The Royal Society of Edinburgh

UK–Taiwan Workshop on Tidal Current Energy

Organised by the Royal Society of Edinburgh and the National Science Council of Taiwan, in cooperation with the University of Edinburgh

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Islands linked by science

The UK and Taiwan may be islands on opposite sides of the planet, but the workshop on tidal current energy highlighted how much they have in common in terms of the energy challenges they both faced, their renewable resources and the science required to develop commercial solutions. And ultimately, this may lead to 'powerful' partnerships between the two, involving industry as well as academic researchers.

Several themes emerged during the workshop to emphasise these common interests:

1. As well as the need to develop renewable sources of energy, while reducing emissions and dependence on carbon-based fuels, both the UK and Taiwan have enormous resources around them – particularly the power of the sea.

2. In Taiwan, scientists are focusing on a phenomenon called Kuroshio – an ocean circulating current which runs in one direction up the east coast of Taiwan, capable of producing 60GW of power. In the UK, we have similar resources, with biodirectional tidal currents in the Irish Sea, the Pentland Firth and around Orkney, where projects are already underway, including the world's first twin-rotor tidal current turbine – SeaGen.

3. Both are also concerned about the environmental impact of developing renewable resources, and are working hard to ensure that we not only have greater knowledge of long-term effects but also minimise potential damage.

4. Within the UK and Taiwan, partnerships are key to the success of renewable energy projects, because they tend to be multi-disciplinary and require close cooperation between so many different interested parties, including government, the general public, universities and business.

5. Similarly, international partnerships will help to accelerate progress at national and global levels by sharing the results of our experience and avoiding duplication of effort.

Even though the UK and Taiwan are surrounded by water, when it comes to solving our energy problems, neither can afford to be an island, and the workshop was a powerful demonstration of this, as well as a great demonstration that everyone involved was willing to share ideas and form strategic partnerships – and friendships which the organisers hope to renew in the very near future.

WORKSHOP PAPERS

1. Energy Research and the Kuroshio Power Plant Project

Professor Chen Falin, Institute of Applied Mechanics, National Taiwan University

Professor Chen set the scene for the workshop by mapping out the energy challenges faced by Taiwan, then describing plans to tap the Kuroshio – an ocean current which runs up the east coast of Taiwan which could provide 60GW of power, using the next generation of turbines. He also revealed that Taiwan's National Science Council will launch a new National Energy Program this summer, investing about £100 million a year in academic research and industrial projects over the next five years.

According to Professor Chen, Taiwan's "inconvenient truth" is that an island one eighth of the size of the UK with a population of 23 million people relies almost entirely on imported energy, in particular oil, coal and gas. Wind and solar energy are simply not practical options, and nor is hydro power, due to geographical and weather conditions, while nuclear energy currently provides only eight per cent of the total.

Taiwan is also a major industrial player, and as a result, its greenhouse gas emissions make it Number 22 in the world in volume terms (one per cent of total emissions) and Number 18 in emissions per capita, growing faster than most others at a rate of five per cent a year. Clean coal, carbon capture and gasification will be major priorities in coming years, spending £4 billion to replace all 18 coal-fired power plants over the next 20 years, at the same time as developing the nuclear sector (if there is political backing) and boosting the renewables sector.

Professor Chen said that Taiwan will face a huge energy problem in future if it does not act now, and that is why the National Energy Program will focus on three major issues:

1. energy security
2. greenhouse gas reduction
3. development of a new energy industry

As part of this programme, Taiwan also recognises the need to work with international partners to develop its renewables sector, including photovoltaic cells, wind power, biofuels and LED. It is already successful in the photovoltaic industry, with 30 manufacturers (Number four in the world) and LED lighting (Number two in the world). Biofuels are now a "hot issue," said Professor Chen, but Taiwan is relatively new to wind turbines, with a capacity of 347MW.

The Kuroshio Project is potentially the most important part of the equation, however – and also the greatest technological challenge. Scientists have already identified the best location for a power plant, in a 100km-wide stretch of water near the east coast of Taiwan, which is not just easier to access but also more reliable in terms of predictable flow. Even with a tidal flow of only two metres per second, however, the "Black Current" has 100 times more power than the Amazon and could provide Taiwan with 60GW of energy – more than it uses today.

Scientists have already started surveying the area with a view to building new power plants and installing turbines, exploring the environmental risks and archaeological implications, as well as likely costs.

One problem is that most existing tidal current turbines are designed for shallow waters, and the turbines required are still artist's impressions. The design of the turbines will therefore be a critical factor – with each one capable of generating 2MW of power. "We need to invest in manufacturing," said Professor Chen, "and we are looking for international technologies, including new mooring and anchoring systems."

2. Marine Energy Research and Development in the UK

Professor Robin Wallace, Institute for Energy Systems, University of Edinburgh

Professor Wallace provided the British perspective on marine energy, focusing on the R&D environment in the UK, discussing recent progress with new technologies and infrastructure, the research challenges and opportunities for collaboration.

He recognised and applauded the significant progress in the sector, noting that in the last five years several technologies had completed the journey “from artist’s impressions to the real thing” – deploying devices at sea. For example, he described the Wavegen LIMPET, an oscillating water-column shoreline wave energy converter deployed on the island of Islay, and plans for a 4MW offshore breakwater device. Other technologies highlighted by Professor Wallace included the Ocean Power Technology power buoys, the Pelamis Wave Power wave energy converter (deployed in Portugal and UK waters), the Open Hydro tidal current turbine in Orkney and MCT’s SeaGen project (described in detail later in the workshop).

These new wave and tidal-current generators are full-scale prototypes with generators plugged into the national grid, demonstrating the UK’s achievements in research and development activity, device construction, open sea testing and deployment – and actual power production from the sea.

Like Taiwan, said Professor Wallace, the UK faces an “inconvenient truth,” including the fact that most population centres were established above the coalfields in the south, with the electricity supply network following the east coast, while the greatest potential resources are found in the north and the west – abundant wind and marine energy.

To exploit its rich marine resources and help solve its energy problems, said Professor Wallace, the UK needs to proceed with “a joined-up campaign of development and deployment and strategic and prudent investment in the network, to ensure that good ideas are translated into real-world solutions, not only taking account of the technical challenges and constraints but also the economic realities. It’s a long way from dreams to deployment, and important to learn from experience”, he added. Above all, said Professor Wallace, it’s important to ensure continuity of funding for winning ideas and technologies from concept to deployment. Technology evolution and learning by doing generally reduces costs as volume deployment increases, but sometimes there can be a challenging funding gap in the journey to commercialisation – what Professor Wallace called the “valley of death.”

Professor Wallace then talked about the world-class research and development going on in many universities; some of them part of the SuperGen Marine Energy Research Consortium. He also highlighted the 1/10th scale tidal test facility at NaREC and the EMEC wave and tidal test sites on Orkney.

Collaboration is key to success, said Professor Wallace, and many energy research programmes in the UK are collaborative efforts, with £200 million invested in sustainable power generation projects involving 14 consortia, with 38 academic and 80 industrial partners. The Energy Technology Partnership (ETP) is another example of “outward-facing collaboration,” he added, by pooling the resources of 250 academics and 600 researchers in Scottish universities – the biggest partnership of its kind in Europe.

There are many research challenges, said Professor Wallace, including the development of better testing facilities, increasing the size and number of devices and moving into deeper water farther offshore, but there are also many exciting opportunities for collaboration as the industry evolves in the next few years into second- and third-generation solutions.

3. Establishment of a CODAR System to monitor Ocean Surface Currents around Taiwan

Dr Yang Wen-chang, National Applied Research Laboratories

If Taiwan is going to take full advantage of its marine energy resources, it is vital to understand as much as possible about the ocean which surrounds it, and Dr Yang's organisation will play a key role in that process, in the process helping in the drive towards sustainable development and better understanding of the full effects of climate change.

Set up last year, the Taiwan Ocean Research Institute (TORI) is carrying out a four-year project to monitor the Western Pacific using a CODAR system and a fleet of research vessels to establish a comprehensive database and information network, including hydrographic, geological, geophysical and biological data etc.

It will also develop new ocean exploration technology, including deep-sea ROVs (Remotely Operated Vehicles) and has commissioned a new 2,700-ton research vessel expected to be operational in 2012.

With a staff of 66 researchers, including 17 with PhDs, TORI will also look at seismic activity and the ecology of the ocean, mapping the habitats and distribution of deep-sea organisms, as well as studying storm surges, coastal erosion and the movement of sediments, coral reefs, water quality and atmospheric conditions.

The CODAR real-time observation equipment includes site data acquisition systems plus transmitter and receiver, with a range of 220km. The ultimate aim is to cover an area approximately twice as big as Taiwan itself with a network of intelligent buoys, and installation is scheduled for completion in 2011.

4. Tidal Current Characterisation

Professor Ian Bryden, Institute for Energy Systems, University of Edinburgh

Professor Bryden started by declaring that tidal currents are a mechanistic process that is well understood and relatively easy to mimic, using computers and wave tanks. Tides are also easy to predict because they are determined by the push and pull of the solar system. He also explained that the North Sea is like a semi-enclosed basin, and that tides produce kinetic energy in a similar fashion to waves or wind. To tap this power, we need the right coastal topography, but many countries have accessible "hot spots" where this can be found, including the Pentland Firth in north-east Scotland, where tidal currents can reach speeds of up to six metres per second. Even though the hot spots move around in the Firth, there are enough stable locations where energy capture is a practical option, and a channel roughly 1,000 metres wide by 40 metres deep is capable of producing enough electricity to power large cities like Glasgow or Edinburgh.

After showing a "scary" film of the tide in the Pentland Firth moving at less than two metres per second, to illustrate the huge amounts of energy available even in relative calm, Professor Bryden then explained that kinetic energy is only part of the story. Friction and potential changes in the sea surface level can produce twice as much power as tidal currents. The extraction of energy from a tidal flow also alters the underlying hydraulic nature of the flow, and this may affect the environment, he added.

Professor Bryden then explained that if we extract 25 per cent of the kinetic flux in a current, the energy in the current actually increases rather than decreases, but he also cautioned that there is an absolute limit on the amount of energy that can be extracted, based on the laws of physics, and that because tides are turbulent, it is better not to interfere too much with nature or there may be undesirable effects on the environment.

5. Current Developments in Taiwan Ocean and Coastal Engineering

Kung Cheng-Shan, Senior Vice-President, Sinotech Engineering Consultant Ltd

Dr Kung described a number of marine and coastal projects in Taiwan, including five harbour development schemes, modeling Typhoon Wave and storm surge analysis. He also talked about how Taiwan exploited its deep-sea resources, tapping water from 300 to 1,000 metres under the sea surface for use in cooling processes as well as for drinking, aquaculture and mineral extraction. He then described how Taiwan has established its first offshore wind farm project, and has learned from UK experience and adapted that to local conditions (such as typhoon and earthquake). The jacket-type foundation will be the most suitable for future projects.

Taiwan is also seeking to achieve the right balance between nature and human activities, said Dr Kung, monitoring the effects of offshore industrial estates as well as trying to design the most suitable dykes to protect the coastline without damaging its appearance.

6. SeaGen – Moving Tidal Turbines into Deeper Waters

Professor Peter Fraenkel, Marine Current Turbines (MCT)

One of the highlights of the workshop was the talk by Peter Fraenkel describing the development of SeaGen, "the largest rotating device in the sea," which the delegation visited later in the week, in Northern Ireland.

Warning of the risks of "getting into deep water," Fraenkel started by outlining his four conditions for marine energy projects:

1. scale – the device should be able to generate at least 1MW to be economic
2. access – it should be close to land so it is easy to service
3. reliability – to minimise the need for repairs/intervention
4. life – it should last for several decades

Then having outlined these conditions, he stated that "few technology developers are anywhere near to meeting these criteria."

Moving on to the technology itself, Fraenkel then said that the design of the rotors was not the big challenge. The simple rule is to use the least amount of material over the greatest area. When it comes to location, he added, "the seabed is not the place to go," because 75 per cent of the energy is found in the top 50 per cent of the water column.

MCT, said Fraenkel, has deployed three of the five tidal turbines now being tested in the UK, with output ranging from 300kW to 1MW. He also said that MCT was the first company to achieve commercial viability, with SeaGen's twin 16-metre-diameter turbines producing up to 1.2MW of power – and strong enough to carry three double-decker buses. Early versions developed by MCT, such as the world's first tidal current turbine (deployed in Loch Linnhe in 1994) which produced 15kW, or the more recent Seaflow (deployed in 2003), with a rated power of 300kW, were experimental prototypes.

Fraenkel then described the installation of SeaGen in Strangford Lough, including the design of a new "Quadropod" – a temporary platform used for construction. Even though SeaGen was up to full power by December last year, Fraenkel said that it would be another year or two before MCT would have a reliable system.

As well as power output, MCT's investment has accelerated over the years, rising from about £350,000 from 1992 to 1995 to £3.4 million in Seaflow and over £20 million in SeaGen. The next step for MCT will be to deploy an array of turbines in the Irish Sea by 2011, capable of generating 10MW, and this will need a further investment of about £52 million, said Fraenkel. Above all, he added, MCT has been able to learn so much from its experience that the risks should be less and the costs should be lower – ultimately leading to a lower cost per megawatt than wind turbines.

Looking to the future, Fraenkel said that second-generation designs will need more reliable power units, and will have to be capable of scaling up and down, with 24-metre-diameter rotors the maximum size, deployed in arrays with a surface area of 1,5000 square metres, as compared to SeaGen's 400 square metres. He also talked about deploying horizontal arrays, incorporating six rotors, and floating vertical arrays, submerged in deep waters, which could be the solution for the Kuroshio Power Plant Project in Taiwan.

7. A Contra-Rotating Marine Current Turbine

Dr Cameron Johnstone, Energy Systems Research Unit, University of Strathclyde

Following the discussions of rotors and mooring systems, Dr Johnstone described his "revolutionary" design for a second-generation tidal current turbine which would not need a solid structure for support in the water, thanks to the use of two dissimilar rotors (one 3-blade and one 4-blade) which turn in opposite directions, thus counter-balancing each other and stabilising the turbine.

Dr Johnstone then explained how the design had evolved from research into wind turbines. What makes tidal current turbines different, however, is that they operate in a very different environment, and if they could float in the water, tethered to a single-point mooring, this would cut roughly 40 per cent of the cost – the cost of the solid structure usually used as foundation (like SeaGen).

The other advantages of contra-rotation are a reduction in torque ("zero-reactive torque"), which makes the turbine more stable, a longer lifetime, greater power-capture area, and a reduction in the turbulent flow downstream of the rotors. In addition, because it is possible to pack more into any given area, you don't need bigger rotor blades to increase power output – simply more rotors.

According to Dr Johnstone, the "unique selling points" of contra-rotation are higher power output, reduced environmental impact, lower maintenance costs and no need to construct expensive seabed foundations. Add these together, and the new design fits the requirement for deep-sea deployment, with the added bonus of reduced system and operational costs. The new device also generates power using a direct-drive alternator, which eliminates the need for a gearbox, while the open-to-water design enables natural cooling at the same time as eliminating the need for complex seals to protect the power equipment.

The development of the prototype has already moved on from $1/30^{th}$-scale testing to $1/7^{th}$-scale testing to sea trials in the west of Scotland (Kyles of Bute and Islay). The results of these trials have confirmed the low deployment and maintenance costs (six minutes to deploy and eight minutes to recover) and proved the viability of single-point mooring. The flexibility of configuration for different depths and resistance to marine growth also make it suitable for deep-sea deployment in a wide range of climates.

8. Geochemical Dynamics and Anthropogenic Impacts of Estuarine, Coastal and Shelf Waters of Taiwan

Professor Wen Liang-Saw, Institute of Oceanography, National Taiwan University

To underscore Taiwan's concerns about environmental impact, Professor Wen described his comprehensive study (from 2000 to 2003) of the estuaries and coastal waters surrounding Taiwan. The focus of his study was on water quality and the balance of nutrients found in the water, analysing how the land interacts with the ocean. The results of the study have widespread implications, not just when it comes to measuring the impact of future marine energy projects but also to establish present conditions, to help with plans for sewage treatment, industrial pollution, aquaculture and agricultural run-off.

After explaining that Taiwan has 118 rivers and streams, and that 24 of them provide about 85 per cent of the water supply, Professor Wen then outlined the different conditions affecting the estuaries and coastal waters of Taiwan, not just because of rapid industrialisation and urbanisation but also because of its sub-tropical climate and historical problems with waste-water treatment. Professor Wen also revealed that despite covering only 0.024 per cent of the surface of the planet, Taiwan produces 1.9 per cent of estimated global sediment discharge. And to illustrate the scale of the problems it faces, it is only today that the capital city, Taipei, has adequate sewage facilities – a few years ago, less than 60 per cent of households had proper sewage and even very recently, 10 per cent were still without modern facilities. According to Professor Wen, old industries also cause problems – with disused outlet pipes buried from view still responsible for some degree of pollution.

Professor Wen's study covered a number of factors including water quality, precipitation, water temperature, salinity, particulates, turbidity and dissolved oxygen, phosphates, carbon dioxide, nitrogen, copper and silver. One of the findings was that household pollution is a more pressing problem than industrial effluents, with traces of silver (used in domestic disinfectant) betraying the scale of the problem. Professor Wen is confident, however, that the silver pollution has a negligible global impact.

As a result of the study, the government has closed down the pig farms on the banks of the river, due to excess copper flowing into the water from the cleaning agents used on the pig farms. Measuring the effects of sewage has also driven policy changes, and over the last two years, nitrogen levels have decreased by 50 per cent.

"Economic growth over the last 50 years has brought prosperity and rapid development," Professor Wen concluded. "This had serious environmental consequences – and now we are trying to fix it."

9. Environmental Monitoring in Strangford Narrows

Dr Graham Savidge, Queen's University Belfast

After describing the advantages of Strangford Narrows for tapping tidal current energy, such as tides of four metres per second, easy access from land and good shelter, Dr Savidge then explained the possible down side – the lough (lake) is an area of major conservation interest and several agencies are concerned about the danger to wildlife posed by the construction of SeaGen and its giant rotors.

The environmental monitoring programme managed by Queen's University Belfast and St Andrews University's Sea Mammal Research Unit was not just designed to satisfy the Northern Ireland Environmental Agency (NIEA) and the Maritime & Coastguard Agency (MCA) but also European agencies, the general public – and MCT itself. As well as praising MCT for being so willing to support the programme, Dr Savidge also stressed that it was important to get input from all stakeholders, to avoid missing anyone out who may raise a concern, especially considering the damage which could be caused by media images of damage to wildlife. He also pointed out that there were risks for MCT, since one of the conditions of the programme was that in the event of a "significant environmental impact," the turbine could still be shut down. By welcoming the programme, however, MCT was clearing the way for future projects by establishing the environmental facts right from the start, rather than waiting for something to happen and dealing with it after the event. "This will soften the pressure on developers," said Dr Savidge.

The study looked at the impact on common harbour seals, cetaceans, birds and benthos (seabed creatures such as hydroid turf and sponges), including tagging seals with GPS tracking devices, visual observation, acoustic monitoring of porpoises and sonar to detect approaching creatures in the water, which could even be used to shut down the turbines automatically (in about four seconds). Seals are intelligent and inquisitive animals, said Dr Savidge, but little is known about their ability for close avoidance of hazards, so the researchers went to great lengths to minimise risks to the seals at the same time as closely observing their movements.

The researchers also monitored changes in the flow pattern of the Narrows to measure the impact of the turbines on currents.

The data gathered covers the two years before SeaGen was constructed and the two years following deployment. The objective is to establish the environmental impact on factors such as long-term population and short-term behaviour of wildlife. In the process, said Dr Savidge, the researchers learned more about seals than expected, including the discovery that they behaved more individually (in some cases swimming long-distance, alone) and did not always stay in the Narrows in groups.

The divers also took a lot of risks to examine the benthos, Dr Savidge explained, in their attempts to capture images of life on the seabed, in the 10-minute calm between fast-moving, turbulent tides.

The results so far indicate some degree of impact but no significant damage. Benthic surveys show little change. Seabird diving has increased in the wake of the turbines, but no major changes have been noticed in activity patterns. Porpoise activity has reduced in the area near the turbines, but SeaGen is already becoming part of the landscape.

10. Wave and Typhoon Activity in the Western Pacific

Professor Kao Chia-Chuen, National Cheng-Kung University

The Kuroshio is a natural phenomenon with the potential to power the whole of Taiwan, but what is provided by nature with one hand is taken away with another. The island is located in an area of sometimes spectacular weather conditions which could play havoc with future energy projects, and mean that the design of any turbines will have to be extra strong to survive.

Taiwan is in the firing line for several typhoons a year and some of the waves observed in coastal waters are as large as Tsunamis, according to Professor Kao, whose work involves measuring waves and other oceanic phenomena using a network of 12 solar-powered wireless buoys.

In addition to *in situ* observation and analysing the data produced by the buoys, Professor Kao's department uses numerical modelling and remote sensing to keep a close watch on the ocean – particularly tides, waves, winds, pressure and surface currents. The data is provided to a number of agencies, including the marine weather bureau, the water resource agency and the tourism office. During major storms or typhoons, the equipment is capable of taking measurements every minute, to avoid missing any large waves, using X-band radar to monitor the sea state. And his equipment has monitored waves as high as 30 metres, with the highest recorded wave in October 2007.

11. A Review of the Tidal Current Power Plant of the US

Chang Sen-Tsun, PhD Student, National Taiwan University

Mr Chang described his study of the various tidal current energy projects underway in North America, ranging from Alaska all the way to Nova Scotia, via San Francisco's Golden Gate. Taking into account a number of factors such as local topography, cable installation, structural elements, grid connections and the design of the turbines themselves, Mr Chang's research was designed to compare the cost of installation and the cost of electricity over the long term. His basic conclusion was that the Minas Passage in Nova Scotia has the greatest potential to generate power. Tidal current energy is reliable and predictable, said Mr Chang, but his study was also concerned with the large variations in power over the course of a day, and the critical gap at certain times between power generation and demand.

12. Wake Effects of Tidal Current Turbines

Matthew Topper, PhD Student, University of Edinburgh

Just when you thought that you understood something about tidal currents, along comes Mr Topper with his mathematical theories about the complex interaction between the surface of the ocean and the turbulence created in the wake of turbines – or "decomposing power curve free-surface effects." This is important because it helps to understand why power generation is so variable with full-scale tidal current turbines, and the problem for Mr Topper is that the numerical models used to analyse these highly complex effects are not good enough – one model may be very good at understanding surface dynamics while the other may be very good at analysing turbulence, but neither can cope very well with the interaction between them. "There is more than one type of physics going on at the same time," Mr Topper explained, describing the fact that a wind turbine produces a steady wake while a tidal turbine produces an unsteady wake because it interacts with the free-moving surface (i.e. waves in the water). Mr Topper uses the boundary element method to model free-surface problems, studying the flow and interactions, but said we don't know much about the turbulence effects in high-energy tidal channels which flow at a rate of three metres per second, such as the Pentland Firth and Strangford Narrows.

DISCUSSION

During the discussion which followed, Professor Bryden explained that even though tidal currents are mechanistic, they are also modified by atmospheric conditions. Wave effects not only reduce power output but can also damage the turbines, and that is why the study is so complex – as exemplified in the last paper.

Professor Chen explained that the Kuroshio current is not as variable as the Gulf Stream, and in the channel identified for exploitation, the current is steady and strong all year round. He also said that the costs of tapping this power could be very low and that the project could transform the whole economy of Taiwan and end its dependence on imports of carbon-based fuels.

Professor Wallace concluded that at the start of any renewables project, aside from the technical issues, researchers should be realistic rather than over-optimistic about the future costs of the technology and how much energy the project will produce. "This is because the costs of hardware and gaining experience increase as the technology increases in size and first goes to sea, before the benefits of economies of scale and learning by experience gather momentum as larger numbers of devices are deployed," he explained.