. But creating it anywhere near the scale that proponents suggest will be expensive. The financial uncertainty of just this element is acknowledged by the Zero Emissions Platform, whose 2011 report *The Costs of CO2 Capture, Transport and Storage* states that estimates for transport and storage costs vary by a factor of 10. The fact that the most voluminous repositories are the most distant and difficult to access does not augur well for costs on the low-side of the curve. And consider the scale: Professor Vaclav Smil of the University of Manitoba has estimated that sequestering a mere 1/10th of today's global CO2 emissions (< 3 Gt CO2) would need an industry and infrastructure that would have to force underground every year a volume of compressed gas larger than or (with higher compression) equal to the volume of crude oil extracted globally by the petroleum industry. Yet this infrastructure and capacity has been built up over a century of development.

Looking for other innovation analogies, the view from telephony – once a similarly entrenched and static utility - suggests CCS is not the innovation to bet on. Since the widespread dispersion of fixed telephone and electricity networks over the past century, tariff rates for both have dropped dramatically. But the cost trends over the past generation or two are divergent. As measured against the Consumer Price Index (e.g. the inflation rate) in the United States, both electric and telephone rates have risen less than the annual 4.1% CPI rate of change for the period of 1956 - 2006: 3.6% for

[1]Danish Energy Agency.

[2]German Ministry for the Environment and Reactor Safety.

[3]Bundesverband Solarwirtschaft e.V.

electricity but only 1.7% for telephone. More recently, though, telephone inflation has been negative – -0.3% for 1996 to 2006 - versus 2.5% for electricity[4]. Both sectors have liberalised, but only one has been fundamentally transformed by new technology and new entrants whose services are marked by their highly distributed nature, breadth of choice and multi-functional efficiency. Mobile / cellular communication's track from high initial costs to mainstream penetration on to massive diffusion shows an innovation arc unlike anything seen in the energy sector. Again, only the benefits and opportunities of distributed renewables and efficiency / demand management can approximate the analogy. More importantly, the communications revolution (telephony, coupled with personal computing) may both necessitate and enable a major shift in energy forecasting, production, and distribution.

The author and economist Jeremy Rifkin has theorised on the relationship between energy and communication regimes[5]. He posits that throughout history, the convergence and interrelationship between significant economic system changes alongside communication revolutions dramatically increases the demand for energy, and thus propels innovation in energy conversion and technology. Put very simply, these linked energy and communication trends shadow key historical economic milestones. The earliest agriculture surplus urban societies mastered innovative water conveyance while creating Cuneiform to coordinate and organise economic activity. Fast-forwarding several centuries, the printing press coincided with improvements in water-based energy generation, and mass literacy accompanied the development of steam power and the early industrial revolution. The second industrial revolution, powered by far more extensive fossil-fuel exploitation, matched the rise of the telegraph and telephone, railways and automobiles. Rifkin sees our current communication revolution and economic re-organisation as similarly demanding greater energy throughput to support it. But it cannot, he argues, be sustained by the existing energy paradigm. The history of these linked communication / energy step changes suggests a significant reordering in energy systems to match that in communications may be forthcoming. This, coupled with the scientific consensus for carbon reductions and the economic consequences of resource constraints (partly revealed in the shift to unconventional fossil energy reserves) points to the diffusion of renewables. In fact, the diversity of supply and distributed nature of renewable energy is symbiotic with emergent technologies driving the current communications revolution.

There are arguments that CCS is needed as a low-carbon fossil-fuel bridge until renewable technologies are ready to shoulder a bigger share of the generation portfolio. Technologically, there's no evidence to support the 'bridge' assertion. The past decade of CCS has delivered a few pilots in the tens of megawatts and some enhanced oil recovery projects – which, as a fossil-fuel extraction strategy hardly address the carbon mitigation basis for putting CCS out there in the first place - but

[4]All figures from US Bureau of Labor Statistics. Note that the cost of piped gas service has exceeded the inflation rate: 5.5% for 1956 – 2006, and 7.5% for 1996 – 2006.

[5]See, mainly, The Empathic Civilization (Polity Press, 2010).

little else. Rather, there's plenty of evidence of technological improvements in the renewables sector to show such a bridge is superfluous anyway. Between 1980 and 2010, solar has shown an exponential 7% cost drop year on year and there's no let-up in sight[6]. Efficiency improvements in wind energy, propelled by larger turbines, are also driving down the cost of generation curves. In fact, both technologies are pushing toward grid-parity, with a couple of years on either side of 2020 pegged at the point where the cost curves of these renewables and fossil generation cross. This same end-of-decade mark is pegged only for enough large-scale CCS pilots in place to return evidence on cost and efficacy in advance of a wider roll-out.

Theories of innovation and diffusion posit that it is never the technological advancement in isolation. The technology must be supported by organisational and societal changes. Here too, CCS is at best on par with renewables. Organisationally, the obstacles to CCS are myriad and run counter to any arguments for simplicity or efficiency. Socially, there are legitimate concerns about renewables, particularly wind installations. But these reservations do not connote an inherent bias toward fossil energy. Arguably people are by and large fuel agnostic, with their allegiance pledged to low-cost energy. And historically, this is something only centralised carbon-based energy could deliver. But CCS does not appear destined as a low-cost energy source. Acceptance for CCS, then, has to be predicated on a societal shift toward low-cost and low carbon energy. But when that shift occurs, the innovation head-start in technology and institutions / policy-setting of renewables will make CCS irrelevant.

Either renewables or CCS may initially cost more than the predecessor – system changes in transportation demonstrate low-cost is not the initial driver anyway – but only renewables offers convincing evidence for near-term price parity and long-term price decreases. Over the past decade, global wind generating capacity has been doubling every 3.1 years[7] and solar every 1.3[8]. If these two trends were to somehow continue, their combined output would meet the worlds entire projected energy demand by 2030[9]. That level of penetration is certainly beyond expectations, but ICT precedents show such momentous shifts are possible. In fact, using 1980 as the starting point, reaching that threshold by 2030 would effectively match the march toward saturation in railways. Countries that are past or well on their way to crossing the 10% renewables generation line offer lessons on societal expectations and institutional frameworks that are transferrable and scalable, in the same way that late adopters of transportation systems were able to replicate the transition of the leaders.

The Eastman Kodak company invented and patented the first digital photography, but are now operating under bankruptcy protection because they clung too hard to their base technology. The technology changeover and the decline of that firm's fortunes have been breath- taking and almost unimaginable in their speed and scale: in 2002, less than a decade after digital cameras first became widely available as higher-priced

[6]National Renewable Energy Laboratory of the U.S. Department of Energy.

[7]Global Wind Energy Council

[8]REN21, Bloomberg New Energy Finance

[9]Renewable Energy News, The Good News: Why Climate Change Doesn't Matter Anymore

and lower-performing options relative to film cameras, Kodak's market capitalisation exceeded $10 billion. Today, it is no more than 1/50th the size. Perhaps there's a cautionary tale for energy supply and its incumbent utilities that governments should take heed of. In the case of Kodak, they anticipated the innovation but failed to move to meet it. In fact, they doubled-down on their core technology. Low-carbon energy has also been anticipated and widely acknowledged as necessary. CCS, with its clunky add-ons to the existing system in an attempt to prolong the incumbent, seems the same sort of doubling-down and losing bet.

Through this lens of innovation theory and practice, CCS appears a rear-guard action by an outmanned army – aided and abetted by pliant governments. One might argue that government ought not to pick winners and losers and that the very broadest range of mitigation prospects should be considered and publicly supported. But this is naïve. Governments have only so much subsidy to go around, and anyway, the winners and losers are clear enough to anyone objectively measuring the science and technology. No doubt there's much to be done to move the cost and reliability of renewables toward the historic norms of fossil-based centralised energy: improved grid dynamics, dispatchability, and storage to name a few. Governments would be far wiser targeting innovations in these sub-sectors than prolonging outmoded incumbents.

Author

Matthew Ulterino holds a masters degree in urban planning from Columbia University. He is an independent consultant based in London who specialises in matters of energy efficiency, renewable energy and climate change in the built environment. In his work and writing, he advocates for low-carbon city and regional development premised on energy demand reduction and deployment of distributed renewable energy.