INTRODUCTION TO THE SPECIAL ISSUE ON INNOVATION

by

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INNOVATION IN ENERGY: EXPRESSIONS OF A CRISIS, AND SOME WAYS FORWARD

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ABSTRACT
Using academic, journalistic and statistical sources, this paper situates energy innovation in historical context before describing the current sclerosis of Western energy R&D. It explores how rising energy prices denote weak innovation, and how society's emphasis on green technologies, green subsidies and green jobs has effectively supplanted a rounded programme of innovation. The paper refuses to prefer one source of energy to another, suggesting that this is to ignore the potential for technological change. It treats the rebound effect as positive, delves into the limitations of energy efficiency, and gives even shorter shrift to energy conservation. The paper shows how energy innovation has become synonymous with risk, reviews failure in energy innovation, and attacks innovations around smart meters and the behaviour of energy users. We conclude by briefly inspecting the relationship between finance and energy innovation, and, throughout, suggest elements of a new political approach to the latter.

1. ENERGY INNOVATION IN HISTORICAL CONTEXT

Since the financial crash of 2008, world elites have been fixated on financial matters. However, both in America and Europe, a small minority of opinion-formers has emerged to suggest that the roots of the financial crisis originate not so much among banks and mortgage providers, as in declining innovation among manufacturers and service providers [1, 2, 3, 4]. In energy and elsewhere, innovations are not always positive – we will come to that. However, in both energy and beyond it, innovation is on the whole more talked about or hoped for than actually achieved or properly funded. This Special Issue of Energy & Environment therefore needs little justification. In the old days innovation in energy was understood as broad, deep and long-run technological change – change that would produce more energy more cheaply, and in a way that was easily available to more people. There is no need to be nostalgic for the old days, but the classical understanding of innovation in energy could do with restatement in terms relevant to the 21st century.

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In the past, real commitment to innovation – scientific, technological, institutional – has characterised not just the energy sector, but many others as well. Take, as an example, the rather special year of 1957.

In 1957, the American economist and, 30 years later, Nobel laureate Robert Solow published a key paper explaining how important technical change had been to the doubling in US gross output per man-hour, 1909-49. Though he was careful to say that "technical change" was a shorthand for any kind of change in the production function – "slowdowns, speedups, improvements in the education of the labour force… all sorts of things" – Solow determined that just 12.5 per cent of the doubling of US productivity was due to the increased availability of capital per head. By contrast, no less than 86.5 per cent of the increase was attributable to technical change [5].

Table 1. Some key Western innovations in and beyond energy during 1957

Industry	Innovation	Type of innovation
ENERGY		
Nuclear energy	First US plant, a Pressurised Water Reactor, Shippingport, Pennsylvania	Technological
	First federal radiation regulations become effective in the US [6]	Scientific, regulatory
	Formation of the International Atomic Energy Agency	Institutional
	Formation of Euratom	Institutional
Climate change	Revelle and Suess paper on CO_2 exchange between the atmosphere and the oceans [7]	Scientific
BEYOND ENERGY		
Molecular biology	Crick speaks and writes on his "Central Dogma" [8]	Scientific
Materials	Theory of superconductivity [9]	Scientific
Optics	Gould invents the acronym LASER [10]	Technological
Computer software	Fortran programming language	Technological
Airliners	First flight of Boeing 707 jet	Technological
US Defence	Creation of Defense Advanced Research Projects Agency (DARPA)	Institutional

Solow's paper proved of monumental significance to post-war theories of economic growth. But it was more than that. The author's endorsement of technical change was part of a wider drive, in the middle of the 20th century and, importantly, in the middle of the Cold War, to recognise the potential of technological innovation. In Table 1, on the previous page, we list some of the innovations that, in the West, emerged around energy and other industries in that year that Solow published.

As the table hints, in 1957 there were few easily detectable major innovations in oil, gas and renewable energy. Moreover since the mid to late 1970s surveys of and experiments with shale gas and other kinds of "unconventional" fossil fuels have born fruit [11]: in this arena, it has been proved that significant innovations in energy are still possible in the second decade of the 21st century. However, the pace and profundity of innovation in 1957, shown in the table, was by no means a fluke. In the Soviet Union, the satellite Sputnik was launched in 1957; in America the integrated circuit was developed in 1958 and, more modestly, the tungsten-halogen lamp patented in 1959; around the world the wearable and implantable heart pacemaker was developed in 1958. In biomedicine the first 3D structure of a protein, myoglobin, was outlined in 1958, and in energy, in the same year, the US launch of the Vanguard 1 satellite saw the first use of solar cells outside toys. After that many other significant innovations, across a whole variety of sectors, followed for several years.

Can we really say that we are in a similarly dynamic period today? There are important breakthroughs, such as CERN's finding of the Higgs boson, the successful landing of the space vehicle Curiosity on Mars, and advances in DNA sequencing – though all of these have been quite a long time coming. However if we examine statistics of energy R&D today, the impression is not so much one of delay, as of outright sclerosis.

2. THE SCLEROSIS OF WESTERN R&D

A glance at some of Europe's leading energy suppliers certainly confirms that contemporary funding for R&D is very low. A majority of European energy suppliers spend well under one per cent of their revenues on R&D – that is, what are termed their *research intensities* are pretty poor:

Table 2. Research expenditures and research intensities of some leading European energy firms, 2010 [12]

Firm	R&D spend, €m	R&D as percentage of sales
Shell	760	0.3
Total	715	0.4
BP	581	0.3
Areva	520	4.7
EdF	486	0.7
Vestas	358	5.2
RWE	261	0.5
GDF Suez	222	0.3
ENI	221	0.3
Vattenfall	208	0.9
Iberdrola	130	0.4

In fields such as IT, or pharmaceuticals, research intensities of between five and 15 per cent are more the norm among large companies.

Since the 1980s, "R&D in energy has declined by two-thirds", in the broad soundbite of Maria van der Hoeven, executive director of the International Energy Agency (IEA) [13]. More accurately, budgets for research, design and development (RD&D) over the period 1980-2010, denominated in millions of 2010 dollars, have fallen:

Table 3. IEA member states' budgets for energy technology research, design and development (RD&D), 1980-2010, in constant 2010 dollars, million, by region [14]

Region, Fuel source	**1980**	**1990**	**2000**	**2010**
US and Canada				
Nuclear	3788	1533	429	1192
Fossil Fuels	2089	1533	328	897
Renewable	1648	185	299	1482
Energy efficiency	739	335	731	1492
Total	9725	4374	3156	5920
IEA members, Europe				
Nuclear	4981	2148	1515	1310
Fossil Fuels	812	363	165	553
Renewable	656	479	403	1330
Energy efficiency	529	425	300	1291
Total	7468	4160	2859	5262
Japan, Republic of Korea, Australasia				
Nuclear	2696	3089	3154	2898
Fossil Fuels	558	515	269	639
Renewable	292	165	217	492
Energy efficiency	122	34	731	522
Total	3847	4010	4725	5032
IEA members, World				
Nuclear	11465	6770	5098	5400
Fossil Fuels	3459	2411	762	2089
Renewables	2596	829	919	3304
Energy efficiency	1390	794	1762	3305
Total	21040	12544	10740	16214

The situation does not appear quite as grave as Maria van der Hoeven suggests, but it is grave enough. In constant 2010 dollars, member states of the IEA in the Americas, including the US and Canada, have lowered their expenditure on the totality of energy RD&D by about 40 per cent, 1980-2010. And this has happened despite the growth in GDP over that period. Among European members of the IEA, a group that embraces most countries in Europe as well as Turkey, the decrease in the totality of energy RD&D is about 30 per cent. Worldwide, the funds mustered to perform RD&D in the fossil fuels sector are weak, even if they have revived over the period 2000-2010.

Among IEA members in *Asia and Oceania*, which amount to Japan, the Republic of Korea, Australia and New Zealand, total energy RD&D has grown in what appears to be a continuous manner over the period 1980-2010 – and spending on nuclear RD&D has for many years been buoyant. But on *both sides of the Atlantic*, patterns of expenditure among IEA members show important distortions:

1. Nuclear RD&D is right down
2. Expenditure on renewables RD&D was, in 2010, marginally higher than that on nuclear in both IEA Europe, and much higher in North America
3. For the year 2010, lumping together RD&D around renewable energy with RD&D on measures of energy efficiency makes the aggregate of "green" RD&D much bigger than the aggregate of RD&D in nuclear power and fossil fuels
4. It is the aggregate of green RD&D that, over 2000-2010, has lifted Atlantic, European and world IEA members' total expenditures on energy RD&D back to levels that begin to approach those of 1980s.

Of course, with both corporate and national sums spent on energy R&D, there is no need to suggest that, say, doubling expenditures will double the amount of innovations that emerge. It is in the nature of research that one cannot predict outcomes. Nevertheless, the overall decline of North American and European energy R&D must give grounds for concern.

It is here that the paper by Hore-Lacy in this Special Issue is so valuable. In a comprehensive manner, it makes clear that, despite the political reversals suffered after Fukushima, nuclear power still has a whole range of new technical avenues to explore. Around the enrichment of uranium, the design of reactors and of fuel, and the recycling of used fuel, many new paths of technological progress are available.

When people write or speak of "nuclear power", it is often forgotten that, though fission is a singular enough principle in terms of physics, the different ways of realising that principle in practice are very numerous. Today's "preponderance" of pressurised water reactors (PWRs), in the words of the pioneering nuclear scientist Alvin Weinberg, grew out of a relatively arbitrary choice made from a long menu of options: "I have calculated that", Weinberg wrote, "if one calculated all the combinations of fuel, coolant, and moderator, one could identify about a thousand distinct reactors". Once PWRs gained a foothold, Weinberg continued, "other possibilities were pre-empted because their pursuit was simply too expensive" [15].

If the political will is summoned, then the money to explore those other innovation possibilities can be found. Indeed, there are more options available than ever before.

For instance: a patent has been filed for Super X Divertor, a means of making a tokamak nuclear fusion reactor more compact, and therefore more easily able to fire neutrons at reactor waste, on-site, in a way that reduces the typical radioactive half-life of a waste product from 10,000 years to just a few decades [16].

3. RISING ENERGY PRICES AS A SYMPTOM OF WEAK INNOVATION

Technological progress is no longer the main event in energy today. Even a relatively optimistic US energy specialist, who looks forward to "a Moore's Law equivalent in energy", is forced to note:

> *"Most daunting, the expectations that drive the majority of energy investment today – including the assumptions of all-important institutional investors – focus not on technological progress, but on such external factors as the price fluctuations of oil, reserve replacement ratios, and government regulations such as carbon taxes or NIMBY ('not in my backyard') restrictions"* [17].

In fact today's *obsession with energy prices* goes beyond just the oil industry. States, the media and every kind of energy supplier wrangle over prices and tax regimes. Subsidies have price tags attached. EU Directives range from feed-in tariffs to green taxes. Few trust markets to deliver the right prices; market failure is widely acknowledged, making state intervention around prices widely accepted. The most obvious, if discredited example: the price now attached to carbon through the European Union's Emissions Trading Scheme.

It is important to understand this point about the state. Instead of Schumpeterian "creative destruction" among rival firms and rival technologies bringing about lower costs in the energy sector, lowering or at least checking prices is now seen as the business of the state. Official wisdom clearly sees both government fiat and the price mechanism, or price signals, as powerful tools for the application of renewable technologies, even if not for innovation in those technologies. But do regimes of price control, tariffs, taxes, subsidies and other, non-price targets, too, really encourage fast, effective innovation in energy technologies?

Perhaps some of officialdom's romance with the price mechanism as a lever for innovation follows from energy's special characteristics. In gas and electricity, products lack differentiating features and benefits. As a result, price remains very prominent. Yet when we look at the actual record of energy prices in, say, the UK, it's clear that government measures around prices have failed to stem inflation.

That is interesting. Other things being equal, one might expect technological innovation in energy to bring about increases in productivity, and therefore decreases in the price of any unit of energy output. Yet in the UK, as in other parts of the world, energy prices are rising. Some of that rise may have to do with rises in the price of fuel (especially gas), or of labour in energy industries. But also to be considered, as we have seen, is that R&D in energy is weak, and that innovation in energy has not achieved the quantum leaps in performance that have characterised innovation in IT. As a result, the inflation of energy prices can all too easily reflect, at least in part, weak investment, weak productivity rises and weak innovation.

The UK's belated and intense commitment to renewable energy may have lent impetus to upward movements in energy prices. The relative expense of renewable technology as a means of generating energy is also reflected in international price comparisons. The EU, for example, is commonly acknowledged to have among the world's most aggressive programmes of support for renewables. Is it just a coincidence that energy prices in the EU are also among the world's highest?

It is true that the price of natural gas in the US has dropped precipitously since the advent of shale gas – indeed, prices are the lowest they have been for 10 years. However, Peter Voser, the CEO of Shell, is not alone in believing that the long-term pricing outlook for natural gas "remains strong", as – in his account – Asian-Pacific nations switch from powering their industrial plants with oil to doing the same with gas [18]. What is all too easily forgotten in such a broadly supply-and-demand perspective is how technological dynamism in the gas industry could, once the shale gas fillip is over, *go on* cheapening the cost of gas. The Commentary contributed to this Special Issue by SUBSEA UK gives evidence of some of the advances already achieved – not just in gas, but also in oil. If such advances are more widely defended, indeed, the world will no longer have to prepare for rising gas prices as just one more symptom of weak energy innovation.

4. "CLEANTECH", PRICE SUBSIDIES AND "GREEN JOBS", NOT BROADER INNOVATION

Where has the sclerosis of energy R&D, along with its the inflationary consequences, come from? Some of the explanation lies in the tightfistedness that surrounds general R&D nowadays. But there are a number of other causes of R&D sclerosis that relate specifically to energy – causes to which we now turn.

4.1. Much of cleantech is low-tech

In the first place, innovation in energy is today broadly subordinated to lowering carbon emissions, or "cleantech". That can only narrow opportunities. For proof, look at how the management consultants McKinsey go about what they call "carbon abatement". They write:

> *"More efficient lighting (particularly compact fluorescent lightbulbs) and higher efficiency standards for appliances are the low-hanging fruit in the residential sector: they require little capital and pay back their costs quickly"* [19].

Now whatever we might feel about energy efficiency (see section 5.2), it is clear that there is not whole lot of technology in the politically prominent residential branch of cleantech. Despite the sums recently spent on energy efficiency, especially in the West (Table 3), improvements in lighting, appliances and insulation, while very proper, are likely to embody innovations that are relatively modest. Almost by definition, McKinsey's "low-hanging fruit" is not particularly R&D-intensive. Indeed a search of *McKinsey Quarterly* brings up no fewer than 10 mentions of its fruity phrase across all fields of enquiry – a telling pattern from a firm reputedly committed to innovation. One of those mentions is by Al Gore, who says, about energy:

> *"The demand side, we also think, is an underappreciated opportunity. The efficiency of buildings – insulation, specifically – is low-hanging fruit in terms of economic opportunity"* [20].

In terms of innovation, the Goresque drive to cut carbon means taking the line of least resistance. Instead of arduous but ultimately groundbreaking R&D, we are offered just the opposite of what John F. Kennedy said in the famous speech in which he announced a drive to put a man on the Moon:

> *"We choose to go to the moon. We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too"* [21].

It is not necessary to applaud JFK's every act to recognise that R&D and innovation in energy, like R&D and innovation elsewhere, is about doing things not because they are easy, but because they are hard. Yet surmounting difficulty is not the zeitgeist in energy today. Indeed Gore is entirely wrong. The demand side with energy, which is inherently light on R&D when compared with the supply side, is not "underappreciated". In today's public discourse it is pretty much, next to energy prices, the only game in town.

Logically, of course, the single-minded quest for cuts in carbon should mean a stress not just on renewable, low-carbon energy supply, but also on nuclear power. However, in practice the stigma surrounding nuclear power has ensured that, in the contest between the two, renewables have lately, in the West, had the upper hand in terms of R&D. And what about fossil fuels? Here, to be fair, many carbon-conscious authorities have given a rhetorical commitment to carbon capture and storage (CCS). Yet this technology has only recently been granted some of the R&D boost it really requires. In Britain between 2004 and March 2009, for example, the last Labour administration invested the grand sum of £6.4 million in R&D around CCS [22].

4.2. Price subsidies ignore R&D

When mania about energy prices is combined with mania about carbon, we reach another unpalatable result. For the past several years, European governments, ever anxious to set the rest of the world a moral example through their conduct around carbon emissions, have spent enormous sums to subsidise renewable energy. Yet as the vivid papers in this Special Issue by Whitmill and Standish show of the UK and Italy respectively, the results in terms of innovation have not been pretty. Subsidies have incentivised renewable energy suppliers to deliver just a lot of installations of the same old technologies.

It is hard to work out how subsidies for renewables compare with those for nuclear and fossil fuels. Subsidies for nuclear power may or may not reflect the cost of decommissioning end-of-life plant. Nearly all the subsidies for fossil fuels are made in developing economies such as Iran, Saudi Arabia, Russia and India. Nevertheless, the

IEA is probably right to suggest that subsidies for fossil fuels are much larger than those for renewable energy. Table 4 gives IEA estimates of what are, presumably, world totals of subsidies:

Table 4. IEA estimates of energy subsidies in 2010, by energy source, billions of nominal dollars [23]

Oil	193
Gas	91
Coal	1
Fossil fuel-based electricity	122
Total fossil fuels	409
Biofuels	22
Renewables-based electricity	44
Total renewables	66

While its decarbonising instincts force it to inveigh against fossil fuel subsidies, the IEA misses the point. In a special box devoted describing different kinds of subsidy, the IEA carefully distinguishes between consumption subsidies, aimed at lowering prices for consumers, and production subsidies, aimed at raising prices for producers. Also, the IEA mentions subsidies to renewable energy "technologies – some of which are still in the early stages of their development – to improve their competitiveness"; and it recognises that if subsidies are not "well-designed and properly targeted", that "can lead to an inefficient allocation of resources and market distortions by encouraging excessive production or consumption" [24]. Yet throughout its 33-page chapter on subsidies, the IEA at no point discusses, still less endorses, state support for energy science and technology. Debates in energy revolve very much around prices; energy subsidies revolve very much around prices; IEA "analysis" of subsidies falls into the same pattern.

By failing to ask whether state subsidies should focus on R&D, the IEA, like both statist supporters and free-market critics of price subsidies, pushes energy innovation on to the back burner. Similarly, the Conservative Party – the main component of the UK's coalition government – is reportedly split

> *"between green modernisers, those worried about the cost of subsidies and back-bench MPs angry about the blight of wind farms in their constituencies… [A] source said there would be a drive to reinvent the Conservatives' green agenda as a pro-business policy that will help boost growth and create jobs.*
> *"The Department of Energy is led by Ed Davey, a Liberal Democrat, who won a battle against [Conservative Chancellor] George Osborne to stop deep cuts to green subsidies this year. In return, the Chancellor introduced tax breaks for the oil and gas industry, including new measures to help controversial "shale" extraction"* [25].

What strikes here, and what it might be wise to highlight, is not just official confusion around energy policy, but the complete absence of R&D from the discussion.

4.3. Energy initiatives prioritise jobs, not productivity: the case of shale gas

In most sectors of industry, there is at least an inchoate drive for increases in productivity. However with energy generation and transmission, the task in hand is rarely understood as replacing labour. Instead, it's thought that the purpose of initiatives in energy is to create more jobs. In its reference to reinventing the green agenda for the UK, the quotation above already hints at this. But let us now turn to the US.

The Great White Hope among American energy-makers and free-marketeers is shale gas. But gas of a wider provenance than shale also figured in Barack Obama's 2012 State of the Union address. Obama said:

> *"We have a supply of natural gas that can last America nearly 100 years. (Applause.) And my administration will take every possible action to safely develop this energy. Experts believe this will support more than 600,000 jobs by the end of the decade"* [26].

This ambition for 600,000 jobs "supported" by natural gas is worth interrogating. Obama's reference to safety strongly suggests that he was not just talking about natural gas, but specifically shale gas. That, after all, is extracted by the hydraulic fracturing of rock ("fracking"), a technique whose safety is controversial. The experts to whom he refers probably consist of the Colorado information provider IHS Global Insight. Its 2011 report on the economic and employment impact of shale gas in the US, prepared for America's Natural Gas Alliance (ANGA), estimates that by 2020, shale will take 50 per cent of natural gas production, up from 34 per cent today [27]. But it didn't say what Obama was all too easily interpreted as saying – that getting hold of *shale* gas would employ getting on for two-thirds of a million Americans by 2020.

Table 5. Projection of jobs created by US shale gas, by industry, 2020 [28]

	Direct	Indirect	Induced	Total
Agriculture	0	2,796	11,582	14,378
Mining	122,071	10,501	1,324	133,897
Construction	42,130	28,938	4,941	76,008
Manufacturing	66,679	56,523	27,200	150,401
Transport and utilities	12,790	35,474	28,082	76,346
Retail & wholesale	0	31,972	101,063	133,035
Services	5,052	198,514	323,755	527,321
Government	0	5,164	6,791	11,954
Total	**248,721**	**369,882**	**504,738**	**1,123,341**

So Obama's figure of "more than" 600,000 natural gas jobs in 2012 appears to come from adding, to just under a quarter of a million direct jobs in shale gas facility construction, on-site manufacturing and mining, more than a third of a million indirect jobs that are "supported" by such activities – the bulk of them being in retail, wholesale and other services, which are typically labour-intensive.

Perhaps adding in indirect jobs to the reputed shale gas jobs bonanza is fair enough. In the car industry, for instance, many jobs totals include staff in components, showrooms and repair. But if a new car assembly line is established, everyone knows that, though the line will have new jobs on it, it will be highly automated. And a high level of automation should be true, and is true, of a new, operational shale gas well – and indeed of every sensible energy innovation. Society should not expend a lot of labour around energy; instead, minimising labour around energy should make it as forgettable as, say, the act of breathing.

In US gas as a whole, the "rig count" has fallen by more than 70 per cent since 2008, while production is at a record high [29]. With shale, fracking has become more sophisticated, and horizontal wells have extended from 300m to as much as 5000m [30]. The disassembly, movement and reassembly of rigs has speeded up. How credible, then, is the hoped-for 600,000 jobs around natural gas? Here are some comparisons:

Table 6. US energy jobs in perspective: percentage composition of primary energy production, by source, 2011; numbers and projected growth in general and energy jobs, thousands, 2010-20

	Percentage of primary supply [31]	**Jobs, thousand**	
Percentage of primary production, 2011 and employees, thousands, 2009-2011			
Nuclear power, including plant design and components firms	11	120	[32]
Coal mining	28	86	[33]
Oil and gas extraction	15 and 30	163	[34]
Employees in key energy sectors, thousands, 2010			
Nuclear power reactor operators [35]		6	
Power plant operators, distributors, and dispatchers [36]		56	
Electric power generation, transmission and distribution [37]		396	
Job growth in key sectors, 2010-20 [38]			
Health care and social assistance		5600	
Professional and business services		3800	
Construction		1800	
Retail		1800	
State and local government		1600	
Leisure and hospitality		1300	
Education		800	
Manufacturing		–73	
IHS projections for shale gas: direct; both direct and indirect [39]		**100; 260**	

If IHS's projections for the sum of direct and indirect jobs in shale gas in 2020 are right, that total is half as big again as the entire headcount occupied making electricity in the US – a remarkable feat. On the other hand, the growth in total and especially direct shale jobs over the period 2010-20 stands as nothing against the truly enormous jobs growth projected for all kinds of services.

But more importantly, why would anyone want to create so many jobs around gas? Of course, the scale of unemployment in the US is disastrous. But it is not the responsibility of shale gas, or of any kind of energy supply or transmission, to create hundreds of thousands of jobs. Rather, it is the responsibility of energy-makers to develop, through innovation, the most advanced, cheap and forgettable forms of energy output. *Drilling* for shale gas is certainly labour-intensive compared with traditional ways of drilling for oil or gas. As *Fortune* puts it, "rather than poking a hole in a big reservoir and letting the crude flow, shale development requires repeated drilling and fracking to unlock gas from new corners of a play" [40]. But once this work is complete, the output payoff for a shale well's *operations* is a lot higher than that for a natural gas well's operations. Here's how IHS Global Insight explains the difference:

> *"Because unconventional production techniques allow such a broad range of source rock to be accessed by a single well, the productivity of shale gas wells is very high, with typical initial production (IP) rates of 3 million cubic feet (MMcf) per day or higher, compared with 1 MMcf per day or less for a conventional gas well. As a result, although a shale gas well costs several million dollars to drill and complete, its full-cycle cost per unit of gas produced is much lower than for a conventional well. IHS ... estimates that the full-cycle cost of shale gas produced from wells drilled in 2011 is 40-50% less than the cost of gas from conventional wells drilled in 2011"* [41].

Right now there is a jobs boom, of sorts, around shale gas. But these jobs include the temporary, indirect jobs created around "set-up": jobs among gas extraction equipment manufacturers, and among service firms in procurement and construction and so on. Jobs in Texas that have caught the attention of *Fortune* also include what IHS Global Insight calls "induced" jobs: those created in food services for shale gas workers, for instance [42]. But once shale gas operations are up and running efficiently, those jobs will decline. Then, if gas ever manages to displace coal and oil in America's ranking of primary energy sources, it will strip jobs out of those two sectors. Coal and oil may not decline absolutely, but they will be forced to become more productive in order to compete. It would be idle to deny this.

When we look at the tables above, it's clear that though shale gas extraction is apprehended as a major source of jobs, it is set to be too productive, in terms of output per head and thus output per man-hour, for it to be a major job creator. In energy as elsewhere, innovation can create new industries, and thus new jobs. But as innovation in a new industry continues, productivity rises and, eventually, jobs decline.

By talking up jobs in energy, it is easy to forget all about the role of innovation there.

4.4. Energy initiatives prioritise jobs, not productivity: the case of green jobs

Back in 2009, Greenpeace UK and London's Institute for Public Policy Research (IPPR), a Labour think-tank, hoped that offshore wind in the UK could provide 23,000 -70,000 jobs, with a capacity of 14-33GW, by 2020. However, when the IPPR reviewed the US experience with green jobs more recently, it was forced to conclude that energy efficiency schemes have "struggled" to create green jobs, "both in quantity and quality" [43]. The IPPR drew upon research by the Blue Green Alliance in the US. That research shows that, by December 2010, most of the jobs created through the $93bn obligated to green economic activities under the American Recovery and Reinvestment Act (ARRA) of 2009 were in construction:

Table 7. Impact of ARRA green investment on US jobs, by broad industry, end 2010 [44]

Industry	Direct	Indirect	Total
Natural Resources and Mining	4,411	8,765	13,175
Construction	259,062	2,490	261,552
Manufacturing – Total	20,769	56,092	76,861
Wholesale Trade	0	17,255	17,255
Retail Trade	0	23,586	23,586
Information	11,347	11,965	23,312
Financial Activities	1,419	15,413	16,832
Professional and Business Services	19,081	41,698	60,778
Education Services	0	524	524
Leisure and Hospitality	0	17,101	17,101
Other Services	35,635	36,234	71,869
Utilities	3,724	1,339	5,062
Transportation and Warehousing	11,367	16,766	28,133
Government – Total	0	12,508	12,508

As the table shows, 10 times more direct green jobs have been created in construction as in manufacturing, natural resources and mining. These construction jobs are in trades such as insulation. Yet it is just such jobs that are likely to be most transient, and most vulnerable to economic downturns.

We saw in section 4.1 that much of cleantech is weak on innovation. Now we can add that, just as Obama hinted that shale gas is a jobs bonanza, he made the same claim about "weatherizing" homes – after being in the White House just 15 days [45]. Indeed there is a wider, international consensus that cleantech is cool not just because it is innovative, but also because it *creates employment*. By contrast with shale gas extraction, however, the green dimensions of America's state-led recovery have been entirely low-tech and labour-intensive, as well as even more transient. Once more, innovation is effaced.

5. THE FOCUS ON ENERGY SOURCES, AND ON ENERGY EFFICIENCY AND CONSERVATION, DISTRACTS FROM INNOVATION

5.1. Energy sources, household bills, and the Cinderella of innovation: fossil fuels

There is another way in which ideologies around energy tend to consign innovation to the background of theory and practice. Policies on energy are mostly about the relative merits of different *sources* [46] – nuclear, fossil fuel, renewable – and not about how, through particular innovations, the technology around *every* source can usually be developed. It is as if the potential of every source is fixed for all time, and impervious to improvement. Of course, industry people earnestly plot declining cost curves into the future, and there is an extensive academic literature on "grid parity" for solar photovoltaic panels. But such a dynamic, not static approach to sources is rarely presented to the public. What are held to govern future projections of our old friend, energy prices, are two other old friends: supply and demand. Conceptually, there isn't much room for technology and innovation to mediate between these two factors.

In considering how energy sources can distract from energy innovation, take the UK. As both household bills for energy and fuel poverty have risen there, so claims about different energy sources have tended to concentrate on how much each source will add to family expenditures. Thus, in a report to Parliament, the official Committee on Climate Change (CCC) writes, in a chapter on reducing emissions from buildings:

> *"[T]here has been much debate about rising household energy bills and the extent to which this is or will be due to costs of financing low-carbon investments… the recent increases in residential energy bills have primarily been due to increased wholesale gas costs, with an increase of around £100 projected for a typical household by 2020 due to funding of low-carbon investments. Energy efficiency offers opportunities to offset bill increases, improving energy affordability and reducing fuel poverty"* [47].

The problem with approaches like this is not simply that it is households, rather than organisations, that are the main object of attention. It is true that, in a report that runs to nearly 300 pages, the CCC mentions households more than 100 times; but in British discussions of a forthcoming "energy gap", the *capacity* planned for *different kinds of sources* is fairly frequently discussed. However, the larger problem is that *a wave of the hand is enough* to represent the cause of big increases in average British household bills for gas and electricity – from £1105 in May 2010 to £1310 in May 2012 [48] – as "wholesale gas" in the past, and, much less so, "low-carbon investments" eight years into the future. The CCC makes just two, commendable references to the need for "technology support" for "less mature technologies". It makes eight more to the government's need to establish targets for minimum levels of such technologies – especially for levels of offshore wind. And among just three CCC mentions of "innovation", two concern policy innovation and just one – on electric cars – is about the technological sort.

Altogether, Britain has a passion for a computing how different energy sources will change household bills – not for computing how technological innovation could lower those bills. Yet as even sympathetic criticism of a recent Greenpeace UK "infographic" on the composition of British energy bills suggests, it is impossible, with the best will in the world, to pin down which source of energy is responsible for what component of household expenditures [49].

Anyway, costs are relative and also dynamic: the cost of increasing capacity in a given energy technology must be fairly compared to others, so that it may turn out more rational to look for innovations in fossil fuels than for those in renewables. To its credit, the Department for Energy and Climate Change (DECC), in its scenarios for fossil fuel prices to 2030, does give a nod to innovation in fossil fuels. Of the demand elasticity of fuels, it notes the impact of "innovative processes", and adds: "Over time, innovation can provide new commercial sources of energy or more efficient systems to reduce fuel demands" [50]. Yet even here innovation is conceived of in the framework of demand; and meanwhile, despite boundless evidence to the contrary, DECC adds, to its fear of climate change, the fear of supply shortages:

> *"Long run extraction costs for oil are rising as conventional oils are depleted. A similar situation is true for gas and coal although for gas there are relatively larger conventional reserves and in the long-term there is the potential for unconventional gas"* [51].

With fossil fuels regarded as "dirty" and their supply felt to be broadly in decline, or at least the subject of competitive rivalry from large oil and gas users such as China, sources other than fossil fuels gain an exalted status. Meanwhile, and despite all the advances achieved in fracking technology, dramatic technological development in the handling of fossil fuels is in practice felt more trivial even than innovation in nuclear power, CCS and renewables. In the latter, "low-carbon" technologies, for the four years between April 2011 and March 2015, DECC is pleased to dig deep in the pockets of the British Exchequer to stump up "over £200 million" not for research, but for the much more expensive business of development, demonstration and pre-commercial deployment [52].

To remark on the small size of this sum is not to suggest that the state can always successfully assist energy innovation, any more than the market can. However one need only follow Adam Smith on the merits of state-regulated scientific qualifications [53] to believe that the state has a role to play in supporting *basic* research.

The British government now plans what the CCC, recalling energy policy in the 1980s, now calls a "second dash for gas". Climate sceptics say that gas, a source, will lower household bills. On the other hand, the CCC has already said that gas will "increase costs and risks [sic] of meeting carbon budgets" [54].

In this bloodless landscape of the supply of and demand for different energy sources, innovation once again recedes into the background. If, on the other hand, partisans of energy innovation press the importance of technological dynamics over the static world of sources, society can at last hope to move on.

5.2. Energy efficiency and energy conservation

We already characterised measures to improve residential energy efficiency – around lights, appliances and insulation – as relatively low-tech, and able to create jobs that are, in the main, transient. This section asks: can general innovations in energy efficiency really lower the demand for energy?

Not content with insulating homes, President Obama, in his 2012 State of the Union Address, called for more energy efficiency in factories and business buildings. In the UK, the government's Green New Deal promises to help households improve the efficiency of their homes. China wants energy efficiency. The IEA reckons that, to reach by 2035 its "450 Scenario" of an atmospheric concentration of CO_2-equivalent of just 450ppm and a rise in average global temperature of just 2°C, efficiency measures will have to account for no less than 72 per cent of CO_2 abatement by 2020, and still a hefty 44 per cent by 2035 [55].

Despite the consensus, several authors have recently challenged the conventional wisdom on energy efficiency [56, 57, 58, 59, 60]. In general they refer to the English economist William Stanley Jevons (1835-1832), and quote his famous assertion: "It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth" [61]. Jevons pioneered what is now known as the "rebound" effect: in general, a more efficient and therefore cheaper supply of energy will encourage more use, not less. Still, in a recent paper, significantly titled *Spreading the Net: the Multiple Benefits of Energy Efficiency Improvements*, the IEA has tried to answer critics of its stance on energy efficiency. Usefully, it distinguishes between three kinds of rebound effects, and gives a table outlining examples:

Table 8. IEA examples of different rebound effects [62]

	Consumer		**Producer**	
Rebound Effects	*Income*	*Substitution*	*Output*	*Substitution*
Direct	Turning up the heat, driving more	Buying a bigger house	Increasing production	More energy use relative to other factors
Indirect	Taking a holiday		Lower cost cars lead to more transport consumption	
Macroeconomic	Lower prices for energy services increase demand for all goods and services economy-wide; increased employment		Increased productivity, higher profits/dividends implies investment in the economy	

While the table strongly conveys that the rebound effect has many *merits*, the rest of the IEA's paper is very weak.

First, the IEA says that the benefits of energy efficiency go further than energy savings – though it admits that the benefits it likes to talk up are "non-market, somewhat intangible [and]…. difficult to quantify". Then, importantly, it admits that the rebound effect "will be of greater concern to energy conservationists" – those who want an outright reduction in the demand for energy – than those with wider goals.

Then the IEA concedes that the energy saved through a particular energy efficiency measure "can be difficult to quantify", only to go on to announce that savings in energy remain the "primary" objective of energy efficiency policy. Finally, the IEA issues the following dismissal of those who inherit the mantle of Jevons:

> *"The claim that energy efficiency improvements do not deliver energy savings because of the rebound effect resurfaces regularly (*The New Yorker*, 2010;* The Economist*, 2008;* The Wall Street Journal*, 2009;* The New York Times*, 2011)…*
> *"[R]einvestment of energy savings can act as a driver for achievement of many other policy goals. Many of these benefits, in particular poverty alleviation, health improvements, consumer surplus and development goals, come with an energy consumption price tag and thus are drivers of the rebound effect. However, from a societal perspective, these rebound effects can be seen as a positive overall outcome….*
> *"Many economists and engineers have studied the rebound effect both empirically and theoretically and the vast majority has concluded that it does exist but is not strong enough to outweigh the energy and financial savings resulting from energy efficiency."* [63]

This will not do. The IEA is wrong to say that criticism of energy efficiency "resurfaces regularly": the recent wave of books and serious papers, cited earlier in this section, is a special and quite contemporary development. The IEA dissembles by citing just four journalistic articles, and fails to quote a single one of the "many economists and engineers" whom it believes support its position. But just what are the rather intangible and unquantifiable benefits that the IEA believes go beyond energy savings? The main ones are as follows:

1. Improvement to public health "as a result of improved heating and cooling of buildings and air quality from more efficient transport and power generation and less demand for both"
2. Cheaper bills for the poor; more efficient utilities extend popular access in developing countries
3. Increased disposable incomes
4. Increased industrial productivity and use of capacity; lower resource use, pollution and maintenance
5. Increased asset values, especially for commercial property
6. Job creation
7. Increased energy security in terms of fuel availability (geological), accessibility (geopolitical), affordability (economic) and acceptability (environmental and social); though the multidimensional nature of energy security makes benefits here "difficult to quantify"
8. Increases in GDP
9. Decreases in greenhouse gas emissions
10. Lower energy prices
11. Lower pressure on natural resources – for example "in the context of peak oil" [64].

For the IEA, it seems, there are very few problems that higher energy efficiency cannot solve. On top of creating jobs, it can perform another extrinsic function: it can create good health. By moving the goalposts far wider than what unspecified "energy conservationists" are supposed to want, toward "multiple benefits", the IEA allows energy efficiency indirectly to solve everything – and thus nothing.

But it is not just "energy conservationists" who want to lower demand for energy. One of the main claims of those who are so single-mindedly focused on energy efficiency is that gains in it will lower carbon emissions by lowering demand for energy. As McKinsey puts it, "Studies show that large numbers of people aren't aware of many things they could do or technologies they could use to reduce their energy demand and energy bills" [65]. And as the paper by Whitmill reminds us, the EU's "20-20-20" Directive includes the target that energy efficiency measures reduce energy demand by 20 per cent by 2020. Now, a prolonged and deeper recession in Europe might just produce such a drop in demand. But that would not at all be the same as improvements in energy efficiency bringing about the same result.

The IEA is unable to make a convincing case against the rebound effect. The world needs to plan for innovations that will realise a greater energy supply, not for those that lower energy demand. As for carbon emissions: decarbonising energy supply through innovations in nuclear power, CCS and renewable energy is one thing; believing that innovations in energy efficiency will have the same effect is quite another.

Progress in energy efficiency, and especially is that of energy supply, is just that – progress. The rebound effects that energy efficiency brings are *positive*. However,

> *"There are limits to efficiency. It takes a certain amount of energy to move objects, say, or to heat them up. The infamous Second Law of Thermodynamics sets further limits of how efficiently energy can be converted from one form to another. Once efficiencies have reached the maximum allowed by the laws of physics then, to do even more, there's no choice but to generate more energy"* [66].

Given the energy density of nuclear fuels, the enormous amount of solar energy incident on the Earth, and the possibilities with expanded hydroelectric investments and a ramp-up of tidal and especially geothermal power, why narrow the focus of energy innovation to efficiency measures? Or consider transport. With the motorisation of China and India, the world faces a massive rise in demand for transport fuels. These fuels need not all be fossil-based; through crops, plants and algae, their genetic modification, and the artificial synthesis of hydrocarbons, it should be possible to develop what Joe Kaplinsky and I have elsewhere termed a New Carbon Infrastructure (NCI), to take full advantage of the unrivalled energy density of carbon-based fuels and, through reviving research on the chemistry of CO_2, to manage it more carefully than is done at present [67]. Innovations that bring closer an NCI will likely prove a better bet than those that try to go on wringing what will be diminishing improvements in the efficiency of internal combustion and jet engines.

There are two other arguments that characterise hype around energy efficiency. The first is that climate change is so urgent a matter that the world does not have time for long-term R&D into new, low-carbon sources of energy. In this respect energy efficiency measures are a "quick fix". The second argument is one that McKinsey makes explicit: efficiency measures are profitable – they are relatively low in cost, and pay for themselves.

In the light of these arguments, and accepting the case for demand-side energy efficiency for a moment, let's now turn to what kind of measures around residential energy efficiency are the most sensible forms of innovation, and what kind of other relevant measures might also be appropriate.

As my colleagues Lemon and Wright at De Montfort University and their collaborators Crilly, Cook and Shaw show so clearly and exhaustively in their paper on energy efficiency and UK social housing, retrofitting homes for energy efficiency requires a multi-faceted, integrated and not simply technical approach. The paper rightly argues that it is vital, in retrofitting projects, to take account of the needs of householders – for example, their need not to have their lives disrupted by the process of renovation. The paper also hints that, even with the help of modular components (for example, roof pods or bay windows manufactured off-site), retrofitting can be a complicated business. And how much retrofitted solutions actually reduce energy use, given the rebound effect, remains open to question.

Evidence from America certainly suggests that the process of retrofitting homes for energy efficiency is not only laborious; it is also very slow, and very costly. Between April 2009, when work under the ARRA began, and the end of September 2012, President Obama's one-time supplemental appropriation of $5 billion for the US Department of Energy's longstanding Weatherization Assistance Program (WAP) allowed one million homes to be fitted with insulation and high-efficiency windows [68]. Since this sum of $5 billion may not all be exhausted yet, one may reasonably take the net cost of retrofitting as, say, $4000 per home. With this assumption, and given the official *maximum* of $400 in energy bills saved per home per year, a home retrofitted for energy efficiency under WAP in the US will have to wait 10 years before the investment shows a net return.

That is quite a lengthy period. But the more telling timeframe is not "payback", but the speed of retrofitting of America's housing stock. Now, households at or below 200 per cent of the US poverty line are eligible for WAP. This means that, while it has taken nearly three-and-a-half years to fix a million sub-standard American homes, there are a further 37 million households still eligible for WAP. At this rate, it will take something like 120 years to improve the energy efficiency of just the poorest layer of US households.

In this light, improving residential energy efficiency through amendments to existing homes is not at all a "quick fix". Similarly, the fruit with insulation and double-glazing is not at all "low-hanging". Indeed long-term programmes of R&D in energy supply appear positively short-term compared with the rhythms of retrofitting. This is particularly the case in a country like Britain, where it has recently been suggested that residential use of electricity has been severely underestimated [69] – so severely, indeed, that it may now have overtaken residential use of gas for central heating, hot water and cooking. It is innovations back at power stations, not in retrofitted insulation, that promise to do the most for those carbon emissions that are triggered by householders.

To the extent that homes are the site for direct emissions of CO_2, of course, something should be done strictly around residential energy efficiency. However the something to be done is the *mass manufacture* of energy-efficient *new* housing stock [70, 71], equipped with building-integrated photovoltaic (PV) panels, building-integrated vacuum-insulated panels (VIPs) and other energy-generating devices. The turmoil that has beset the solar PV industry [72] in China would seem to be a signal that this means of energy supply still needs a lot of R&D. The literature on VIPs and similar technologies also suggests that there is a long way to go before they do everything that is required of them [73, 74, 75]. Yet the way forward for residential energy efficiency lies not through patching aged homes up, but through 21st century factories, complete with robots, complex components made through 3D printing, nanotechnology, IT-based customisation and all the rest. The plans of the Chinese firm Broad Sustainable Building, which hopes to construct a 220-storey edifice in the space of three months, may come to nothing [76]. However, with 200 people, the company has built a 20-storey, five-star luxury hotel with 350 rooms, underground parking, roof-top pool and helicopter pad in just 360 hours [77].

The mass manufacture of buildings will prove a less utopian course for innovation than attempts to mend homes whose draughts have often been around for decades.

6. ENERGY INNOVATION AS RISK

So far, we have been concerned to show how various issues divert official and popular discourse on energy away from innovation. Yet the issue of energy also tends to foreground innovation, in that it highlights how innovation in energy can be perceived as an inherently irresponsible enterprise.

The energy industry is more globalised, more privatised, but also more regulated than it used to be. More crucially, though, today's cultural apprehensions of economic, social and environmental disaster make every kind of energy, and every kind of energy innovation, controversial. Energy is not, of course, the only kind of industrial sector in which concerns about technological innovation are rampant – a glance at today's worries around media and IT confirms this. Also: following Michel Foucault's *The Birth of the Clinic: An Archaeology of Medical Perception* (1963), which first questioned the epistemology of modern medicine, the classic tract *Medical Nemesis* (1975) saw the then-popular Swiss priest Ivan Illich go further in directly contending that medicines (along with doctors and hospitals) made people ill [78]. Nevertheless, when the German sociologist Ulrich Beck published his book *Risk Society* in 1986, he not only attacked medical progress, calling it (the emphasis is his) "*the institutionalized revolution of the lay public's social living conditions without its consent*" [79]. No: on top of that, much of the force of Beck's polemic was directed against what he called the "uncalculable threats" of nuclear power, as well as – and here he struck what has since become a whole new and very contemporary coinage – "the length and irreversibility of mega-technological decisions that trifle with the lives of future generations" [80]. While hostility to IT and medicine, then, has for the most part been a minority pursuit, hostility to innovation in energy, and especially toward nuclear energy, has proved much more popular.

Historically hazards associated with, say, the mining of coal or the residential provision of gas were more associated, in the public mind, with primitive technologies – for example, pit props, or poor piping – than they were with advanced ones. With the advent of nuclear power, however, energy, mediated by radiation, came to be linked with the devastating consequences of war. By the 1970s, the Arab oil boycott and the subsequent Three Mile Island nuclear incident in the US established energy security and energy technology, respectively, as major sources of upset.

Since the energy crisis of the early 1970s, Western society has decreased its reliance on oil – especially in power generation. As we have seen, growing R&D budgets have emerged for renewable energy and energy efficiency. Yet if being held hostage by foreign oil suppliers, along with exposure to nuclear power, climate change and fracking for shale gas, are all now thought dangerous, suspicion has also come to attend renewable and other kinds of energy technologies as well – and not just on the side of climate sceptics, but also among environmentalists. Lowering energy consumption by doing without energy, or the insulation of buildings for higher energy efficiency without resorting to major technological innovations: these activities are not the subject of stigma, because they are regarded as safe. But the same cannot be said for wind turbines, solar panels, hydroelectric dams, or geothermal energy.

It is one thing for a British journalist and climate sceptic to wail that wind turbines may cause dizziness, high blood pressure and depression [81]. But in Australia, a Bill lies before the Senate to outlaw wind farms that generate a background noise of just 10 decibels within 30 metres of any premises where people reside, work or congregate [82]. Indeed, "wind turbine syndrome" has what Simon Chapman, a University of Sydney professor of public health, calls an "astonishing" 155 medical problems attributed to it [83].

One might imagine that the health problems associated with wind turbines are a special case. But this is not so. If one conducts Internet searches, through Google and Google Scholar, for the phrase "health problems" alongside phrases describing major renewable technologies, one gets the following results:

Table 9. Association of major renewable energy technologies with the phrase "health problems", when searched by Google and Google Scholar, October 2012, by approximate number of results

Phrase describing renewable technology	Search results: Google	Search results: Google Scholar
"Wind turbines"	180,000	1360
"Solar panels"	5,560,000	1680
"Hydroelectric dams"	66,300	623
"Tidal energy"	73,200	196
"Geothermal energy"	424,000	928

Of course, it can properly be objected that some of the results consist of articles or books praising renewable technologies for *obviating* the "health problems" associated with burning fossil fuels, biomass and so on. But even if just a third of the search results contain articles or books which do criticise renewables on medical grounds, that still gives a strong signal about the way in which "green" technologies, like every other energy technology, are today regarded as in some way perilous. The fact that tidal energy, for example, is linked to risk in the way that it is can only be thought remarkable, since the world at present boasts just a handful of completed tidal energy systems with installed capacities higher than 100 MW.

In the conventional narrative, nuclear technologies are potentially too explosive, and fossil-based ones already too polluting; so if innovation is to be pursued, it should be pursued in the arena of cleantech. What we are proposing here is a different kind of chain of causality. Since the late 1960s and early 1970s, the slowdown in Western economies has sapped ruling elites of confidence – not least, confidence in the future, and in technological innovation. In the framework of this paper, then, anxiety about climate change, while probably well grounded, is also exaggerated by the prevailing zeitgeist of fear. The result is that even innovations designed to combat climate change, such as renewables, come to inspire doubt.

What the sociologist Frank Furedi has called "society's free-floating consciousness of risk", and in particular "a strong undercurrent of fear about the *side-effects* [our emphasis] of any technological innovation" [84], is in this conception the independent variable, more than are risks, real or imagined, the outcome of particular technologies. With the right scientific analysis, technological development and operator ethos of professionalism, few energy innovations will be inherently or eternally lethal. The scope for destruction presented by any energy technology is an issue that revolves around the level of investment society is prepared to make in safeguards, and is thus an issue that comes down to political priorities.

Having said all this, however, it is certain that alarmism about climate change has done its own bit to ratchet up the general level not just of foreboding about the future., but of generalised *uncertainty* about it. One consequence of this is that, in Britain, at least, the national market for energy has, in the words of the London newspaper *The Economist*, "become too uncertain for investors to entertain the risks of new projects"

[85]. And what is the widely approved antidote to such uncertainty in Britain? Why, given the obsession with prices which we have already commented on, it is the state… setting a "carbon price floor" in the electricity sector, thus encouraging low-carbon solutions and, in the mangled prose of Her Majesty's Treasury, "reducing the uncertainty of revenue and investment risk uncertainty" [86].

Another, more direct result of growing uncertainty is that is that those technologies that are envisaged to deal with climate change and that come under the title "geoengineering" are felt questionable, because they wrongly raise the prospect of mankind finding an easy way out from its climate problems. As a well-known report by the Royal Society notes, referring to submissions made to it by Greenpeace and others,

> *"The very discussion of geoengineering is controversial… it may weaken conventional mitigation efforts, or be seen as a 'get out of jail free' card by policy makers… This is referred to as the 'moral hazard' argument, a term derived from insurance, and arises where a newly-insured party is more inclined to undertake risky behaviour than previously because compensation is available…. the risk is that major efforts in geoengineering may lead to a reduction of effort in mitigation and/or adaptation because of a premature conviction that geoengineering has provided 'insurance' against climate change"* [87].

Earlier, we had cause to criticise the doctrine of energy efficiency in domestic appliances, lighting and homes as "low-hanging fruit". It is too facile an approach to technological innovation, and, in the case of retrofitting homes, not very easy to realise. Our criticism is fair because such energy efficiency is a relatively low-tech exercise, and because energy efficiency in buildings has proved, *in practice*, a complicated matter. By contrast, geoengineering measures, which are on a scale of low- to high-tech, have yet to be seriously undertaken. However, even the most modest experiments in this kind of innovation are taken to be a bridge too far. Far from law and policy lagging behind accelerating technologies, received opinion seems, with geoengineering as with other energy-related innovations, to rule them out ahead of even the most primitive prototypes being tested. It is also notable that some energy specialists already fret about the scale of low-carbon power generation that they imagine will in the future be required by electric cars and heat pumps, even though these innovations are set to diffuse at a very slow pace for many years to come.

Apart from its intriguing argument for dealing with climate change without resort to the vagaries of international diplomacy, the paper by Fox is a commendable survey and defence of one particular kind of geoengineering – the capture of atmospheric CO_2. Since it was submitted, Air Fuel Synthesis, a firm in Stockton, UK, has won widespread media coverage of its success in converting atmospheric CO_2 into petrol. Yet here again we encounter environmentalist objections, in the shape of the familiar trope that the energy return on energy invested, or EROEI, is less than one. Thus the senior technology correspondent on the London *New Scientist* writes, of the efforts made by Air Fuel Synthesis:

> *"[S]ome media coverage overlooked the key point: the energy efficiency of the process has yet to be demonstrated. This matters because the technique uses electricity for key stages. It should not require more energy input than is gleaned from burning the fuel it produces"* [88].

So zealous is the writer's opposition to air capture that he forgets how, apart from the energy flows that surround this particular technology, more energy also goes into oil refineries, power stations and laser eye surgery than comes out. That, though, does not prevent humanity finding petrol, electricity and corrected vision to be useful innovations.

Those who go on about EROEI offer only a catch-all argument against fresh thinking and practice in energy supply. They should be unmasked as the charlatans they are.

7. FAILURE AND "SMARTNESS" IN ENERGY INNOVATION; BEHAVIOURAL INNOVATION

Having made a case for energy innovation, shown how neglected that case is, and outlined how much energy innovations are intuited as prone to mishap or worse, we now turn to those instances where innovation is more or less *misguided*. One of the reasons for going into such instances is obvious enough: particular energy innovations that are judged not to have panned out can be taken, rightly or wrongly, as a sign that energy innovation in general is too risky to bother with.

Before looking in a little detail at two, linked and questionable kinds of innovation – those around residential energy metering, and those around human behaviour – some more general remarks are in order about failures in energy innovation.

7.1. Failure in energy innovation

To its critics, everything about nuclear power denotes a failed innovation. Apart from reciting the accidents at Three Mile Island, Chernobyl and Fukushima, critics hold that nuclear power has failed in economic terms. To the charge sheet, they also add the dangers of against nuclear proliferation.

A full defence of nuclear power is beyond the scope of this Introduction, and we have anyway made such a defence elsewhere. There are two observations, however, that are worth making here.

First, to broaden the point made in the previous section about the politics of investing in safeguards, the yardstick for judging an energy innovation, like any other, a "failure" is ultimately not just economic or even social, but political. The hundreds of fatalities that attended Chernobyl, for example, need to be judged against the thousands of deaths that occur in world mining every year. They must also be judged in the context of the political and safety failures of the regime in the Ukraine that presided over the disaster. Similarly, the economic viability of today's costly Generation 3.5 reactors demands judgement about the likely future cost of such machines, given the lessons learned from Olkiluoto and Flamanville, the regulatory regime surrounding them and so on. In the same way, the economic appraisal of nuclear power must involve a judgement of what value should be assigned to its low-carbon properties, and how likely mankind is to develop an inexpensive and safe means of disposing of radioactive waste.

By these measures, it would be foolish to rush to a glib verdict on nuclear power's "failure". Yet there is more to consider here.

The second thing to note about nuclear is, as we have already underlined, that there is more than version of this technology. And here a critical standpoint is perfectly permissible. Alvin Weinberg traced the drive toward PWRs from the US Navy. If the world had the 1950s and 1960s over again, it would by no means be given that this particular kind of device would be the principal reactor design of choice. History will have be the judge of each energy technique.

This is a simple contention, but again it counts against superficial attempts to write off particular technologies. After all, in the 19th century the first cars were electric, not petrol-driven, and tomorrow – or more likely the day after the tomorrow – there is a chance, if battery technology improves by at least an order of magnitude, that electric vehicles finally prove a worthy contender against the internal combustion engine. By the same token, electric power in the 19th century began as a direct current (DC), not an alternating current (AC) phenomenon; and today DC transmission is back, not least because it suffers from fewer energy losses than AC.

Take the question of failure as it relates to a still more controversial technology – offshore wind power. This is not just a matter of wind speeds, turbines and gears, but also of civil engineering (especially around foundations), the laying of cables, logistics, tugs, and the mechanisation of ports. With the London Array, the Thames Estuary will see some 175 turbines installed. At this kind of scale, success or failure will greatly depend on the extent to which the Array's suppliers can industrialise their various processes – not least, because many offshore wind turbines built today may have to be replaced within 20 years. One does not need to be a carbon-conscious supporter of wind turbines to agree that its may be too early to pronounce the aggregate of technologies around this source of energy as failed innovations.

Of course, the claims made around particular innovations don't always face a hung jury: they can sometimes simply be dismissed. In this Special Issue, the almost unanswerable Commentary by Flood effectively closes four decades of speculation, if not about some kind of role for hydrogen in the future of energy, then certainly about visions of a "hydrogen economy". It is not just that such a phrase is fundamentally imprecise, in the same way as the phrases "nuclear economy", "new carbon economy", or indeed "Internet economy" are imprecise (we will leave aside "zero-carbon economy": after all, human beings are made of carbon). Rather, the basic laws of chemistry and physics make it pretty much impossible that hydrogen can play even a decisive role, let alone an exclusive one, in either transport or electricity generation. Indeed it is entirely revealing that the American management guru Jeremy Rifkin, a major inspiration to Democratic Party thinkers of an environmentalist persuasion, published his 2002 airport bestseller *The Hydrogen Economy* [89] without once giving a mention to John O'Mara Bockris, the man who much more innocently coined the phrase some 40 years before.

The hydrogen issue has some contemporary relevance. In Britain, Liberal Democrat Energy Secretary Ed Davey has suggested that power generators can be exempted from cutting their carbon emissions as much as had been anticipated if, in the words of *The Times*, "technological advances made it cheaper for other sectors, such as transport, to go green instead". And what were those technological advances? Mr Davey "said that if hydrogen-powered lorries became viable in the 2020s, for example, this could relieve the burden on the power sector to cut emissions" [90].

How sublimely convenient is such a hypothesis! In Britain as elsewhere, it is not often that politicians eulogise technological innovation in energy. Yet at just this moment, a government minister elects to speculate about hydrogen for road-based freight transport, and about how this could relieve electricity suppliers – in the first place, those relying on newly ennobled gas-fired plants – of what were supposed to be binding, legal commitments to lower their carbon emissions. Here a technology has not so much failed as emerged as a non-starter beyond what one optimistic but carefully nuanced account terms "niche applications" [91]. However it is precisely innovation around hydrogen that government, in a throughly bogus style, talks up – as if, too, using hydrogen in transport would never run foul of today's pervasive risk consciousness.

Advocates of energy innovation must more often and more publicly discriminate between the real deal and the fictitious sort. By being selective, they will convince more people of their case.

7.2 "Smartness" and smart meters: of energy conservation, health scares, privacy… and cybersecurity

The paper by Thomas represents a timely demystifying of a fraudulent innovation: "smart meters". Given the sums of money involved in the UK case, it is astonishing that the basic critique made in this Special Issue is not more widely acknowledged. The paper shows that smart meters in Britain will not deliver "time of day" pricing, and will therefore will only provide a kind of usage monitoring that has for some time been available from meters already on the market. Anyway the benefits of "time of day" pricing are far from unequivocal.

Here we look at what is clearly a bogus innovation in the UK from a complementary angle. We do this is not because smart meters are fascinating in themselves, but because they bring together illusions about energy savings, condescension about user behaviour and delusions about risk in a very poignant way.

In cynical style, many critics like to put heavy inverted commas around the adjective "smart". In a matchless literary innovation, a leading writer in *The Observer*, London, begins an article with the Oxford English Dictionary definition of "smart". It means, he reports, "capable of independent and seemingly intelligent action", and must therefore, he hints, immediately invite ridicule [92].

This oh-so-hip, worldly and knowing stance errs, for the basic premise of "smartness" lies elsewhere. In technologies associated with the built environment, which clearly include smart meters but extend also to smart cities, smart buildings and smart transport systems, "smartness" means that previous ways of organising these things have been… well, stupid. In the usual environmentalist descant, it is implied that mankind has been "dumb" in its past conduct. It is suggested, however, that modern technology, in the shape of IT, can now compensate for humanity's profligate ways and help it manage demand down; especially demand for energy. To put things another way: around "smartness" in energy, what the London economist Daniel Ben-Ami terms growth scepticism [93] – a distrustful attitude toward economic growth, often informed by green sentiment – combines with modish postures on IT to put forward innovations which, their software "intelligence" notwithstanding, are fundamentally misanthropic in intent, portraying energy users as irresponsible wastrels who need to change their "behaviours" (the plural always gives the game away) and cut back on their energy use. In Britain, the French energy supplier EDF is quite explicit about this: smart meters, it says, "can play an important role in helping reduce energy usage and carbon footprint" [94]. It is the same with British Gas:

> *"Smart meters work with a smart energy monitor to show how much energy you're using and how much it's costing in real-time. So you can see how much you're spending by leaving your phone charger plugged in all the time, or the heating on at night. And when you can really see how much you're using, you can start to make small changes to use less and save money on your bills….*
> *"Your smart energy monitor makes it really easy to understand your energy. Traffic lights show you at a glance how much you're using in real time. If the display is red, you're using a lot – if it's green your use is low – it really is that straightforward"* [95].

Here the obligatory reference to "your phone charger" speaks volumes. On this question, the top UK energy expert David Mackay properly upbraided the BBC for the poor quality of its reporting back in 2008, when he noted that the energy saved in switching off a charger for *a whole year* is equal to that in a single hot bath [96]. It is astounding that British Gas still talks down to people about their phone chargers.

Smart meters are not, then, smart in terms of helping consumers adjust their use of electricity and gas to take advantage of times when these two things are cheap. Nor are such meters smart in the sense of bringing about a significant reduction in energy use. According to the project leader of the Centre for Studies on Sustainable Development at the Free University of Brussels, Grégoire Wallenborn, European studies have shown that consumers using energy monitors in the home cut their use by no more than four per cent, and that, only over the first year after their meter were installed [97].

So perhaps it would be better to describe smart meters as "guilt meters". They are about focusing popular thoughts about energy not on the continuing reasons for its supply being so costly, which relate to lack of innovation, but on the merits of personally cutting back – or *trying* to cut back – on energy use. They are about that wider and wholly patronising exercise known as "raising awareness".

The irony is that this most elementary side of smart meters is, in popular critiques of them, not at all the principal object of attack. What draws fire is not the redundancy of smart meters, but the *risks* that they are thought to carry with them.

To start with, a Google search for the linked phrases "smart meters" and "health problems" brings up no fewer than 60,800 results emerge. Mirroring this level of panic, and reproducing a warning letter on the health hazards of smart meters that was signed by 40 international experts, one Canadian research organisation proclaims:

> *"Over the past two years, there has been mounting medical and scientific evidence of the grave biological dangers…. In the US, there has never been a mandate to force these utility meters on millions of unsuspecting people. There has been no Precautionary Principle used, while corporate greed has abounded….*
> *"As long as a 'revolving-door' policy remains between corporations and [no longer] public agencies, citizens will not have their medically validated concerns ever addressed….*
> *"Over the past year, I have already personally seen the damage these dangerous meters have done to numerous people and several animals I know – all across the US. Although not generally reported by mainstream media, the serious impacts on peoples' health are already evident. A short list includes: neurological impairment, ear pain and hearing problems, breathing dysfunctions, chest pains and heart ailments, burning skin, sleep disturbances, headaches, depression, vision troubles, blood pressure changes, sterility, autism, and neurodegenerative diseases"* [98].

The congruence of this account with the views and tone of climate alarmists cannot go unnoticed. Yet health is not the only cause for hysteria about smart meters. The European Data Protection Supervisor (EDPS) has warned that they could be used to track what "households do within the privacy of their own homes, whether they are away on holiday or at work, if someone uses a specific medical device or a baby monitor, or how they spend their free time" – leading, in the words of EDPS assistant director Giovanni Buttarelli, to consumer profiles being used for "marketing, advertising and price discrimination by third parties". Citing research in Germany, Anna Fielder, a consumer rights advocate and campaigner at Privacy International, has likewise suggested that if data is gathered from households – "even a few things at the end of each day", and certainly if collection is done in real time – "you get an awful lot of information about people's lifestyles" [99].

Perhaps. But why stop the worry there? After all, smart meters might also give malign foreign agents the ability to enforce power cuts in every home. As *The Observer* opines of smart meters and British households:

> *"The utilities love the technology because it will enable them to disconnect consumers remotely who don't pay their bills.*
> *"But the capacity for remote cutoff in a networked system opens up a huge national cybersecurity vulnerability. After all, if E.ON can remotely disconnect every house in East Anglia, so too can a hacker in China."* [100]

Once again it is all too apparent that risk consciousness has the last word. Such consciousness makes not just for a rather distorted emphasis on R&D and investment in renewable energy, as well as the still more wrongheaded health and other kinds of objections that are raised against renewables, geoengineering, electric cars and heat pumps, and air capture devices. In addition, it makes for a chase, employing smart meters, after the mirage of cuts in residential energy use and carbon emissions; and it makes also for another set of wrongheaded *objections* to such meters – on the specious grounds of their negative impact on "wellness", privacy, security and all the rest.

If genuinely propulsive innovations in energy supply melt away from popular consciousness or are thought risky, then dubious, IT-based "innovations" in the control of residential energy use will substitute for advances on the supply side. Just as bad, though, is those innovations being thought to be part of a whole series of *conspiracies*.

Those who make and research energy need to satirise smart meters, pointing out that mendacious symbols of innovation can never amount to the real thing.

7.3 Behavioural innovation

On the morning of 25 September 2007, the Subcommittee on Research & Science Education of the US House of Representatives held a hearing on what it called "The Contribution of the Social Sciences to the Energy Challenge". In an opening statement, Subcommittee ranking member Vernon Ehlers, a Republican from Michigan, declared that he was "particularly interested in what influences individuals to make energy efficiency decisions". He went on:

> *"We all assume that if people understood their return on investment from energy efficiency measures – say, home improvements to save on winter heating bills – then they would quickly make those changes. But… it is much more complicated. We are not always as rational as we'd like to believe… being well-educated about energy efficiency does not necessarily translate into action. Consumers are a fickle bunch, especially in a society where individualism and personal freedoms are highly-cherished"* [101].

Among the witnesses who then took the floor was Robert Cialdini, Regents' Professor Emeritus of Psychology and Marketing at Arizona State University.

Cialdini had form. Just a few months before, with colleagues led by California State University's Wesley Schultz, he had, using energy meters, published a seminal paper for the journal *Psychological Science* based on research among 287 households in San Marcos, California [102]. With the help of what were termed "visible energy meters", the researchers determined that those households behaved in interesting ways when given certain kinds of information. Told that they were consuming more energy than the average household in their neighborhood, households that were engaged in what the researchers decried as "destructive behaviors" produced "a significant decrease in energy consumption" – namely 1.22 kWh a day. By contrast, households told that they were consuming *less* energy than the average produced a "boomerang effect": they *increased* their consumption by 0.89 kWh a day. But if the information given each type of household was supplemented with a handwritten "sad face" or "happy face" emoticon, respectively, things changed. Those with "destructive behaviors" cut use not by 1.22 kWh a day, as they had when given "descriptive norms" about their neighbours' habits, but, once they were given "injunctive norms", by 1.72 kWh a day. Meanwhile the better behaved, given a joyful emoticon, produced less of a boomerang effect: they only raised their consumption by 0.24 kWh a day.

This paper, which was part-funded by the William and Flora Hewlett Foundation (total assets: $7.29 billion), is endlessly cited as empirical confirmation of the relevance of behavioural economics to energy use. The starting point of those citing it is, following Vernon Ehlers, that people are rather irrational – but that wiser counsels can prevail.

Perhaps the paper is entirely accurate; but it is amazing what its admirers will read into it. Thus we find David Roberts, a staff writer for the Seattle-based environmental magazine *Grist* ("At *Grist*, we're making lemonade out of looming climate apocalypse"), opining that, in making buildings more efficient, "it helps to understand human behavior". Roberts writes:

> *"In a 2007 experiment in California, homeowners given an emoticon on their bill in addition to information about their neighbors' energy usage saved 40% more energy than those given information alone.* ***:o***
> *"It turns out we're surrounded by cartoon faces, all sorts of cues and stimuli that trigger behaviors without engaging the conscious mind. Most of these automated behavioral reactions evolved over time because they helped human societies…. But precisely because they have evolved to be automatic, they can lead us astray.*
> *"The fact that human behavior is governed in part by automated, non-rational behavioral routines is old news to any number of disciplines, from sociology and psychology to history to neurobiology. It's also well known among corporate marketing departments. But the news has been somewhat late coming to economics, which at least in the Enlightenment west begins with the assumption that human beings are rational actors who weigh costs and benefits and maximize self-interest"* [103].

Misreporting the date of the experiment in California (it was done in 2005, or earlier), and adding in his own "Wow!" emoticon – :o – Roberts, in a few short swipes, condemns energy users as automatons, and the Enlightenment as premised on cost-benefit analysis. Now of course, it is wonderful to surmise that Enlightenment opponents of religion such as Diderot and Baron d'Holbach "began" with the assumption that human beings are rational actors. But what about the still more wonderful news that an emoticon can make a 40 per cent improvement in energy savings?

If the Schulz-Cialdini paper is true, then Roberts' observation is also true, for a daily saving of 1.72 kWh compared with 1.22 kWh is, in fact, an increase in saving of 41 per cent. But there is one thing that Schulz and his collaborators barely mention and Roberts, with his percentage figure, not at all: the improvement wrought by a "sad" emoticon among "destructive" energy users was obtained against a "baseline" use of *more than 20 kWh* a day. More accurately put, information on descriptive norms alone wrought a cut in energy use of 1.22 kWh divided by 20.25 kWh a day, or six per cent; information to which injunctive norms were added cut it by 1.72 kWh divided by 20.63 kWh a day, or eight per cent. Giving energy wastrels a sad cartoon face cut their energy use, therefore, by a princely two per cent. And, though low energy users in the research recorded baseline consumption figures of only 10 kWh a day, were the heavy users such wastrels, anyway? Perhaps they had big families, or worked from home. Or perhaps the meter-readings done by “trained research assistants” in users’ homes themselves brought about changes in behaviour – as many a social scientist, invoking the famous (and controversial) “Hawthorn effect”, might aver. However no information, with or without emoticons, was provided on any of these matters by the learned authors of the paper for *Psychological Science*.

As with the studies of smart meters invoked by Wallenborn from Brussels, the big innovations on offer when behavioural economics is applied to household energy use revolve around single-figure percentage reductions. Repeating Wallenborn’s finding that “improvements’ in energy use fade after time, the results reported by the Schulz-Cialdini paper and recorded above applied only to behaviour one week after messages were distributed. After just three weeks, the energy savings brought by sad emoticons lower: not 1.72, but 1.23 kWh a day – in other words, back to about six per cent.

Overall, similar researches done on energy savings produce weak results. On Bainbridge Island, off Seattle, a further trial of what is known as “social norms marketing” has reduced electricity use by a transformational three per cent; while at 17 homes in Brighton, UK, just six months had to elapse for an equivalent experiment to bring the number of households continuing in electricity use reductions down to just two [104]. Again and again the same studies are rehearsed, with the same miniscule results. From Boulder, Colorado, cleantech market researchers Pike trumpet that “with a personalized home energy report, [US energy company] Opower reports seasonal savings as high as 3.5% achieved through providing information, neighborhood comparisons, and action steps to residential energy consumers” [105]. At the Cabinet Office, London, a 30-page report titled *Behaviour Change and Energy Use* (2011) breathlessly states that, with Opower, “At least nine independent evaluations have demonstrated consistent average energy savings in the order of 2-3%” [106]. Two other studies [107, 108], the more recent of which involved Opower, recorded maximum savings of 2.1 per cent. They also found that the effect of sending Home Energy Report letters to US householders in “a business style envelope” helped cut energy use; but as a sympathetic but useful University College London commentary on these two studies (and others) points out, the two “do not provide conclusive evidence on which types of behavioral change drove the bulk of energy savings – for example, a switch to more efficient durable appliances or changes in day-to-day behaviors (e.g., switching off appliances nightly)” [109].

So: the hopes of the behavioural economists lie in meters, emoticons, envelopes and, perhaps, energy-efficient durables. These are the breakthrough, ultra-rational innovations that an irrational populace can look forward to in the 21st century. In terms of annual emissions abatement in the US, two authors report, a programme like one run by Opower could, if “scaled nationwide”, cut CO_2 by 12.7 million metric tons (MMT), compared with a national total of 2,400 MMT from the electricity sector: with some optimistic arithmetic, the authors compute this as “nearly one percent” – when it is in fact 0.53 per cent [110]. Yet since 2008, when Richard Thaler and Cass Sunstein published their mass-market book *Nudge: Improving Decisions about Health, Wealth, and Happiness* [111], the idea has grown that the state’s job is to act as a paternalistic “choice architect”, guiding feckless consumers to the right path. From America through France and Denmark to Britain, governments which lack vibrant interactions with normal people and are disdainful of the "plebs" bother little with supply-side innovation, but much more with curbing what they regard as personal excess in the realm of consumption. Moreover, Thaler and Sunstein give energy this treatment very explicitly. "People", they imperiously declare on the first page of their book, "can be nudged into saving energy". The best way to nudge? Issue warnings that people will *lose* $350 a year by *failing* to use "energy conservation methods" [112].

This is not a nudge. It is an elbow in the ribs, the politics of fear. But the contempt Thaler and Cass feel for energy users goes further. In their chapter on "Saving the planet", they write:

> *"If your use of energy produces air pollution, you are unlikely to know or appreciate that fact, certainly not a continuing basis. Those who turn up the air conditioning and leave it on for a few weeks are unlikely to think…. about all of the personal and social costs"* [113].

Energy users are so stupid, aren't they? After all the attempts to raise awareness about climate change and the environment, they know nothing. Indeed not content with thinking that energy users are stupid, the authors believe their readers are too. They write:

> *"Clive Thompson (2007) has explored the efforts of Southern California Edison to encourage its consumers to conserve energy – and its creative, nudge-like solution…. what worked was to give people an Ambient Orb, a little ball that glow red when a customer is using lots of energy. In a period of weeks, users of the Orb reduced their use of energy, in peak period, by 40 percent"* [114].

One of the hallmarks of the literature of what we might call behavioural energy economics is its dishonesty. Unlike the way they handle other research, Cass and Sunstein give no reference to "Clive Thompson (2007)". It turns out (as the conjurors of behavioural economics so often like to write) that the article in question, which castigates "energy hogs", was written for the Democratic Party hipster magazine *Wired* [115]. And while Cass Sunstein, in crowing about his own role as a (recently resigned) adviser to the Obama administration, referred to the Clive Thompson as recently as 2011 [116], the strange claim of a 40 per cent reduction in energy use "in peak period" has been confirmed, as far as this author can make out, in none of 262 search results, in Google Scholar, for the phrase "Ambient Orb".

It appears that, not content with believing that energy users are stupid, scholars like Thaler and Sunstein think that their readers are stupid, too. Why then do governments bother with them? The answer is contained in the ministerial foreword to the UK Cabinet Office paper to which we have already referred. There it is stated:

> *"These insights are not alternatives to existing policy. They complement the Government's objective to reduce carbon emissions across all sectors, and show how we can support these efforts in relatively low-cost ways.*

> *"Behaviourally based changes that reduce emissions have major advantages. First, the benefits can be very fast, unlike major infrastructure changes that can take years, or even decades – a 1% gain today is worth more than a 1% gain tomorrow. Second, they can be highly cost-effective. Third, they can provide savings and other benefits directly to citizens"* [117].

The snag with this is not just that the British Government seems to have turned one, microscopic type of energy and cost benefit into no fewer than three. The snag is also that it has almost no "existing policy" on energy infrastructure, preferring to engage in electricity market reform founded on price-based contracts for difference aimed at reducing the very uncertainty that it has done so much to create. It is true, as a London School of Economics critic of the Cabinet Office paper notes, that "No sensible behavioural economist would claim that behavioural economic-informed policy is a panacea, which is something that the critics of this general approach tend to overlook" [118]. Yet the view that a one per cent saving in household or indeed transport energy today is worth more than a 50 per cent gain in the productivity in energy supply 20 or 30 years away is the purest form of sophistry. It relegates serious innovation to the far future, and always implies that the tiniest innovations in the present are, indeed, a panacea. Not for nothing does *Behaviour Change and Energy Use* devote nearly six of its 30 pages to a graphic design makeover of residential Energy Performance Certificates [119].

If anyone is "stupid" it is the supporters of behavioural energy economics. With the usual air of high discovery, in May 2012 *The Economist* explicitly endorsed nudging in British energy, with the fanfare: "trials have shown that householders will take up energy efficiency grants three times more readily if insulation firms offer to clear their lofts first" [120]. Just five months later, however, and despite years of incessant government and media campaigning against energy waste, the tune was very different. Even though it recognised the rebound effect, *The Economist* accused Britain's government of lacking "any strategy" for reducing demand, "even at peak times" – and among consumers whom it generously described as "gluttonous" [121].

The ultimate logic of behavioural energy economics is brought out in a paper by Costa and Kahn, at the University of California, Los Angeles. They argue that, confronted with Home Energy Reports on their energy consumption, registered political conservatives in the US will decrease their mean daily kWh by 1.7 per cent; while, in response to the treatment, registered liberals "will reduce consumption by 2.4 percent". They conclude:

> *"[E]nvironmental nudges are most effective in relatively liberal communities. What works in California may not work in Lubbock, Texas…. Future research should continue to test for what might be effective conservation messages with political conservatives"* [122].

Clearly behavioural energy economics is not much about economics, and not at all about technological innovation. But it is very much to do with political intervention. Already affection for particular sources of energy is a badge of political identity [46].

In the same way, it appears, the response to behavioural initiatives around energy consumption is as political as the motivation for those initiatives in the first place.

We can now see that the fears of corporate invasions of privacy around smart meters which we detailed earlier are misplaced. While the state may be as unable as companies to deal with reams of data on residential energy use, its tendency toward getting every neighbourhood to engage in "peer comparison" around behaviour and the environment is far from innocent. The fact that, in America, it is companies that are ahead of the state in going down this road should not be allowed to obscure the fact that the state fully sanctions those companies, and provides the ideological atmosphere in which they are free to engage in quite physical invasions of privacy.

The sooner behavioural energy economics is subjected to the derision it so richly deserves, the sooner the revival of energy innovation can take place.

8. A NOTE ABOUT FINANCE AND ENERGY INNOVATION

Much of the expert discussion on energy concerns not just energy prices, but the problems of financing investment – let alone innovation. These problems are believed to be particularly acute, given that the future course of energy prices is rather unpredictable. The factoring of instability in the Middle East into the oil price, the contentious issue of stock market speculation around oil prices, and the reputed decoupling of not just American but also European gas prices from world oil prices add to complications here.

Clearly prices bear on levels of energy investment – and the relationship, which is not straightforward, is the subject of a large literature. Also the subject of a large literature is whether energy investment, as well as different stages of the innovation process in energy, should be backed privately or with public money. Here, however, we want briefly to repose discussion away from the familiar debates.

In a slightly different context, we have already criticised the official fixation on prices. Here we will simply note that concentrating on private or public finance for innovation is an equally sterile exercise. Both at the level of national energy policy and with individual energy projects, conventional interpretations of how to fund energy are wrongly framed. Few really argue a free-market line of liberalisation, privatisation and exclusively private-funded projects and technologies. All sides agree that there must be state regulation, beginning with the regulation of prices and taxes, in the energy sector; and even among private-led energy projects, the rhetoric of partnership with government or community around reasonable costs and prices is never far away. Private-led projects are often strongly reliant on government support.

What is even more interesting is to investigate how much energy companies, like companies generally, have made the financialisation of their operations the subject of massive efforts – by contrast with the modesty of their goals in innovation. Elsewhere, we have attacked energy companies' love affair with services ("think billing, call centres, web sites and IT systems for customer relationship management", we wrote) and with different "business models", or different ways of organising revenue streams. We argued that these were subterfuges which marked a perverse turning away from technological innovation [123]. Yet today there is something more to add to this. On both sides of the Atlantic, the cash reserves of general companies are the subject of mounting criticism, as the fidelity of business to innovation and investment withers with each passing year. Moreover energy companies are by no means immune from this trend:

Table 10. Cash and short-term investment of selected energy companies, $ billion, 30 June 2012 [124]

Chevron Corporation	21.46
TOTAL	19.27
Exxon Mobil Corporation	18.02
Royal Dutch Shell	17.28
BP	15.18
Statoil	14.32
PetroChina Company	14.08
ConocoPhilips	6.044
ENI	5.963
China Petroleum & Chemical Corporation	2.213

Firms which hoard cash, which elevate the value of their shares by engaging in "buybacks" of them, or which prefer acquiring other companies to building new laboratories – these firms are vivid evidence of risk consciousness and distaste for innovation. After all, it is hard, nowadays, to earn much interest on cash deposited in banks, so the willingness of a company such as Apple periodically to run worldwide cash reserves at more than a $100 billion says quite a lot about the fear it has of a really thoroughgoing commitment to R&D. It is the same with energy companies.

Nor are the kinds of malaise registered above the only signs of risk aversion in energy finance. In Britain, at least, finance houses and banks prefer equity investments and bonds to loans, and industrial energy efficiency to the residential sort. They are not keen on electric vehicles, because they wonder who will build the infrastructure. For offshore wind projects, the cost of capital, can be 26 per cent; for wave or tidal projects, 50 per cent or more. While insurers understand North Sea oil and gas, they don't understand wind turbines, and are exceedingly reluctant to insure towing operations for them [125].

It is time debate on energy finance moves away from the vapid confrontations of the past, and instead shines a light on the links between financial neuroses and the torpor in energy innovation.

9. IN PLACE OF A CONCLUSION

In October 2012, the prices that Britain's "Big Six" utilities charge the nation's householders for energy became front-page headlines [126]. In off-the-cuff remarks in Parliament, Prime Minister David Cameron felt compelled to reassure the population that, henceforth, the utilities would be obliged to charge consumers the minimum possible tariff available. Confusion among those utilities then broke out; the parliamentary opposition smelt the making of policy "on the hoof", and even consumer groups criticised the government – one, indeed, accused it of jeopardising competition between the utilities.

Now the bills faced by customers for energy are, without obsessing about prices, of proper concern in Britain, as elsewhere. Moreover it is widely recognised that, despite all the utilities' protestations about their attachment to "transparency", the tariff structures they offer are labyrinthine, and given also to endless and protean variations. Even a household's switch to another utility in the hopes of finding lower prices does not at all guarantee it a better deal. Yet what was telling about the national debate about energy in Britain in the autumn of 2012 was the almost complete absence even of rhetoric, let alone action, about innovation in energy.

Perhaps this was just an expression of the British authorities' preference for producing reports about energy rather than energy itself. Yet as we have tried to show, though energy has all the special features, as a sector, that Britain does as a nation, the trend toward *evading* innovation goes further than either of these entities. R&D still goes on in general Western industry (though to a much lesser degree in services); but in energy, and particularly around nuclear power and fossil fuels, it is far from being the top priority. Despite all the collapse in demand around the world since 2008, inflation, and specifically the inflation of energy prices, has in most countries yet to be checked by the higher productivity of supply that innovation in energy technologies could be expected to bring. The probably transient case of low US gas prices, reflecting the technological progress made in the extraction of shale gas, is the only major exception to this rule. Cheap energy for all, let alone energy that is "too cheap to meter", remains an evanescent prospect. Instead, an unbridled passion for with energy efficiency lead a body such as the IEA to speculate about how its "Efficient World Scenario" could halve the global growth in energy demand that is likely by 2035, and at the same time buy the planet five years' grace with carbon emissions [127].

A fondness for questionable green solutions, for subsidies and for the creation of evanescent jobs dominates. Indeed state intervention, while weak in field of basic research, extends not just to economic and political support for cleantech, but also elsewhere. It extends to the wholly political nudging of consumers into what is termed more responsible behaviour around energy efficiency and energy conservation. It extends to smart meters, and to the kind of bills, handbills and certificates that will encourage behaviour modification. Moreover even climate sceptics hardly ever dare to take a magnifying glass to the stratagems of nudging. Instead, governments get away with the nicely open-ended admonition that what are in fact coercive policies are merely aimed at helping people make "informed choices" about energy use.

Any kind of substantive energy innovation may receive favourable publicity. But energy innovation is taken, more or less, as much less inviting than, say, innovation in IT. From different quarters, innovations in nuclear power, coal, oil, gas, transport, renewables, geo-engineering and air capture all meet with intransigent hatred.

Nevertheless, we are confident that this situation cannot last forever. Events will see to that.

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