

Report to Simon Wolff Charitable Fund on Santa Fe Institute Complex Systems Summer School 2012

Gareth Haslam

*Science and Technology for Sustainable Societies,
United Nations University - Institute of Advanced Studies,
1-1-1 Minatomirai, Yokohama, Japan**

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*haslam@ias.unu.edu; www.ias.unu.edu

I. PREVIOUS AND CURRENT RESEARCH

A. Promoting development of clean transport options

Tackling the related problems of urban air pollution and greenhouse gas emissions caused by the current reliance on combustion of fossil fuels such as petrol and diesel in car engines to move people and goods around is a major issue for both industrialised nations and developing nations. The approaches to deal with this problem can be roughly classified into either policy-based or technology-based. On the policy side there are initiatives such as increased use of bike lanes, bus rapid transit, or congestion charging. On the technology side there have been long-running programs by both universities and the private sector to develop non-polluting transport options such as battery-electric vehicles and fuel cell vehicles (FCV). Both of these alternative propulsion technologies use electric motors as the power-train and thus avoid producing harmful emissions. Whilst electric vehicles such as the Nissan Leaf are now becoming available for consumer purchase, FCV still face a number of technical challenges which make them significantly more expensive and impractical compared to petrol vehicles.

Part of the reason that FCV are so expensive is that they require the use of platinum as the electrocatalyst for both the hydrogen oxidation and oxygen reduction reactions. It is these reactions that produce the flow of electrons that is used to drive the vehicle's motor. The electrocatalyst's function is to speed up the reaction rate so that there is enough current flowing through the system. My PhD research at the Department of Materials Science, University of Cambridge, focused on trying to develop alternatives to Pt using transition metals such as nickel and tungsten combined with carbon. The difficulty is that the properties of Pt which make it so useful - high electrocatalytic activity and resistance to corrosion in the acid environment of the fuel cell - are difficult to replicate in other material systems. However, by using magnetron sputtering to produce thin-films of carbon-encapsulated nickel nanoparticles, I produced a material that showed remarkably good passivity against corrosion whilst still being active towards the hydrogen oxidation reaction. These results point the way to the development of a new class of non-Pt electrocatalysts which may one day help put affordable FCVs on the road.

B. Innovation policy for alternative energy

After finishing my PhD, I was offered a fellowship to study at the United Nations University - an institute dedicated to connecting the UN with academics and policymakers who can contribute to tackling issues of relevance to the UN. My goal was to understand some of the wider issues concerning the development of alternative energy technologies such as incentives, funding, and the roles of both the public and private sector in making such technologies more widely available. This is quite different from the science/engineering focus on producing e.g. solar cells which can harvest more sunlight or fuel cells that are more tolerant to contamination. Using patent and academic publication data I have tried to analyse how innovation policy in three key Asian countries has helped to stimulate the fuel cell industry, and in another case, how developing countries can prepare for the possible future growth of an algae biofuel industry.

II. SFI COMPLEX SYSTEMS SUMMER SCHOOL 2012

A. Impressions and learning outcomes of the course

The Santa Fe Institute (SFI) Complex Systems Summer School (CSSS), held annually in Santa Fe, New Mexico, is the longest-running course of its kind - introducing graduate and postdoctoral students to the interdisciplinary field of complex systems. Out of over 300 applicants to the course, I was selected for one of the 50 places available. The course featured a wide range of both lecturers and students, ranging from anthropologists and linguists, to applied mathematicians and evolutionary geneticists. Having such a mixture of backgrounds was both exciting and daunting, as on the one hand, it was great to learn more about other fields, but on the other hand, it could be difficult establishing common ground and having to justify your own research. The lecture courses covered such topics as: non-linear dynamics, agent-based modelling, understanding and modelling networks, the growth and death of languages, the limits of computation, the spread of disease, biologically inspired computing, science of cities, and innovation in technology. Being exposed to so many interesting topics was fascinating but also made me realise how much I don't know. However, whilst it was not possible to become an expert just from attending the lectures, it did provide me with a starting point should I wish to develop my knowledge and skills in some of these areas later.

In particular, the introduction to agent-based modelling is something which I would like to explore further in my research as it has wide applications from modelling the particles in an ideal gas to how ideas spread through a network of people.

B. Complex systems and the SWCF

The topic that I found of most interest and which I think is most directly related to the interests of the SWCF, was on scaling and cities. This is an exciting new area which looks at trying to understand the macroscopic picture of cities in terms of underlying laws by studying everything from the average length of roads in cities to the number of restaurants and real estate agents. Research has found that, on average, as cities double in size they experience 15% more crime but need 15% fewer petrol stations and produce 15% more patents. This exciting but controversial research may lead to better design and planning of cities in ways that may encourage them to be healthier, safer, and cleaner places to live and work. I had the great pleasure of meeting with the originators of this work, Geoffrey West and Luis Bettencourt, during the summer school and am working with a group of other students from the course to hopefully develop a future publication on a related topic.

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