Institution: University of South Wales

Unit of Assessment: B12 Engineering

Title of case study: National and international strategy development and implementation of hydrogen systems for low emission transport and industry

Period when the underpinning research was undertaken:
1st January 2008- 31st December 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Jon Maddy	Director Hydrogen Centre	2003-present
Stephen Carr	Lecturer	2007-present
Christian Laycock	Lecturer	2010-present
Fan Zhang	Lecturer	2010-present
Alan Guwy	Director of SERC	1989 - present

Period when the claimed impact occurred: 1st August 2013 to 31st December 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

University of South Wales (USW) researchers have developed an innovative, commercially viable and safe approach to producing Hydrogen as part of the strategy to decarbonise industry, transport and the energy sector. As a direct result ITM Power deployed their first commercial PEM electrolyser and quickly implemented refuelling stations and hydrogen plants worldwide. ITM have now grown revenue 50-fold over the decade (recently raised £172m with order book of £118m) and developed a significant market share of worldwide deployment of electrolytic hydrogen, which has grown from 0.04Mt/yr in 2010 to 0.46Mt/yr in 2020, an increase of 1150%. Important guidance to the UK and Welsh government policy on hydrogen has triggered, for example, USW development of novel techniques to recover major volumes of hydrogen from steel making and established an extensive South Wales Industrial Cluster (SWIC, 40 diverse companies) targeted at hydrogen-based decarbonisation. Finally, USW has been instrumental in changing policy at the nationalised State Grid Corporation of China (SGCC) to incorporate electrolytic hydrogen as an electricity grid balancing mechanism and to deploy hydrogen refuelling stations in China.

2. Underpinning research

Hydrogen has been deployed as an industrial gas for over 100 years and has a current demand of over 75 Mt/year to satisfy demand in many industrial sectors. Nearly all of the hydrogen meeting this demand is produced from fossil fuels and generates over 700 Mt of CO_2 per year (equivalent to twice the overall CO_2 emissions of the UK as a whole). Research conducted since 2008 at the University of South Wales' Hydrogen Centre[1] in Baglan and its Sustainable Environment Research Centre (SERC) laboratories in Glyntaff, has developed cost-effective hydrogen production and recovery approaches that dramatically lower the carbon footprint of existing industrial hydrogen demand, and unlocks new lower carbon industrial processes. These hydrogen technologies can also play a major role in the decarbonisation of transport, buildings and the energy system as a whole. This multi-disciplinary research is targeted at the enhancement of electrolytic hydrogen production, the development of novel techniques of recovery of hydrogen from industrial by-product streams and the application of hydrogen technologies for carbon emissions reduction from transport and industry. Since the establishment of the Hydrogen Centre, the research programme has had a clear focus on collaborative research with industrial partners to achieve these aims. Various sources of funding supported this research including the Engineering and Physical Sciences Research Council (EPSRC), European Regional Development Fund (ERDF), Innovate UK and Government funded projects, together with direct industry funded research. In particular, two major European R&D projects currently support this activity:

- FLEXIS (Flexible Energy Systems) (2015-present, £24m) project with Cardiff and Swansea Universities, where USW investigate Hydrogen Energy Storage, Sustainable Production and Purification of Hydrogen, Syngas, and the efficient use of Hydrogen.

[1] The Hydrogen Centre was established in 2008 as part of the University of Glamorgan, which became the University of South Wales in 2013

- RICE (Reduced Industrial Carbon Emissions) (2018-present, £9.2m) with Swansea University. USW is investigating solid oxide hydrogen and CO_2 electrolysis, hydrogen separation from industrial process streams, and hydrogen transport applications.

These projects also reinforce the development of hydrogen technologies in addressing security of energy supply and the positive impact that application of hydrogen technologies can have on improving air quality.

1) **Electrolytic Hydrogen Production:** A key element of the research at the USW Hydrogen Centre has been on establishing electrolytic hydrogen production techniques operating with a variable renewable electricity feed to make these techniques robust for application in a commercial and industrial environment. This is critical in the application of electrolysis as a means to enable greater penetration of renewable electricity onto electricity networks. In particular, since 2010 USW has conducted collaborative research with ITM Power PLC (ITM), a UK based company specialising in hydrogen technologies, in the enhancement of hydrogen production from PEM electrolysis. PEM water electrolysis is considered one of the most promising techniques for high pure efficient hydrogen production from renewable energy sources since it emits only oxygen as a by-product without any carbon emissions. In partnership with ITM, this research led to the deployment of two novel polymer electrolyte membrane (PEM) electrolysers, HBox and HPac 40, the first deployments of their kind. This stimulated further research with ITM into hydrogen capture of fluctuating solar photovoltaic and wind electricity, to ensure the maximum decarbonisation of the process. Work with ITM also involved energy-balancing power-to-gas application and the establishment of refuelling stations with on-site electrolytic production. Through the Innovate UK project "Island Hydrogen" (2013-2016, £4.7m) with ITM and other industrial partners and as a result of further collaborative research with the State Grid Corporation of China (SGCC), the Hydrogen Centre research team published their research detailing the optimal configuration of electrolytic hydrogen refuelling stations with a direct wind power feed [R1]. This research also addressed optimisation of the operation of this type of hydrogen refuelling station within the UK electricity market, reducing wind curtailment in a grid constrained scenario, and extending on earlier research conducted into Hydrogen for energy storage [R2]. In particular, this built on USW's research conducted as part of the EPSRC UK Sustainable Hydrogen Energy Consortium (2007-2014) using an optimal power flow (OPF) methodology to investigate the maximum wind power generation in relation to a constrained electricity network [R3].
2) **Hydrogen Vehicle Refuelling:** Through the establishment in 2009 of the first hydrogen refuelling station in Wales, USW Hydrogen Centre has also investigated the environmental impact of electrolytic hydrogen production routes through to vehicular use, using a lifecycle methodology [R4]. This research confirmed that utilizing a combination of renewable hydrogen fuelled vehicles and grid powered electric vehicles was considered to be a viable option for meeting UK policy ambitions.
3) **Large-scale Hydrogen production including recovery of Hydrogen from Steel Making**: Identifying the need and mechanisms to address large-scale hydrogen production and based on the research at the Hydrogen Centre with expert academic colleagues from other UK institutions, the Royal Society published "Options for producing low-carbon hydrogen at scale" in 2018 [R5]. Further work on establishing methods to high volume, low-cost hydrogen was conducted in collaboration between USW and Tata Steel (UK), HyET (NL) and Skyre (USA) (2015-present), through the FLEXIS and RICE projects. This work has specifically investigated the enhancement of steel works gases (Coke Oven Gas and Blast Furnace Gas) to amplify and recover high flow-rate hydrogen product at lower cost than established industrial hydrogen production methods. Two novel techniques have been investigated: i. combined pressure swing adsorption / electrochemical hydrogen purification and compression (PSA/EHP/C) [R6] ii. solid oxide electrolysis for co-electrolysis of coke oven gas [R7]. The research has revealed the potential to recover nationally significant volumes of high purity hydrogen from steel making processes, at a substantially improved efficiency and lower cost than the incumbent steam methane reforming process.

3. References to the research

R1. Optimal operation of a hydrogen refuelling station combined with wind power in the electricity market. Carr, S., Zhang, F., Liu, F., Du, Z. & Maddy, J. 3 Oct 2016 In : *International Journal of Hydrogen Energy*. 41, 46, p. 21057-21066.

R2. The Survey of Key Technologies in Hydrogen Energy Storage. Zhang, F., Zhao, P., Niu, M. & Maddy, J. 7 Jul 2016 In *: International Journal of Hydrogen Energy*. 41, 33, p. 14535–14552.
R3. Hydrogen storage and demand to increase wind power onto electricity distribution networks. Carr, S., Premier, G. C., Guwy, A. J., Dinsdale, R. M. & Maddy, J. 24 Jun 2014 In : *International Journal of Hydrogen Energy*. 39, 19, p. 10195-10207.
R4. Life cycle assessment of the electrolytic production and utilization of low carbon hydrogen vehicle fuel. Patterson, T., Esteves, S., Carr, S., Zhang, F., Reed, J., Maddy, J. & Guwy, A. 5 May 2014 In : *International Journal of Hydrogen Energy*. 39, 14, p. 7190-7201.
R5. Thomas, H., Armstrong, F., Brandon, N., David, B., Barron, A., Durrant, J., Guwy, A., Kucernak, A., Lewis, M., Maddy, J. and Metcalfe, I., 2018. Options for producing low-carbon hydrogen at scale. *The Royal Society*.
R6. Simulation of integrated novel PSA/EHP/C process for high-pressure hydrogen recovery from Coke Oven Gas. Van Acht, S.C.J., Laycock, C., Carr, S.J.W., Maddy, J., Guwy, A.J., Lloyd, G. and Raymakers, L.F.J.M., 2020. In: *International Journal of Hydrogen Energy*. 45, 30, p.15196-15212
R7. Czachor, M., Laycock, C.J., Carr, S.J., Maddy, J., Lloyd, G. and Guwy, A.J., 2020. Co-electrolysis of simulated coke oven gas using solid oxide electrolysis technology. *Energy Conversion and Management*, *225*, p.113455

4. Details of the Impacts

When USW's Hydrogen Centre was established in 2008, with University investment of £2.3m, there was limited acceptance of the role hydrogen could play in decarbonising industry, nor understanding of the requirement to act across industrial sectors to facilitate hydrogen as a vector to reduce industrial, transport or energy sector emissions. Deployment of hydrogen for these purposes has consistently been dogged by major barriers, including:

- Immature technology for economically viable deployment of low-carbon production
- Absence of policy support and funding
- Effective dissemination and cross sector co-operation

Our impacts include significant and robust research and actions that have addressed each of these barriers such that governments across the world, industrial manufacturers in numerous sectors and energy suppliers are now not only considering hydrogen seriously for the first time but in many cases actively researching it and deploying it. In addition, we have also importantly instigated a sea-change in mindset that has contributed to significant policy/funding changes towards the deployment of hydrogen [S1] and the development of a wide-ranging collaborative industrial cluster in Wales, which directly embraces the use of hydrogen as a key feature in achieving net zero carbon and industrial growth [S2].

USW research has influenced hydrogen policy and development in the UK and China

As director of the Hydrogen Centre, Maddy worked with Welsh Government to set up their Hydrogen Reference Group in 2017 [S1] and as recognition of USW's research into hydrogen transport [R1][R4] sits on the Welsh Government Low Carbon Vehicle Expert Steering Group [S1]. He has also provided expert testimony to the Welsh Government's Climate Change, Environment and Rural Affairs Committee on the future role of hydrogen for heat [S1]. Maddy's expertise in these groups has led to the inclusion of hydrogen options for decarbonising rail transport in Welsh Government rail policy [S1] and in 2019, the inclusion of hydrogen fuelling capability in the development of the Welsh Government-led Global Centre for Rail Excellence [S1]. Since 2020, as recognition of the expertise in hydrogen research and hydrogen production methods [R5] Maddy is one of only two academics on the UK Government's Hydrogen Advisory Council [S7], working with UK Government to create the UK's Hydrogen Strategy, and influencing UK policy on business models, deployment and standards for Hydrogen. Measures developed as part of this policy advice is anticipated to lead to the support of 60,000 jobs by the establishment of the UK as a world leader in the deployment of hydrogen and carbon capture technologies, as outlined in the UK Government's Energy White Paper *Powering Our Net-Zero Future*[https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/945899/201216_BEIS_EWP_Command_Paper_Accessible.pdf]. This builds on previous advice given to UK Government on the development of a UK "Green Hydrogen Standard"[S8], to assess the environmental performance of various hydrogen production routes. Maddy also advised UK Government on the creation in 2019 of the Hydrogen and Fuel Cell Energy Innovation Needs Assessment [S9], which has informed UK Government in the

development of various large-scale funding calls, including the Low Carbon Hydrogen Supply Competition, Industrial Fuel Switching Competition and the Industrial Decarbonisation Challenge.

A £120k joint research contract between the USW Hydrogen Centre and the Chinese State Grid Corporation (2015-16) addressed the role of electrolytic hydrogen as a transport fuel and grid balancing mechanism for the electricity network in China [R1][R2]. The research has informed SGCC's approach of using hydrogen as the penetration of renewable electricity increases on their network, as well as the possibilities for optimal operation of electrolytic hydrogen filling stations integrated into the Chinese electricity grid network [S10].

USW research led to an innovative and commercially viable method of producing Hydrogen

Through the Low Carbon Research Institute "CymruH2Wales" project (ERDF £34m, 2008-2015), USW pioneered research into low carbon hydrogen production, storage and application. PEM electrolysers were not commercially available in 2008 and through collaborative research between ITM and USW, the first commercial PEM electrolyser was deployed by ITM at the USW Hydrogen Centre in 2011. This early unit was only 12kW capacity, but the research conducted between USW and ITM was essential to the development of the technology, which has now grown to deployments at 10MW+ scale as of 2020. Through this early research partnership and continued R&D engagement, ITM have now grown revenue 50-fold over the decade and developed a significant market share of worldwide deployment of electrolytic hydrogen, which has grown from 0.04Mt/yr in 2010 to 0.46Mt/yr in 2020, an increase of 1150% [https://www.iea.org/reports/the-future-of-hydrogen]. Specifically, USW's research with ITM resulted in the company's first commercial scale PEM Electrolyser (HPac 40) [S3], which led to the design of HGas PEM Electrolyser that forms the basis of the PEM electrolyser product platform deployed at present. Through this R&D engagement between USW and ITM, these PEM electrolysers have been deployed in refuelling stations and electrolytic power-to-gas plants including tenders in 21 countries, resulting in worldwide spread of the technology [S3]. USW continue to work with ITM to identify and develop major hydrogen projects based on this technology, including ITM's REFHYNE project with Shell (2018-present). Funded by the European Commission's Fuel Cell and Hydrogen Joint Undertaking (FCHJU), the REFHYNE project is at the forefront of the effort to supply clean refinery hydrogen for Europe. The project is installing the world's largest hydrogen electrolyser(10MW/330kg/day) at the Shell Rhineland refinery in Germany, employing electrolysers built by ITM [S3] [https://refhyne.eu/]. ITM now have plans scale to 100MW and beyond in the next 2-3 years and have built the world's largest PEM electrolyser factory in Sheffield, with a capacity of 1GW p.a. [https://www.itm-power.com/news/manufacturing-commences-at-the-itm-power-gigafactory]. In October 2020 ITM raised £172m on the LSE and had a project backlog of £118m of work [S3]. The collaboration between USW and ITM has also led to key projects such as the HyDeploy, the first in the world to implement hydrogen blending with natural gas networks at scale [S3].

USW's research in this area also includes improved techniques to recover, purify and compress hydrogen [R6][R7]. This has enabled key impact within the steel industry and with Tata Steel UK in particular. USW's research into improving methods of hydrogen recovery and use from steelworks gases, has influenced planning for decarbonisation of steelmaking and identified a regional potential to produce over 200,000t/yr hydrogen, with a global potential for several million tonnes per year, at lower cost than current reforming approaches [S4].

USW's hydrogen refuelling initiatives led to adoption by numerous organisations in the UK

The hydrogen station at Baglan was one of the first to be installed in the UK and the first in Wales. It has operated continuously since 2009 as a renewable hydrogen facility fed by the electrolysers on site. It was further upgraded in 2016 and used by hydrogen fleet vehicles operated by Mid and West Wales Fire and Rescue Service, Western Power Distribution, Swansea University, other private users and as part of a broader development programme for the Riversimple Rasa fuel cell vehicle[https://gov.wales/sites/default/files/consultations/2021-01/baselining-report-hydrogen-development-in-wales.pdf]. In recognition of USW's hydrogen R&D, the UK Government and Welsh Assembly Government awarded the University the lead of the designated UK Low Carbon Economic Area (LCEA) for hydrogen energy [S5]. Early impacts of the LCEA, was the first nationally significant hydrogen refuelling corridor along the M4, including stations at Baglan, Glyntaff, Swindon (Honda), Bristol and Abergavenny, using USW's technology and expertise. In addition, USW's collaboration with ITM and the Welsh Government also led to the award of a £1

million grant award to establish the ITM Motive subsidiary[S6] that builds owns and operates hydrogen refuelling stations. USW also collaborated with ITM and other partners in the InnovateUK Island Hydrogen project (£4.6m 2016-2018), led by ITM and USW, enabled zero-carbon hydrogen refuelling stations for marine craft on the Isle of Wight and fed by wind energy in Sheffield [S3]. USW joined with ITM and a number of other major industrial partners in the UK Government led UK H2Mobility programme, which to developed UK strategy for deployment of hydrogen refuelling stations in the UK [S3].

USW research resulted in the nationally significant decarbonisation cluster SWIC

USW's research in the FLEXIS and RICE projects, particularly into hydrogen recovery and decarbonising steel processes through the industrial engagement with Tata Steel [R6][R7][S4], led to co-founding and USW as the lead academic for the **South Wales Industrial Cluster (SWIC)**, in January 2019 [S2]. The cluster includes over 40 active industrial partners from several sectors, such as Tata Steel, Valero, Tarmac and RWE, with a shared goal of achieving a reduction in carbon emissions of 16Mt/yr (i.e.net zero emissions) by 2040, largely through the implementation of hydrogen-based solutions. This represents nearly 40% of the UK's industrial carbon emissions. To November 2020, SWIC had been awarded five major Industrial Decarbonisation projects through UKRI (£3.53m) with the objective of detailing key steps to deep decarbonisation, including these industries fuel- and process-switching to hydrogen [S2]. The USW Hydrogen Centre, together with SWIC partners submitted a proposal to Innovate UK in November 2020 to take forward the engineering for the largest collective industrial decarbonisation activity in the UK via the 2nd phase Industrial Decarbonisation Challenge Deployment programme. This project will enable the bulk of the 16Mt/yr reduction in CO_2 emissions from the steel, oil refining, power and cement sectors. This has been successful and has raised £38m, of which the grant value of this project to USW Hydrogen Centre is initially £1.05m and is expected to rise significantly [S2].

5. Sources to corroborate the impact

1. Testimonial letter from the Senior Energy Advisor to the Welsh Government on USW Hydrogen Centre role in advising Welsh Government on Hydrogen technologies.
2. Testimonial letter from the Head of Industrial Decarbonation, Industry Wales (Welsh Government) on USW role in creating and developing the South Wales Industrial Cluster and establishing the path to major industrial decarbonisation.
3. Testimonial letter from the CEO of ITM Power on the Hydrogen Centre's role in supporting ITM Power's PEM electrolyser development and deployment.
4. Testimonial letter from Technical Director Tata Steel UK indicating the impact of SERC R&D supporting development of Tata Steel processes for hydrogen recovery and decarbonisation.
5. "South Wales to pioneer hydrogen energy in UK" Fuel Cells Bulletin. Volume 2010, Issue 3, March 2010, Pages 8-9 evidencing the creation of the Low Carbon Economic Area for Hydrogen in South Wales
6. "ITM Power wins Welsh government backing, expands UK operation". Fuel Cells Bulletin. Volume 2013, Issue 11, November 2013, Page 9
7. Letter of appointment to the UK Hydrogen Advisory Council.
8. Department of Energy and Climate Change, Green Hydrogen Standard, July 2015. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/454538/Green_Hydrogen_Standard_CfE_Government_Response_v1_0.pdf
9. Department for Business, Energy and Industrial Strategy, 2019. Energy Innovation Needs Assessment: Hydrogen and Fuel Cells. Online Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/845658/energy-innovation-needs-assessment-hydrogen-fuel-cells.pdf.
10. Testimonial Letter from Project Manager, State Grid Corporation of China on the collaboration with USW and how this has informed SGCC's approach to deployment of hydrogen in China.