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Energy Group

NEWSLETTER **February 2016**

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Editorial

Welcome to a new edition of the Energy Group Newsletter. A special thank you to Edwin Carter of PassivSystems for sharing with us some of the early findings of a UK smart heat pumps trial, and to John Twidell and Anthony Webster for reporting on the Energy Group's July conference held last July. The subject of the meeting was the challenges and opportunities involved in scaling up renewable capacity, in terms of materials' availability and suitability for large-scale projects, renewable resource, electricity grid consequences and costs. A further thank you to those who spoke at and attended the day and contributed to the important and challenging discussions around the UK's energy future.

Jenny Love

This newsletter is also available on the web and in larger print sizes.

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Making heat pumps smarter

Edwin Carter (PassivSystems) reports on findings from a trial of smart heat pump controls in real houses

A substantial fraction of the UK's carbon emissions come from heating our homes. As we move towards a low-carbon economy, this energy needs to move over to renewable resources. It is likely that we will heat our homes using heat pumps, but this will come with new challenges, as renewable electricity generation will be quite variable through the day. Part of the solution to this problem will be a smarter electricity grid which is able to balance loads, storing much more energy than at present when there is a surplus supply for retrieval later during periods of high demand. This future scenario includes **smart heat pumps** that are able to interoperate with the smart grid, and run at maximum efficiency.

PassivSystems is a small UK company providing home energy management services such as remote heating control and solar PV monitoring. They recently completed a project funded by DECC's Energy Entrepreneur's Fund called “Seamless Demand Response” (SDR), which is focused on making heat pumps smarter and demonstrating demand response capability in a real-world trial. The trial had a number of aims:

- **Make heat pumps easier to use.** Participants in the Energy Saving Trust field trial of heat pumps reported[1] that the biggest problem with their heat pumps was the “lack of usable controls and displays”, and 44% did not understand “how to operate their system for optimum efficiency and economy.” The SDR trial aimed to demonstrate that with innovative technology, many of the complexities of managing a heat pump can be hidden from the user: participants simply specify when they want their house to be warm using PassivSystems' in-home display or smart phone app.

- **Reduce the running costs of heat pumps.** Many heat pump trials focus on improving the efficiency (COP or SPF) of the heat pump, but customers simply want lower energy bills and their house to be warm. PassivSystems have been developing a technology that explicitly

[1] Caird, Sally; Roy, Robin and Potter, Stephen (2012). *Domestic heat pumps in the UK: user behaviour, satisfaction and performance.* Energy Efficiency, 5(3), pp. 283–301. http://core.kmi.open.ac.uk/display/109723

calculates the optimal control strategy that uses the least energy while maintaining occupant comfort. It learns the thermal properties of a house and uses this (together with a weather forecast) to determine the correct tuning of the heat pump, which is dynamically updated over the course of the day. Conventional heat pumps use fixed settings, which are roughly estimated at installation time and rarely changed – sometimes leading to unnecessarily large bills.

- **Shift demand by storing heat in the fabric of the home.** If electricity prices change with time ('time-of-use tariffs'), the heat pump can be run hard when energy is cheap (e.g. at times of plentiful wind energy) and shut off when electricity is expensive (perhaps the early evening demand peak). One example of this is an Economy 10 tariff, which has three periods of cheap electricity per day. PassivSystems estimate that 38% savings in running costs of a heat pump are possible on an Economy 10 tariff using their technology, and the SDR trial aimed to find out if this is possible in real houses, and what impact it has on the occupants. PassivSystems are also developing technology to aggregate the total electricity demand across multiple homes, so that the portfolio can be used as a "virtual power plant" to help balance the electricity grid by shifting demand away from peak periods.

A conventional heat pump is typically controlled in one of two ways:
(a) with a programmer and thermostat in a similar way to a gas boiler [see Figure 1, Before], or
(b) running constantly with a weather-compensated heating system (radiator) water temperature [see Figure 2, Before].

Whilst *(a)* results in lower thermal losses as the house is cooler when the heat pump is turned off, the heat pump has to run harder and less efficiently (at a higher water temperature) when heating the house back up again. Scenario *(b)* runs the heat pump efficiently, but thermal losses are greater as the house is warmer; and the weather compensation is rarely configured correctly, which can result in unnecessarily warm room temperatures that are hard for an occupier to adjust. Smart heat pump control enables a quantitative trade-off between thermal losses and inefficient running; this is learned automatically for each individual house, requiring no configuration of weather compensation, and adapting to different sizes of heat pumps and radiators.

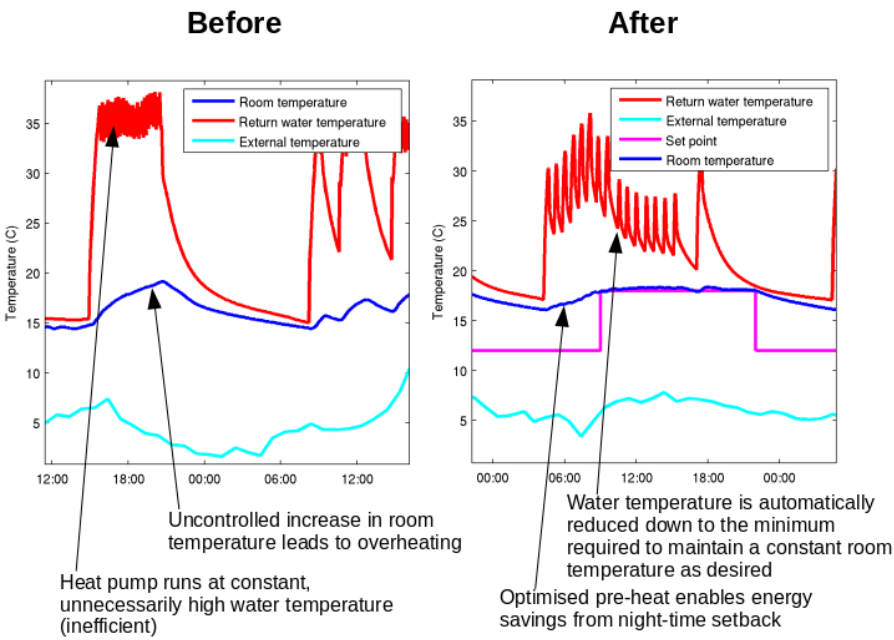

Figure 1: regular vs smart heat pump

Figure 1 above shows sample results from one house, a three-bedroom bungalow in Cornwall heated by a ground source heat pump and radiators. The smart controls enabled efficiency improvements by bringing down the temperature of the radiators to the minimum required to keep the house warm, at the same time as managing the room temperature to achieve exactly the comfort levels desired by the occupants. The optimised pre-warming makes a quantitative trade-off, comparing the greater heat loss from keeping the house warmer overnight against the inefficiency of heat pumps when driven harder to warm a house up quickly. Even though the heat pump is running more of the time, less electricity is used because the house is not overheated (reducing thermal losses), and the heat is produced more efficiently because of the lower water temperatures (more units of renewable heat per unit of electricity).

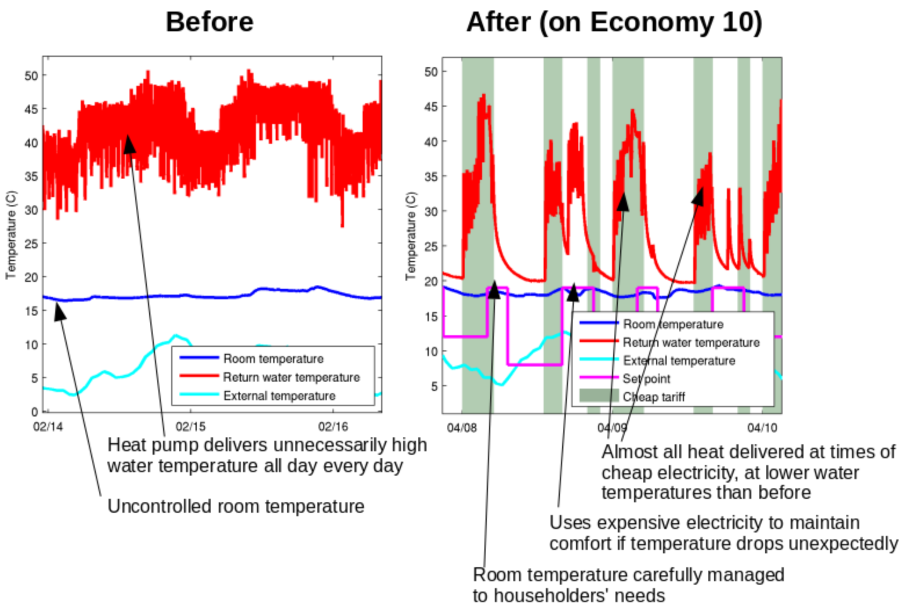

Figure 2: regular vs smart heat pump

Figure 2 above shows sample results from a three-bedroom terraced house in Oxfordshire, heated by an air source heat pump and underfloor heating. The smart controls enabled substantial reductions in the delivered water temperature (as beforehand the weather compensation has been set such that water temperature was unnecessarily high), and shifted the majority of the heat pump's electricity load to cheap Economy 10 times, without impacting the comfort of the householders. Note that the heat pump is not just turned on and off as the electricity tariff changes: a careful trade-off is calculated.

There are a number of barriers to wider deployment of this technology:

- **There is no standardised control interface for heat pumps** – the SDR trial is limited to a few select manufacturers PassivSystems has partnered with, and the interfaces are too expensive for commercial deployment. Many heat pumps are installed with crude timers and thermostats that are designed for boilers, but what is needed is an open-standard interface that permits the heat pump to be tuned to the properties of the house and the requirements of the occupants. The first step towards a smart grid needs to be a requirement that all manufacturers of heat pumps (and in fact all other household electrical appliances) include sufficient communications capability for their loads to be controlled effectively and efficiently.

- **There are no government incentives for the improvement of heat pump controls.** The current Renewable Heat Incentive provides encouragement for heat pumps to be installed. Heat pumps qualify solely on the basis of estimated SPF (seasonal performance factor), but this is not the whole story as smart controls can reduce the heat load of the house. SPF is calculated on the basis of the heat output of the heat pump, but this is largely irrelevant to the consumer, who only cares about being warm at least cost. Tools such as SAP do not credit smart controls, and need to be overhauled to recognise the benefits of innovative technology that encourage consumers to behave in a way that saves energy.

- **The energy market is not ready.** The deployment of smart meters will take us one step closer to providing consumers with greater engagement in energy markets but policy has not gone far enough in unlocking real financial value. The network needs to be designed to provide consumers with affordable clean energy, at the same time as making the grid cheaper to run. Customers need to be discounted into the energy market with real incentives for buying cheaper energy in return for reducing peak energy consumption and making renewable generation plants work harder. The heat pump control technology is almost ready but the commercial incentives for smart grid technology have to be present.

Edwin Carter studied physics at Cambridge and Birmingham, and now heads up the R&D team at PassivSystems. His main responsibilities are developing new generations of control algorithms, and providing insight into energy consumption and the properties of houses and heating systems.
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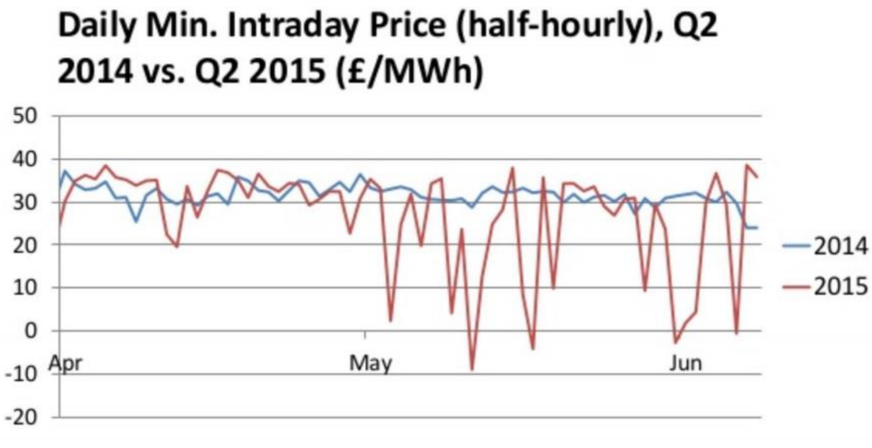
Renewables at Scale: Realising Gigawatt Generation

John Twidell and Anthony Webster report on this one day meeting hosted by the IoP Energy Group on 13th July 2015

The meeting of roughly 45 participants was opened by Robin Morris from the Energy Group, who explained that the meeting's focus was on electricity-producing renewable technologies that have the potential to be scaled up to Gigawatt scale energy production. He overviewed the UK picture, with roughly 7GW installed solar PV capacity and 12 GW installed wind power capacity, with a rapid growth in both of these during the past few years. The growth in renewable energy production has coincided with the closing of fossil fuel plants, and a reduced network electricity demand from 340 Tera Watt hours (TWH) in 2007, to 290 TWh in 2014[2].

Robin noted that the peak daily demand tended to be driven by households and was reflected in price peaks for electricity. He also noted that widespread PV deployment had led to the possibility for negative price peaks on e.g. sunny Saturdays when production is high but demand is low – see example graph below.



[2] Unmetered generation (e.g. from microgeneration and generation into local distribution lines) influences these numbers

Electricity system in transition – no easy options

Prof Geoff Hammond, Professor of Mechanical Engineering and Director of the interdisciplinary International Centre for the Environment (ICE), University of Bath

Geoff described how from 1850-2050 the world has experienced a sequence of energy transitions between different dominant supplies, from renewable biofuels (wood), to successively: coal, oil, gas, and nuclear. The electricity produced from each source has tended to rapidly grow towards a maximum and then later has reduced in dominance.

The present UK situation: Currently (e.g. Nov 2013-Jan 2014), the UK's electricity is supplied by Coal (35%), Gas (25%), Nuclear (20%), and Renewables (18.5%) (!) The UK is committed to reducing its carbon emission by 80% from 1990 levels by 2050, and due to continuing falls in North Sea gas production, the UK will import 2/3 of its Gas by 2020, expecting to make gas more expensive and energy security more challenging.

The challenge: Geoff described the "trilemma" of needing to simultaneously minimise costs and carbon emissions, while maximising energy security. To allow informed choices to be made, his group at Bath University had performed a number of whole-system studies for different aspects of the problem, some results of which he presented. His key points regarding the role of each technology are summarised below:

The role of Carbon Capture and Storage (CCS): CCS is regarded as potentially valuable for the UK to meet its targets - otherwise much larger capacity increases in renewables, energy storage and grid stability would be needed. Also, without CCS transport (presumably considered as being electrified) would be very difficult at the reduced level of overall emissions needed to meet UK emissions targets. Over the longer term biomass with CCS (BECCS) could potentially provide a net sink for carbon emissions. However, to date, no full-size CCS system is in operation.

Limitations of CCS (with coal): Whole systems studies indicate that CCS can only reduce carbon emissions from coal power plants by about 2/3 (70%). It was suggested that CCS with gas may be cheaper than with coal and oil; CCS with biomass is better still, since there is no initial use of fossil-carbon and the removal of non-fossil carbon provides an overall decrease in atmospheric carbon.

The role of nuclear fission: Although capital costs and disposal costs are high, and there are unresolved waste-handling issues, since long-term waste disposal is not currently available, nuclear fission is an international industry, is reliable, and will be here for decades. However, energy efficiency saves 2.5-20 times more CO_2 per pound spent than nuclear, so a large growth of nuclear power would send the wrong signal.

Renewable options: Combinations of wind, solar PV, combined biomass heat and power (CHP) plants and hydro now offer viable generation, with addition from future tidal and wave energy. The resulting distributed generation at large scale would however require a combination of proven technologies, large energy storage systems, and network changes. Geoff summarised the work of an inter-university/industry study of 3 pathways to future change:

1. “Market rules” – market driven with minimal interference.
2. “Central coordination” – centralised generation.
3. “Thousand Flowers” – a bottom up approach with distributed generation.

All of these pathways involve CCS, and all have a similar rate of reduction in CO_2 emissions. The “Thousand Flowers” pathway has considerable land use implications and consequently a large environmental-space impact. Of the contributing technologies, this environmental-space impact is largest for biofuel– 10s of percent more than coal. Towards 100% renewable generation was thought to be technically feasible with the use of back-up gas generation and more energy storage capacity.

Overall, there were no easy options. The pathways aimed to conserve depleting resources with improved efficiency and the use of nuclear and renewable energy production, while mitigating greenhouse gas emissions with CCS.

Solar photovoltaics – think big systems or small systems?

Prof Nicola Pearsall, professor of renewable energy, Department of Physics and Electrical Engineering, Northumbria University.

The presentation started with a summary of Solar Photovoltaics (PV) power in the UK. The present installed capacity is ~7.3 GW (End of May 2015), produced from roughly 710,000 systems, with on average 10kW capacity per system (larger than might be expected for rooftop systems due to large megawatt scale arrays). Of these,

- Feed-in-tariff (FIT) schemes account for roughly 695,000 systems, with on average 4.5kW capacity per system.
- The Renewables Obligation certificated schemes has led to another roughly 12,000 systems, of about 280kW capacity per system, with a total capacity of 3.3 GW.
- In addition there are 2,815 other systems with an average capacity of 316 kW.
- Farms: The largest PV solar farm in the UK is presently 48MW, but larger ones are planned. (The largest PV solar farm is presently in the USA, capacity 250MW.)
- Commercial Roofs: Jaguar Land Rover in South Staffordshire has covered its manufacturing factory roof with PV to provide a capacity of 5.8MW, supplying about 30% of their electricity needs. The array took 11 weeks to install, required no extra land use, and is generally not visible from the ground.

In 2014 PV produced 1.2% of UK electricity. This was about 6.3% of the UK's renewable electricity, but this proportion is growing rapidly and expected to increase by about 50% during 2015 (!). The UK has the 8th most installed PV capacity than any other country in the world, despite our comparatively small size and northerly geographic location, and presently the annual installation rate of PV capacity in the UK is the 4th highest in the world.

TABLE 1: TOP 10 COUNTRIES FOR INSTALLATIONS AND TOTAL INSTALLED CAPACITY IN 2014

	TOP 10 COUNTRIES IN 2014 FOR ANNUAL INSTALLED CAPACITY		TOP 10 COUNTRIES IN 2014 FOR CUMULATIVE INSTALLED CAPACITY	
1st	China	10,6 GW	Germany	38,2 GW
2nd	Japan	9,7 GW	China	28,1 GW
3rd	USA	6,2 GW	Japan	23,3 GW
4th	UK	2,3 GW	Italy	18,5 GW
5th	Germany	1,9 GW	USA	18,3 GW
6th	France	0,9 GW	France	5,7 GW
7th	Australia	0,9 GW	Spain	5,4 GW
8th	Korea	0,9 GW	UK	5,1 GW
9th	South Africa	0,8 GW	Australia	4,1 GW
10th	India	0,6 GW	Belgium	3,1 GW

NUMBERS HAVE BEEN ROUNDED

Source: IEA PVPS

Nicola went on to give a technology overview:

- In the last few years there have been small increases in efficiency of panels.
- Crystalline silicon cells take about 90% of the solar PV market.
- There has been an increase in average capacity of panels (modules) due to increased panel size.
- Thin film technology is holding its share of the market, but not significantly growing that share.
- New developments include further increases in efficiency, reduced cost materials (perovskites). Lifetime of systems is also key, and part of the development process is to ensure long life.
- In addition to the PV array, developments are being made to the DC/AC inverters, and to their control and measurement systems.

The potential for UK PV was summarised as follows. The UK government ministry (DECC) set a target for 10 GW capacity by 2020, but the actual installed capacity seems likely to reach a new 20 GW target by 2020. This would require about 160 square km of installed PV, which is about 15% of the estimated 2,500 square km of UK south facing UK roofs. The original 10 GW goal was set low enough to allow for constraints from the UK's transmission and distribution system (the grid), since overcoming grid connection constraints is increasingly becoming the main obstacle to meeting our PV goals.

Due to the variability of received solar intensity, national PV output prediction and balancing are important. Whereas some output variations are highly predictable (e.g. day and night!), there are uncertainties in UK weather predictions and timings used for modelling. It was noted that balancing of regional output may be made easier by having suboptimal orientation of individual PV systems (e.g. East and West facing, as opposed to South facing). Modified invertors with intelligent control can be used to reduce peak oversupply on the grid.

PV costs per kWh, which are continuing to reduce, are determined by technical efficiency, costs of hardware and installation, and lifetime. Overall the costs per unit of generation are now less than for offshore wind generation, but more than for onshore wind generation.

To answer the question proposed in the talk's title – big or small systems - Nicola proposed that in general all PV array sizes and shapes, in any reasonable location, are beneficial. For example, as mentioned above, non-optimal orientation of PV can help with grid connection and balancing, and there are many suitable rooftops and land areas still available.

Flexible connections: innovation and network constraints
Steve Atkins, Head of Scottish and Southern Electricity Power Distribution (SSEPD), UK.

"Presently there is a record level of applications for grid connection of larger scale installations of multi-roof and ground-level arrays"

Reinforcement, the upgrading of the grid to cope with extra demand and renewable generation, is often required to cope with new grid connections including microgeneration. This leads to higher costs and longer lead times per installation. Unfortunately, due to the cost-risks of grid capacity not being taken, reinforcement ahead of need is not allowed by the regulator. The cost of connection is made up of the cost of assets used, a proportion of the network reinforcement costs and then any reinforcement costs exceeding £200 per kW. Steve gave suggestions as to how to mitigate the cost of reinforcements:

- Avoiding the need for reinforcement by using ‘timed connections’ – ie disconnecting at certain periods. However, this does not allow the use of all of the available energy.

- Limits on the maximum allowed power which can be exported to the grid. Devices are being developed to assist with this.

- “Intertrip”, whereby clusters of systems can be tripped together by external signals from the grid controllers.

- Active network management with intelligent monitoring and remote switching to prevent grid ‘hotspots’. Such methods are usually cheaper than grid reinforcement.

- Estimating energy production using historic load and generation, and planning for curtailment of generation.

- Consortia to share reinforcement costs – however these can be difficult to manage.

- Queue management – this operates with a ‘last in’ ‘first off’ (“LIFO”) stack system, whereby the last person to join would be the first required to curtail production. If a generator fails to supply, then it loses its place in the stack.

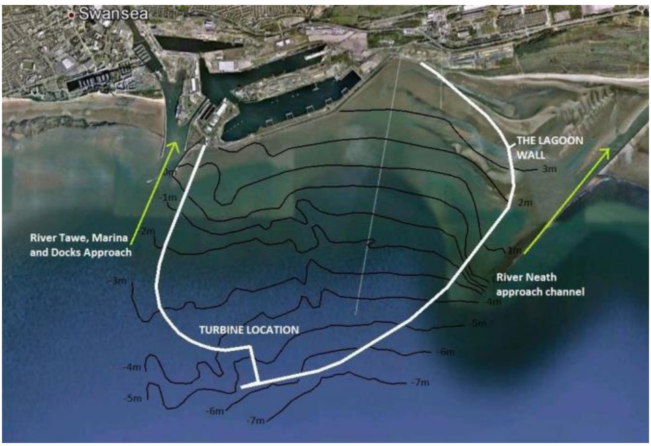
- Curtailment of not only generation but also of large individual demand (demand side management) allows significant capacity of renewables installation. This is being introduced in the South West of England (mostly Cornwall) and the Isle of Wight.

Modelling and turbine selection for efficient tidal energy
Mike Case, Tidal Lagoon Power Ltd, UK.

Mike started by describing the development of the '1st of a kind', GW scale, Swansea-Bay tidal lagoon power station. Using a 9.5km long barrage enclosing an 11.5 km^2 lagoon, it is designed to have a 120 year lifetime, generating for 14 hours per day, with approximately 240MW output capacity at 4.5 m head, using variable speed generators.

Turbines: generation occurs at both ebb and flow, with turbines controlled by variable vane angle and controllable water-flow wicket gates. Variable speed generators (17 to 70 rpm) operate with solid state electronic interfaces with the grid.

The turbines and their control are key to the project, using state of the art hydropower technology. Calculation and tests show turbine-generator efficiencies of 93% (inflow) and 89% (outflow), with a hydrodynamically symmetric design. The turbine size is similar to the Channel Tunnel's cross section (7.6m diameter), and is designed to allow regular cleaning to remove marine growth such as mussels. The turbines have been designed to operate over a large range of flow speeds at roughly 90% of their optimum efficiency. This allows the maximum extraction of total potential energy from the lagoon as water enters and leaves during the tidal cycle. The lagoon and the turbine races have been modelled with a combination of 0-D, 2-D, and 3-D modelling methods, suggesting that 57% of the maximum available potential energy can be extracted.



A fleet of lagoons: Plans are being developed to have a “nuclear scale” fleet of 5 to 6 UK lagoons each with a 120 year lifespan; 4 are planned for the Severn Estuary (Swansea Bay, Cardiff Bay, Newport and Bridgwater). The next would be constructed in Cardiff Bay, and would supply at 1.8-2.8 GW. The largest proposed would be near Bridgwater. Others are proposed for the Solway Firth and Colwyn Bay. Together such lagoons would have a capacity of 5 to 6 GW. Because of their different tidal characteristics and phases, the fleet of lagoons would naturally smooth their combined output into the National Grid.

But how much does this type of energy cost? The pricing had been expected to be similar to nuclear, but with a 120 year lifespan (and no long-lived radioactive waste). However, the estimated cost of the project has recently doubled, and at the time of writing the subsidy per MWh requested for the electricity produced is around twice that of nuclear energy.
An audience member asked whether sea level rise due to climate change (expected to be around 1m over a 120 lifetime) had been taken into account. The answer was that a degree of sea level rise had been allowed for, and that it was also possible to retrospectively increase the wall height if required.

Large-scale offshore wind
Prof Peter Tavner, Emeritus Professor in the School of Engineering and Computer Science, Durham University

Offshore wind benefits from high wind speeds and high capacity factors for turbines. In terms of how it has been operationalised in the UK, Prof Tavner expressed the view that the UK’s approach to wind energy had been very effective, with mistakes being made on a small scale, then corrected for in larger scale deployments. He described how the UK’s fleet of offshore wind turbines has been deployed in three phases:

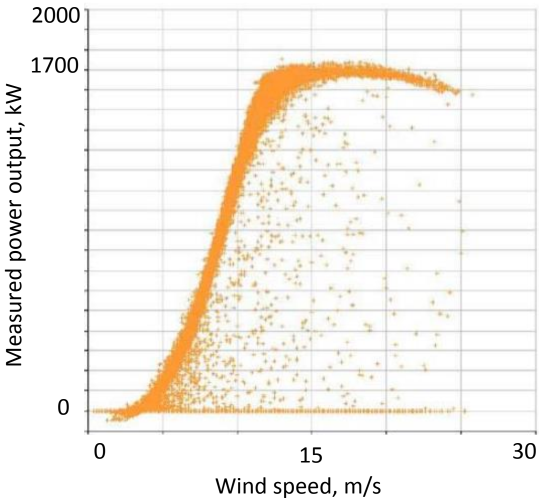
Round 1 (1990): Relatively small initial deployment, but highlighting a number of difficulties and problems that were subsequently solved or mitigated.
Round 2 (2003): 5GW installed capacity with typically 3 to 6MW capacity turbines.

Round 3 (2008): A total of 29GW of installed capacity is planned.

The deployment has been run by Crown Estates (not government), and has been steady and well planned, with Crown Estates operating a bidding process during which the competence of installers was determined.
The mechanical availability of the turbines has a big impact on cost of the generated electricity, and it was stressed that this was most significantly reduced by effective maintenance of the turbines.

The cost of offshore generated electricity is roughly 50% more for than onshore generated power, and the initial costs are roughly double. Deployment of 29 GW of wind turbines (with a large proportion of these offshore) will require:

- New offshore foundation-technologies.
- Bigger offshore substations.
- Bigger maintenance ships and use of helicopter transport.



Example plot of power output vs wind speed, for a 1.67 MW rated turbine

Balancing for high renewable penetration

Malte Jansen, Fraunhofer Institute for Wind Energy and Energy System Technology, Kassel, Germany

Malte described the project “Kombikraftwerk2”, whose purpose was to explore whether Germany could have electricity from 100% renewable energy and with stable grid performance.

They examined an energy production scenario with wind turbine installation where the wind speeds are largest (generally north west Germany), and PV installation primarily in urban areas where demand is largest. An even distribution of biofuel electricity production and use, and availability of a flexible power generation and backup system were also assumed. The “flexible power generation and backup” was assumed to be a combination of power-to-gas via renewable methane (including hydrogen to methane transformation) and methane power plants, pumped hydro storage, batteries and biomass fuel. Furthermore, it was assumed that there were sufficient storage and grid reinforcements, including a high voltage DC north-south grid connection (because a high percentage of wind power generation is in the north).

The team found that a stable grid with 100% renewable energy production is possible, but that grid support (ancillary services), are required beyond 60-65% renewable penetration, requiring electricity generation from renewable gas backup. Secure and powerful communication standards between the sites of production, storage, and backup are also required.

It was argued that the recent solar eclipse provided a demonstration that grid stability can be maintained despite large surges in PV power production that day. During a usual day, German PV power production increases and decreases with gradients of about 4.5 GW per hour. During the eclipse these gradients included a decrease at about 7.5GW per hour, and an increase at about 14.5 GW per hour. It was argued that this demonstrated that a higher level of renewable penetration was possible (14.5 is nearly 3 times the usual power gradient, so it would suggest that up to three times more PV installation should be possible with minimal further grid reinforcement).

Conclusions from the meeting

Overall the meeting was successful and gave the impression of a rapid growth and deployment of new GW scale renewables throughout the UK, primarily as PV and wind turbines, but also via the Swansea tidal lagoon. There was also the impression that grid connections are increasingly becoming a bottleneck for future development, suggesting it may provide the greatest risk to a continued rapid growth in UK renewables. Hopefully the development of new storage and other technologies will keep pace and allow renewable supply to continue growing at its present rapid rate. If this is the case, then it looks likely that the UK can meet its targets for 2020 and beyond, with the benefits of renewable energy outlined by Malte Jansen, namely: clean and safe energy, reduced energy imports, and increased security of supply.

John Twidell, FInstP, has many years experience with renewables in universities and professional associations. The updated and enlarged 3rd edition of his jointly authored textbook 'Renewable Energy Resources' has recently been published by Routledge.

Anthony Webster is a physicist formerly based at Culham Centre for Fusion Energy, presently studying for an M.Sc. in Applied Statistics with St. Hugh's College at the University of Oxford. He has publications on theoretical and experimental aspects of fusion research, on applications of Bayesian probability theory and statistics, and his Ph.D. discussed the aging and stabilisation of foams and emulsions. Anthony is on Research Gate:
https://www.researchgate.net/profile/Anthony_Webster3

Energy News

Highlighting developments in a variety of energy technologies over recent months – beginning with two concepts combining renewable technologies

Wind-hydro scheme in the Canary Islands

A combined wind-hydro system has been implemented in El Hierro, the smallest of the Canary Islands. Five wind turbines (total capacity:11.5MW) have been built along with two reservoirs, one 700m higher than the other. The reservoirs are connected by two 3km-long pipes, and water running from the upper to the lower reservoir passes through a series of turbines, generating electricity through the standard hydropower mechanism.
At times of sufficient wind resource, electricity is produced and distributed through the grid. Excess wind power is used to pump water from the lower reservoir to the higher one; when wind resource is low, the water is released from the higher to the lower reservoir and generates electricity.

The response time of the reservoir system, when wind resource is low, is claimed to be "within milliseconds". Although the system changes back and forth between mode (wind power mode, hydropower mode) quickly, one limitation of the joint setup is the length of time for which hydropower can be generated in one go. This is determined by the volume of the smallest reservoir - in this case, the lower one, which is less than half the size of the upper one. As soon as the lower reservoir is full, hydro generation has to stop. This is because the scheme uses freshwater, which is in short supply on this island and cannot just be released into the sea.

Image source: Getty Images, BBC news magazine

Solar-hydrogen concept in modelling phase

Researchers in Indiana and Switzerland are modelling a system using concentrated solar-thermal concentrators to both produce electricity directly and superheat water to produce hydrogen.

During the day when there is solar energy available, superheated water is used to produce steam for turbines and also to reactors which split water into hydrogen and oxygen which can be stored. Then, at night when there is no sunlight, electricity can be produced from the hydrogen.

This concept is similar to combining solar PV with batteries, in that efficiency of energy conversion from sunlight is increased due to being able to store excess energy and use it at times when sunlight is low or zero. Model results so far are yielding an energy-from-sunlight efficiency of around 35%, competitive with current commercial PV and battery systems.

Generating electricity from cheese

A power plant in the French Alps is using residual waste from nearby cheese production facilities to generate almost 3,000 MWh per year of electricity: enough to power 1,500 households in the surrounding area. The power plant in Albertville, Savoie, uses residual skimmed whey - an unneeded by-product of making Beaufort cheese – in an anaerobic digestion process.

The whey is placed in a tank along with microorganisms known as “archaea”, which break down the organic matter (fermentation) to produce biogas, primarily made of methane and carbon dioxide. The gas is then purified and connected to engines. These engines drive the generator that produces the electricity, which is then sold to the French electric utility company EDF.

Carbon Inheritance

Anthony Webster and Richard Clarke summarise their recent work

In a recent paper [1], we observed that a carbon tax would not provide revenue to mitigate the consequences of climate change in a post fossil-fuel era, and suggested that the notion of “carbon inheritance” might offer a solution to this problem. This short note explains what we mean by carbon inheritance, and why it is important.

What is carbon inheritance?
Carbon inheritance generalises the notion of a carbon tax, and is argued to be necessary if revenues to mitigate climate change are to be retained in a post fossil-fuel era.

Carbon inheritance is not about an allocation of blame for historic emissions, instead we argue that past carbon emissions have led to many positive outcomes, such as improved standards of living and improved healthcare, and that these benefits are being felt by an increasingly large population.

Carbon inheritance is the notion that <u>all</u> modern technologies have resulted from the 200 years of fossil fuel driven industrial growth that has provided the conditions needed for their innovation and development, and that the modern-day consumer is benefitting from (those) past emissions.
It is argued that responsibility for past emissions rests with all modern technologies, and should be accepted at the point of purchase or use of modern technology. This responsibility needs to be reflected in a small price increase to pay for the climate change costs that we have inherited.

Carbon inheritance is essential for a long-term solution
If a carbon tax or insurance-led levy were to successfully reduce carbon emissions, the consequences of climate change would remain, but the revenues to mitigate them will have reduced. Carbon inheritance would instead allow mitigation costs to be gradually transferred to the consumers and users of modern technology, allowing a long-term mitigation of (the effects of) climate change.

How would this work in practice?
Carbon inheritance could be implemented with various degrees of complexity.

One suggestion is through an energy tax or insurance levy on all energy producers, that is lower for low carbon energy producers. Over the long-term the costs will gradually transfer from high-carbon to low-carbon producers. An example for how the scheme might work is in Ref. [1].

Summary

It is argued that the concept of carbon inheritance is necessary for a long-term solution. Its implementation through an energy tax or insurance-led levy [1], in which the greatest polluters pay more, is intended to offer a sufficient (financial) mechanism for a long-term minimisation and mitigation of the consequences of climate change.

[1] A.J. Webster and R.H. Clarke, An Insurance-Led Response to Climate Change, submitted to Climatic Change, (arXiv:1509.01157v2), 2015.

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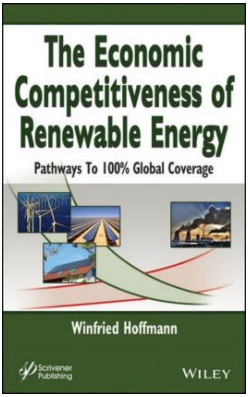
Book Reviews

The Economic Competitiveness of Renewable Energy: Pathways to 100% Global Coverage
Winfried Hoffmann
Wiley

Review by Roger Welch



This book addresses many of the key points which will enable renewable energy systems to become competitive with traditional forms of energy generation to the extent that they completely displace the use of fossil fuels and nuclear. The book goes some way to describe what will be required to reach 100% renewables and by when. But in a book of just over 200 pages one would not expect a complete explanation of such a mammoth task. As a reference book it has some useful analysis and data on the worldwide energy mix and how energy is used. The publisher has also created a well laid out book with clear text and section headings, however, as the print is monochrome some of the diagrams are indistinct and unclear.

The book discusses a range of topics in some detail including the history and technology of PV and also describes various state and government intervention schemes which have either worked or failed in the past. Hence, the book is informative to any student of the subject but is of particular relevance for the technical advisers of policy makers to enable them to make informed decisions when implementing and managing incentive schemes for the adoption of renewable energy technologies. The book raises some interesting points for consideration relating to the market adoption of renewables and provides a meaningful contribution to the subject. It also leaves the reader with the belief that, given sufficient political will, a switch to 100% renewables over the period of several decades is possible, even with the anticipated population growth; the author should be congratulated for this alone.

The main arguments for the switch to 100% renewables are that fossil fuels will become increasingly more expensive (although the book was published prior to the recent dip in oil prices), and that nuclear is not a viable long term option (in particular with the large subsidises provided and the unsolved waste storage problem). The book acknowledges that some incentives will be needed to encourage adoption (in particular feed in tariffs) but that these can be funded from the subsidies provided to oil production (although the book provides references to support these statements, it would strengthen the book if these were explained in more detail within the text).

The author admits his bias towards PV, and as someone who has worked in senior positions in the PV industry he is well informed and many of his arguments are well made. He predicts that 60% of renewable energy will be generated from PV, 20% from wind, and 20% from other renewables. The book covers PV technology in significant detail, but only briefly describes other important technologies relevant to a switch to renewables such as grid improvements and energy storage technologies, both of which are necessary if micro-generation is to play an important part in a future energy strategy.

The aspects of the book describing the technical development of PV are good and interesting. However, the sections of the book that differentiates it from a standard text on technology relate to the economic and market drivers behind the adoption of renewable technologies. The author stimulates a debate with economists regarding the market failure in the adoption of renewable technologies. This section of the book is interesting and thought provoking. Given the title of the book it is arguable that this section should be a more significant part of the text.

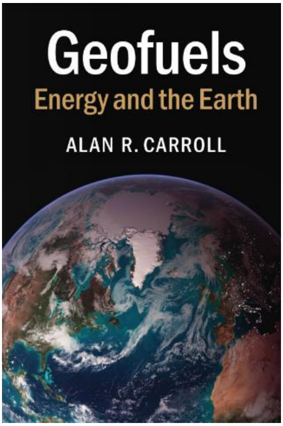
The book describes the likelihood that costs for producing renewable energy systems (especially for PV) will continue to decease since industry will learn from its previous experience and produce better cells cheaper (but that for wind technologies the costs will decrease more slowly). Perhaps stating that goods become cheaper and better as technology develops and products become commoditised is not surprising in itself, but the author does provide arguments as to why PV will decrease in cost faster that other renewables, which is an interesting observation.

In summary the book provides a good background to the need for a switch to 100% renewables, it argues what will be the dominant technologies in the future, and maps out what financial interventions will be necessary to accelerate the adoption of renewables. The book is good as far and it goes and raises interesting questions that scientists and policy makers should consider when enabling a pathway to 100% renewable energy.

Geofuels: Energy and the Earth

Alan R. Carroll
Cambridge University Press

Review by Colin Axon, Institute of Energy Futures, Brunel University, London



By geofuels Carroll means any resource provided by the Earth which humans can transform into useful energy. Which means just about everything could be covered, but Carroll is a geologist and the thread he follows is that of ‘Earth history’.

This has some advantages such as being a natural lead to discuss climate, the formation of fossil fuels, and the distribution of resources. His ‘thinking like a geologist’ is perhaps most evident where Carroll places geothermal energy and nuclear fission in the same chapter. As physicists we see these as separate entities with wholly different process for exploiting the fuel source (plus the engineering to achieve it). However, Carroll links them by the deep geological process following the Earth’s formation and radioactive decay which leads to the heating of the mantle and crust. For Carroll it is but a short hop to controlled uranium decay in a reactor (to also produce steam) with the whole of the nuclear industry summed-up in one short paragraph! However, he doesn’t mention thorium. Another example is that he draws together solar-driven processes such as wind and rainfall, thus wind turbines and hydro in the same category. Whilst it is an interesting concept, it doesn’t tie together as neatly as it might.

The chapter entitled ‘Out of sight, out of mind’ also links together what to energy researchers might seem disparate topics, namely enhanced oil recovery, CO_2 sequestration, and the long-term underground storage of spent nuclear fuel. Like the nuclear industry in the previous chapter, geological storage is dealt with a bit too briefly and in a US-centric way. This is disappointing as it seems that Carroll could say much that is informative. The point that he makes about the injection of CO_2 into saline aquifers is interesting. There is a significant lack of knowledge of sizes and location, but capacity may be 10-100 times greater than that of oil and gas reservoirs. He goes on to mention several geoengineering schemes for sequestering CO_2 such as using Olivine, fortunately he nails these as hare-brained capers that use too much energy or have other undesirable side-effects.

Carroll states in his introduction that all energy use prior to the 19th century was ‘green’, but deforestation was already a significant problem. This point is easy to overlook. Clearance for agriculture and grazing, timber for house-building, and charcoal production were placing a probably unsustainable demand on forests in many parts of Europe.

There are examples of unnecessarily imprecise language which will be noticeable to physicists and engineers. For example, in chapter three Carroll says that only two energy sources are independent of the Sun, namely nuclear fission and tidal. But geothermal is a third. Carroll perhaps means fission also in terms of radioactive decay of uranium and thorium deep in the Earth’s interior, but the context does not suggest that. Another which caught my eye is ‘The rotisserielike [sic] movement of the earth around its axis presents a major inconvenience for solar power production because half the globe is always kept in the dark.’ I’ve news for Professor Carroll…unless we are caught between two suns somehow, half the globe can only ever be in the light at one time. I’m sure that he meant that the Earth’s rotation is not yearly, but that’s not what was written. On a matter of accuracy, Carroll defines insolation as Wm^{-2} of land surface – it is surface area, whether land or ocean.

Some of the language is irritating too. The author has adopted a jocular style at times, but frequently it just gets in the way of the point that he is trying to make. Plus this is dispersed amongst some quite complicated language rather less suitable to non-specialists. An example of poorly considered language is when Carroll is explaining the Sun’s fusion process. He explains that K means Kelvins and that a Kelvin has the same magnitude as a degree Celsius, however, in the same sentence mentions absolute zero without explanation. The chapter on solar energy left a lot to be desired. Another example is when he is discussing shale oil, where

Carroll assumes that the non-specialist reader understands in situ and surface retorting. There are a great many such examples. Another irritating point was the inconsistent level of explanation. This ranged from material which would be taught at Year 7/8 to assuming that the reader isn't baffled by what a gas chromatograph actually looks like. However, there is a useful reference list at the end of each chapter.

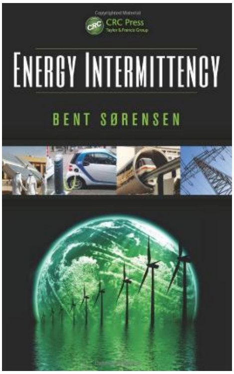
Given that this book is published by CUP and that it is meant to be about global resources, it is disappointing that the examples used are overwhelmingly North American. Although I welcomed learning some new examples, Carroll has missed a trick to widen his book's appeal by not researching and selecting more examples from around the world. Another curious US-oriented aspect is that the abiogenic theory of the origins of oil and gas has to be explained (and dismissed, thankfully) by the author. This would not need airing in a book not aimed at a North American audience.

Carroll is evidently more comfortable and confident in writing about geology, soils, and Earth systems. For example, the chapters on biofuels have good sections on the characteristics of soils which clearly affect the global distribution of biomass productivity and the effects of fertiliser use. Also in the biofuels chapter, Carroll has a nice example of 'energy return on energy invested' (EROEI)….only he doesn't formerly introduce the idea until much later in the book. The biofuels example isn't even listed in the index. Other good chapters are those on oil and gas and fracking. There is a lot of very interesting technical information on how fields form, the geological conditions and what is going on in the rock formations themselves. In the fracking chapter, Carroll also pays some fairly well-balanced attention to the environmental risks associated with the process. The chapter on tar sands and methane hydrates are also rich in geological detail.

The final chapter, intriguingly entitled 'How Long is Forever?', has a couple of interesting graphs which Carroll has partly constructed himself. They combine the (misplaced) discussion of EROEI with data on reserves – for both renewables and non-renewables. There is an interesting section on the rate of discovery of reserves. In the end, Carroll correctly points out that how much of the reserves are extracted will depend on that cost, the cost of the alternatives, and the demand for energy and power.

It's a curate's egg, but I learned interesting new things by reading this book. His final conclusion is one to which we can all subscribe '…the only truly 'green' energy strategy is to use less of it.'

Energy Intermittency
Bent Sørensen
CRC Press, Taylor & Francis Group
Review by John Twidell



Users of energy want their energy supply to be sufficiently available when and where they want it. If it is not, then this book defines the supply as 'intermittent'. Consequently, all energy supplies are intermittent in one way or another, but the perceived challenge falls on renewable energy and its distribution systems to overcome their natural variability and provide services that are not inconveniently intermittent. This book considers the overriding principles for harnessing renewables for reliable supplies of electricity, heat and fuels, as supported by extensive referencing and indexing.

Bent Sørensen takes a very theoretical approach to the problem by first establishing graphic symbols and networks that he uses to draw systems for energy supply and use. These distinguish between 'power' (i.e. electricity), 'heat' and 'fuel'; between 'renewable energy' and 'fuel conversion'; and between supply methods and user demands for 'power', 'gas' and 'heat'. I found this confusing, since I was never sure whether or not he considers fossil and nuclear fuels as energy stores. Moreover, readers surely need practical case studies to introduce types of equipment and terminology, such as 'heat pumps', 'fuel cells' and 'district heating'. However, after the definitions of these graphic symbols and networks in chapter 2, they are never used again in the book.

The author explains that 'intermittency' is predominantly caused with fossil and nuclear fuels by failures and accidents, and with renewable energy by natural variations. So coping with intermittency in renewables first requires an understanding of the natural variations. We begin with biomass. Sørensen is a theoretical physicist at heart and in mind, so he starts with the 'Normalized Difference Vegetation Index' and its associated equations depending on the reflectance of plant leaves at two wavelengths. Satellite photo-detectors allow this index to be plotted as maps for the whole Earth and by season, and thereby the variation of biomass growth is known. Other satellite instrumentation leads to a further set of world maps of solar insolation by month in the year. More world maps show monthly hydropower potential, using algorithms based on precipitation, evaporation, and geological and geographical form. Worldwide monthly wind power production maps are reproduced, as based on satellite and surface measurement, and likely power production with commercial wind turbines.

A discussion on 'Cooperation across Areas and Regions', includes electricity transmission and distribution networks, liquid and gas pipelines, and bulk transport, especially ships. Outline details are given of the structures and power exchanges by such methods now in worldwide areas, including Europe, North America, Asia and Africa. There is a critical and well-referenced summary of how power from renewables, especially wind and solar power, can be exchanged on such a.c. and d.c. networks. The experience of wind power in Denmark and hydropower, especially in Norway, within the linked Nordic system is explained in more detail. For North America, the results of simulations for large transfers of renewables' electricity across the continent are reviewed. The discussions of pipelines for liquids and gases, including hydrogen, is brief, yet includes both known technology (e.g. district heating) and speculation (e.g. airborne pipelines). Bulk transport of biomass as part of significant worldwide energy supply, e.g. as pellets, includes the challenge returning ash and nutrients to the soil.

Energy storage is considered in 3 chapters. First, well-established systems, including hydropower reservoirs, oil, and gas containers, and vehicle fuel tanks. The author goes on to consider 'dedicated systems' of low-quality energy, e.g. seasonal heat, perhaps augmented with heat pumps, and storage in the thermal mass of otherwise insulated buildings. High-quality energy, e.g. for electricity, is stored long-term in hydro reservoirs and in compressed air and gas reservoirs. Similar large-scale storage of hydrogen is likely to be most important, but challenging. For shorter periods, established experience with batteries will increase with innovation. The author finally concentrates on decentralised energy generation, storage and supply, as in households. Photovoltaic generation, batteries, heat pumps, fuel cells (hopefully reversible) are vital technology, including the integration of vehicle power stores with building needs.

Sørensen ends by tackling the ultimate problem; can renewables provide 100% of national energy supplies? This requires both economic and technical consideration, with the sad realisation that ‘good sense’ seldom results from vested interests and political policy. What the modelling and case studies show to be possible is very difficult to obtain nationally and internationally. The final conclusion overlays all the technical options with the questioning of present-day economic behaviour. For instance is optimising monetary Gross National Product a valid criterion for human satisfaction? Sørensen believes otherwise, suggesting that financial transactions should be weighted according to their value before summing them for national value. Thus the weightings could be positive for basic needs such as food supply, zero for inessentials, e.g. advertising, and negative for polluting activities. With such an assessment for political decision-making, Sørensen clearly believes that the 100% renewables scenarios are likely to triumph, but progress towards this will be much slower than needs be.

This review first appeared in the Elsevier journal ‘Energy’,(2015), pp 1904-1905

Vacancies in the IoP Energy Group Committee

The Energy Group is always looking for enthusiastic members to join the group committee. The committee normally meets twice a year. Its work is mostly about deciding what events to run, with the detailed planning work conducted by email between those involved in each specific event.

The following vacancies exist:

Honorary Secretary
Treasurer
Ordinary members x 3 (including Student representative)

Nominations for Energy Group committee members/officers are invited. The form accompanying this newsletter should be completed and emailed to the Chair, Robin Morris or posted to the Science Support Officer, Institute of Physics, 80 Portland Place, London W1B 1NT, by **Friday 18th March 2016**.

Energy Group Contacts

We welcome comments and suggestions for events and items for the Newsletter.

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