REVAMPING DOCTORAL TRAINING FOR **A DECARBONISED FUTURE**

Fig 1: The CDT's Academic Director, Professor John Underhill at its official launch in 2014

To equip students with the skills to tackle the grand challenges demands a new approach to education. **John Underhill** discusses the role that doctoral training needs to play in addressing decarbonisation

At a time when prospective students are being put off by the perceived association of geologists with 'dirty' industries, energy resources and environmental damage, it is rather ironic yet apposite that geoscientists and their skill sets are a vital part of the solution, not just the cause.

While a better understanding of the subsurface was central to the carbonisation of our environment through the exploration, extraction and use of fossil fuels, the same skills and expertise that developed these resources can significantly contribute to decarbonisation solutions.

To address this issue (and the other grand challenges faced by humanity), and to provide a legacy and new generation of relevant, skilled geoscientists, we must reassess how we educate and undertake research. As the latest reports have highlighted (GETI, 2019: OPITO, 2019), the landscape is changing rapidly. There is a skills gap that needs addressing and new methods of training that embrace new technologies and innovation are required.

To meet the demand, we need to change and evolve our geoscience provision and teaching to equip students. This means not just building essential geological and environmental expertise, but also giving students a broader bandwidth that includes elements relating to economics, engineering, social science, science communication and media relations.

The National Environment Research Council (NERC) Centre for Doctoral Training (CDT) model, of the type governed and run by Heriot-Watt University (**https://www.nerc-cdt-oil-and-gas.ac.uk/**) is extremely well placed

Fig 2: Significant lithium resources exist in brine deposits associated with giant salt flats found in Argentina, Bolivia and Chile—South America's 'lithium triangle'

to adapt and evolve to meet the challenge. Awarded in 2013 and launched the year after (Fig. 1), the CDT programme is an exemplar of how post-graduate research and training can evolve to move away from a specific oil-and-gas remit that it was originally ascribed, to address some of the key issues facing us and the changing world that we live in today.

Reducing the carbon footprint

As the world's population grows and becomes more prosperous, there is an ever-increasing need to provide more energy to heat and light homes, fuel transport and power economic growth. Such development comes with a large carbon footprint that drives climate change, so we must ensure that as development progresses, it does so with reduced greenhouse gas emissions (Lovell, 2010; Stephenson, 2018). It is imperative that along with our commitment "to keep the lights on" and also achieve ambitious targets for converting to electric cars, we must also have in place a public mandate and social license to operate.

Additionally, as demonstrated by the major power outage that affected large swathes of the UK last month, the complex inter-linkage and intensity of energy sources can strain systems to the point where they fail, highlighting the key challenge to continue to secure and carefully manage our energy supplies as we decarbonise.

To meet the need for a sustainable, low-carbon energy future, measures are being introduced throughout the entire energy conversion chain, from the more efficient utilization of fossil-fuel resources for power generation and transportation, to improvements in consumption through energy efficiency. Consequently, more countries are developing their renewable-energy resource capabilities and introducing clean energy solutions, in keeping with the United Nations' blueprint for a sustainable future for all (UN Sustainability Goals, 2019).

The UK is leading the way, with a number of initiatives taken and papers published by the UK and Scottish Governments (such as the HMG Industrial Strategy 2017; HMG Clean Growth Strategy 2017; BEIS Energy & Climate Plan 2019; Scottish Energy Strategy 2017), as well as by influential organisations like the Royal Society of Edinburgh (RSE Energy Inquiry Report, 2019) and the Committee for Climate Change (such as *Net Zero: The UK's contribution to stopping global warming* 2019).

The outcomes of several recent workshops, including a major Geological ▶

Fig 3: The CDT has a very strong governance structure, with committees overseeing the management, training and research of the programme. There is also an Industry Advisory Board and Graduate Committee to provide external input and provide direct feedback from the students

Fig 4: The CDT consists of a mix of field tuition and classroom-based practicals

Fig 5: The CDT students attending the field course examining an exhumed continental margin in the Alps

▶ Society conference, also help to promote the decarbonisation agenda (such as the AAPG Energy Transition Forum 2018; The GSL Bryan Lovell Meeting 2019; Stephenson, *Geoscientist* 2019; Launch of EAGE's Decarbonisation Special Interest Group in June).

Crucial role for geoscience

The geoscience of the subsurface clearly has a vital role to play in the decarbonisation world, through electricity production, industry, transport and heating. We need a combination of state-of-the-art technology, improvements to efficiency and low-carbon fuel switching to achieve both ambitious UK and international climate change and decarbonisation targets.

Some of the specific areas where geoscience will play a crucial role are in subsurface storage, geothermal energy, the sustainable and safe extraction of metals and mineral resources. An understanding of subsurface complexity can also provide essential quantification and an important sense check on remaining or potential resources (Underhill, *The Conversation* 2017a; Underhill & Corbett, *The Conversation* 2017) that may extend the life of productive basins.

Subsurface storage

For some industrial processes, such as steel manufacturing, cement production, and refining, all of which have a large carbon emissions footprint, subsurface carbon-capture technologies are the only viable decarbonising solution. Whether those solutions involve converting to a hydrogen-based economy from a methane-driven one (like the H21 project for Leeds), the continued extraction of oil and gas from the UK Continental Shelf (UKCS) as a bridge during the low-carbon transition, or an attempt to decarbonise the country's industrial clusters in Humberside, Teeside, the Midland Valley, Merseyside, the Thames Valley and South Wales, carbon storage is needed.

It is therefore crucial that we select the right sites for safe long-term storage, since selection of the wrong ones could lead to failure and loss of credibility (Underhill, *The Conversation* 2017b). That need demands geoscientific expertise to accurately characterise and parameterise the geology of the traps and the reservoir-seal pairs of the depleted fields or saline aquifers, and test which are suitable as potential carbon storage sites.

Similarly, if nuclear power generation is going to form a significant part of the UK's energy mix, as seems likely (e.g. with the build of Hinkley Point), it is essential that the safe geological storage of its waste products is addressed.

Geothermal energy

Use of geothermal energy for electricity, heating and cooling has great potential, but irrespective of whether the more traditional, deeper, high-heat sources (such as in Cornwall and the Cairngorms) or less orthodox ones (like the re-use of old coalmines) are promoted, an understanding of the subsurface is required.

Successful deployment of coal mines as low-enthalpy heat sources could address one of the leading social challenges in the UK today, fuel poverty, which leads to more than a quarter of households struggling to make ends meet (Underhill, *The Scotsman* 2018; *Adams et al., Geoscientist* 2019). The largest concentration of households affected lie in densely populated urban areas that grew up around heavy industry, coal mining and manufacturing centres. Many of these have long since reduced in size, or closed, leaving a landscape and community blighted by high unemployment and deprivation.

Despite the demise in the use of coal for fires for domestic heat, a major benefit is that most of the mines are located close to and often directly beneath the large conurbations where the problem is most acute. Significantly, unlike much of the subsurface, where natural porosity, permeability or fracture patterns dictate flow, water can pass through a coalpit's trellised network of adits and shafts more easily since they are akin to fluid 'super highways'.

It's ironic and perhaps paradoxical therefore to suggest that a solution to the fuel poverty crisis could come from the most polluting, black and dirty fossil fuel that we, as a nation, have worked so hard to remove from our energy mix. However, it could be a case of the old black becoming the new green.

Sustainable metals and mineral resources

To source the raw materials for electric cars, wind farms, solar panels and other technological needs, there has to be a sustainable and secure supply of mined materials (such as cobalt, lithium and rare earth elements), an ambition that looks extremely challenged. At present, the sources of key minerals are in places like the Democratic Republic of Congo and the "Lithium Triangle" that straddles the borders of Argentina, Chile and Bolivia (Fig. 2). Given the laudable but ambitious Government targets that have been set to electrify transport, the question is "can these source areas meet the demand in a sustainable way and, if not, are there other regions that could be developed without causing environmental damage?"

The Centre for Doctoral Training

The UK has considerable experience in subsurface development and a wealth of knowledge that will be invaluable as we address the decarbonisation challenge. It is essential that we train future generations in the skills required for the emerging geoscience sectors and subsurface industries. However, to deliver such a workforce requires support for geoscience education. In particular, continued support for doctoral training that focuses on equipping students with advanced technical and scientific skills is vital. The benefit and impact of such support is proven by the thematic CDT model, a hugely successful, collaborative initiative involving 17 UK Universities, two Natural Environment Research Council (NERC) Research Centres (the British Geological Survey (BGS) and ▶

National Oceanography Centre (NOC)) and eight industry partners.
Originally funded through a £3 million award from NERC that enabled the recruitment of 10 four-year PhD students in each of its first three years, the attraction of the CDT model has leveraged an additional £11.5 million to enable a further 110 PhD students to join the programme. £1.5 million of that has come from industry to support its training programme, £6 million from university scholarships and £1 million through the Department of Business, Energy and Industrial Strategy (BEIS) National Productivity Investment Fund (NPIF) initiative that has financed additional studentships in Clean Energy and Artificial Intelligence (AI).

That support has now enabled the extension of the CDT programme for two years beyond its original period. The scheme has proved popular, as exemplified by the gender balance (>40% women have enrolled) and there is a keen competition for PhD places in the CDT programme. The first cohort of students have graduated in the past year and gone into jobs in Government, academia, industry and the media.

Addressing the skills gap

The training agenda is central to the programme's success and adds value to a student's PhD research focus. It consists of 20 weeks of bespoke modules undertaken by the students during the course of their PhD. The component parts cover a spectrum of topics with the dual aim of placing the student's individual specialist PhDs in their wider context and introducing the students to the full bandwidth of the research challenges faced in the subject area.

There is a mix of mandatory and optional modules, which are under continuous review. Reassessment led to the inclusion of more topics in environmental impact and regulation, as well as a substantial field-based component to address gaps in, the pressures upon and the demise of training in these areas in undergraduate and industry development programmes.

Fig 7: NERC's inaugural workshop on decommissioning was brokered by the CDT, held in Aberdeen and subsequently led to a call for proposals

Fig 8: The UK Energy Minister, Matt Hancock, visited the CDT and is seen learning about the challenges of subsurface mapping in the Southern North Sea

Fig 9: Scottish Energy Minister, Fergus Ewing, addressing the CDT Conference in 2015

The Geological Society recognised the quality and relevance of the training provided by the CDT, as well as the good governance afforded by its committees (Fig. 3) and Industrial Advisory Board, by bestowing the course with Accreditation. The fact that those graduating from the scheme are securing jobs in industry, academia, policy and communications attests to the fact that the training they received enhances their employability.

The benefit of the CDT approach means that students feel a part of a bigger connected community and a UK-wide initiative, as well as their host university's graduate school. The combination of lab- and field-based residential classes (Figs 4, 5) generates a strong "esprit de corps". This network will undoubtedly serve the students well throughout their subsequent careers. We have also seen more cross-university, collaborative, co-supervised projects that tackle key issues that spring up.

All students present posters and talks at an annual conference. The meeting is now an important date in the geoscience calendar, with nearly 200 attendees last year (Fig. 6, online). An additional benefit of having such 'critical mass' is that the CDT effectively becomes a one-stop-shop in the chosen theme. That value has seen UK Research & Innovation (UKRI) and individual research councils, like NERC, being able to convene meetings with all the key players from Government, industry and academia in one room (Fig. 7). The CDT has also gained significant political traction, and has hosted visits from the Secretary of State for Scotland and the respective UK and Scottish Energy Ministers (Figs 8, 9) amongst others.

Collective effort

It is evident that the commitment to decarbonise requires the provision of skilled practitioners, who have the pre-requisite technical expertise across the whole spectrum of energy systems. We will need a wide variety of geoscientific skills to evaluate safe carbon storage, supervise decommissioning and to examine the impact and potential of renewable sources, be they geothermal, wind, wave, hydro, solar, nuclear or in other novel forms, such as cold energy or heat storage.

We will continue to need people who can undertake the environmental monitoring of oil and gas extraction (both conventional and unconventional, such as shale gas), including human-induced seismicity, as well as those who are best placed to extend the life of UK basins like the North Sea as we seek to move away from our fossil fuel dependence.

The CDT's training provision already embraces innovation in areas like digital technologies, augmented reality, virtual reality, immersive 3D vision, machine learning and artificial intelligence (Fig. 10), but is open, keen and able to develop doctoral skill sets in these areas.

To achieve all of this demands a collective effort and partnership between research and training providers. It is essential to break down academic silos and accept that no one place has all the solutions. As the CDT model demonstrates, when collaboration is effective, the whole is greater than the sum of the parts. The scale of the geo-energy and decarbonisation challenge dictates that we adopt such an approach. The CDT stands ready to build upon its strong foundation to address the need to decarbonise.

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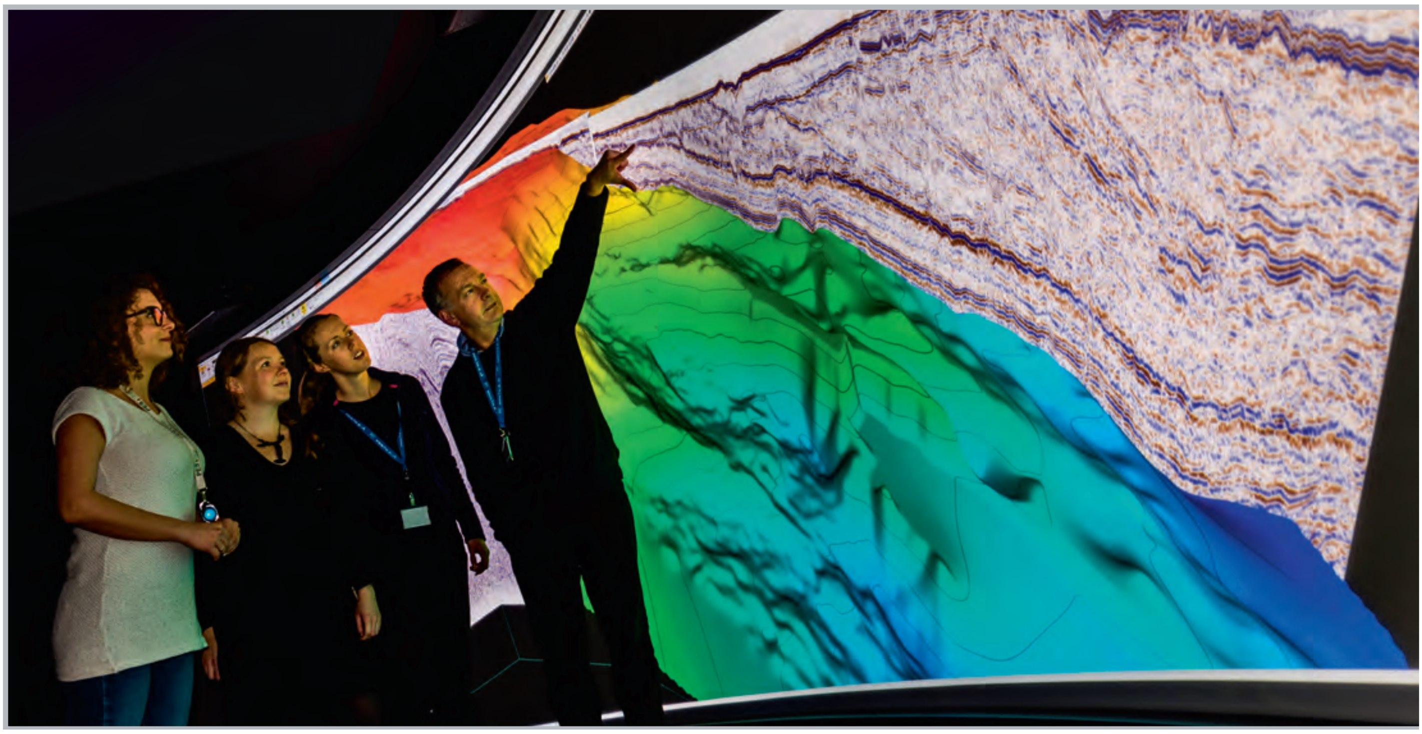

Fig 10: Subsurface geology of the Inner Moray Firth in the North Sea and the disposition of the Captain Sandstone, a saline aquifer proposed for Carbon Storage. Use of new visualization and digitalization technologies will be vital in characterizing the subsurface. (Image: Taken in Heriot-Watt's Ogilvie-Gordon 3D Audio-Visualization Centre, used with permission of Stavros Vrachliotis).