NOCS response to the Innovation, Universities and Skills Committee inquiry into engineering.
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The National Oceanography Centre, Southampton, (hereafter NOCS) welcomes the opportunity to respond to this inquiry. As one of the world's top 5 centres for marine science NOCS depends upon engineering to provide access to the ocean interior for a variety of sensors, using platforms developed in-house, or through national/international collaborative programmes, or purchased from the commercial sector. We also require skilled engineers as members of our shore-based and sea-going staff.

- **how we use engineering, including which programmes it plays a major role in;**

The NOCS science mission would be impossible without the products of engineering, and the expert knowledge of engineers, both in-house and as contractors. Every science programme we carry out relies upon the ability to make measurements, gather samples, or obtain images from above, within and underneath the bedrock of the global ocean, which averages over 3000 metres depth. Every 10 metres gives an atmosphere of pressure, so at 3000 metres all of our equipment has to be able to withstand 300 atmospheres of pressure and still function perfectly. At 6000 metres it's 600 atmospheres – and we routinely operate complex systems at that depth.

In order to obtain remote-sensed data of the ocean we rely upon orbiting satellites, global wireless datalinks, submarine optical cables and other highly sophisticated systems that are products of engineering. Without engineering, we would know no more about the oceans than the ancients Greeks and Romans.

- **how we develop technology for our own use (and commercialise it);**

For many years NOCS and our predecessor organisations have developed technology in-house. In the past this was because there was no commercial or military requirement for equipment that could function at full ocean depth. For example, even today military submarines only operate in the top 1000 metres of the ocean, usually the top 300 metres. Civilian research submersibles are rated to 4500 (Alvin, USA) to 6000 (Mir, Russia) metres. With the development of ever-deeper offshore oil and gas exploration and production, it is now possible to buy commercial off-the-shelf (COTS) equipment rated to depths in excess of 2500 metres, but 6000 metre ratings (the typical level we aim to achieve) are still quite rare outside of the marine science community.
Until the 1970s virtually all oceanographic scientific equipment was developed and designed in-house. Since then a large number of relatively small manufacturers – often ex-employees of research institutes – have started up in Europe, USA, Australia, Canada and Russia. Many of these manufacturers employ less than ten people and it is common for only one or two products to be produced by the company. In many cases companies in the USA have been able to count of US Navy contracts to provide R&D money and sufficient baseline orders to ensure many years of trading stability, in Europe military funding is less significant and the main customers are civilian oceanographic research centres, the offshore oil and gas exploration and production sector, and agencies concerned with monitoring the marine or freshwater environment. Companies tend to expand their product range through acquisition of other specialist companies.

Examples of how we develop technology and commercialise it:

1. Standard seawater is required to calibrate salinity measurement in every instrument used in the world. The former Institute of Oceanographic Sciences Deacon Laboratory (which became part of NOCS in 1995) developed a methodology and production system, and in 1989 this was privatised as Ocean Scientific International Ltd (http://www.osil.co.uk). Since then, OSIL have been the only recognised provider of IAPSO Standard Seawater and provide salinity calibration standards worldwide.

2. If a ship can measure the physical and chemical characteristics of the ocean whilst underway it greatly expands the amount of useful data that can be gathered. The towed instrument SeaSoar was developed to be deployed on a cable behind the ship. SeaSoar undulates over the top 500 metres of the ocean gathering data. SeaSoar was licensed to Chelsea Instruments Ltd http://www.chelsea.co.uk/Vehicles%20SeaSoar.htm and has sold to research organisations and navies throughout the world.

3. The Autosub autonomous vehicle was developed to provide a platform that could carry sensors into places difficult to access by ship, such as underneath polar ice, or to extend the coverage of a ship by being deployed to undertake routine measurements whilst the mother ship performed complex tasks such as coring or ROV operations. Autosub 1 technology was licensed to offshore survey company Subsea 7 who intend to use the vehicle for mapping pipeline routes and charting the seafloor (http://www.subsea7.com/rov_geosub.php). The investment possible through licensing has enabled NOCS to move on to the latest Autosub 6000 specification, which permits operation to 6000 metres and uses an innovative rechargeable battery system.

4. Today the commercial sector has more experience and market requirements to develop their own systems, it is possible to work with industry to adapt commercial designs to our needs, however we still develop innovative new technologies and some will be commercialised in future. For example we are active in solid-state sensor development and in further evolving autonomous underwater vehicle design, so that future Autosub derivatives will be able to hover in one place to take samples, and be equipped with high levels of on-board intelligence. See http://www.noc.soton.ac.uk/nmf/usl_index.php for information about our world-class underwater systems laboratory.

- **how we work with engineers, e.g. on such projects as satellites, autonomous vehicles, algal bioreactors, CCS and the environmental impact of new technologies (e.g. artificial reefs on off-shore wind-turbines)**

Scientists are members of the programme steering committees for major projects such as satellites, autonomous vehicles and advanced computer systems. For example NOCS scientists were part of the Huygens programme that successfully landed a probe on Saturn's moon Titan. The Huygens engineers needed to know what characteristics the surface of Titan might have so that the lander could be designed to withstand the conditions. There was a possibility that Titan might have had a methane ocean, hence the involvement of oceanographers who could advise on what the properties (e.g. wave conditions on a frigid moon) might be.
Nearer to Earth, it is normal for oceanographers to be involved in the design of instrumentation for earth-observing satellites. It should be noted that in the satellite remote sensing community a number of scientists hold engineering rather than physics backgrounds, and they have migrated discipline from instrument development towards operational use of the instrument.
NOCS scientists and engineers worked closely together to develop the Autosub series of vehicles. Initially Autosub was driven by a science requirement (i.e. sensor platform for difficult-to-access areas), and by the desire of the engineers to be able to fulfil that requirement. The drive and vision of senior NERC staff at the time such as Professor John Woods was critical in driving a potentially risky programme to completion. NERC also needed to face the risk issues inherent in deploying expensive platforms in circumstances where there was a high probability of loss, such as under Antarctic ice sheets.
Lessons learned from Autosub have been very helpful in other areas of operation, such as risk management in the Rapid Climate Change moorings array across the North Atlantic.

- **geoengineering, e.g. any comments you've sent to Andy Chalmers at Defra**

Geoengineering is of great interest to the oceanographic community, particularly as a means to capture and store anthropogenic carbon dioxide. Whilst the community supports geological storage in saline aquifers and depleted oil and gas reservoirs, there is near universal concern that iron fertilisation of the upper ocean is NOT a safe, proven method of enhancing carbon uptake. I've copied Prof John Shepherd FRS detailed comments to Andy Chalmers below, and also Tyndall Centre paper attached as relevant.

Hi Andy

Thanks for the opportunity to comment on this: I think it's a very useful and much needed initiative (since we, i.e. the Tyndall Centre, have in the past failed to get anyone in government to take any real interest in this: see below).

1) I hate the way you've done the references, please put them all (including url's) at the end in the usual way so that one can check at a glance what sources you have consulted.

2) You may not be aware that the Tyndall Centre co-hosted a meeting on this in Cambridge in January 2004. The summary report of this seems to have disappeared from the Tyndall web-site, so a copy is attached herewith. The Tyndall Centre is indeed considering convening a further workshop on Earth System Engineering later this year, and the Royal Society is considering initiating a study on geo-engineering (Beverley Durkin may be able to provide more information on this).

3) one person missing from your contact list is Brian Launder <brian.launder@manchester.ac.uk> who was one of our conveners for the above meeting, who made a presentation on it to David King's High Level Energy Working Group in 2004, from which we got essentially a null response. He has since been involved at the RAEng on the subject, and who is currently co-editing a special edition of Phil Trans Roy Soc A on geo-engineering

4) There is are several schemes you have not mentioned, i.e.

a) neutralisation of sequestered CO2 using carbonate rocks (a less complex but slower version of the House et al accelerated weathering scheme) see Rau, G.; Caldeira, K. Enhanced Carbonate Dissolution: a means of sequestering waste CO2 as ocean bicarbonate. Energy Convers. Manage. ***1999****, 40, 1803-1813.*

b) sequestration of biogenic charcoal in soils (which is different from conventional CCS insofar as it involves enhancing a natural sink (see P Read, Biosphere carbon stock management: addressing the threat of abrupt climate change ,in the next few decades: an editorial essay, Climatic Change, DOI 10.1007/s10584-007-9356-y)

c) Deep sea disposal of agricultural crop waste (Benfield, submitted: see also Metzger, R.A., G. Benford, and M.I. Hoffert, To bury or to burn: Optimum use of crop residues to reduce atmospheric CO2. Climatic Change, 2002. ***54****(3): p. 369-374.)*

[NB I actually think that (b) and (c) are non-starters, but perhaps they should be mentioned]

5) You do not specifically mention (except as a footnote to the summary table, and in relation to the mirrors) one serious deficiency of ***all*** *of the albedo management schemes, namely that they do nothing to reduce ocean acidification (which would probably become the dominant problem). Page 7 is probably the best place to say this.*

6) ***Overall, I think that your note has an unjustified and undesirable negative flavour. There are major uncertainties w.r.t. all of these schemes, but if there is any reasonable prospect of doing something useful at reasonable cost without serious environmental side-effects, they need to be kept in play, not dismissed (even if only with faint praise)***

7) e.g., on Page 4: the comment by the IPCC that you quote is fair and correct, but is an argument for further research on any schemes which may be promising (as you actually suggest on page 5), not for doing nothing.

8) a) Similarly the summary table on page 6 needs (in my view) quite a lot of work: e.g. entries like "unknown effects" are not very helpful. If you want to send me Word version I'd be happy to have a go at editing it for you...

b) Also, the short residence times of some of the schemes means that on the one hand they require continual replenishment (etc) but on the other hand they are reversible (if you stop replenishing them they go away). This is generally regarded as an advantage (don't do anything irreversible, in case it goes wrong)

9) page 8: the space sunshade devices are generally supposed to be emplaced at the L1 Lagrange point, which is a saddle point (not a minimum) of the gravitational field, so they would need active control & management to prevent them from drifting off sideways

10) page 8: re stratospheric aerosols (and more generally) I think that the listing of unquantified risks without parallel discussion of advantages (e.g. in this case, no direct interference with biological systems, relatively low cost (especially for SO2) etc) is unbalanced.

11) In relation to this and other shemes, a finite and fairly short residence/life time is generally to be regarded as an advantage, since it means that a scheme is not irreversible if it has unexpected side-effects.

12) page 9: I am not a fan of stratospheric aerosols but 1 million tonnes per year of SO2 is tiny (order of 1%) compared with existing emissions from coal and oil burning , and the additional ocean acidification effect would be minimal c.f. that of CO2. It could easily and cheaply be delivered by addition to aviation fuel.

13) The spatially variable cooling effect was not found in Ken Caldeira's modelling study (rather a surprise, actually)

14) page 11: the cooling would certainly be maximal in the vicinity of the clouds, but if it affects the lobal energy balance their must be a global cooling too. It is true that there would also be an opposing nocturnal warming effect (as for all clouds) but the type of clouds involved are carefully selected to maximise the overall cooling effect.

15) The negative aspects of this proposal are much overstated. There is much doubt over use of CCN to enhance rainfall, but much less about sea-salt being effective CCN for increasing cloud optical thickness (which is all that is required). The key feasibility issue is whether the aerosol can be generated in the quantities required at a sensible cost. The potential side-effects are tiny compared with most other schemes.

16) page 17: ocean fertilisation by ocean pipes or otherwise ***will*** *have very low efficiency (not may) because we know that almost all organic carbon is remineralised in near surface waters (it's food for grazers and scavengers, and they will proliferate to use any additional resource). Andrew Yool and I have just completed a modelling study using an ocean GCM which confirms (no surprise) that only about 2% of the extra carbon makes it into the deep ocean.*

*17) The ecological side effects of ocean fertilistaion on any useful scale (say one Sokolow wedge, such as might be produced by doubling global ocean primary production) are at present unforeseeable but likely to be massive, so that to say "*The impact of this process on marine life would also need to be taken into account.*" is a good entry for the* ***understatement of the year*** *competition.*

18) I therefore think that it is wholly inappropriate to call this scheme "promising" and advocate further research on this (and not some of the other schemes), especially compared to your generally negative treatment of some of the other schemes.

19) Page 18: re "artificial trees": I know Klaus Lackner and some of his team quite well, and I regard this as one of the more promising schemes (when I first heard about it I thought it was nuts, but I checked his calculations and it isn't). They have actually made enormous progress in the past few years, but they have now formed a company to develop the technology and do not publicise the details. The problems of disposal are no greater than for any other sequestration scheme. This is definitely one to watch. Note that the much publicised "tree" structures are an inessential part of the process, as absorption by ponds (see below) would work just as well (needing about 0.1 % of land area in total)

20) Page 19: I think your comments re marine algae are also unnecessarily negative. As long as it is done in ponds (not the open ocean !!!) this could also be attractive. One can culture algae at many (order 100) times natural nutrient concentrations, and at the resulting densities the ponds would only need to be ca 1 meter deep. It would make sense to produce biofuels so that one can recover and recycle most of the nutrients. The main problems may be harvesting the algae and drying the product before processing (so it needs to be done in a hot, dry, sunny coastal location). It should then be possible to make the gas transfer of CO2 to the open water surface the limiting factor. An area of ca 0.1% of all land surface area would then be needed to remove/process ca 1 GtC/yr (as for Lackner's scheme above). Definitely worth pursuing actively.

21) Breakdown of heavy oils. This is new to me. It sounds as though they have a scheme to process tar sands (or something similar) and ***unless thay have a way to sequester the CO2 produced, this would be a very Bad Thing...***

22) page 20: your comments on the electrochemical weathering are also unnecessarily negative (see my recent Journal Club piece in Nature). What is the basis for asserting that "in reality the energy inputs and bulk materials required will almost certainly have the net effect of increasing, not decreasing, atmospheric CO2." ??? That's not at all obvious to me. You also comment that "It would seem preferable for the geothermal energy to be used directly as an alternative to carbon-based fuels." which is only true if the geothermal energy is (a) available in the right place (while the sequestration can be done anywhere suitable) and (b) a fully exploited resource (if there is more than can be used directly it may as well be used for sequestration). I also don't think that "unknown potential reations" is a fair comment. The chemistry is quite straightforward, and while returning slightly alkalinified water to the sea would need to be done carefully, it's not a very seriously worrying process. I can easily imagine this being done with little difficulty at Iceland or other mid-ocean volcanic islands.

23) I agree with the general comments on page 21 and the top of page 22, but the suggestion that "political restrictions may be less critical for ocean fertilisation..." is ***definitely incorrect*** *(I for one would argue that this scheme probably has the highest potential for damaging environmental side-effects of all those considered)*

24) Page 22, lines 12/13 et seq: it is true that the cost of dealing with each 1GtC/yr is going to be substantial, but carbon prices of several $100 per tC are not unthinkable, so this is the appropriate yardstick. These schemes could and should be considered as complementary rather than competing with ways of "carbon-free energy generation" (do you know of any cheap & easy ways of doing that ? If so, what are they ???)

25) Page 23: I think that it is ***probably too soon to produce a ranking of these options****, but if you are going to do it I think that marine algae should be on it (probably at about No 3) and that ocean fertilisation and ocean pipes should be well down the list (after stratospheric aerosols).*

I hope these comments are helpful, and look forward to seeing a revised version. If you wish to take this analysis further (perhaps as a longer term exercise), the Tyndall Centre would be happy to discuss ways and means of doing so with you

John Shepherd

- **our in-house engineering capability, how we support relevant training, and any comments on skills needs;**

National Marine Facilities Sea Systems (http://www.noc.soton.ac.uk/nmf/sea_sys_index.php) has a well equipped engineering capability including:

Machine Shop, consisting of 4 centre lathes, 3 vertical turret milling machines, CNC machining centre, CNC Lathe, Surface grinder, Bandsaw, Horizontal Bandsaw plus assortment of smaller machines,drills, grinders, etc.

Inspection Room, Air conditioned inspection facility.

Clean Room, workshop for assembly of fibre optics, etc.

VMC600 Machining Centre, made by Hardinge (600 signifies its table travel). It is a 3 axis machine with additional 4th axis, and has a Siemens 'Sinumerik' control system with Shopmill, which simplifies programming.
A spindle speed of 8,000 rpm with automatic tool change from a 20 tool change carousel.

Combi K2 Lathe, made by Colchester. This is a full CNC lathe that has advanced electronic and manual operation. It has an 8 station indexing turret with a 400mm swing over the bed with a 1.3 Metre nominal length between centres. It is controlled by Fanuc cnc control.

There is also the additional bonus of a manually operated vertical milling machine.

Technical staff are recruited with appropriate qualifications but are trained in-house or through external agencies to achieve proficiency in the use of our workshop facilities. Sea-going staff are further trained to ensure safety and competence carrying out engineering duties on board moving platforms (ships) remote from full scale workshop facilities. Our graduate staff come from engineering courses from UK and overseas universities. We train and support PhD and EngD students, and encourage their integration with the science teams at NOCS to ensure a culture of providing engineering solutions to scientific requirements rather than to develop an instrument or platform and then see if any scientists want to use it.

- any relevant funding information;

Our ocean engineering work is supported through NERC as part of National Capability funding, and also through the Oceans 2025 programme. National Marine Facilities exists to serve the needs of the whole UK Marine Science Community, not just Southampton-based researchers.

- case studies (I will look through the KE brochure and UNS but please flag significant things or anything new)

Provided above (Autosub etc.) but can expand if required.

- the roles of industry, universities, professional bodies, Government, unions and others in promoting engineering skills and the formation and development of careers in engineering.

The Professional Bodies (e.g. Institute of Marine Engineering, Science and Technology IMarEST www.imarest.org) and Learned Societies (e.g. Society for Underwater Technology www.sut.org) have important roles in advocacy and promotion of engineering. They also provide accreditation of skills, platforms for shared knowledge and continued professional development which is essential in this field. For staff (including myself!) who did not enter marine science through the academic route but through industry, professional status (e.g. chartered marine engineer; chartered marine scientist) afforded through IMarEST and other professional bodies ensures recognition of competence for those who do not hold a PhD and enables free cross-sector transferability of employment.

There is certainly a shortage of engineering staff in the marine and offshore sector, and there are problems retaining newly trained PhD staff in the sector because their skills are greatly valued by other sectors such as banking and insurance who pay far higher starting salaries. Although industry continually complain about shortage of engineers, very few companies pay sponsorship to students or even contribute to the scholarship and bursary funds operated by Learned and Professional societies.

Sea Vision UK perform a useful role in encouraging young people to consider careers at sea, but the message is targeted at deck crew rather than engineers.

Engineering in the UK still lacks the esteem with which the profession is held in other countries such as Germany, in part because of the way in which our language uses 'engineer' to denote the person who fits your satellite dish or unblocks the drain. Engineering is perceived as a difficult subject which requires better mathematical ability than our education system is able to routinely instil in students, Role models in engineering are not adequately promoted in the UK – the public see lots of TV chefs, sporting heroes and singers but few engineers or scientists. In comparison the generation I work with grew up with engineering and science role models such as Jacques Cousteau, the early years of the North Sea oil industry, the Apollo moon landing programme, and even our fiction programmes were engineering orientated – e.g. the vehicles designed to rescue people in *Thunderbirds*. I've met nuclear reactor engineers who cite Mr Scott of the *USS Enterprise* as their inspiration.

Today there are very few engineers or scientists in parliament – and current NERC rules prevent us from standing for election to parliament unless we resign. (This is a problem for the public sector as a whole having representation in Parliament, but in deep-ocean oceanography most staff are public sector employees.)

Globally there is a good supply of engineering graduates, with China and India forging well ahead of Europe. If the UK is serious about retaining a home capability in the most advanced areas of technology, such as advanced materials, efficient systems, aerospace, nuclear fusion, nanotechnology and robotics we must encourage and invest in engineering.

Steve Hall February 27 2008