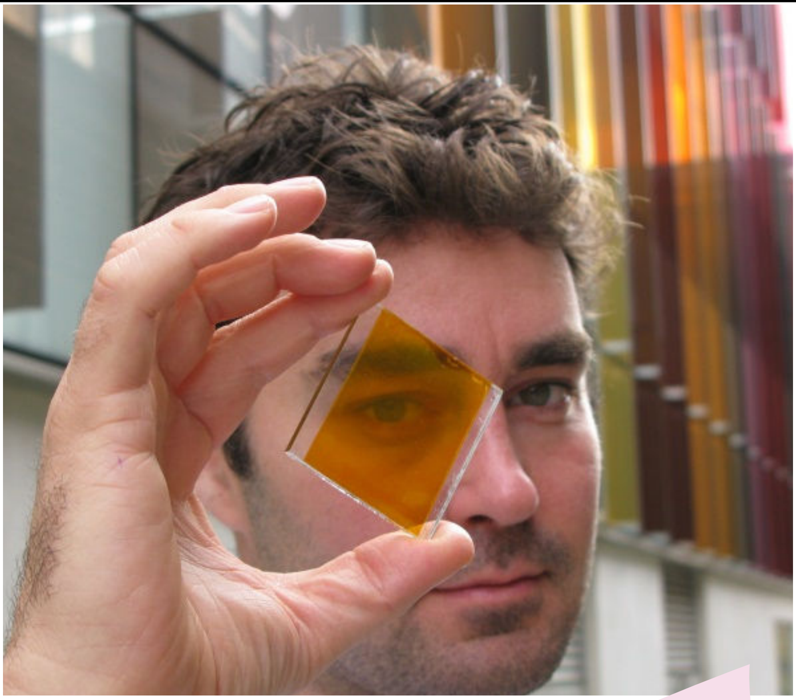
UNIVERSITY OF OXFORD

OXFORD Energy

Number 2
Spring/Summer 2014

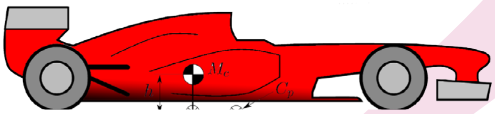


Henry Snaith: One who matters

Nature Magazine rated him one of 10 people who mattered in 2013.

Find out what led Henry Snaith to become one of the world's leading pioneers in photovoltaics (page 2) and how his technology could revolutionise the cost of PV electricity (page 3).

Formula 1



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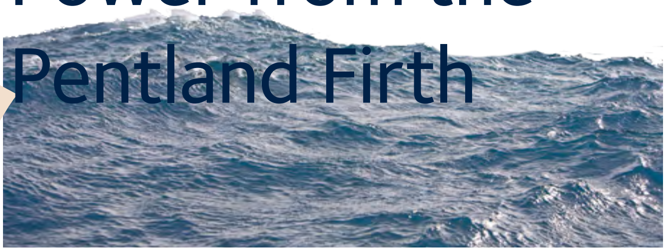

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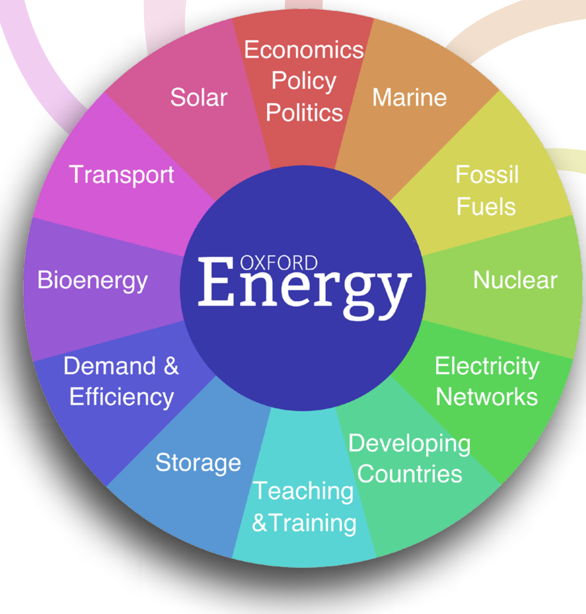


Skiing to solar success

Professor Henry Snaith has been named on of the 10 people who mattered in 2013 for his ground-breaking work on perovskite solar cells. His impressive journey started out on the ski slopes of the Alps.

"Why wouldn't you put a billion dollars into this"

Henry Snaith can barely suppress his enthusiasm for solar photovoltaics (PV). Ever since his degree he sought to do something 'useful' and in his view "PV is a good thing to do as a physicist. Solar is going to explode. The cost is coming down and it is getting very competitive." Henry himself is now playing an important part in future cost reductions in this industry. New solar cells developed in his group in the Oxford Physics Department have the makings of a revolutionary technology and could soon rival established technologies on efficiency and cost (see page 3).

It all began with his other big passion: skiing. After his PhD at Cambridge he went on a snowboarding holiday in Switzerland. On the bus home he announced to his friend that he had to come back here - if only there was a good PV group in the Alps. His friend replied "Ah, well, have you heard of Graetzel's group?". Michael Graetzel, the famous inventor of the "Graetzel cell", is a leading PV pioneer with his lab conveniently located at the EPFL in Lausanne. So Henry sought him out and applied to Michael's group. "Primarily because I wanted to go skiing. Through luck rather than judgement I ended up in the best lab for dye-sensitised cells."

The research in Switzerland allowed him to explore widely. "We tried a lot of solution processed photovoltaic materials, around nano-particles, mesoscopic solar cells, dyes, inorganic quantum dots and then after returning to the UK we experimented with solution processable inorganics". Perovskites were "just another absorber to try", and quite an easy one to make: "You just mix these components together". The expectation was to get about 1% efficiency, "and then we started seeing these remarkable properties".

He realised that the perovskites also make a good crystaline material, with 100s of nanometer crystal dimensions and excellent change transport, which makes for good semiconductors. "Instead of it just being these little particles sitting on the TiO_2, absorbing light, it could be the semiconductor itself - it is really that, that we got a lot of credit for here in Oxford."

This success is a testament to fundamental research at Oxford. "It was not about taking an existing system and iteratively moving forward. It was about spreading the net broadly. We tried probably 100 different approaches." And perovskites weren't even his number one candidate to begin with. "I thought the one that would really start working was polymer-semiconductors in mesoporous metal oxides. And that never got above 1% efficiency - but it should!".

When he saw the unexpectedly high open circuit voltage of his perovskite cells Henry realised "this is a completely different category". He confesses to being "totally carried away with perovskites" and sees them as a serious contender for mass markets.

The race is on to capitalise on this opportunity. "It feels like war—in a good way. It is an IP and technology war, and we are in a good position."

The next step is to move from the lab into production, which could see first modules being produced as early as 2017. This requires serious funding, but as Henry puts it "why wouldn't you put a billion dollars into this and blast everyone away".

Skiing had to take a break, but now his own children develop a passion for skiing and Henry actively encourages them. After all it can take you places.

Excited by Perovskites

A new material developed by Professor Snaith at Oxford has the potential to revolutionise the solar photovoltaic world. Perovskite solar cells could surpass dominant technologies in both efficiency and cost in the very near future.

The exponential growth in solar photovoltaics (PV) over recent years has surpassed the expectations of many. However, in absolute terms its contribution to world energy is still small and the technology comparatively expensive. The most dramatic developments may therefore still lie ahead, if costs can be reduced further.

Now researchers at Oxford have developed a new class of photovoltaic cells that could do just that and may even surpass some of the most efficient products on the market.

The new material is called perovskite and is in fact not that new at all. Back in the 1990s perovskites received considerable attention as a transistor and LED material. Curiously, for PV applications they were overlooked, in favour of organic and thin-film PV, and only re-discovered as late as 2009.

Since then perovskites have taken the community by storm. First it was just used as an absorber material, but Professor Snaith and his team discovered that perovskites can do much more, and created a new highly successful solar cell based on perovskites.

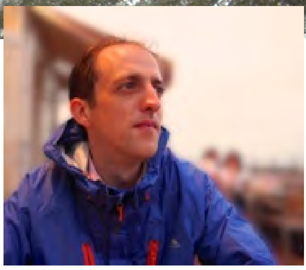
Efficiencies are rapidly improving and already rival the best thin film PV materials. The fundamental properties are promising. Professor Snaith has set his ambitions on surpassing silicon—the dominant PV material—which would move perovskite cells from special applications, like building integrated PV, towards a mass market with substantial growth potential.

This ambition is supported by some of the key properties of this material, such as its high open circuit voltage, diffusion lengths and very low exciton binding energies. Once impurities and deposition processes have improved, efficiencies above 20% are expected to be possible based on these properties. The race is on to capitalise on this potential and start manufacturing modules.

And here lies another attraction of perovskites. They can be manufactured with conventional processes or with solution based methods, which would require neither vacuum nor high temperatures. Material and production cost of these cells could therefore be lower than conventional cells and their components could be less toxic and more abundant as well.

The importance of this work has not gone unnoticed. Nature magazine declared Henry Snaith to be one of the ten most important people of 2013, worldwide in all science. His work could have far reaching consequences for the use of PV as a low cost renewable source of future energy.

Power from the Pentland Firth



The UK has one of the best tidal energy resources in the world. Professor Thomas Adcock and his group are calculating the potential contribution of tidal energy towards our future energy mix using sophisticated flow models.

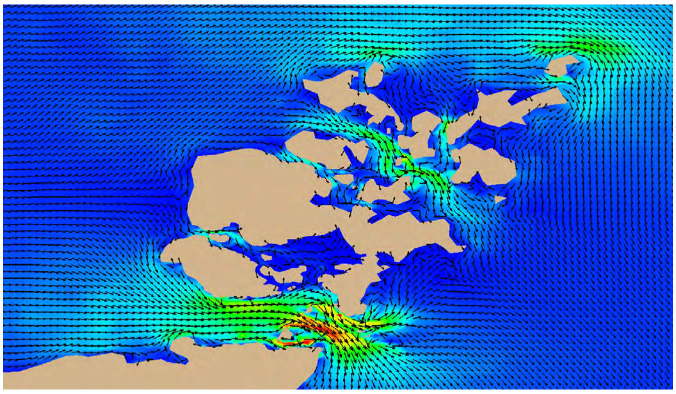
The strait between mainland Britain and the Orkney Islands, known as the Pentland Firth, is probably the most promising location for tidal stream energy anywhere in the world. Numerous claims have been made about how much energy the site might be able to produce based on a variety of methodologies. Professor Thomas Adcock and his Oxford Tidal Energy Group are informing the debate by deriving an upper limit on the power potential.

To understand the tidal dynamics in the region they developed a numerical model to seek the optimal amount of energy recoverable. Consider first the case when no turbines are installed in the channel: the velocity of the current in the strait will be the maximum but no power is extracted. Conversely, if you place too many turbines in the flow the current stops and again no power is generated. The optimum is clearly somewhere in between.

Professor Thomas Adcock and his team modelled this optimal point regardless of the type of turbine. For the Pentland Firth they estimate the resource to be about 5 GW averaged over time.

Unfortunately, this is far more power than could be generated in practice for two reasons. Firstly, tidal stream turbines have inherent inefficiencies. Energy is lost as the fast flow passing around the turbine mixes with the slower flow through the turbine. This is modelled with an approximation for the energy lost in the wake for a turbine of a given size and thrust.

The second inefficiency comes from the slowing of the flow caused by neighbouring devices. The more turbines are placed in the stream, the less effective each additional unit becomes. At some point adding further devices is no longer viable. One possible criteria is to set the cut-off point where the energy extracted per area swept becomes less than for off-shore wind. At this point, one might rather install wind turbines instead of more tidal devices, potential differences in cost notwithstanding.



Based on this assumption, the modelling suggests an upper limit to power generation from the Pentland Firth to be around 1.9 GW—about half the electricity needs of Scotland.

In reality the power produced will be considerably lower. Turbines are not as efficient as the idealised model assumes. The power will also be intermittent—not just on a daily basis but also over the fortnightly spring/neap tidal cycle. Professor Adcock estimates that one would generate eight times as much power in a day at spring tide than during a neap tide. On the plus side, these variations are predictable far in advance.

Thus, a significant amount of power can in theory be generated from the Pentland Firth. But recent comparisons to Saudi Arabia may be more than a little over-optimistic and Professor Adcock's work provides important guidelines to manage the expectations for this new energy resource.

Controlling F1 cars efficiently

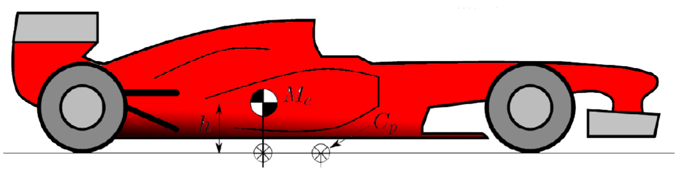
Sophisticated control systems are helping modern cars to become more fuel efficient. Oxford Professor David Limebeer pioneers mathematical models to take full advantage of new energy recovery systems in Formula 1 cars.

From 2014 Formula 1 has introduced a strict 100kg limit on the fuel used per race, down from 160kg the previous year. This restriction is one of the most substantial changes in the history of motorsport, and has forced Formula 1 designers to develop innovative ways to improve efficiency. The results are some interesting fuel-saving and power-generating technologies.

The kinetic energy a car loses when braking is usually irreversibly lost as heat. Now Kinetic Energy Recovery Systems (KERS) are able to convert this energy into electricity, store it in batteries and release it again when the car accelerates, or to provide a boost during overtaking. The new Formula 1 regulations have seen the capacity of KERS double to 120kW, and the battery capacity had to increase tenfold as a result. A second system recovers energy from the exhaust, where around 70% of the energy is lost as heat. Some of this heat can be captured and converted into useful energy to drive the car.

These systems now make a fundamental contribution to the power of Formula 1 cars, which poses new challenges for the control systems managing the energy allocation during braking, cornering and accelerating. When and in what proportion should energy be drawn from fuel or released from energy recovery systems? When should energy be stored? These decisions need to be taken in real time, without impacting the driver.

This is where Professor Limebeer's research is critical. His group develops computer-based mathematical models that incorporate the various parameters. Their control system takes the physical properties and limitations of the different power sources into account, as well as road conditions and aerodynamics.



The algorithms of Professor Limebeer's group help to control the new devices and also act as a teaching tool in car simulators, where changes to parameters can be tested without the need to build expensive prototypes. This helps the Formula 1 teams to ensure that the car stays within its physical limits, delivers optimal performance and complies with the efficiency regulations.

The advanced control systems adopted in Formula 1 are increasingly relevant to road cars as well. Some buses already use KERS and racing teams are translating their R&D to passenger vehicles where they help to improve fuel efficiency, without the driver even being aware of the complex decisions being taken by these systems on their behalf.

Energy.ox.ac.uk

The Oxford Energy website has attracted over **4500 individual visitors** with more than **22000 page views** in the first six months.

The **People** section, where researchers can be found by keywords and affiliation, got the most use.

Of the research pages **Solar** proved the most popular followed by **Bioenergy** and **Fossil Fuels**.

Border Carbon Adjustments

New trade arrangements could deliver much needed global emission reductions. Professor Hepburn and colleagues use game theory to show how unilateral actions on border carbon adjustments may deliver global results.

Years of international climate change conferences have done little to address the continuing rise in greenhouse gas emissions. Despite the widespread agreement on the need for action and a patchwork of efforts around the world, global emissions have not even been dented since 1990. An international agreement remains out of sight and unilateral action is not attractive for today's large emitters for fear of putting themselves at a trade disadvantage.

Professor Hepburn and colleagues have analysed arrangements that could turn these dynamics on their head. Border Carbon Adjustments (BCA), which change the focus from production to consumption based emissions, may hold the key to unlock the current stale mate in climate negotiations. These arrangements could avoid trade distortions and lead markets towards convergence on a global carbon price, even if adopted unilaterally to begin with.

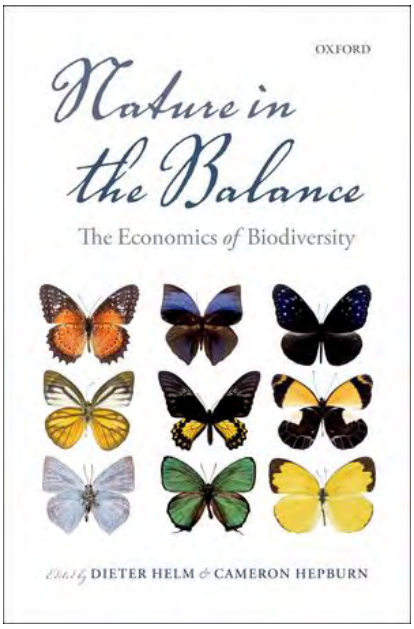
Under present arrangements some governments impose a tax or issue tradable permits on domestic emissions, while others still subsidise fossil fuels. The resulting imbalances in the effective price of carbon distort trade and lead to an undesirable side effect called 'carbon leakage'. Domestic production is put at a disadvantage relative to countries with a lower or even negative price on carbon emissions. Fewer goods are exported, while emissions through imported goods rise. Thus, the local economy suffers and globally little has been achieved. Not surprisingly, governments are reluctant to take strong unilateral action.

This is where BCAs could provide a better solution. Permits are based on emissions at the point of consumption, creating a level playing field between imported and domestic emissions. Domestic 'clean' producers are protected and the prospect of collecting revenue from imported emissions would make BCAs more amenable to governments.

BCAs could even be phased in unilaterally, without the need for a Kyoto-style global agreement, and initially only in selected carbon-intensive sectors. Once this first step has been taken, virtuous cycles could result. Professor Hepburn's game theoretical models suggest that the presence of a BCA in one market creates a desire among its trading partners, facing export duties, to apply carbon adjustments themselves. An incentive to participate, rather than to abstain, has been created.

The arrangements are in principle compatible with WTO's rules. In fact, welfare is increased by avoiding losses from environmentally damaging trade.

The work of Professor Hepburn and other Oxford economists could thus open up new ways to reach global emission reductions in an economically balanced and politically practical and pragmatic manner.



See also:
C. Hepburn, D. Helm and G. Ruta, Oxford Review of Economic Policy, 28:2, 2012 and

Nature in Balance Edited with Dieter Helm & Cameron Hepburn (January 2014)
Oxford University Press
www.oup.com/uk/isbn/9780199676880

Shale gas – how much is hype?

Senior stakeholders are cautious about direct comparisons with shale gas developments in the US. The impacts of fracking need to be communicated openly, to dampen overblown expectations.

An Oxford Energy meeting of experts under the Chattham House Rule, heard senior stakeholders debate three central aspects for shale gas in the UK: 1) the scale of the exploitable resource, 2) the impact on energy prices and 3) the social and political implications.

The US has witnessed a rapid increase in shale gas exploitation through fracking in recent years, which—with significant investment in gas infrastructure—has led to large reductions in domestic gas prices. The meeting considered whether this experience is likely to be repeated in the UK. Participants broadly agreed that the UK is different from the US in relation to shale gas exploitation in several ways:

Geology: Geological conditions are less favourable. UK shale is fragmented and many fault lines make identification of 'sweet-spots' harder and drilling more risky. UK data are relatively sparse and there was broad agreement that further exploration is needed.

Industrial infrastructure: The oilfield service industry in the US has been able to take advantage of economies of scale. The UK industry will be smaller and will need to be established from a lower base.

Population density: Potential regions in the north and the south east of the UK are highly populated compared to many shale gas producing regions in the US. Environmental sensibilities in the UK are likely to lead to greater opposition.

Mineral rights: In contrast to the UK, US land owners own the mineral rights under their properties and have an incentive to exploit any shale gas. Land is often bought outright by new owners who are 'free to do what they want'. It was suggested that more money has been made out of land deals than from the gas itself.

Finance: The ability to raise finance in the US is 'quite extraordinary'. Given the high degree of uncertainty and higher costs in the UK, finance may prove to be more costly.

World gas markets: Unlike the US, the UK is extensively connected to world gas markets through LNG terminals and pipelines. Even if production costs were low, gas would be traded at world market prices, which will not be affected by UK production levels.

The discussion brought up concerns over the high level of expectations raised by politicians and parts of the media. Even after 10 years of continuous well development, the contribution to UK gas supply might only be expected to reach some 10% and would not constitute a 'game changer' in either energy supply or prices.

Considerable uncertainties were highlighted about the UK resource and how much of it could be turned into recoverable reserves. Poland, for example, had to downgrade estimates by 90% since beginning drilling two year ago. Uncertainty factors in the UK could be between 10 and 100, and perhaps as high as 1000.

The fragmented UK geology is more challenging to survey than in the US, where shale basins allow for relatively easy identification of sweet spots. In fact, as one participant pointed out, exploration in the US often does not employ sophisticated surveying techniques at all, but takes a more 'statistical approach' made possi-

ble by scale. Only 25% of sites drilled in the US produce anything. This approach is not deemed feasible in the UK, where higher population densities, regulation and environmental opposition are likely to lead to higher costs per site.

Public opinion on shale gas is still undecided, with about 44% in favour. However, some of the participants asserted that those favouring shale gas, do so on the mistaken belief that it would lower energy prices. This impression was said to have been created by senior politicians and needed to be corrected if shale gas was to avoid a 'PR car crash'.

Some participants pointed to the tax revenue potential from a shale gas industry. The decline in north-sea gas would leave a large taxation gap of 1.25% of GDP. Despite the tax break for the shale industry (a reduction in tax from 62% to the high forties), the industry would still be a 'high contributor'. In addition, according to the Institute of Directors, a multi-year development of 100 shale pads (a factor of four more than in one scenario presented to the meeting) could support 74000 direct, indirect and induced jobs[1].

One participant raised concerns that, once a country has taken a path of shale gas exploitation, it is very hard to revert back, because of capital and jobs bound up in the sector. Concerns were also raised over the distraction which the shale gas debate has brought about for the UK's cross party consensus on decarbonisation targets and associated low carbon pathways. Both CCS and shale were said to have been overhyped as 'easy solutions'. Public recognition is needed that a) energy prices may go up and b) there will be difficult choices. 'Only then can we have a conversation with the community'.

The meeting also heard that 'no community in their right mind would not object to fracking'.

One participant with extensive experience in the sector conceded that he himself would not want to live near a drilling site. A game plan for local communities is needed. However, 'throwing money at communities for anything' was not seen as a viable long-term solution.

Some participants expressed concern over the industry's openness about the impact of fracking on local communities, especially in relation to truck movements. A strategic planning conversation was proposed to save the industry from the 'horrendous brand image' the wind industry has suffered.

[1] See IoD.com report. Others give lower estimates, e.g. naturalgaseurope.com. For the Industry's view of UK prospects see UKOOG.org.uk report.