Cairncross Speculation

Ronald MacDonald[1] *Donald MacRae*[2]

"It is fascinating to speculate on what might have been, had the industrial revolution been based on electric power instead of steam. Possibly the great centres of population would have been found in the north rather than the Glasgow-Edinburgh-Dundee belt."

A.K. Cairncross[3]

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[2] HIAlba-IDEA.
[3] *The Crofting Problem*, Adam Collier, Foreword & Edited by A.K. Cairncross, Glasgow University Economic and Social Study, Publisher University Press, 1953.

Contents

Could the Highlands and Islands grow and sustain major population centres?
Could the far north of Scotland become the renewable energy hub for Europe?

1. Summary

The first of these questions is considered by the authors in papers elsewhere[4] and in doing so they identify and gauge the opportunities that would arise for the other major regions of Scotland: North East, Central Belt, and the South West. This paper considers the second question by outlining industrial development prospects of far north Scotland - Caithness, Sutherland and Ross - entirely based on dispatchable renewable electric power with **zero intermittency and near zero losses in electricity transmission**. With the recent opening of the Beatrice offshore windfarm in Caithness, we believe this second question is timely. The main focus of the paper is on prospects that could arise from the far north playing a key role in enabling a fossil-fuel free energy-independent Europe in collaboration with energy majors. This would build on and massively extend the already impressive renewable energy electricity infrastructure of the **far north to emerge as the renewable energy hub for Europe**. Also noted are existing human resource capacities to realise these prospects. Consideration is then given to options that could enable industrial development at various locations throughout the far north. Finally, we propose a test of the zero-intermittency solution, noting that as a first step it has the potential to reduce burgeoning constraint payments[5] to zero.

2. Speculation on How and What

How can Scotland's far north become the renewable energy hub for Europe? By building and operating a **24x7** dispatchable renewable electricity "supergrid", first servicing the UK then Europe, with the aim of delivering fossil fuel free energy independence. At this scale it would be essential to think only in terms of vast arrays of offshore windfarms that obviate claims of visual pollution. This requirement is likely to increase the pressure for floating windfarms. The sheer extent of new subsea and overland cables required to establish the supergrid will accelerate existing initiatives to commercialise super-conducting technologies capable of achieving electricity transmission with near **zero losses**. For the far north renewable energy is mainly from onshore windfarms with increasing uptake of offshore windfarms in the Moray Firth, the North Sea notably east and west of the Shetland Islands and the Western Isles. Significant initiatives are also seeking to put Scotland in the lead in tidal and wave power. For the far north this includes tidal and wave energy projects in the Pentland Firth, the Orkney Islands and the Shetland Islands considered below. And from left field we have Scotland's lead in kite power.

2.1 Offshore Windfarms and Floating Windfarms

Nigg Energy Park in the Cromarty Firth has adapted operations from assembling oil & gas rigs to renewable energy developments. Currently this involves assembling wind turbine towers and transporting 123 km to Wick for offshore wind farm developments, initially the Beatrice Wind Farm about 21km offshore from Wick with a 450,000 home capacity, due to start up by late 2019 and subsequently for Moray West and Moray East offshore wind farms in the early 2020s. The world's first floating wind farm is now operated by Hywind Scotland about 29 km east of Peterhead.

Having been left behind in the first generation of wind turbine design and manufacturing, it could pay Scotland to collaborate actively in the design and manufacture of the next generation of wind turbine blades such as the folding 200 metres long blade for a 50MW offshore wind turbine, "nearly

[4] The reports Maximising Scotland's Well-Being by Bravely Innovating and Hydrogen Scotland: A Route to Export Powerhouse at www.hialba.org outline industrial development prospects for Scotland arising from the global emergence of hydrogen economies which are outlined in the newspaper articles: Plan to make Scotland a green energy superpower, thanks to hydrogen and Neil Mackay: Scotland can lead the way in green energy industry.

[5] Record payments made to Scottish wind farms in March, Energy Voice, April, 2019.

six times more powerful than a record-setting 8.8MW turbine recently deployed off the coast of Scotland."

Also, worth considering are the recent efforts to develop and test fabric-based blades tension wrapped around a lightweight, easily altered, metal structure to reduce their weight and production costs by 70% while maintaining conventional wind turbine performance.[6]

All this will require efforts to automate the repairs to wind farms to be highly flexible. Not so much in the robot drone carriers but the versatility of the drones to undertake repairs and maintenance of markedly differing types of blades: Robot team set sail for offshore wind farm inspection, The Engineer, May 2019.

2.2 Ammonia Batteries for Zero Intermittency

How 24x7? Build and operate facilities that will store renewable energy during periods of low winds, even across a vast array of floating windfarms extending over several hundred kilometres. One means of storage is to use scaled up versions of Li-ion batteries currently powering electric vehicles (EVs). Another is to use increasingly lower cost renewable energy to produce and store ammonia[7] to generate electricity in periods of low winds. Ammonia (NH3) contains hydrogen which can be extracted and used to generate electricity by means of fuel cells. Until recently the extraction of hydrogen from ammonia has been costly. An Australian breakthrough technology has demonstrated a capacity to reduce greatly these costs. Accordingly, with "battery" like storage of low-cost hydrogen we can power the grid when winds are low. The other take away is that ammonia surplus to the requirements of battery storage can be converted to fertilisers or a range of other products for local use, or export, or it can be added to the very considerable global export trade in ammonia.

Ammonia provides a more effective means of transporting the much less dense hydrogen. The resulting trade would involve converting ammonia to hydrogen at the point of national, regional and local distribution, contributing increasingly to the growth of hydrogen as a clean fuel for transportation: cars, buses, trucks, trains, ships, planes and as always rockets.

Oxygen is another bi-product of renewable ammonia production which together with hydrogen could be used as rocket fuel as discussed below.

It is noted that the development of a prototype ammonia battery could be used to make the case for reducing or eliminating constraints payments currently as considered in the final section.

2.3 Zero Transmission Losses

How zero losses? This prospect arises by replacing copper with the "super-conductor" graphene in electricity transmission cables. There are currently various efforts to commercialise the production of graphene cables. A process that coverts natural gas to produce pollution free hydrogen, carbon in the form of graphite and subsequently graphene is currently being commercialised and is considered below.

2.4 Tidal Power

As reported in *HI-energy*, the area of sea off the northern coast of mainland Scotland, and encompassing the waters around the Orkney Islands, contains 50% of the UK's tidal resource and 25% of Europe's tidal resource. Managed by the Highlands and Islands Enterprise (HIE) in

[6] This is outlined in the HIAlba *Hydrogen Scotland* report: *6.5.3 Revolutionising Wind Turbines and Blades.*

[7] The Hydrogen Scotland paper outlines methods of producing ammonia using renewable energy-based electrolysis and by solid state synthesis of ammonia.

partnership with industry, *HI-energy* represents the energy industry within the Highlands and Islands of Scotland.

The Highlands and Islands are also the home of the Orkney based European Marine Energy Centre (EMEC) established in 2004 and to date the operator of the world's only grid connected wave and tidal test site. The Pentland Firth is also the location for the MeyGen project, the largest planned tidal stream project in the world, currently under construction.

The BBC recently published a major article How hydrogen is transforming these tiny Scottish islands. Orkney islanders are producing more renewable energy than they can use and are using the surplus to generate hydrogen with associated spin-off opportunities.

The Surf 'N' Turf project has installed tidal power devices located at the EMEC test site in the sea west of the island of Eday. The Eday Renewable Energy community own an onshore wind turbine. Together they route their surplus electricity to a 500kW electrolyser to generate hydrogen by electrolysis of water. The hydrogen is stored as compressed gas then transported on a trailer by road and sea to Kirkwall to power a fuel cell that generates electricity on demand.

2.5 Wave Power

Since 2014 Wave Energy Scotland (WES) has managed a programme of wind energy R&D and pre-commercialisation initiatives. Based in Inverness and operating as an entity of HIE, the programme involves selecting concept level research projects for funding which are subsequently evaluated for joint funding/investment to progress through development stages with a view to attracting pre-commercialisation investment in the most promising projects.

With the far north in mind, and with its proven tidal energy capacity and connector advances (see above) to the east of Cape Wrath, would the sea to the west (with no land until Newfoundland) make a suitable region for harnessing wave energy? This April 2019 video Why Can't We Get Power from Waves? only covers seabed-operated blades to turbines and not the range of surface technologies that have been assessed by EMEC. Nor does it consider the WES assessment of Carnegie Corporation's CETO subsurface buoy/piston to seabed turbine and EMEC's recent collaboration with Corpower Ocean in west Orkney to asses a similar but surface-based technology developed in Sweden. CETO has been under development by Carnegie Corporation's for about ten years and claims that surface operation is less reliable, there are no visual impacts from its solution, even from near shore installations, and that they have experienced a marked increase in marine life with its installations acting like an artificial reef. CETO can also use the hydraulic power to power an off the shelf reverse osmosis desalination plant. Efforts are currently being expended to lift the company from voluntary administration for re-listing on the Australian Stock Exchange following the cancellation of a major deal by the Western Australian Government to build a wave energy farm.

Among the major objectives of Scottish tidal and wave energy R&D and commercialisation initiatives are: (a) to ensure that the manufacturing opportunities Scotland missed in the development of the wind energy industry are not repeated; and (b) to use the reliability and predictability of these forms of energy to provide baseload energy capacities for renewable energy generated for the grid.

2.6 Kite Power Systems

Based in Scotland, Kite Power Systems (KPS) are designing a technology to access wind energy that conventional technologies cannot: at higher altitude where winds are stronger and in remote areas, particularly those affected by disasters in need of emergency power. Multiple commercial deployments are anticipated by 2023.

This video on KPS gives an intriguing insight into the potential of this technology. Suggestions for deployments in the far north include: operating from the disused oil & gas rigs in the Cromarty Firth with a view to their wide-scale deployments on disused rigs throughout the North Sea; as a means of supplementing the energy needs of hydrogen powered shipping, perhaps starting with the hydrogen powered ferries planned to service the Orkneys (see Surf 'N' Turf above) and Shetlands – Shetlands looks to hydrogen economy.

2.7 Greening Gas & Oil

Why green oil & gas? Does it make economic sense to invest hundreds of billions of dollars in North Sea oil & gas development in the face of rapidly decreasing costs of renewable energy and the emerging feasibility of Scotland delivering vast amounts of renewable energy to a European supergrid? Should the economic assessment of this reality also account for the impact of higher emissions from oil & gas? The following articles on adverse impacts are a few from those published in the past few months, following a strong flow in recent years:

More drilling in North Sea will 'quadruple emissions', The Times, May 2019

Clean air for all: One in three cars still too dirty despite new curbs on pollution, The Times, May 2109

Air pollution kills more people than smoking, German scientists say – 64,000 extra deaths per annum in the UK and 790,000 pa in Europe, The Times, March 2019.

Outside London the air quality crisis is deadly, and worsening, The Times, May 2109.

Charities call for change in law to tackle pollution threat, The Times, June 2019 **-** the UK has legal limits more than twice as high as those recommended by the WHO. The heads of four charities said that the case for "immediate action" on air pollution was "incontestable", insisting it was the biggest environmental threat to UK public health.

BP headquarters in London blockaded by Greenpeace, The Guardian, May 2019 – Greenpeace activists have blockaded all entrances to the BP headquarters in London, demanding an end to all new oil and gas exploration.

Can Europe Wean Itself From Fossil Fuels? Its Leaders Are About to Decide, The New York Times, June 2019 **-** comes against a background of weekly student protests across Europe that are pressing leaders for urgent measures to stave off catastrophic climate change.

Extinction Rebellion threatens to use drones to shut down Heathrow airport for up to 10 days, Independent, June 2019.

Hydrogen fuel cell powered airplanes or liquid hydrogen-powered airplanes may be more practical courses of action for energy corporates and activists alike.

Would this support the economic case for greening further extraction of oil and gas or at least green the existing extractions, should investment in even greening developments prove less economic? In effect does this portend a turning point in the risk of investing in stranded assets?

Consider also Germany's exigencies of progressing to renewable energy – closing down nuclear power resulting pro tem in increased air pollution from coal fired power stations – that is causing them to consider:

- A 750 km gas pipeline across the Baltic Sea from Russia, notwithstanding the threat that Washington will punish builders of Putin's gas pipeline, The Times, May 2019
- Yet another somewhat small scale offshore windfarm in the low wind Baltic Sea due to saturation in the capacity to increase installations in the North Sea adjacent to Dutch offshore windfarms – What A Baltic Wind Farm Says About EU Energy Cooperation, Forbes, April 2019

Worthy of economic assessment would be the alternative of a 535 miles High Voltage Direct Current (HVDC) subsea cable from Peterhead to Hamburg as a first step in establishing the European Supergrid. This is considered further below in the section ***Installation of HVDC Subsea Cables***. Should "full-cost-pricing" economic assessments indicate the financial viability of investing in green gas and oil, what industrialisation advances would be required? The following sections indicate possible advances.

2.7(a) Greening Gas

The Hazer Group in Australia is commercialising a process to extract hydrogen and carbon in the form of graphite from natural gas, primarily methane (NH4). They are also well advanced in producing graphene from graphite. Given that oil & gas rigs can separate oil & gas and pump them to the shore separately, it may be worth considering the establishment of a hydrogen-graphite-graphene plant in the far north. The hydrogen produced could be fuel cell converted to electricity to power proposed major industrial developments throughout the far north. The graphite produced could be a possible export to EV battery manufacturers worldwide. The graphene produced could be use to manufacture near zero transmission cables, also produced locally. Possible locations include Nigg by restoring the pipeline operations, Shetland near the Sullom Voe Terminal and the Sella Ness Industrial Estate, Orkney adjoining the Flotta Oil Terminal, and Peterhead adjoining the St Fergus Gas Terminal. This is considered below as part of a case to establish a number of gigafactories[8] in the far north to accelerate the development of the proposed European supergrid.

2.7(b) Greening Oil

This is a much more challenging prospect. Cheap renewable energy could provide increasingly economic as well as environmental advantageous ways of greening petroleum. For example, renewable energy could power the gasification of oil to produce syngas much more cheaply and cleanly than fossil fuel-based production processes. Depending on the specific chemical composition of the petroleum gasified, the following table shows a typical percentage range for the gases comprising syngases.

Substance	Composition (%)
H_2	20-40
CO	35-40
CO_2	25-35
CH_4	0-15
N_2	2-5

Air Products has processes for the separation of these gases on major industrial scales (e.g. H_2 for sale to refinery and petrochemical customers via its "vast Gulf Coast hydrogen pipeline network system" and CO for production of formic acid with worldwide capacity of 720,000 tpa for all producers). H_2 could also be used to power local industrial estates and/or to produce electricity for the UK grid. A recent advance in formic acid fuel cells extracts the hydrogen for electric power and recycles the CO_2 back into the production of formic acid. Also worth assessing is a recent advance in

[8] The Tesla Gigafactory for the production of Li-ion batteries for electric vehicles is expected to be the biggest building in the world.

hydrogenation of CO_2 into formate that works at atmospheric pressure and doesn't need hydrogen – Taking the pressure off catalytic carbon dioxide conversion, Chemistry World Feb, 2019 – and from there to a wide range of products manufactured from formate esters and salts.

As taxes are increased to reduce the direct use of fossil fuels for transportation and industry generally, the foregoing may prove attractive economically as well as environmentally, and socially by markedly increasing employment opportunities. The Hazer process could produce hydrogen and graphite from CH_4 as noted above. Residual N_2 may be safely released to the atmosphere or be used in ammonia production.

2.8 Carbon Capture and Utilisation (CCU)
Rather than widely distribute CO_2 for processing into many products worldwide or, where it is a major unwanted by-product, captured and stored at considerable expense and potentially dangerously, why not use it locally? This could include collaborating with the companies and government agencies working to commercialise processes to accelerate the growth of algae for biofuel production, forest growth, and seaweed growth for harvesting as inputs to industrial-scale production of bio-plastics as considered below. The current commercialisation of *Direct Air Capture (DAC)*[9] processes to use the filtered CO2 in combination with hydrogen in processes to produce hydrocarbons is likely to accelerate the local production of the full range of products currently derived from oil and gas, including *Air to Fuel (A2F)*[10] for direct use or serving as battery storage. The availability of low-cost renewable energy will be a prerequisite to maximising the potential for carbon-neutral production of hydrocarbon-based products at local locations anywhere.

An attractive prospect for Scotland is DAC for CO2 produced on disused oil rigs for use in accelerating the growth of seaweeds grown on a vast scale in the surrounding structures anchoring offshore floating windfarms. This presents a range of opportunities for Scotland to take a significant role in the manufacture for global markets of equipment for DAC, attendant production of hydrocarbon-based products including A2F and seaweed biosequestration of CO2, by accelerating the growth of seaweeds and a myriad of other plants for food and other purposes.

Given the scale of industrialisation envisaged in greening oil & gas and CCU, locations such as the Nigg Energy Park and Peterhead may be best suited to deliver these outcomes. Clearly this present manifold opportunities for industrial symbiosis, sometimes referred to as eco-industrialisation or circular economy operations. The ensuing opportunities for the far north are considered in more detail later in section 4. Options for Industrial Symbiosis in Caithness, Sutherland and Ross.

2.9 Electrolysis of seawater
Another co-located industrialisation prospect arising from the availability of the ever-declining cost of renewable energy is the electrolysis of brine (seawater) to produce hydrogen, chlorine and caustic soda: $2NaCl + 2H_2O \rightarrow Cl_2 + H_2 + 2NaOH$. The hydrogen produced could be used to generate electricity or together with oxygen as rocket fuel. The caustic soda could be used with seaweeds and ammonia to manufacture high value fertilisers for local national and global markets. The chlorine produced could be used to manufacture myriad products, including in the production of bioplastics and leather from seaweeds as discussed below.

2.10 Spaceport and Spin-off Opportunities
According to HIE the planned European Spaceport (prosed for land on the Melness Crofters Estate in Sutherland, about 78km west of Thurso) could be the first orbital spaceport space launch facility in
https://science.howstuffworks.com/environmental/energy/carbon-capture-to-fuel-is-almost-here.htm

[9] Companies commercialising DAC and its uses such as A2F include: Carbon Engineering - Canada; Climeworks - Switzerland; Global Thermostat in collaboration with ExxonMobile.
[10] Carbon Capture-to-fuel Is Here.

Europe, if built on schedule. This is dependent on the outcome of a series of "community engagement events" being undertaken by HIE who are heading up the "Space Hub Sutherland" project. Projected outlays of £17.5m includes a grant of £2.5m from the UK Space Agency (UKSA), £9.8m from HIE and the remaining £5m from the Nuclear Decommissioning Authority.

Memoranda of understanding have been signed with launch operators, Lockheed Martin and Orbex, also awarded UKSA funding. It is anticipated that up to six launches will be carried out annually, with the first taking place in the early 2020s. UK-based spaceflight firm Orbex has proposed launching small rockets powered by 3D printed rocket engines carrying nanosatellites from the space hub to altitudes of 1,250 km, fuelled with bio-propane, a "clean-burning, 100% renewable fuel source" that cuts carbon emissions. Orbex envisage more than 130 new jobs could result from the decision to site their mission control and design facility in Forres.

2.11 Electric Steelmaking and Advanced Materials
The ever-decreasing costs of renewable energy could revitalise other major industries such as steelmaking and advanced materials using electric arc furnace technology. Manifold industrial applications include the manufacture of machinery parts for the space industry, tidal, wave and wind tower assemblies.

2.12 Metal and Alloy Powders for Additive Manufacturing
3D printing or additive manufacturing using alloy powders which could be produced in the far north using a solid-state alloy powder technology developed in the UK. This could include powdered steel produced locally. 3D printing of rocket engines by Orbex in the region could pave the way for the additive manufacturing of high-performance machinery in the renewable energy industries.

2.13 Products from Seaweed
The advent of vast arrays of floating wind farms hold great potential to co-establish and operate seaweed farms to sustain industrial scale production of many non-food products including: proven biodegradable bioplastics for the same range of uses as fossil fuel based plastics, including food and drink packaging, leather, biofuels, cosmetics, advanced materials, nanotechnology to produce low cost solar cells, myriad fertiliser applications, and revolutionary feedstock for cattle to reduce to near zero their methane excretions.

Vegan food and drinks products already produced in Scotland from seaweeds or global markets include cheese, caviar, and ale. A vast range of other products are already produced worldwide in which Scotland is well placed to become a dominant player.

2.14 Alba Vegan
A case is outlined in the HIAlba Overview report (page 21) for Scotland to become a major global player in the rapidly growing vegan food industry and associated healthcare, based on the establishment and operation of eco-industrial parks:

> An **eco-industrial park** (**EIP**) is an industrial park in which businesses cooperate with each other and with the local community in an attempt to reduce waste and pollution, efficiently share resources (such as information, materials, water, energy, infrastructure, and natural resources), and help achieve sustainable development, with the intention of increasing economic gains and improving environmental quality.

The EIPs would source crops from major expansions of crofting communities and seaweed harvesting, ostensibly from major expansions of the fishing industry. Other crops often used in vegan food products that grow well in Scotland include hemp, beets, berries, hazelnuts. In the case of hemp, not only is there a wide range of health food products (including hemp seeds, protein powders, flours, oils) but also as a building material. A major competitive advantage could flow from Scotland becoming a major global producer of bio-plastics for food and drink packaging.

It is worth noting here that the authors in their HIAlba Overview report (pages 21-24) considered the prospects for adopting and adapting recent advances in 3D printing of housing supporting a wide range of activities on crofts, including providing major inputs to EIPs.

2.15 Earning Carbon Credits

As noted earlier, biosequestration of CO_2 for the production of biofuels, forest growth and seaweed growth could be accelerated in newly emerging ways. The first is the development of innovative machinery and equipment (possibly utilising advances in additive manufacturing and for major sales beyond the region) to facilitate biosequestration. The second is collaborating in the development and commercialisation of very promising advances in enhancing markedly the biosequestration capacities of plant roots both in quantity and longevity – see How supercharged plants could slow climate change, Ted Talk, May 2019.

Well worth capturing would be not only the flows of income from the production of products in increasing demand worldwide but also the flows of carbon credits as income for all participants in the attendant value chains.

2.16 Installation of HVDC Subsea Cables: Peterhead to Hamburg as a down payment?

A geophysical and geotechnical survey and plans have been finalised for the installation of a high voltage direct current (HDVC) subsea cable from a substation and HVDC converter station at Upper Kergold on Shetland to a HVDC switching station at Noss Heads (about 8 km north of Wick) and associated onshore infrastructure to complete the connection. This will facilitate the connection of: (a) the Moray Firth offshore wind farms; and (b) over 600MWs of renewable generation proposed on the Shetland Islands requiring a connection to existing transmission infrastructure in the UK grid.

The increasing sources of renewable energy from across the far north of Scotland are transmitted by the electrical substation near Spittal (16km south of Thurso), the landing point for a 1200MWs HVDC submarine power cable crossing the Moray Firth to Blackhillock Substation near Keith and hence to the UK grid. Another HDVC cable from Kergold-Shetland is planned to reach Spittal. This could be a forerunner to the transmission capacity that would be required to service the envisaged massive expansion of offshore wind energy from east and west of the Shetland Islands. This would make a significant contribution to the development of the far north as the renewable energy hub for the UK and Europe.

The proposed NorthConnect between Norway (Samnanger near Bergen) and Scotland (near Peterhead) is intended to support the development of the renewable energy industries of both countries and serve as the first connection between Scotland and mainland Europe. Given various delays in this project to date, would it make sense to consider the markedly shorter subsea connector options of Samnanger to Kergold and hence to Spittal or Samnanger to Noss Heads?

Also planned is a reinforcement of the subsea Western Isles link from Stornoway to landfall at Dundonnell in Wester Ross and hence to the converter at Beauly (about 20 km west of Inverness) and from there to the UK grid via the Beauly link to Denny (near Falkirk). From there existing and new HVDC converter stations would be required to distribute renewable electricity throughout the UK grid and to the envisaged Europe supergrid.

One route to service the UK grid could involve accessing the proposed major subsea HVDC link between Peterhead and Hawthorn near Durham. Connecting to mainland Europe could then be via the planned massive expansion of the existing two-way HVDC channel links between the UK and France by means of the joint venture Elecklink, which is developing a transmission capacity via the Channel Tunnel. Perhaps a more effective link to Europe would be a major subsea HDVC cable link between Peterhead and East Anglia near Norwich and from there to mainland Europe via the Netherlands and/or a major subsea HDVC cable link between Peterhead and northern Denmark near Aalborg and/or the 856 km from Peterhead to Hamburg and the industrial heartland of Europe.

2.7 Investing in Ultra HVDC to Accelerate Establishment of the European Supergrid

Ultra HVDC transmission lines (> 800 kV cf HVDC < 600 kV) are now coming to the fore, led by China: China's State Grid Corp Crushes Power Transmission Records, IEEE Spectrum, Jan 2019 – the UHVDC line (extending over 3,000 km from the north west's abundant solar and wind power installations) built by Beijing-based State Grid Corporation of China can transmit up to 12 GW, enough to power 50 million Chinese households.

Replication by Scotland and energy majors of such a capacity would constitute a handsome down payment on the establishment of the European Supergrid. With this in mind consider the statement by the Bob Dudley, chief executive of BP:

> "If somebody came and said, $10 billion, spend it on renewables and low carbon energy, I'm not sure we would know how to spend that in a way that our shareholders could say we're stewarding capital well. They want us to be involved, certainly, and we are moving fast on lots of fronts."

And this from a key player who is also chairman of the chief executive steering committee of the Oil and Gas Climate Initiative (OGCI), an industry group focused on reducing carbon dioxide emissions.

How far would $10 billion go in funding a floating offshore wind farm generating 12GW and an UHVDC subsea cable to deliver this from Peterhead to Hamburg? In their Hydrogen Scotland report (page 4), the authors quote a cost estimate of £12 billion to generate 12.5GW, say 12GW for £11.5 billion or about $15 billion. The cost of a 12GW UHVDC cable would be in the order of $15 million per km or about $13 billion for 856 km: Superconducting transmission lines – Sustainable electric energy transfer with higher public acceptance? (see extrapolation of Fig 7, page 70 for the estimated cost per km). Using the University of Strathclyde estimates of the cost of installation of submarine cables of between £2 million and £5 million per cable km gives a cost for 856 km between about £2 billion and £6 billion or between about $2.5 billion and $8 billion depending on the nature of the sea-bed and depth. Assuming an installation cost of $5 billion gives an all up cost of $33 billion to generate 12GW of offshore wind energy and transmit it by 12GW cable over 856 km of seabed. While over three times Bob Dudley's $10 billion investment conundrum this is $7 billion less than the proposed spend by oil & gas majors to further develop and extend the life of extracting oil & gas from the North Sea: North Sea oil & gas extraction projects to total £34bn in next 7 years. Assigning a value £75,000 to each of the projected 448,000 lives lost[11] over 7 years to oil & gas air pollution would result in damage costs or social divestment that would match the £34bn investment. Apply what would be widely accepted as a much fairer value of a life lost and the damage costs would dwarf not only the investment but also a ten fold ROI.

2.18 Greening Oil & Gas or Renewable Energy Options or Both

This poses the question, even if damage costs could be avoided by greening the increased extraction of oil & gas as outlined above, would greening the proposed increased extraction and the existing

[11] Air pollution kills more people than smoking, German scientists say – 64,000 extra deaths per annum in the UK and 79,000 pa in Europe, The Times, March 2019

levels of extraction be as economic as the renewable option? In the event that the greening option is about as economic as the renewable option would it be worth considering the prosecution of both in a bid to deliver fossil fuel free energy independence to Europe as rapidly as possible?

Is the case for one or both strengthened as the UK advances towards an outlay of about half the foregoing investment on a third runway at Heathrow if significant progress can be made to electric flight by the time the runway is scheduled for completion by 2025? Would oil & gas companies consider investing in greening oil & gas in addition to the OGCI projects in carbon capture, uses and storage CCUS, reduction of methane emissions in extraction of oil & gas and increasing energy efficiency in transport and the oil & gas value chain? Clearly greening oil & gas would obviate CCUS. Investment in reducing methane emissions not only financially benefits producers but also human health and the quality of the environment generally – surely a no-brainer. Efficiency in transport while worthy would deliver gains many times less than hydrogen fuelled transport – as above see hydrogen fuelled cars, buses, trucks, trains, ships, planes and as always rockets. Increased efficiency in the oil & gas value chain would be deliver the same benefits to hydrogen fuelled transport.

2.19 Gigafactories

The Tesla Gigafactory, built to produce Li-ion battery cells for EVs, once completed is expected to be the biggest building in the world. Should Scotland think this big in relation to accelerating the industrial developments proposed in the foregoing?

Based on the foregoing consideration could be given to Gigafactories for manufacturing:

(1) **Wind tower assemblies** - Production of wind turbine tower assemblies, which includes a foundation, a tower, a nacelle (generator, gearbox, drive train, and brake system), a yaw (which may keep blades facing the wind) and a rotor (blades, a hub, and a nose cone) for UK/Europe Supergrid and similar developments worldwide. This could include additive manufacturing of many machinery parts with powdered alloys produced in the region. As noted earlier (pages 2 - 3) advances in blade design and testing provide Scotland an opportunity to carve out a lead in this space.

(2) **Wave, tide and kite energy machinery and equipment** – Could include additive manufacturing of many machinery parts with powdered alloys produced in the region.

(3) **Manufacturing automated drone carriers and drones for wind farm repair and maintenance** – The massive operation of offshore windfarms envisaged in the foregoing would require efforts to automate the repairs to wind farms to be highly flexible. Not so much in the robot drone carriers but the versatility of the drones to undertake repairs and maintenance of markedly differing types of blades: Robot team set sail for offshore wind farm inspection, The Engineer, May 2019.

(4) **Automated ships for seaweed harvesting** – Plans to build hydrogen fuel cell ferries for transportation to the Western Isles, the Orkney Islands and the Shetland Islands are a step in the direction of building automated ships for seaweed harvesting in conjunction with the operation of vast arrays of offshore wind farms. The gigafactory in this case would manufacture a wide range of the parts for such advanced ships, possible adjacent to shipbuilding operations. Perhaps collaboration with Norway would be worth considering given their advances in this space: What lies beneath: the ship that could revolutionise seaweed cultivation.

(5) **Ammonia battery equipment** – Production of plant to produce ammonia from renewable energy, water and air. Production of machinery to extract hydrogen from ammonia. The production of ammonia by either renewable electrolysis Haber-Bosch or Solid State Ammonia Synthesis processes would also lead to industrial scale production of oxygen for steelmaking, welding and rocketry (possibly for launches from the Sutherland Space hub).

(6) **Ammonia, Seaweed and Caustic Soda for fertilisers** – A range of high value fertiliser products manufactured from ammonia, seaweed and caustic soda for local, national and global markets.

(7) **Li-ion v aluminium-air batteries** – Production of batteries for EVs using graphite from Hazer process and imported lithium (Cornwall), copper, nickel, iron, and cobalt. Given the lead by the USA and China and the intense competition between them, it will be a major challenge for Europe[12] yet alone Scotland to produce li-ion batteries for EVs on a massive scale. However, there are strong prospects that li-ion batteries will be replaced by significantly superior battery technologies currently being investigated. For example, conceivably aluminium air batteries would offer Scotland (Fort William) an opportunity, provided it made major investments in early stage R&D and commercialisation of recent advances. They calculate that when scaled up to the size needed for electric vehicles, an aluminium–air battery pack would have one-fifth the weight and half the size of a lithium-ion battery pack[13].

(8) **Natural Gas to Hydrogen and Graphite** – See description above on opportunities arising from greening natural gas. Given the unlikelihood of EV battery production in Scotland a case could be made for conversion of all graphite being converted/processed as graphene for zero transmission electrical cables. The hydrogen produced could be used for this conversion and for local electricity grids servicing local industry, EIPs and settlements.

(9) **Gasification of Oil** – from the description above on opportunities arising from greening of oil it is evident that there would be many opportunities for manufacturing enabling machinery and industrial plants.

(10) **Graphene cables** – Production of graphene from Hazer produced graphite. Production of UVDC and HVDC graphene cables for very low to zero loss of transmission of electricity from offshore wind farms throughout the Moray Firth the North Sea for UK and European markets based on a European Supergrid. Very significant global market potential.

(11) **Seaweed to Bioplastics** – Many possibilities for the production of products from seaweeds are noted in the foregoing with the most significant being the production of bio-plastic packaging and bio-cellophane (from major carbon credit earning seaweed farms operating conjointly with the vast arrays of offshore wind farms throughout the North Sea).

(12) **Electrolysis of seawater** – As noted earlier, could include the production of: (a) hydrogen for electricity for regional industry or together with the oxygen bi-product of ammonia production as rocket fuel; (b) caustic soda to combine with seaweeds and renewable ammonia (produced in the region for baseload electricity) for high value fertilisers; and (c) chlorine for myriad industrial purposes which could include the production of bioplastics and leather from seaweeds.

(13) **Manufacturing of bioplastic packaged food and drink containers** – manufacturing myriad forms of packaging for food and drink produced by crofting communities, farmers and EIPs throughout the Highlands and Islands.

(14) **Product Distribution Centre** – Warehousing and distribution centres for bioplastic packaged food and drink for UK, European and global markets.

3. Industrial Resources of Caithness, Sutherland and Ross

The following extracts from the energy sector overview of the ***HIE website*** and the ***HI-energy*** initiative managed by HIE in partnership with the wider industry reinforces the feasibility of delivering the ambitious industry development proposals in this paper:

[12] Europe Throws Billions at New EV Battery Ventures and Europe Launches Multibillion-Euro Initiative For Electric Car Batteries

[13] Suppressing corrosion in primary aluminum–air batteries via oil displacement

Energy

With superb natural resources, modern fabrication and port facilities, and transferable skills from the oil and gas industry, the Highlands and Islands is bidding to be a world capital for renewable energy. The region's strong legacy in the oil and gas industry, and abundance of renewable energy resources, mean it is ideally placed to be at the forefront of the energy industry. Here you can find out about ground-breaking work many local companies are involved in, from research and development to full-scale test facilities. It's also where you'll find the latest news and analysis from the energy sector plus full coverage of the markets we work in.

HI-energy

The Highlands and Islands of Scotland has a growing global reputation as the energy power house of Europe. Its strong legacy in the oil and gas industry and abundance of renewable energy resources means the region is ideally placed to be at the fore of the energy industry. The region has some of the best natural resources anywhere in the world, a strong infrastructure and skilled workforce. The HI-energy website gives comprehensive and up-to-date information on the development of the energy mix. This is where you'll read about ground-breaking work many local companies are involved in, from research and development to full-scale test facilities. It's also where you'll find the latest news and analysis from the energy sector plus full coverage of the markets we work in. There is, quite simply, no better place to discover why the Highlands and Islands lead the way in energy development.

Also of relevance is the operation of a major nuclear site at Dounreay near Thurso, comprising five nuclear reactors commencing operations from 1955 with the last closing down in 2015. With decommissioning of the reactors expected to continue for the next fifty years, costing several billion pounds, employment while decreasing over time will see the retention in the region of engineering skills.

The advanced technologies and skills in establishing, operating and decommissioning nuclear reactors will be absorbed and extended by the rapid growth of the renewable energy industry and its enabling of myriad R&D and commercialisation opportunities in eco-industrialisation. As such this remnant workforce could emerge as leaders in delivering HIAlba's Greenprint (pages 4-5) to deliver energy independence for Europe.

4. Options for Industrial Symbiosis in Caithness, Sutherland and Ross

Based on the foregoing, proposed industrial developments throughout the far north could be established and operate as **eco-industrial parks** achieving cooperation among various industrial manufacturers, municipalities and crofting communities. This cooperation is characterised as "industrial symbiosis", most notably as achieved over more than 50 years at Kalundborg, Denmark:

> "The name industrial symbiosis was inspired by the world of biology where the waste by-product of one organism becomes the raw material for another. This is taken one step further in the new vision for the symbiosis, in becoming the world´s leading industrial symbiosis with a circular approach to production."

In the following we posit opportunities to establish various scales of eco-industrialisation:

- Eco-Industrial Park (EIP) – local industrial symbioses interconnecting with a local town

- Regional scale EIP – intra-regional symbiosis interconnecting one or more EIPs and towns
- Interregional scale EIP – Symbiosis interconnecting one or more regional scale EIPS

4.1 Wick

Given the experience of supporting the handling of wind tower assemblies for offshore windfarm establishment, a case could be made to establish and operate gigafactories for the production of:

- **Wind tower assemblies** near the port of Wick, cognisant of the need to lead in the design and manufacture of the next generation in blades.
- **Ammonia battery equipment** for not only the proposed European supergrid but also supergrids in other parts of the world.
- **Export ammonia** would require acceleration of proposed development of Wick Harbour to accommodate large scale storage facilities integrated with capacities for tanker loading. Given the envisaged scale of this operation and its proximity to what could become a rapidly growing town population, an alternative location may be necessary. Could options include creating safe harbours near Girnigoe Castle, 4 m north of Wick, or between Castletown and Dunnet, 5 m east of Thurso.
- **Ammonia for fertilisers** with seaweed and caustic soda to produce high value products for shipping to UK and global markets and/or transportation to intensive community crofting of food production and EIP food manufactures throughout the Highland and Islands.

4.2 Thurso

Given the proximity to the main wave and tidal power development sites, a case could be made to establish and operate gigafactories for the production of:

- **Wave, tide and kite energy machinery and equipment** near the port of port of Thurso - Scrabster, cognisant of the need to develop capacities for additive manufacturing of many machinery parts with powdered alloys produced in the region. A case could be made for not only the powered alloys to be produced in this location but also the 3D printing of rocket parts such as proposed by Orbex at Forres as well as for high quality, precision parts for wave, tide and kite energy machinery and equipment.
- **Graphene cables** given the proximity of Thurso to the likelihood of offshore floating windfarms to the west and east of the Shetland Islands. Graphene cables could be produced to meet worldwide demand, notably the establishment of other supergrids.
- **Seaweeds to Bioplastics** with seaweeds harvested from seaweed farms developed in conjunction with floating wind farms.
- **Electrolysis of seawater producing -** Hydrogen for local manufacturing and households, chlorine to support the production of bioplastics as considered above and caustic soda for fertiliser production also as noted above. Locating such an initiative would probably be subject to the same issues as noted above.

4.3 Nigg

Given a restoration of the NIgg terminal and a flow of separated gas and oil, a case could be made to establish and operate gigafactories for the production of:

- **Natural Gas to Hydrogen and Graphite** with the graphite being processed to produce graphene for transportation to the gigafactory manufacturing zero transmission electrical cables (i.e. Thurso if above proposal implemented). Hydrogen could be used for local industry including the carbon neutral processing of natural gas and manufacturing possibilities at Invergordon noted below.

- **Gasification of Oil** economically viable commercialisation of this opportunity would put the far north on the map as a trailblazer in greening oil manufacturing and myriad spinoff opportunities for industrial development as noted above in *Greening Oil* (page 6).

4.4 Invergordon

Given its history of Aluminium smelting and oil rig manufacture, Invergordon would seem well placed to establish and operate gigafactories for:

- **Manufacturing automated drone carriers and drones for wind farm repair and maintenance** – The massive operation of offshore windfarms envisaged in the foregoing would require efforts to automate the repairs to wind farms to be highly flexible. Not so much in the robot drone carriers but the versatility of the drones to undertake repairs and maintenance of markedly differing types of blades.
- **Automated ships for seaweed harvesting** – Plans to build hydrogen fuel cell ferries for transportation to the Western Isles, the Orkney Islands and the Shetland Islands are a step in the direction of building automated ships for seaweed harvesting in conjunction with the operation of vast arrays of offshore wind farms. The gigafactory in this case would manufacture a wide range of the parts for such advanced ships, possible adjacent to shipbuilding operations.

4.5 Inverness

As the Highlands and Islands major urban centre, Inverness is well placed to establish and operate gigafactories for:

- **Manufacturing of bioplastic packaged food and drink containers** – manufacturing myriad forms of packaging for food and drink produced by crofting communities, farmers and EIPs throughout the Highlands and Islands. Transporters of packaging to many centres of food and drink production could return with package goods to be disseminated from the ----
- **Product Distribution Centre** – Warehousing and distribution of bioplastic packaged food and drink for UK, European and global markets, via road, rail, ship and air.

5. Renewable Ammonia Production, Storage and Export to Eliminate Constraint Payments

Unlike much renewable energy today, this capacity for ammonia storage would ensure a steady flow of energy 27/7 365 days a year. Precluding the need for wind turbines to be switched off when there is a surfeit of electricity or for constraint payments to be made – allowing the subsidy to be redirected for other purposes.

The first task would be to assess the costs and benefits of creating ammonia production and storage pilot plants (near Wick as proposed) that would provide a convincing test of the capacity to reduce constraint payments and determine what would be necessary to scale this operation to eliminate these payments.

This would entail determining the scale of the pilot ammonia production plant and where it should be manufactured for assembling and operation near Wick. Should more than one of the proposed renewable ammonia production technologies noted in the foregoing be tested – renewable energy input to electrolyser Haber Bosch process and/or solid state ammonia synthesis (see pages 5-8 of HIAlba Hydrogen Scotland report) and/or other emerging technologies? This could also advance Scotland to the leading edge of developing and commercialising these technologies and thereby capitalise on opportunities to manufacture enabling machinery for global markets.

At the same time this would entail determining the scale of the pilot ammonia storage tank and where it should be manufactured (in Wick?) for assembling and operation near Wick, or near the port berth for pumping to an ammonia tanker ship. Could this be achieved without the planned expansion of the port? Would residents be prepared to have these operation's near the port? Or would there be a preference for a location elsewhere as noted earlier? How would by-product oxygen from the ammonia production be processed and distributed?

Successfully installing and operating these pilot projects would dictate the decision to scale both projects to the level which would eliminate constraint payments.

Beyond this would be determining whether to test emerging technology for low cost extraction of hydrogen from ammonia. Then further determining the use for this hydrogen would include considering hydrogen fuel celled based generation of electricity for the national grid and/or a local electricity grid for proposed eco-industrial parks and/or for local transportation purposes. Relevant source: Record payments made to Scottish wind farms in March, Energy Voice, April, 2019.

6. Proposal to Pilot Test Ammonia-Hydrogen Technologies and Eco-Industrialisation near Portree

This is a proposal to use existing onshore wind power to test:

(1) A small-scale renewable ammonia production plant using best available technology (in collaboration with Australian or USA commercialisation entities, although Norway is well up this learning curve as well, while Scotland slumbers as it did in missing the game changing opportunities to manufacture wind tower assemblies).

(2) Integration with a small-scale ammonia to hydrogen plant (working with CSIRO engineers and Australian commercialisation entities).

(3) Build hydrogen fuel cell to electricity plant connected to the grid (plenty of Scotland based commercialisation expertise to draw on, operating, say, in conjunction with The Scottish Hydrogen and Fuel Cell Association).

(4) Optional local electricity grid (many potential collaborators, including on Skye) to power scaling up of the manufacture of existing local product(s) or deliver power to existing residential and commercial users or a hydrogen fuel-cell ferry (from Uig to Lochmaddy) or Portree-based ships to harvest seaweed from seaweed farms in nearby locations, including the Sound of Raasay.

(5) Or to powering a small scale eco-industrial park to manufacture high value food products from seaweeds/hemp/beets/etc sourced from nearby crofting communities. A fuller scale proposal is outlined in the Overview report *Maximising Scotland's Well-Being by Bravely Innovating*, produced by HIAlba-IDEA a virtual think tank based in Portree (see proposed papers: "5.7 Greenprint for a Lead Community on the Isle of Skye" (page 24) and "Paper 5.9 A Business Case for Operating an Implementation Capacity on the Isle of Skye", (pages 26-26).

7. Game Changing Potential of Renewable Ammonia Battery Solution

Beyond successfully installing and operating the ammonia production and storage pilot projects would be determining whether to test a pilot plant for low cost extraction of hydrogen from ammonia. Further determining the use for this hydrogen would include considering: fuel celled based generation of electricity for the national grid and/or a local electricity grid for eco-industrial parks and/or for local transportation purposes.

As noted above, the production and storage of ammonia and hydrogen extraction for electricity production could be at various massive scales including: fossil fuel free electricity to accelerate simultaneously the transition to a carbon free energy future for Scotland and the UK and then by means of a supergrid for Europe.

Assessing the feasibility of such scaling would involve, among other things, comprehensive economic, social and environmental analyses and extensive consultations with all manner of communities of interest in active collaboration with multinational energy companies (e.g. through the Oil and Gas Climate Initiative) would be required to produce a wide ranging portfolio of financial viable/bankable project proposals.

These assessments could be supported by the findings of a proposal by HIAlba to produce a ***National Hydrogen Roadmap for Scotland***, drawing on the experiences of Australia and Norway – see section "5.3 Investment in Demonstrations of Hydrogen Scotland Technologies" of the HIAlba Overview report (pages 19-20) and the HIAlba preliminary report Hydrogen Scotland: A Route to Export Powerhouse.

8. Decarbonising: from Pressure to Action

The HIAlba Overview report (pages 8-12) considers three great forces of contemporary change: Decarbonisation as a force for not only revolutionising the energy system but also a force for Decentralisation, bringing with it ever diminishing rent seeking development and increasing autonomy in local and regional forms of governance. The third force considered, Digitalisation, could reinforce such outcomes. And in so doing galvanise a strong flow of opportunities for greatly enhanced export endeavour, entrepreneurship, and productive employment with commensurate remuneration throughout Scotland.

In decarbonising, the European membership body for investor collaboration on climate change, the Institutional Investors Group on Climate Change (IIGCC), representing over 170 investor members with €23 trillion in assets taking action for a low carbon future, recently led the cheerleaders in Norway's $1 trillion sovereign wealth fund decision to divest its holdings in coal mining companies and oil & gas exploration companies.

This coincided with Pope Francis meeting the leaders of the world's largest multinational oil companies in the Vatican to impress upon them the scale of the global "climate emergency" and warn that a failure to act urgently would be "a brutal act of injustice toward the poor and future generations". In response, the companies (paragraph 5) stressed the need for carbon pricing by governments to accelerate low-carbon innovation and to inform investors by delivering greater financial transparency. It seems all manner of communities of interest are ahead of most governments, presumably beholden in many cases to vested interests. Hedged vested interests such as explicated by Bob Dudley, Chief Executive, BP:

> "Constructive dialogues such as this meeting are essential in aligning key players on the steps needed to accelerate the energy transition ***while still enabling*** advances in human prosperity."

Would unhedged all-in action require changing "while still enabling" to "to enable sustainable"? And overt vested interests such as reported by London-based data analysts InfluenceMap:

> "Extrapolated over the entire fossil fuel and other industrial sectors beyond, it is not hard to consider that this obstructive climate policy lobbying spending may be in the order of $500m annually."

Imagine the rate of change of all-in action with:

- no such hedging or obstructionism;
- industry agreement on carbon taxation based on full cost pricing and designed to maximise opportunities for trading carbon credits;
- zero subsidies for the fossil fuel industries especially on stoking the hopes of carbon capture and storage;
- economic assessment of industrial development that explicitly accounts for benefits as avoided damage to human and environmental health.

9. Conclusion

We believe that recent advances in generating renewable ammonia and low-cost hydrogen from ammonia mean that perhaps for the first time since the industrial revolution Sir Alec Cairncross's "fascinating to speculate" quote, stated at the top of this paper, can be tested. In this regards this paper focuses on the possibility of the far north of Scotland becoming

- the renewable energy hub for Europe
- a leader in eco-industrialisation based on renewable electric power

Although in this paper we propose testing the Cairncross speculation in the North of Scotland our ideas potentially have implications for the wider Scottish economy. At the heart of our proposal is the technological advances made at CSIRO which have greatly reduced the cost of extracting hydrogen from ammonia. This technological breakthrough we believe resolves one of the greatest shortcomings of Scotland's renewable energy sector, the inability to store surplus electricity when neither the wind blows nor the sun shines, as excess electricity can be stored as ammonia.

Unlike much renewable energy today, this proposed capacity for storage would ensure a steady flow of energy 24/7 365 days a year, precluding the need for wind turbines to be switched off when there is a surfeit of electricity or for constraint payments to be made – allowing the subsidy to be redirected for other purposes. We envisage floating offshore wind farms, as opposed to onshore wind farms, as the main driver for ammonia production, utilising a little of the huge expanse of water around Scotland to create renewable energy. This could make it possible for Scotland to become the backbone of a renewable electricity super grid, powering Europe.

The benefits to be had from harnessing renewably produced ammonia and extracting hydrogen from it are numerous as we have demonstrated here. First and foremost, the opportunity exists to establish a new export industry for Scotland, adding an important facet to the country's existing energy sector. Given that hydrogen is fast being recognised as the fuel of the future, as it is carbon-free and non-toxic, it is in increasing demand to power vehicles. Space rockets, planes, ships, cars, buses, vans and other vehicles, all have the capacity to be fuelled by hydrogen - a market in which the North of Scotland, and Scotland more generally, could play a crucial role.

Many additional benefits would be forthcoming from this export industry, from bolstering the economy to creating jobs, regenerating regional economies where traditional industries have faltered and reinvigorating traditional industries like shipbuilding by harnessing the clean fuel. Whilst urban areas could be freed of heavy polluting vehicles, the bane of policymakers in recent years. In fact, adopting carbon-free energy in vehicles would negate the necessity for eco restrictions in city centres altogether.

In sum, all of this could have the effect of creating an immensely productive sub-economy, rejuvenating industry, improving our infrastructure, housing, transport and farming, creating ecologically friendly industrial parks and assisting with regional development.

The Orkney Surf'n'Turf project to produce hydrogen from tidal power is a leading-edge development which illustrates how renewable energy projects can benefit local communities, as well as creating enormous export opportunities, and underscores the potential import and impact of our proposals.

However, swift action needs to be taken if Scotland is to become an early adopter of renewable hydrogen and reap the benefits of these opportunities: businesses and policymakers need to act now. Specifically, Scotland needs to be a the first mover in Europe in developing and adopting technologies associated with renewable hydrogen if it is to take advantage of all of the potential benefits that could be delivered by implementing the foregoing proposals.