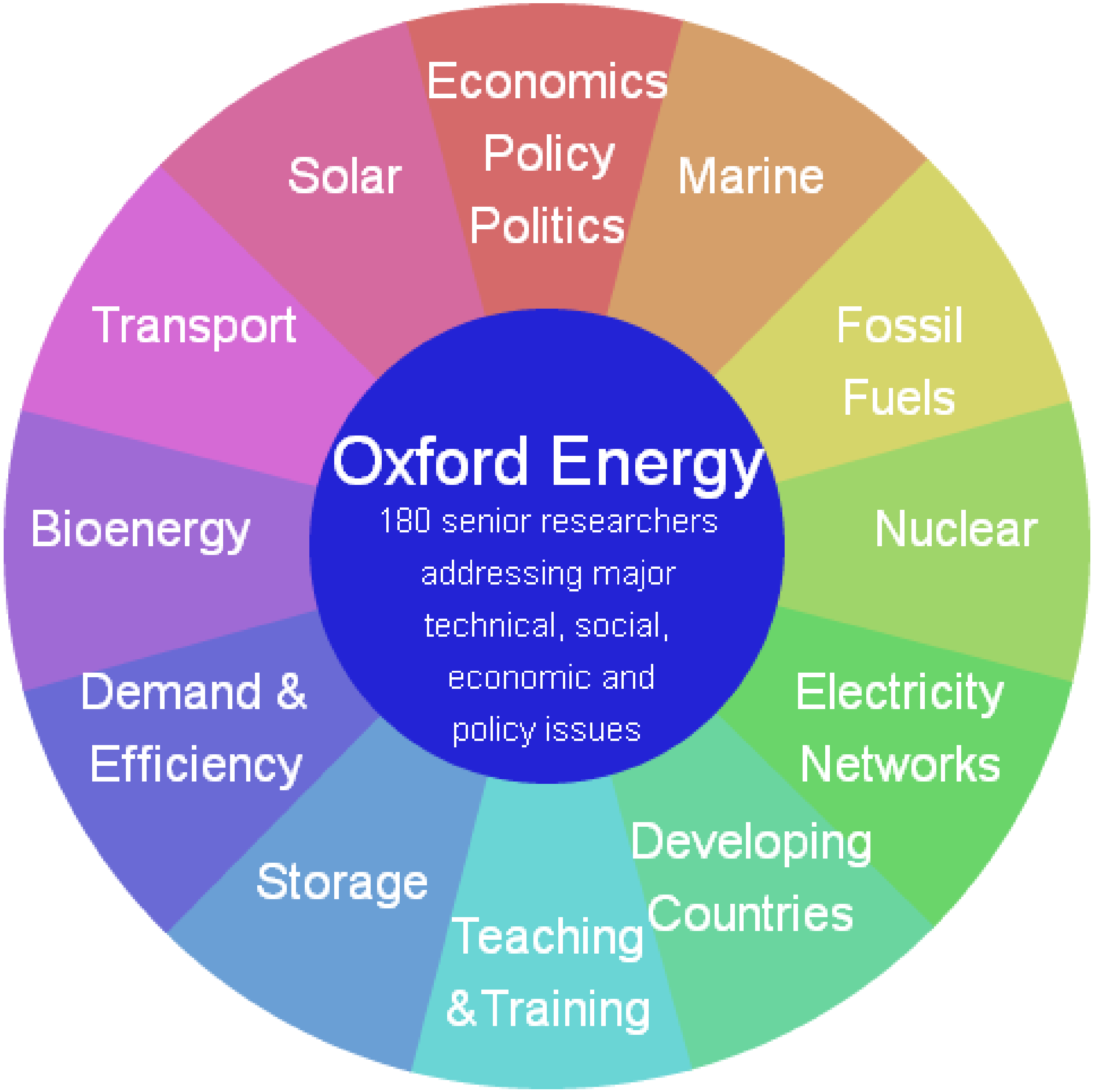

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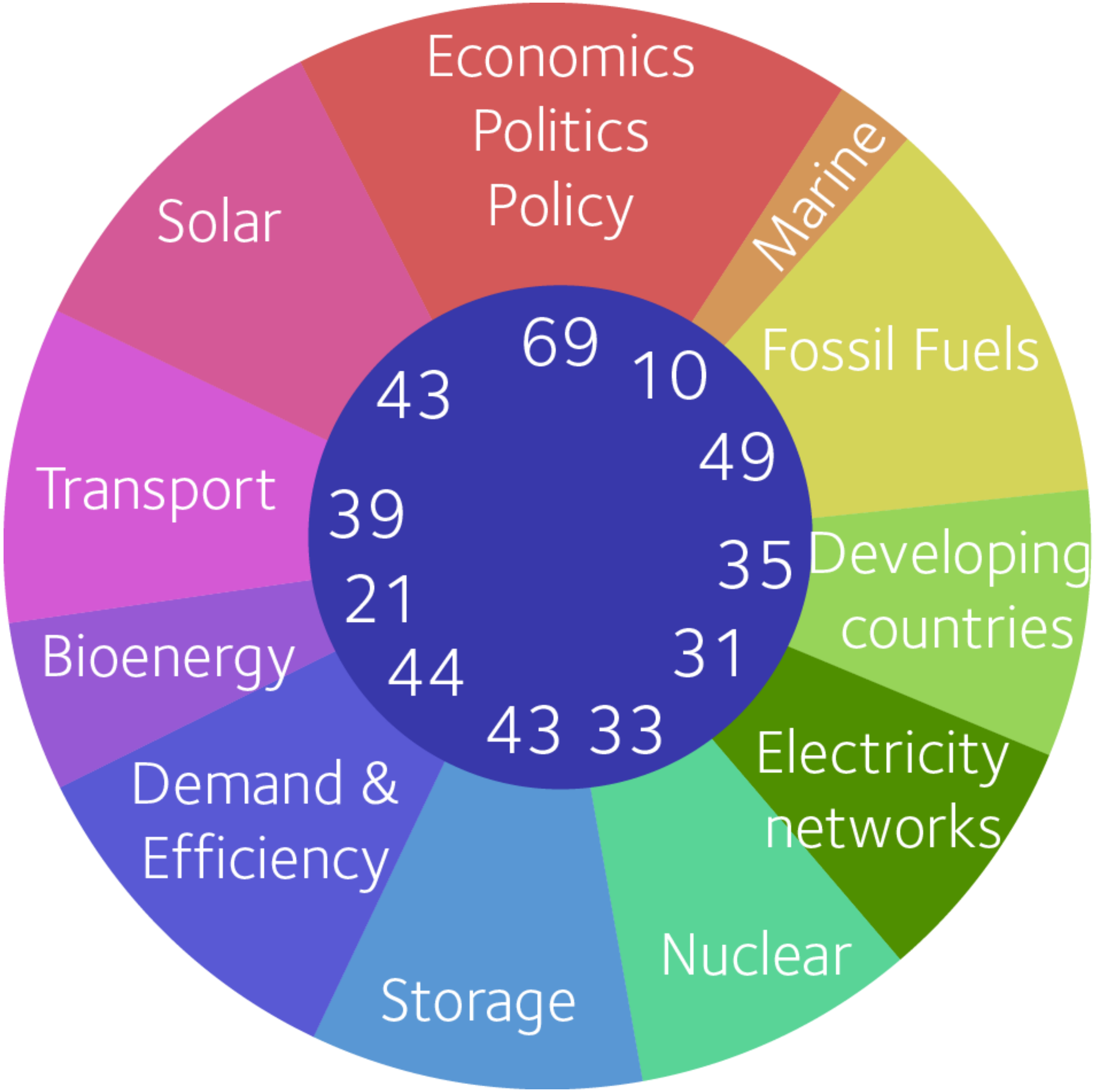
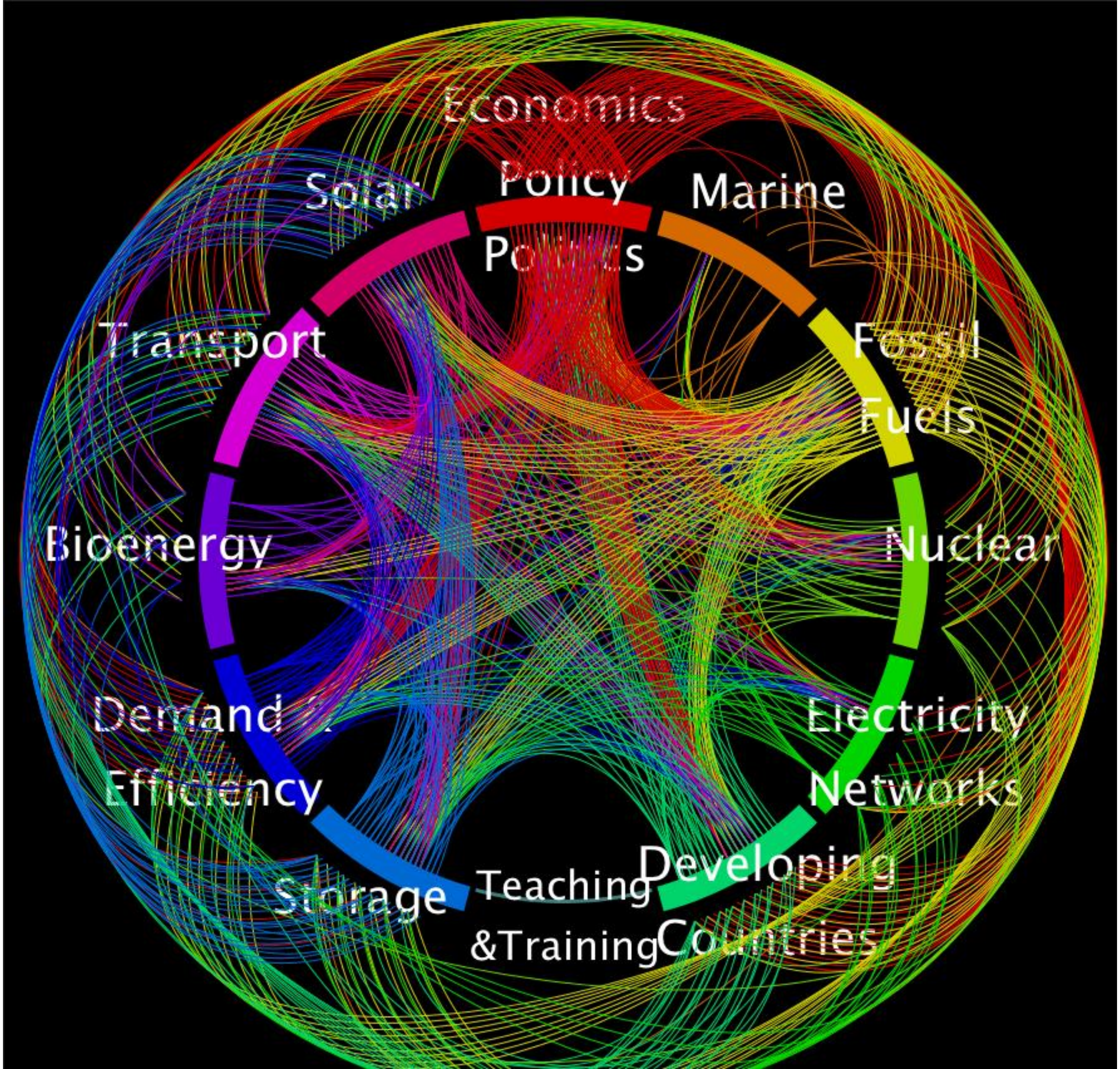


Many people appear more than once:


Economics
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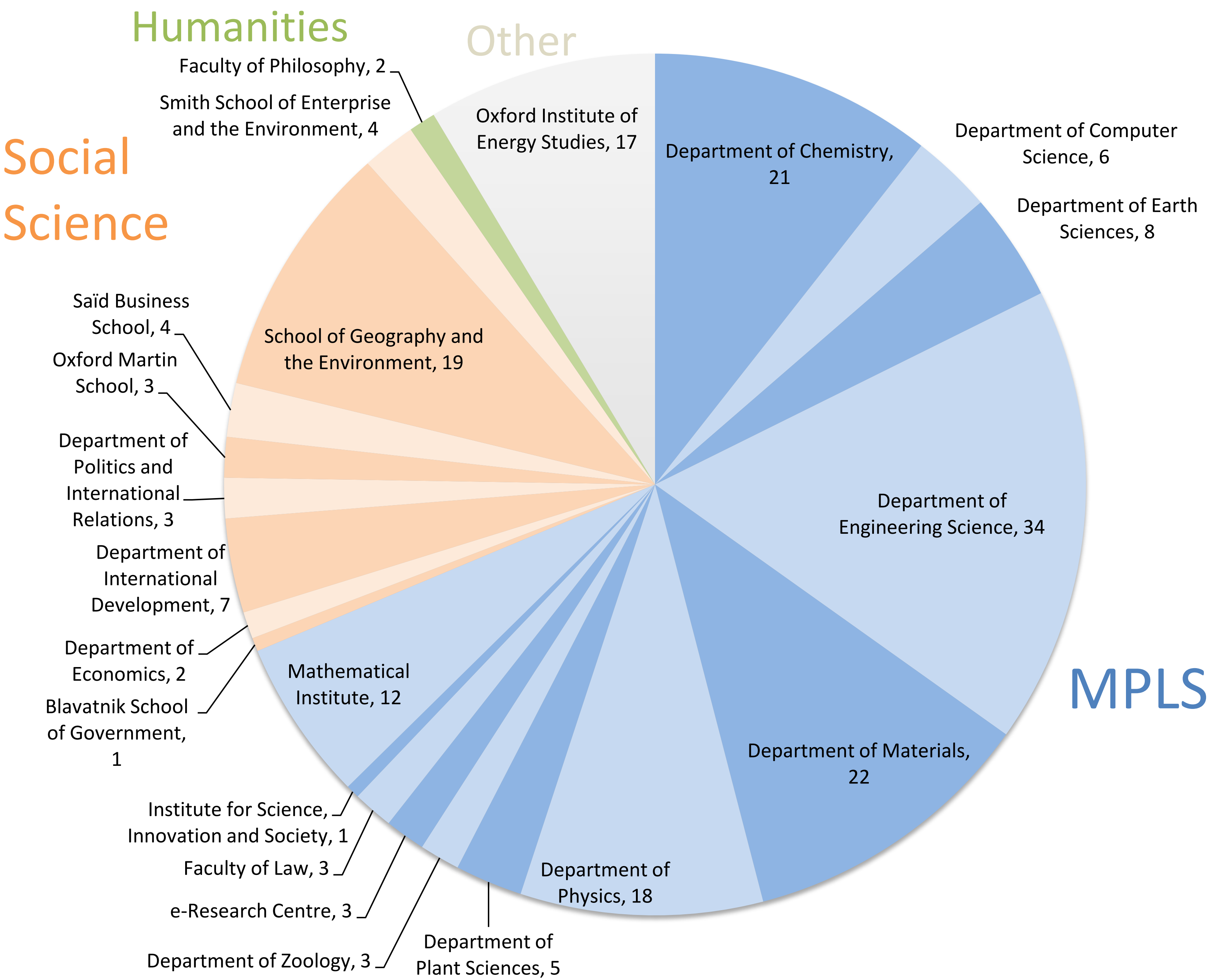
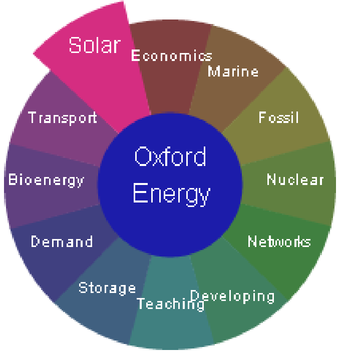
Storage
Demand &
Efficiency
Bioenergy
Transport
Solar

Oxford Energy Network by Divisions and Departments

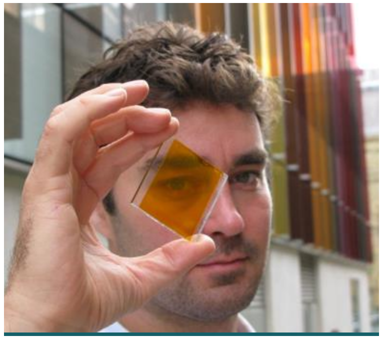




Solar

- **Crystalline Silicon** – production of thin sheets; control of impurities
- **Organic** – experiment and theory
- **Chalcogenides**
  - **Metal oxide transparent conductors and nanostructures**
  - **Quantum Dots**
  - **Thermophotovoltaics**
  - **Organic Hybrids**
- **Perovskites** - *see next slide*
- **Artificial photosynthesis**
- **Concentrated Solar Power** - for solar cooker; return later

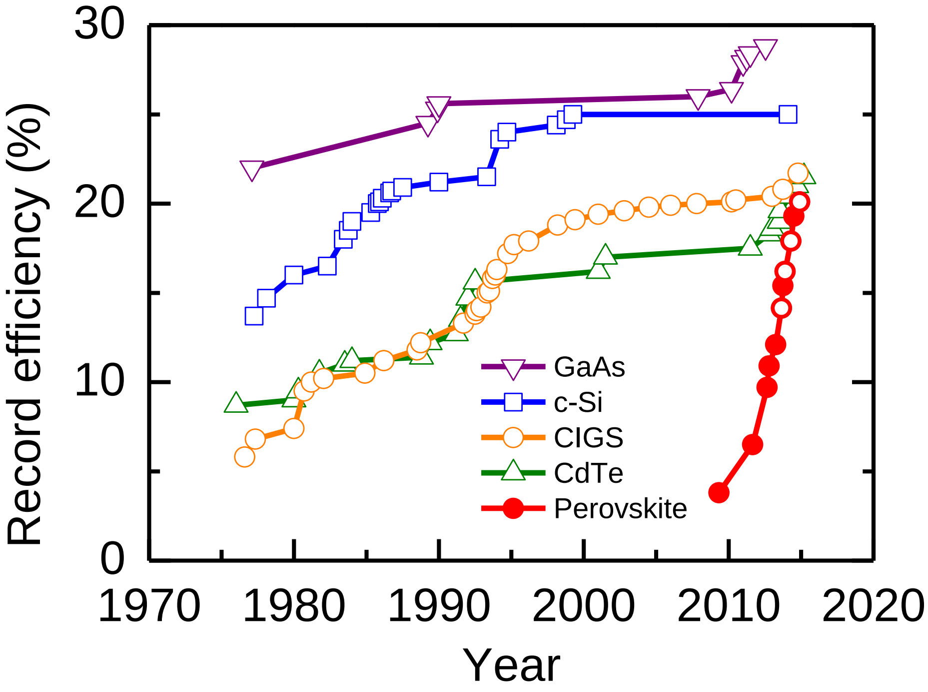
Solar Cells Incorporating Perovskites



Pioneered by Henry Snaith - one of '10 people who matter' according to Nature, Dec. 2013

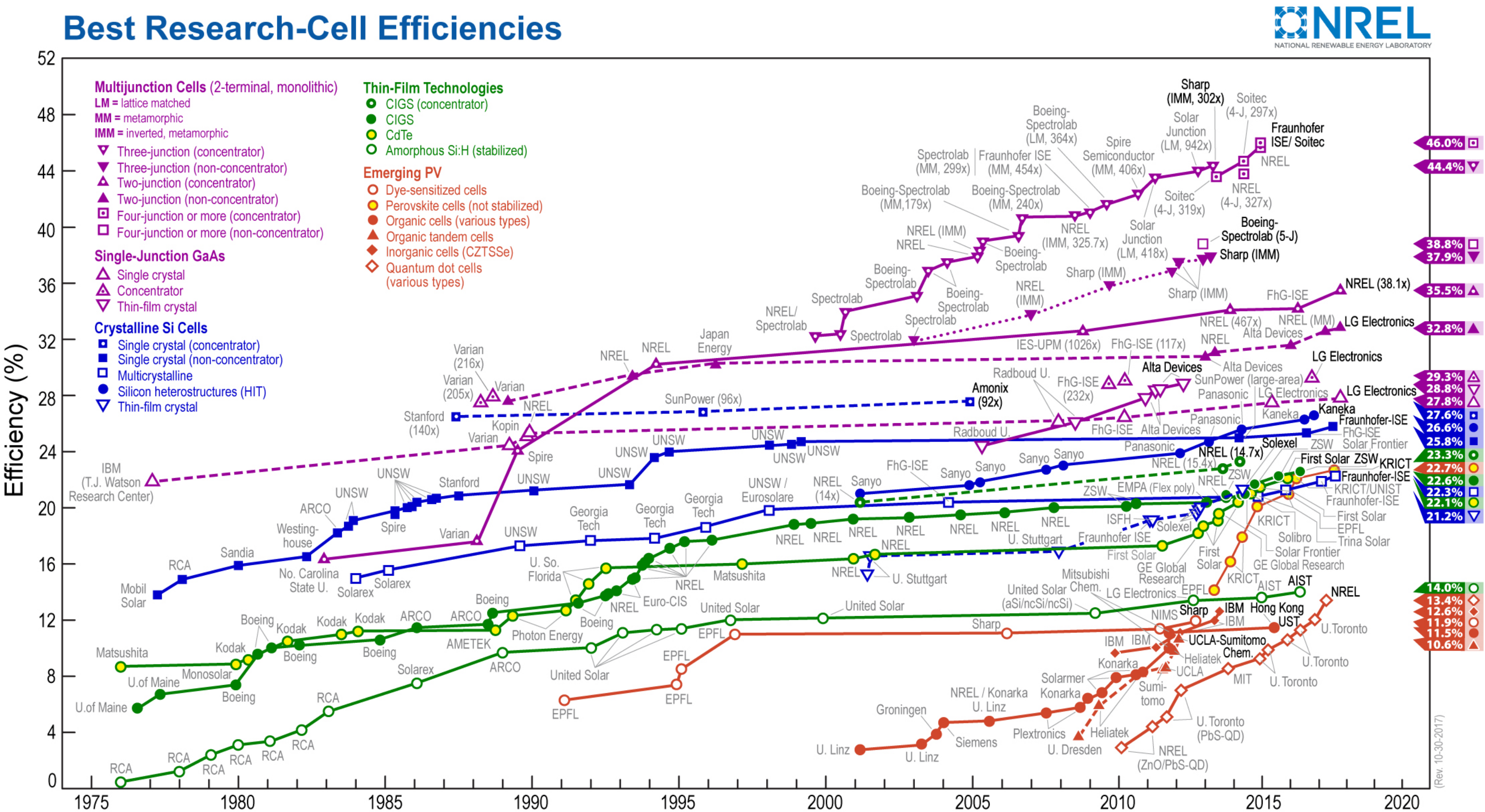
Meteoric rise in efficiency:

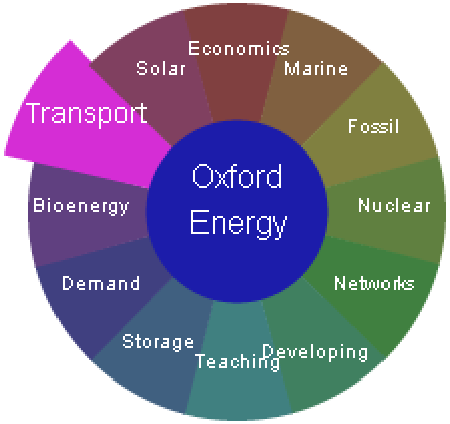
Initial focus on low cost of perovskites as a cheap alternative to Si, but Si got much cheaper. Now focusing on tandem cells "By combining these perovskite cells with a 19%-efficient silicon cell, we demonstrated the feasibility of achieving > 25%-efficient four-terminal tandem cells" (later → all perovskite thin film technology?)



Passed 1,000 hour accelerated aging test, but would like 3-5000 hours

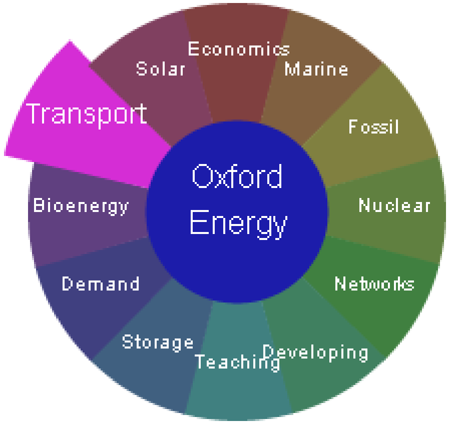
Best Research-Cell Efficiencies





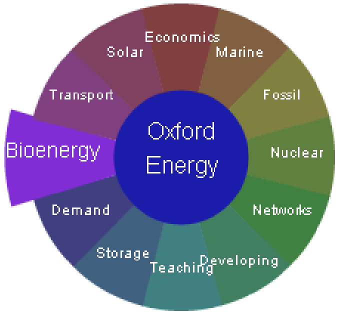
Transport 1

- **Internal combustion engines**
  - improved burn (with JLR); controls (in support of F1)
  - Optimising efficiency of different powertrains and driving styles (EPG), use simulation tool + data → future drivetrain topologies, impact of different fuels, efficient driving styles and relationship between technology performance, consumer choices and policy
- **More efficient aero-engines** (with RR)
- **Electric vehicles**
  - User responses to new on-street charging technologies (Go Ultra Low Oxford) developing a novel qualitative approach combining data from charging installations and interviews with participants and stakeholders
  - Better materials, electric motors, battery management
  - Minimising the effect of EV charging on the grid, *discussed under networks*



Transport 2

- **Autonomous vehicles**
  - Vehicle technologies "pushing the boundaries of navigation and autonomy techniques in both endurance and scale" (e.g. Oxbotica)
  - Social expectations about uptake and impacts in freight transport (CIED)
- **Cities as living labs for low-energy mobility**
  - Integrated transport and smart mobility (e.g. CIED)
  - Shared mobility (e.g. TEMPEST)
  - Home delivery (CSRF)
- **Modelling** of the energy impacts of individual, organisational and policy decision-making in **passenger & freight transport** (UKERC)



Bioenergy 1

- **Biomass production.** Developing energy crops with efficient photosynthesis and water-use, especially CAM plants - mechanisms that plants use to cope with stresses. Engineering solutions for growing aquatic plants in arid regions.
- **Biomass conversion.** Reducing the cost of Anaerobic Digestion (of agricultural wastes and CAM plants), and ‘plug-and-play’ systems to allow methane from AD to balance intermittent renewables. Optimising the combustion of aqueous ethanol/gasoline mixes in spark ignition engines. New generation, cheap, robust and high-performance catalysts for the production of methane and hydrogen.
- **Ecological and social impacts.** Understanding how different biofuel landscapes provide, divert, displace and degrade multiple ecosystem services and affect human well-being. Effect of subsidies and the carbon footprints of biofuel supply chains. Minimising impact of bioenergy production on traditional agriculture.

Bioenergy – energy *and* food?

Oxford colleagues investigating:

Crassulacean Acid Metabolism (CAM) **plants** (cacti, euphorbia*,…) - need only ~ 20% of water (staggering numbers: 4% to 15% of the 2.5 bn ha of potentially available semi-arid land would → 20 % of current electricity)

*trials in Kenya, were going well…

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Cactus as Biofuel Could Help with Food-Versus-Fuel Fight

Plants on arid land, rather than food crops like corn, could be turned into gasoline, new research shows

chemistryworld

By Jack Busby and ChemistryWorld | July 1, 2015

New analysis from UK researchers suggests a previously overlooked group of plants could be key to providing sustainable bioenergy for the future.

Traditional biofuels such as bioethanol are made from food crops like corn and sugarcane that require prime agricultural land—a commodity in relatively short supply. Competition between food and fuel crops means that large scale bioethanol

Prickly pear cactus can make fuel.

Courtesy USDA.gov

+

Improved Anaerobic Digestion

By learning from cows, hope to reduce biogas plant sizes by a factor of 20 → big cost savings

1st experiments under way (early days)

Biogas plant waste can supply charcoal, fish and fertiliser

Biogas (easy to store) + solar perfect for mini-grids

CAM Plants

– from Andrew Smith's Energy Day talk in October

CAM plants grow on marginal or degraded land, with little water
Examples: cacti, euphorbia, sisal (agave sisalana), opuntia (prickly pear), pineapple,…

Plant productivity and water-use efficiency

Photosynthetic type		Water-use efficiency (mmol CO_2 / mol H_2O)	Maximum productivity (tonnes ha^{-1} $year^{-1}$)
C_3	~ 90 % of all plants	0.5 – 1.5	35
C_4	e.g. maize, sugarcane, sorghum	1 – 2	50 (– 80)
CAM	drought-adapted succulents	4 – 10	43

C_3

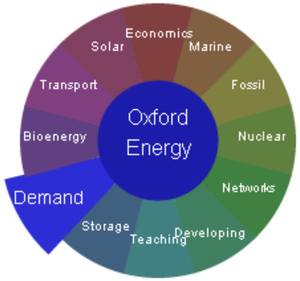
C_4

CAM

As well as being a potential source of energy CAM plants improve soil quality – reduced erosion; improved carbon sequestration

Cutting the cost of AD – bio-mimicry of cows

- A cow can digest AD feedstock 20x as fast as a conventional AD plant
- Both use the same bacteria and chemistry
- Mimicking the cow using Advanced Anaerobic Digestion (AAD) could make electricity from agricultural waste as cheap as burning coal



Demand & Efficiency

- **Technology research**
  - Advanced internal combustion engines and gas turbines
  - Lightweight materials
  - Improved catalysts
  - Improved batteries and fuel cells
  - Efficient electric motors

- **Socio-technical research**
  - Users practices, education and feedback
  - Smart meters, grids, buildings and systems
  - Supply chain issues
  - Community initiatives

- **Policy research**
  - Energy and carbon taxes and tradeable instruments
  - Policy for efficient buildings
  - Policy for efficient vehicles
  - Policy for flexibility and integrating renewables
  - Input to Government, CCC, EU institutions, IPCC etc

Championing Energy Demand Research

- Nick Eyre appointed Research Councils' UK 'Energy Demand Research Champion' from July 2017.
- Aims include to:
  - design and develop a bid a new 5-year Centre on energy demand research. Proposed start date April 2018
  - consult on research needs for a changing energy system.
  - identify new research challenges.
- Centre objectives will be:
  - internationally leading research on energy demand
  - impact in businesses and policymaking; and
  - championing the role of energy demand in a low carbon energy system.
- Thematic structure will be:
  - buildings, transport and industry
  - flexibility, digital society and policy.

WICKED Solutions for the Retail Sector

Working with Infrastructure, Creation of Knowledge, and Energy strategy Development (WICKED) bridges gaps - how buildings perform in practice/in theory

PI: Peter Grindrod, Maths. Grant ended June 2016

Research (on buildings, energy and organisational behaviour) investigates the retail sector at multiple scales → co-design of market-ready energy strategies for diverse user groups + usable products: online energy advisors backed up by large data sets; low-tech "smart-er" retrofits for manual gas and electric meters; new forms of leasing agreements; energy strategies tailored to companies of different shapes and sizes

The academic team combines expertise in energy use, maths, computing, engineering, physics, law, and organisational behaviour

The partners include energy suppliers; retail property owners, landlords, and tenants; business support groups; and energy advice companies

Decarbonising Heat

- **Primary energy ends up providing** (global numbers)

Heat ≈ Electricity *(some → heat & transport)* **≈ 37.5%, Transport ≈ 25%**

Final energy: 50% heat, 30 % transport, 20 % electricity *(some → heat & transport)*

Heat → 49% buildings, 46% industry, 5% other (global numbers, IEA 2011) has not attracted enough attention

- **Buildings –** Nick Eyre has played leading role in drawing attention to the problem and the portfolio of possible solutions (improved insulation,…)

- **Industry**

  Some measures easy *in principle*, e.g. making cement → 9% of CO_2 emissions: 40% from energy, 60% from $CaCO_3 \rightarrow CaO + CO_2$ - could be captured & sequestered

  But decarbonising high temperature process heat is a huge challenge

  Need to re-think all industrial process, e.g.

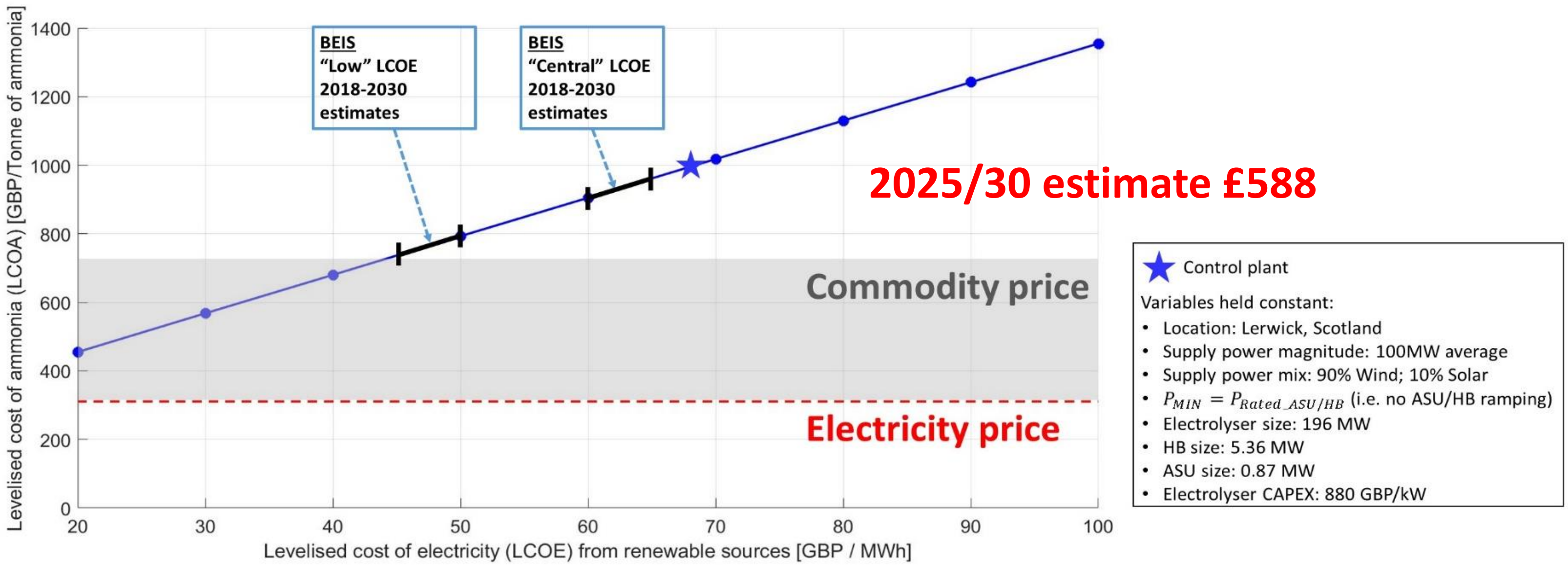
  Production of ammonia - £100bn/year industry → 1.3% of CO_2 emissions

  Alternatives to usual method* being studied in Oxford

  *hydrogen from steam methane reforming [CO_2 vented] + nitrogen (from air) → Haber-Bosch (energy intensive) → ammonia

Green Ammonia?

Near term: can use green electricity + electrolysis. René Bañares-Alcántara, Richard Nayak-Luke, … with Siemens **designed plant & studied economics:**



Proof of concept plant at Rutherford Lab →

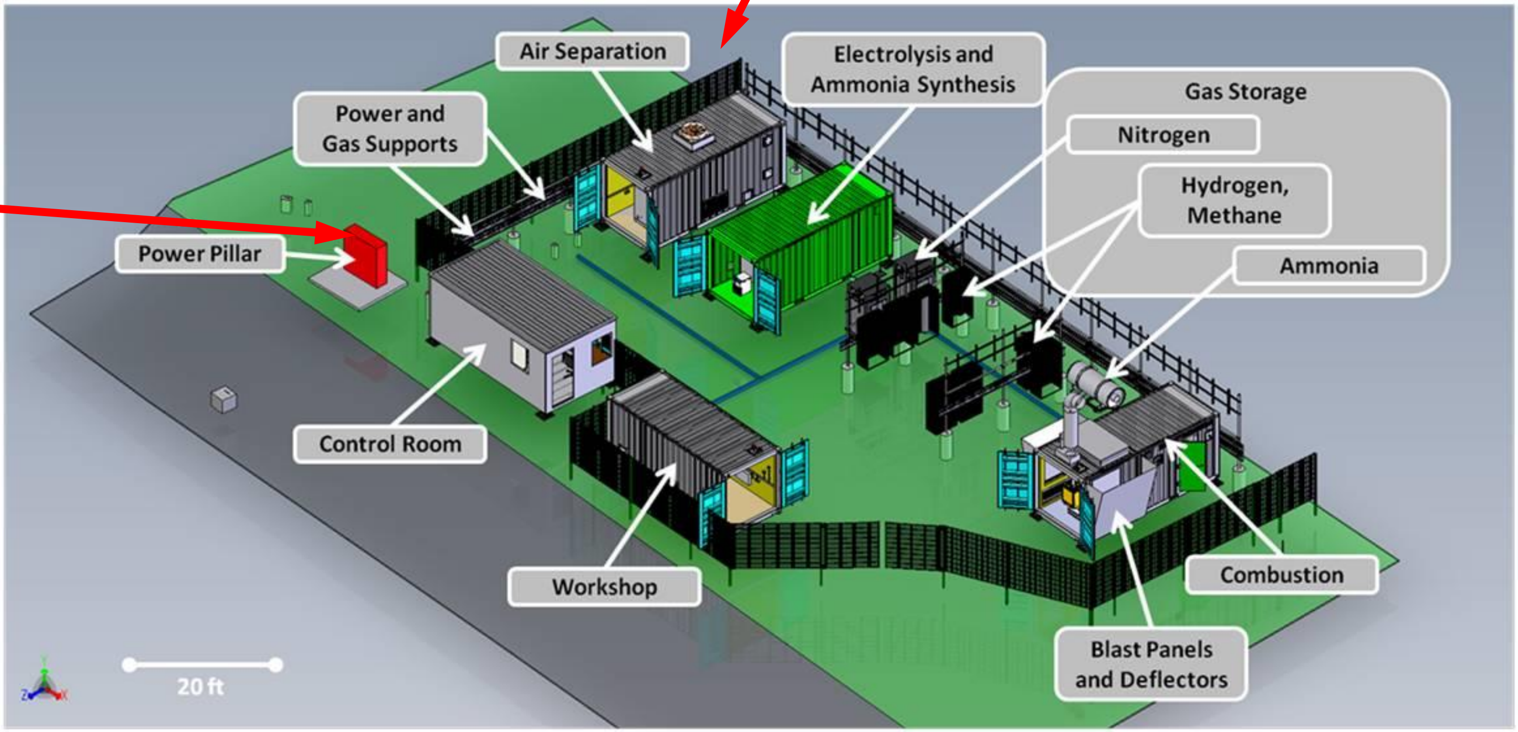
Longer team: can electrochemically synthesise ammonia starting with water and air, but rate is at least two orders of magnitude lower than required – E Tsang studying whether this can be improved

Note: Ammonia potentially provides an excellent means of storing energy*: fed into fuel cells, 1 year's supply of ammonia would power the world for some 5 days* (13.7 days with 100% efficiency)

Siemens 0.3 MW proof-of-concept plant

UNIVERSITY OF OXFORD

Being built at Rutherford Appleton Laboratory, near Oxford



SIEMENS

UNIVERSITY OF OXFORD

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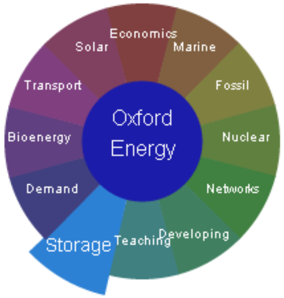
Science & Technology Facilities Council

Source: Ian Wilkinson, Siemens.



Storage

- **Three domains**: mobile devices, transport and grid - biggest challenge

Requires **whole systems** approach.

- Oxford's storage research strongly connected to activities in **networks, demand, transport, bioenergy** as well as **economics** and **policy**.
- Fundamental research builds on Oxford expertise in mathematics.
- S**torage technology – batteries; hydrogen; CO2 to fuel; ammonia….**
- **High profile EPSRC activities:**

– Grand challenge: Energy Storage for Low Carbon Grids (£14.3m, Whole systems approach, consider control, networks and context via scenarios)

– SUPERGEN Energy Storage Hub (since June 2014) £4m, led by Professor Peter Bruce FRS (develop a shared vision for energy storage, first integrated national roadmap for energy storage , engaging with the wider community)

– Oxford has won funding to establish and lead an **energy materials hub**, spanning storage, solar, fuel cells and with Imperial, UCL, Swansea.

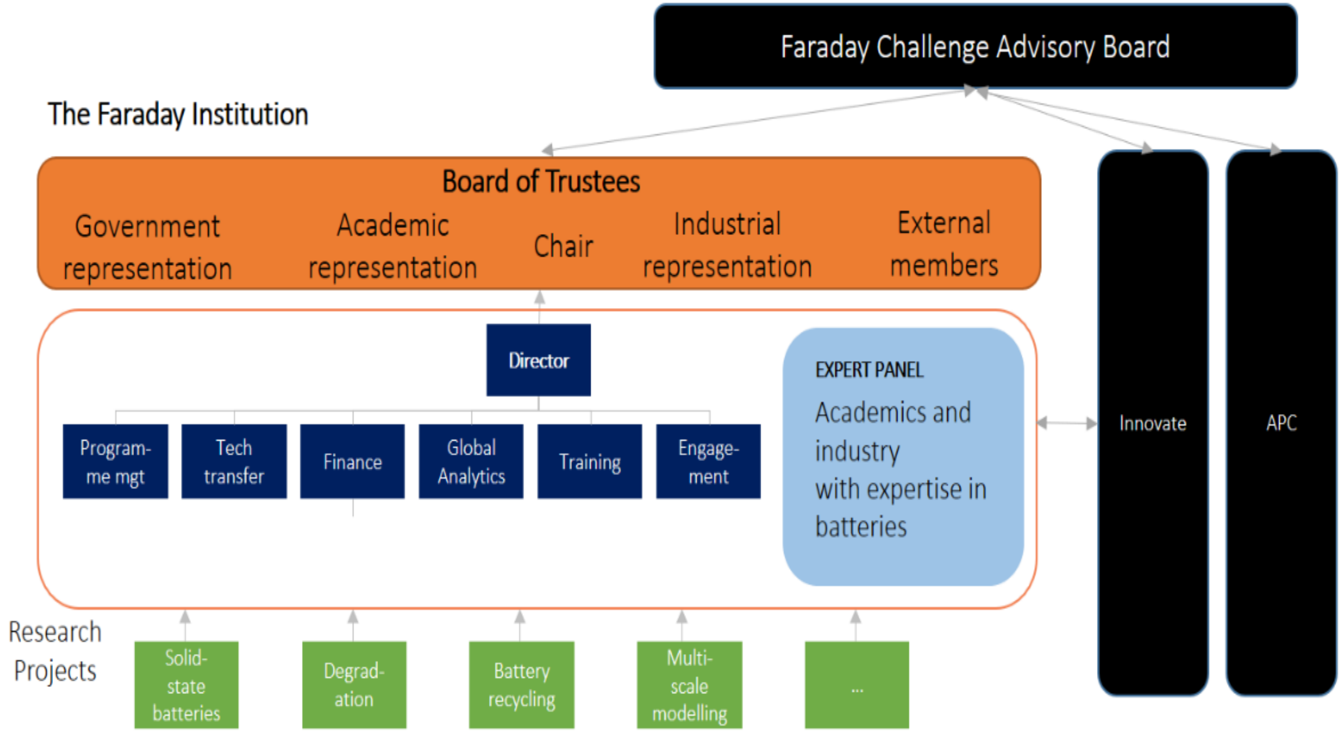
Oxford is the lead University setting up the Faraday Institution, launch early 2018.

The Independent, National Institute which Sponsors and Manages Mission-inspired Research on Electrical Storage

- Independent, National: Managed for the benefit of UK PLC with no privileged owners (academic, industry). All welcome.
- Sponsors: Budget of ~ 20 M/year (from ISCF) to fund research & training in universities & partners. 3.5 years guaranteed, 10 year horizon
- Manages: Active, collaborative, milestone-driven not fire-and-forget.
- Mission-inspired Research: Fundamental research responding to identified high level technology problems, directly connected to industry, bringing large teams to bear. Short- *and* long-term.
- Electrical Storage: Batteries yes, but integrated in systems
- The: clearing house, battery expertise, UK point-of-contact for batteries, serving the community of academia, industry, govt.

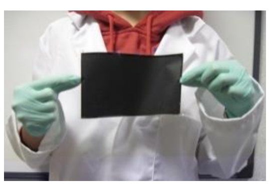
Faraday Institution HQ at Harwell:

Organizational Structure:



Electrochemical energy storage research

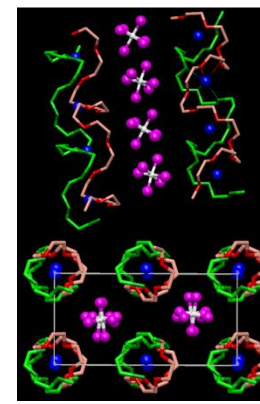
Li-air battery High capacity Electrochemistry fundamentals	**Next generation Li-ion** High power Materials optimisation	**Grid-scale** Na ion Re-purposed waste Aqueous electrolytes	**Safety** Crystalline Solid-state polymer and ceramic electrolytes	**Modelling & Characterisation** High resolution and *in-situ* characterisation



Manufacturing

New processes

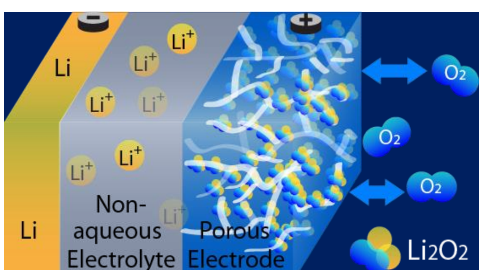
Structured and 3D electrodes

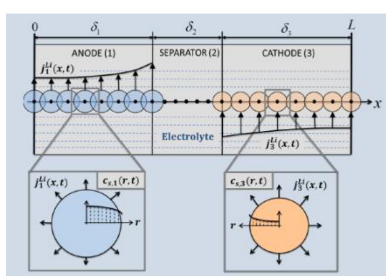


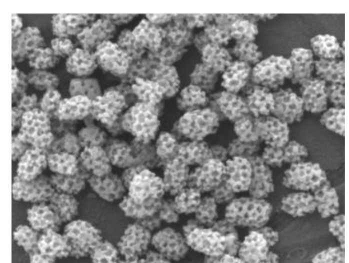
Device assessment and control

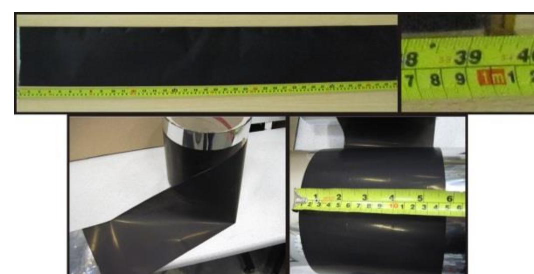
Performance modelling and assessment

Diagnostics, management and failure

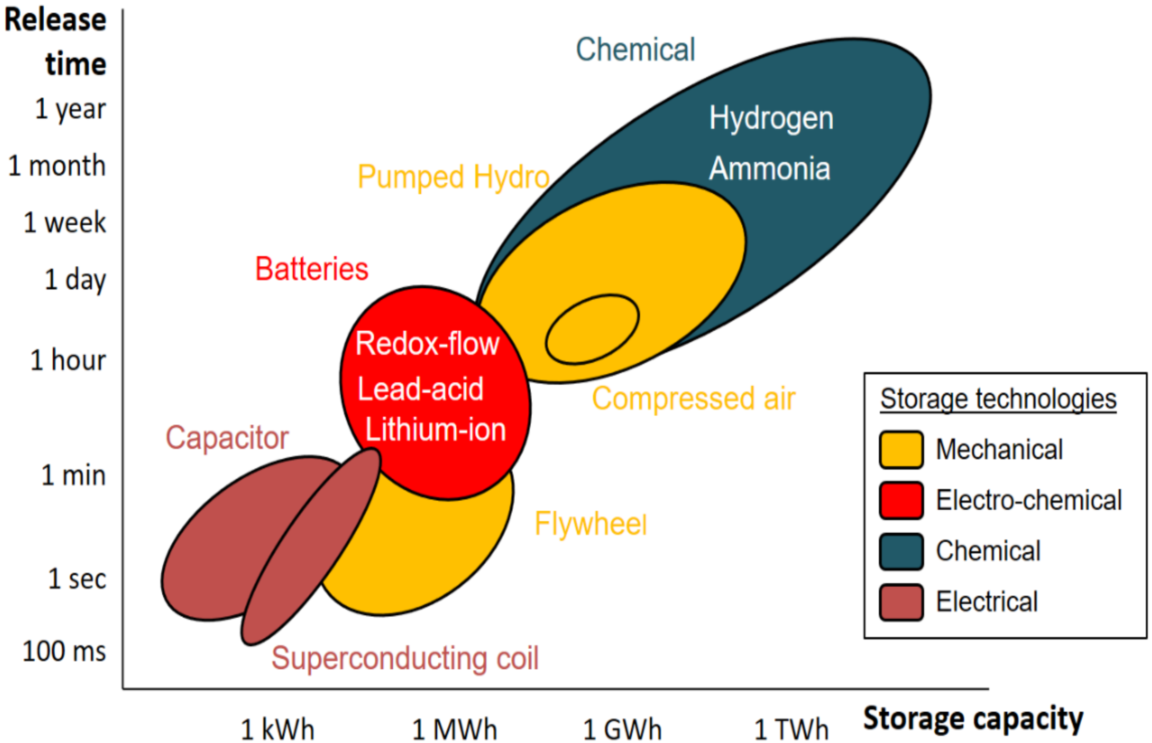








Available energy storage technologies

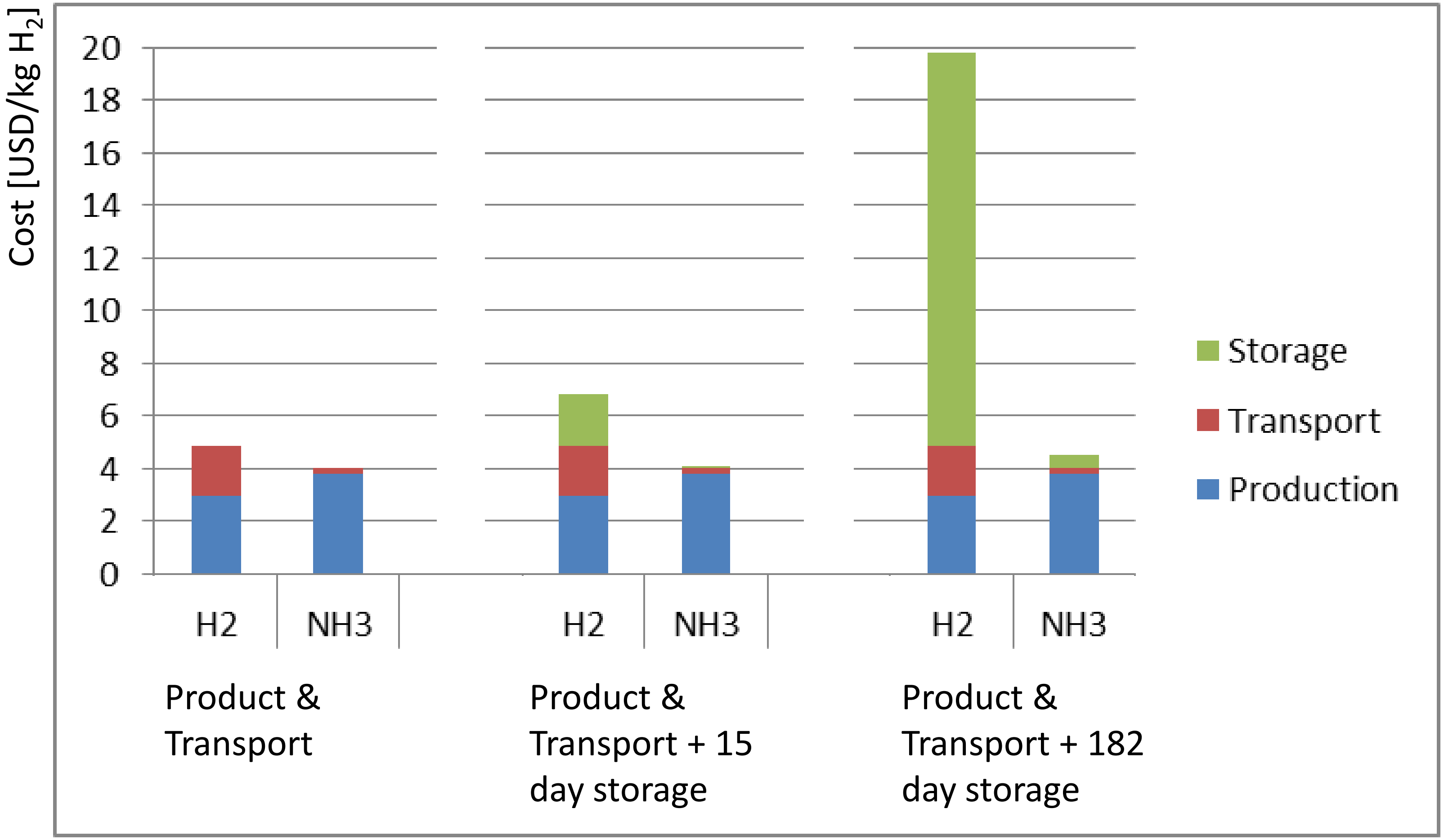


Source: presentation by N Olson (NH3 Fuel Association), Rotterdam, May 2017.

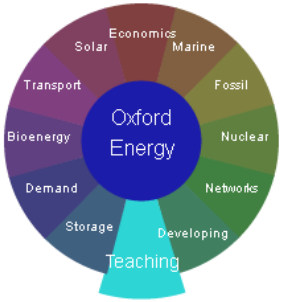
Storage Duration Index (being developed by Richard Nayak-Luke) **→ optimum mix of different electricity storage technologies:**

Given: demand profile, past data on wind and solar availability, and the relative costs of devices that store energy for (say) 1 day (batteries?), 1 week to month (pumped hydro?) and 1 year (power to gas?) → what mixture would have provided all electricity over the last (say) 10 years at minimum cost? The model has the functionality to optimise the storage and RE supply mixtures while varying curtailment, RE penetration and demand side management either individually or in combination.

H_2 vs NH_3 costs of production, transportation and storage



Source: J.R. Bartels, "A Feasibility Study of Implementing an Ammonia Economy", MSc Thesis, Iowa State University (2008)



Teaching & Training

- **MSc in Environmental Change Management**
  - includes an Energy Week providing a broad overview, followed by field trip (CAT) and more expansive modules on key challenges, such as infrastructure
- **Masters in Public Policy includes Energy module (ended)**
- **Centres for Doctoral Training**

AIMS Autonomous Intelligent Machines and Systems

REMS Renewable Energy Marine Structures

Environmental Research (DTP)

New and Sustainable Photovoltaics

Science and Technology of Fusion Energy

Oil and Gas

Gas Turbine Aerodynamics

Industrially Focused Mathematical Modelling

Interdisciplinary Bioscience (DTP)

New Energy Systems Thinkers – NEST@Oxford

A few years ago, Malcolm McCulloch, with the support of the network, started an Energy 'DTC-lite' – voluntary lectures for DPhil Students designed to provide them with broad background knowledge. This evolved into NEST, designed to broaden their perspectives and encourage them to think across disciplines:

- Voluntary programme for graduate students across the University
- Participants from Engineering, Geography, Business School and seven other departments
- Michaelmas term - 4 lectures, typical attendance 40
- Hilary & Trinity -problem solving with industry: two rounds with industrial partners (BP, National Grid, Good Energy, Mainstream Renewable Power who posed problems on which groups of students (20 in round 1, 15 in round 2) worked collectively for 6 weeks (with mentoring sessions)
- A feedback session to the partner companies acts partly as a recruitment exercise, but also for them to benefit from the students' work, and for students to receive professional guidance. The partners found the students 'work to be valuable and indicated their willingness to pay in the region of £5,000 - £10,000 for their involvement in such case studies.

New Energy Systems Thinkers @ Oxford

Oxford DPhil

- Disciplinary
- Academic problem

Depth

NEST in addition:

- Multi-disciplinary
- Practical problem focused
- Engages commercial organisations
- Peer to peer learning

1) **Academic introduction:** one intensive week
2) **Problem formulation:** by non-academic partner
3) **Group work**: 6 students from different disciplines over one term, self-organised, supported by an academic advisor
4) **Research day**: Presentation to academic and external audiences

Plus annual road trips, social events, mini conference

System thinkers

MSc in Energy Systems

Kicked of by meeting organised by the Energy Network. Initial leg-work done by Phil Grunewald. Proposal taken forward by David Wallom – passed MPLS hurdle; submitted to University.

Modular structure to allow part-time as well as full-time participation (to widen participation and encourage industrial attendance as course members, as done with Software Engineering and other courses of high value in industry).

Core themes:

- **Services** – What, why and how is energy provided to society and how may it change or be changed by society?
- **Resources** – How is energy converted, stored and traded?
- **Systems** – How do we distribute energy so that it is usable?

The third term, will involve project work (modelled on; incorporating?) NEST

Developing Countries

Oxford academics are providing technical, economic and policy advice on energy in OECD + non-OECD countries, including China, India, Africa, and South America, e.g.:

Developing domestic resources - work has informed policies in the IMF, World Bank, WTO etc., now focused on new 'energy economies' in Africa, which are developing large recently-discovered hydrocarbon resources

Energy Access in India - research feeds into policy debates

Sustainable travel - Jinan study generated scenarios for urban transport sector in rapidly urbanising Asian cities

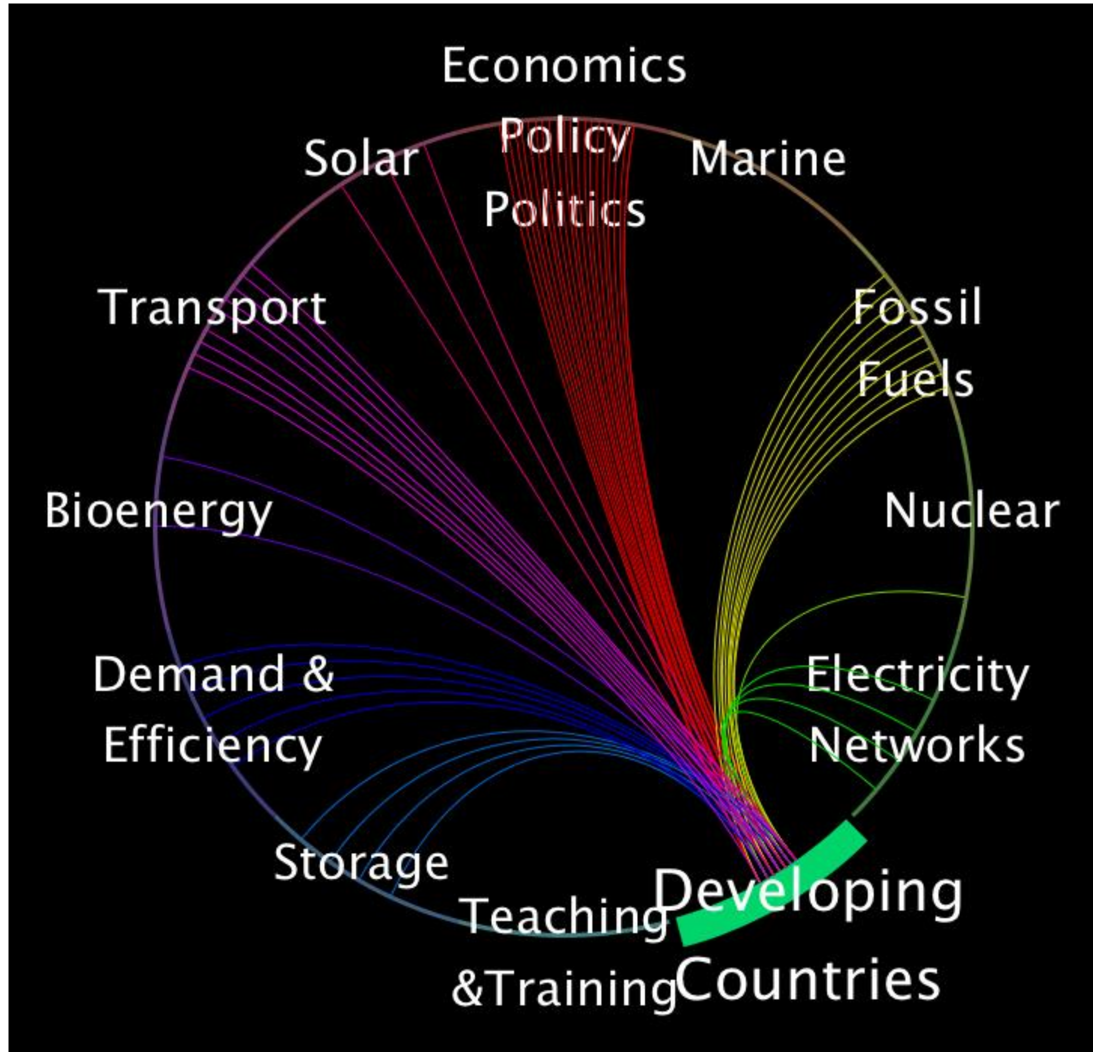
Regulation – is Colombian regulatory framework discouraging development of renewables?

Governance - does experience in the Caspian region support the 'wisdom' that developing countries with major income from energy extraction and export experience dysfunction in governance?

Developing Countries

… and developing robust, low maintenance, low cost energy technologies for use in rural areas.

Note overlapping interests:

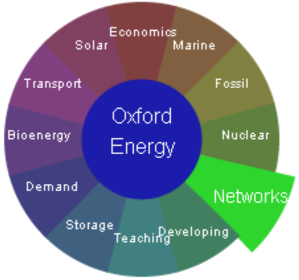


Examples of Technical Work of Special Relevance for Developing Countries

- **Electricity Portfolio Optimisation in Kenya (Integrate programme)**

  provide flexible hydro generation to complement solar and wind; use minimum water to meet energy target by raising levels of key dams. Benefits:
- Increased system resiliency in dry months/years
- More water available for irrigation purposes
- **Solar cooker** based on novel solar concentrator (spun out in Oxford from the experiment that won the 2015 Nobel Prize in physics). Being trialled in Tanzania for day-time cooking + sterilizing water → reduce deaths from air pollution + save money

Concentrator could be used in sunny countries e.g. to melt aluminium scrap for re-cycling



Electricity Networks

Infrastructure - Oxford leads the Infrastructure Transitions Research Consortium ~ energy, including gas and electricity networks, transport, water, waste and telecoms. Work on ICT infrastructure for intelligent grid networks. Smart meters – Spin-out: Navetas.

Analytics – Part of £30M OFGEM LCNF project. Algorithms to exploit data from low voltage smart networks and meters - to monitor networks and improve performance and control. Identification of drivers of failure.

Forecasting - Modelling, 24/7 rolling forecasts and control on low voltage networks to allow companies to identify drivers of network compromise. Short term, real time forecasts to predict peaks and aid control and network response to time of day tariffs, novel technologies, and public attitudes (to lifestyle benefits, ethics, fairness and risk perceptions).

Consumer behaviour and understanding, segmentations of households and substations: a currency for cross- comparisons and identification of emerging behaviours. Balance between automated switching and active consumer engagement + social acceptability and governance (~ data protection and external control of appliances).

Markets - Economics of networks + the way markets function, to promote good policy and better planning, nationally and globally. Implications of low carbon energy for investment, coordinated planning, wholesale market design and regulation, merit order operation, pricing, and the roles of demand and storage in decarbonized electricity sectors

INTEGRATE 1

Oxford Martin School Programme on Integrating Renewables for a Secure, Affordable and Sustainable Energy Future

Programme looking holistically at how to accommodate large scale wind and solar (already causing problems in Germany,…), considering:

-Different level of renewables (using actual data for their temporal availability)

-Different futures for the grids (local, national, continental)

-Storage

-Options for (aggressive) demand management

-Back-up and base-load options (nuclear, gas…)

-Modelling → technical and economic optimum mixes of measures and market changes needed to deliver them

-Economics/policies/politics ~ cost, value, prices, incentives for investment, electrity market implications, political and social acceptability (winners & losers)

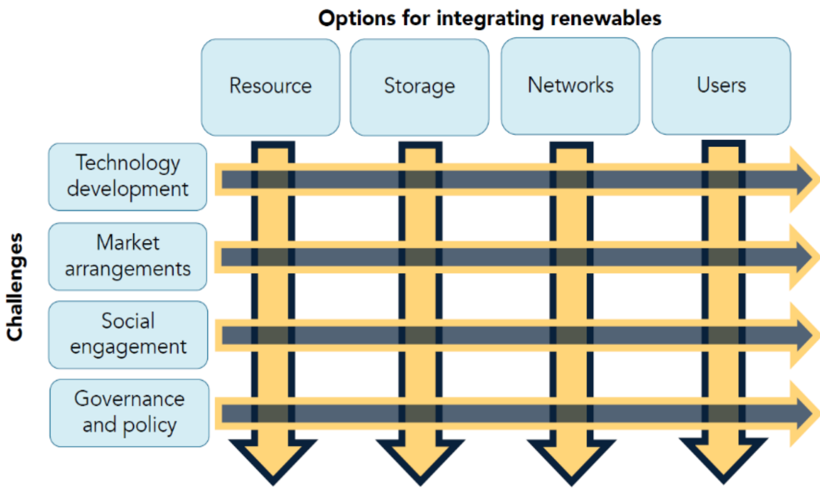
Leaders from: Lower Carbon Futures, Engineering, Institute for New Economic Thinking, Law, Materials, John Rhys/Oxford Institute for Energy Studies

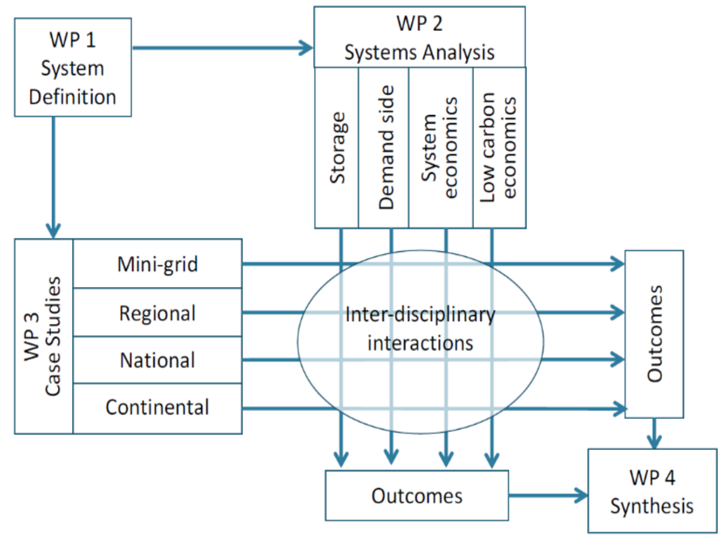
Interested parities: National Grid, Ofgem, Mainstream Renewable Power, Siemens, Aurora,…

INTEGRATE 2

For details see www.renewableenergy.ox.ac.uk and Weekly Newsletter

Conceptualisation of work:





- Agreed vocabulary, undertaken rigorous literature reviews,..
- High level conclusions: flexibility essential; storage vital; blurring of demand/supply – ‘energy services’; cannot decouple futures of electricity, heat and transport; markets and governance need (maybe radical) reform
- Outputs: Electricity Portfolio Optimisation in Kenya; Solar Self Consumption; Peer to Peer Energy Trading; End of Conventional Wholesale Electricity Markets?; Charging Electric Vehicles;…

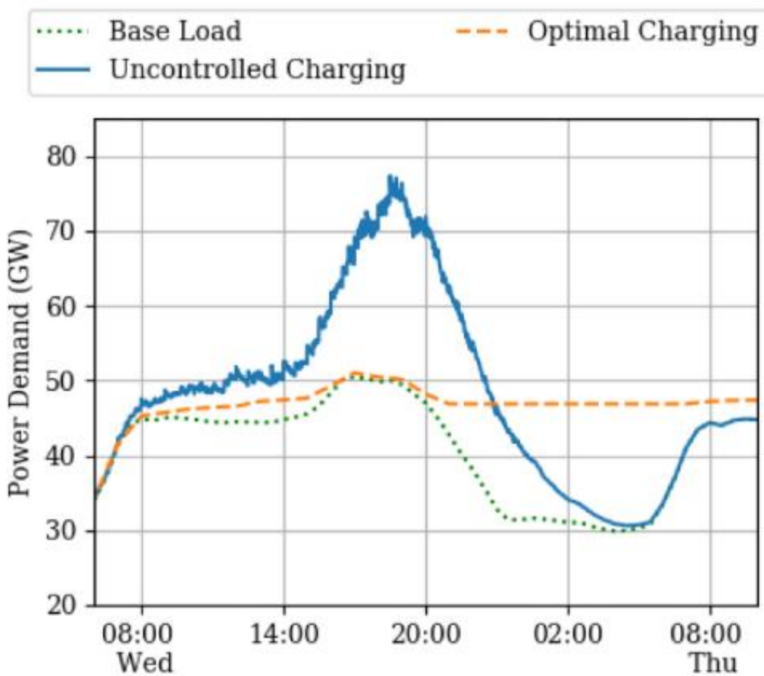
Charging Electric Vehicles 1

Constance Croziera, Dimitra Apostolopouloua, Malcolm McCulloch. Supported by JLR.

Assume all 32 million cars in UK were battery powered (slow charging all simultaneously would consume 100 GW!)

Slow charge	3 kW	6 – 8 hours
Fast charge	7 kW	3 – 4 hours
Rapid charge	50 kW	80% in 30 mins

and (in first approach) that **all cars slow-charged at home** (incorrect – no off street parking for 43% - but over ½ fleet at home at any time, rest on road, at shops or work,…). Using data on car use & assuming cars charged when they get home, with standard profile (0- 80% at constant current/power, then constant voltage) → 'uncontrolled' power demand, for a Wednesday in January:



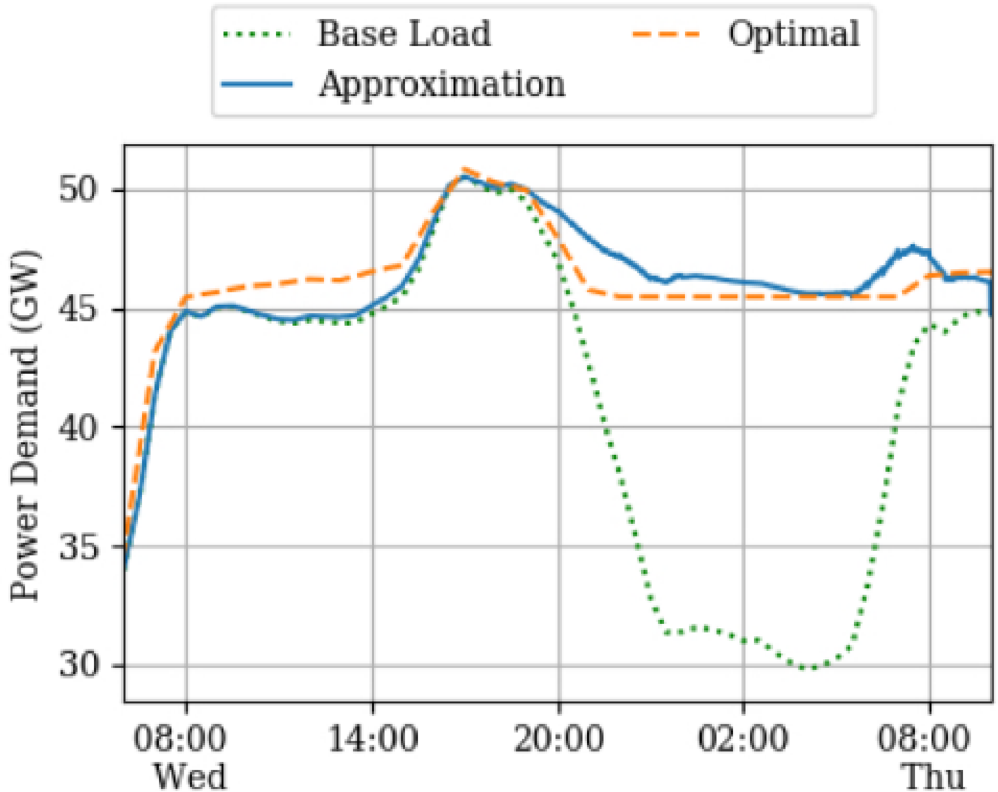
Solutions?

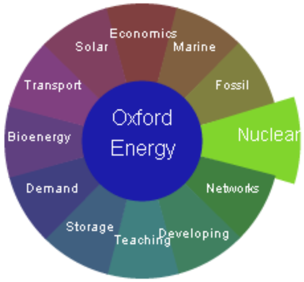
- Price signals, relying on intelligent consumer response
- Central controller → optimal solution, knowing when each car parked + when needed
- **Or….**

Charging Electric Vehicles 2

Change charging profile (effect on battery life?)

Given when charging starts and when vehicle needed, charging profiles are provided (depending on time of year, and of day,…) designed so that the aggregate profile is as flat as possible → good approximation to optimal charging profile:





Nuclear

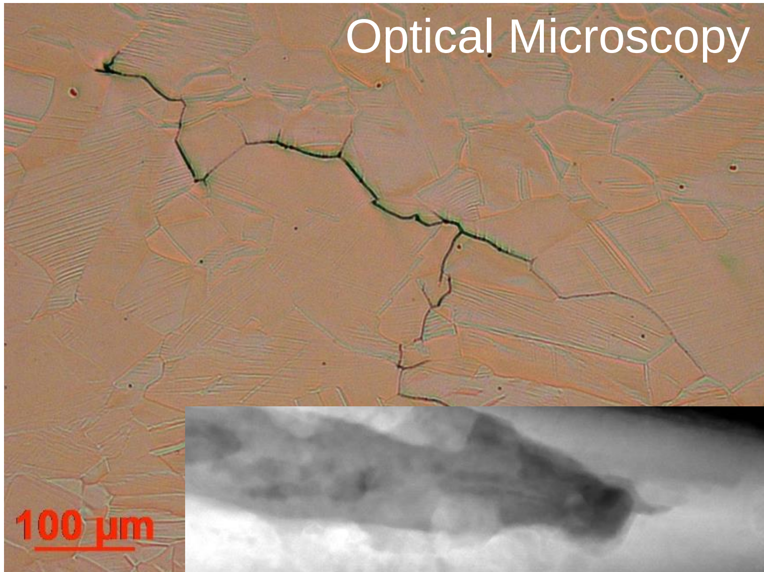
Fission

- **Materials**: for **life-extension** , **Generation IV fission** and **fusion**: stress corrosion cracking mechanisms in corrosion resistant alloys in current plant; interactions between residual stress and creep life in stainless steel welds; enhancement of zirconium fuel cladding alloys for improved safety and performance; fracture resistance in nuclear graphite and high temperature ceramic composites for high temperature reactors; development /fabrication of low-activation oxide-dispersion strengthened steel alloys for extreme environments for fission and fusion.
- **Chemistry of Actinides** in nuclear waste, and robotic sensory networks to monitor stored nuclear waste.

Fusion

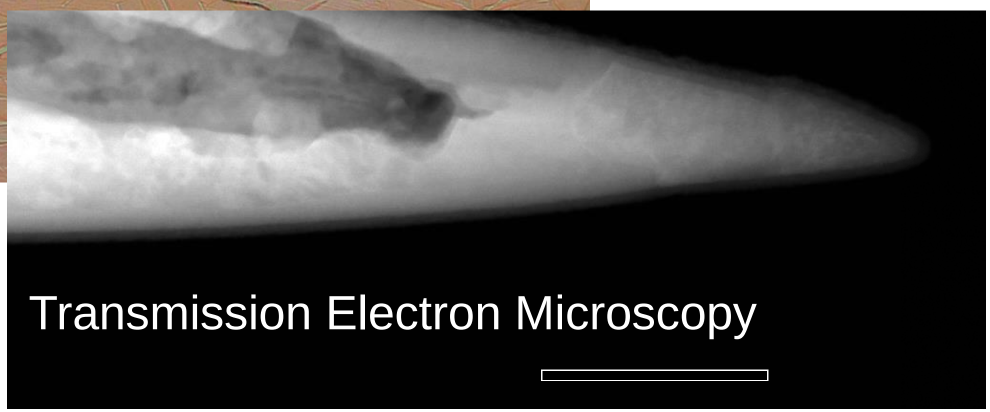
- **Materials** as above + very irradiation-tolerant materials; advanced modelling of irradiation damage mechanisms, validated by micro mechanical testing.
- **Plasma theory** – in collaboration with Culham.

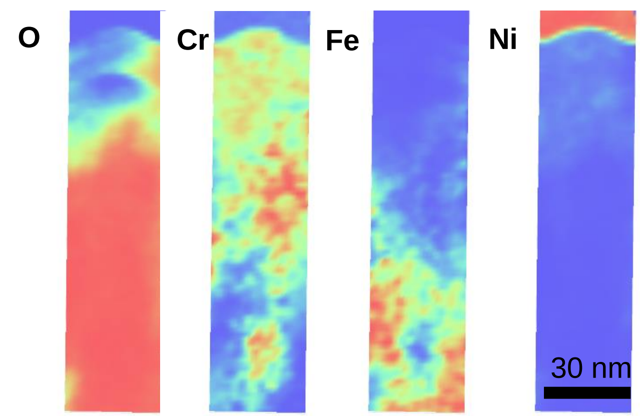
Stress Corrosion Cracking in Stainless Steels (Light Water Fission Reactors)



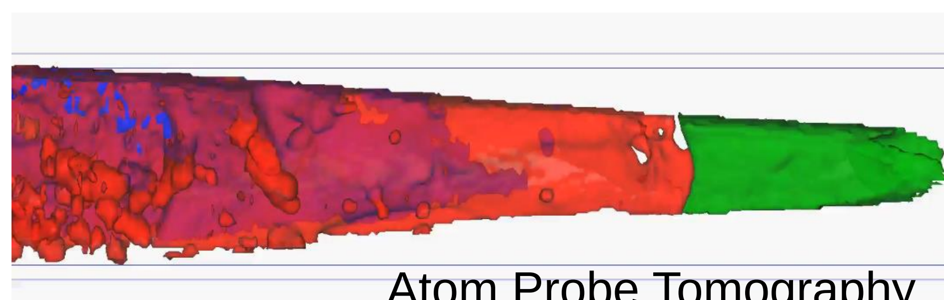
World-leading microscopy applied to study the oxides that develop within a stress corrosion crack, developed in high temperature water

Understanding the sequence and structure of these oxides is the key to predicting the kinetics of stress corrosion cracking in nuclear plant cooling systems

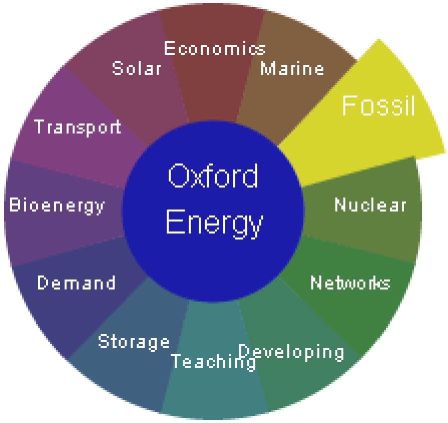




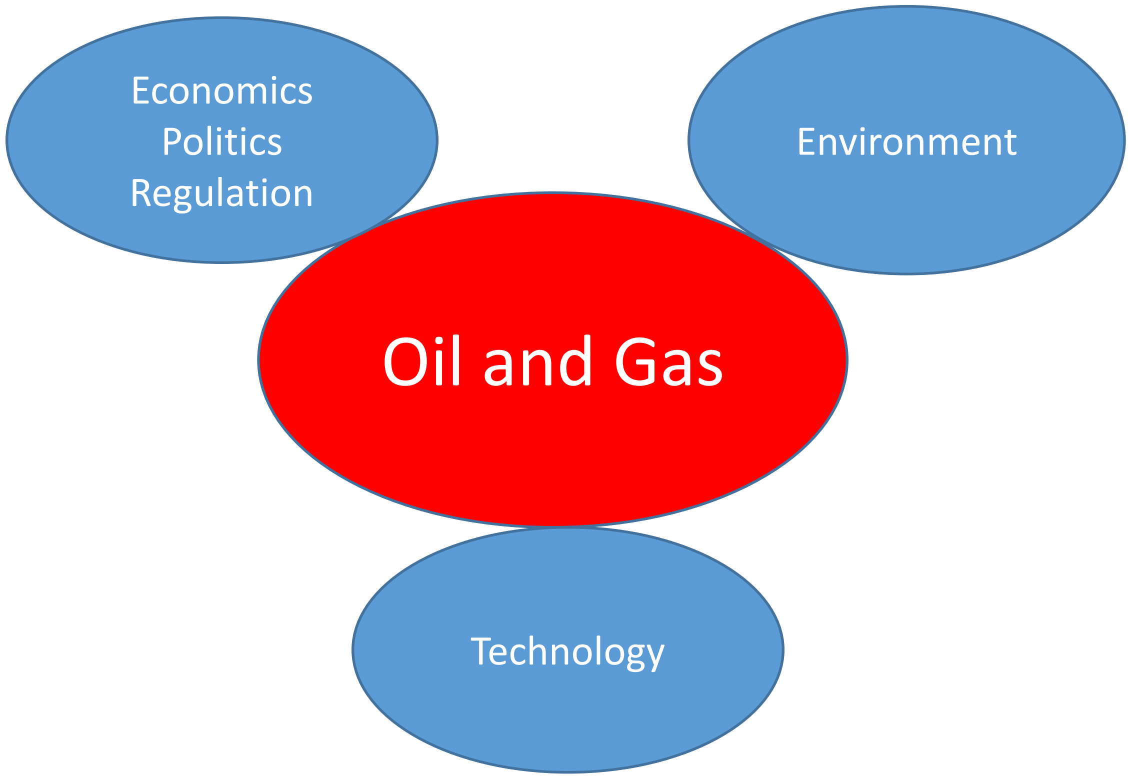
The study shows nickel enrichment ahead of the crack tip, and a discontinuous Cr_2O_3 oxide within the crack

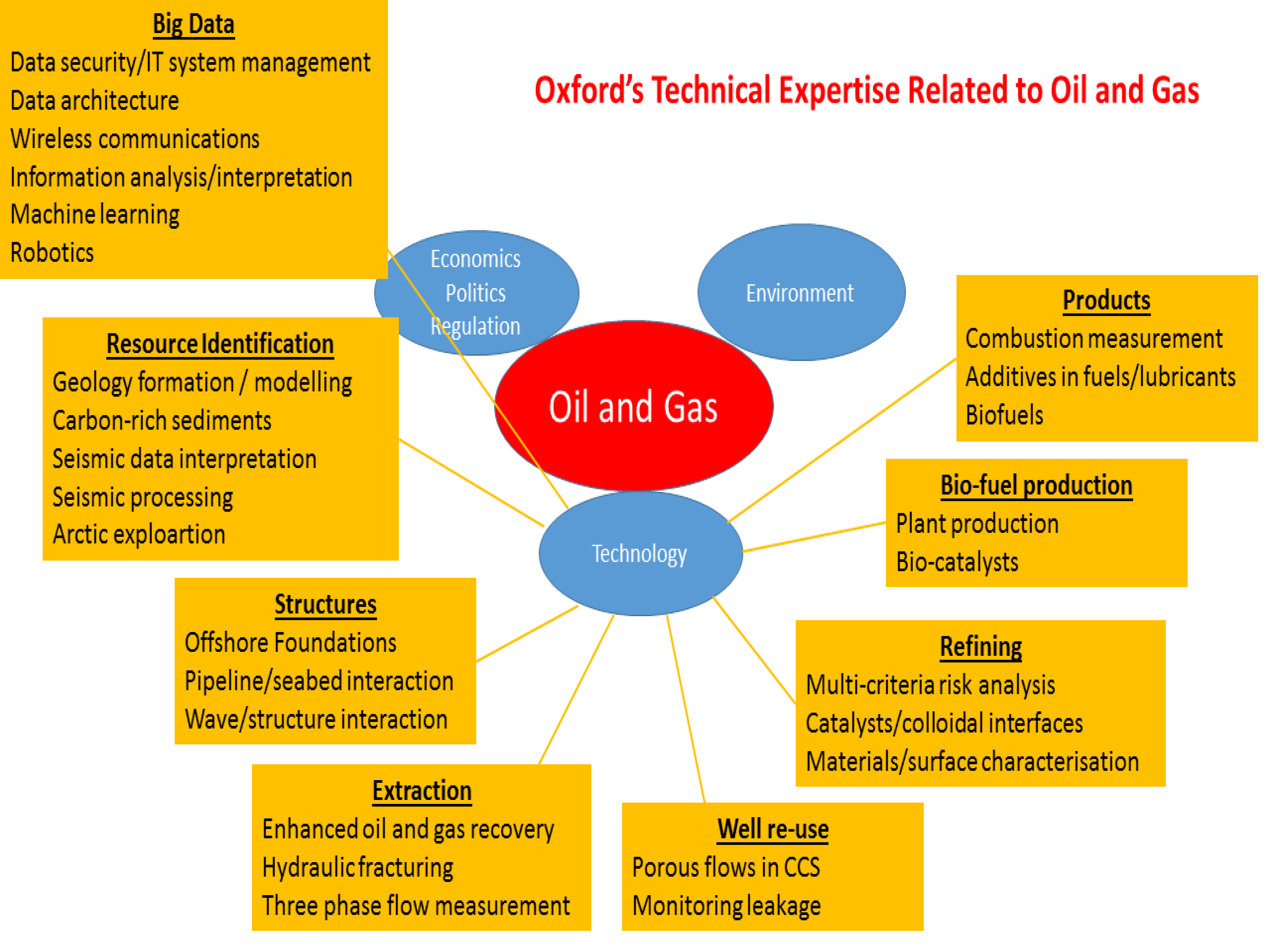


Sergio Lozano-Perez

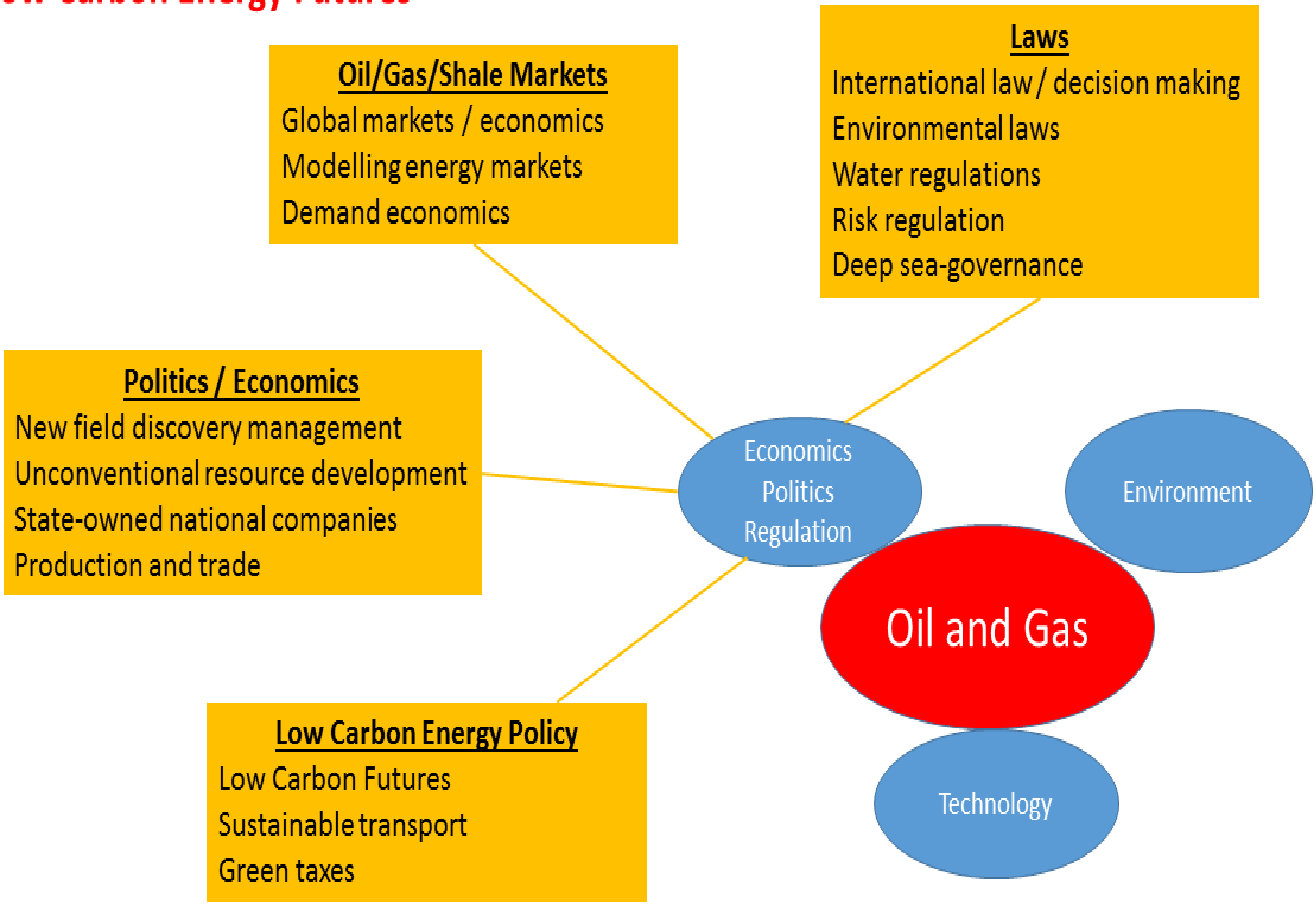


Fossil Fuels

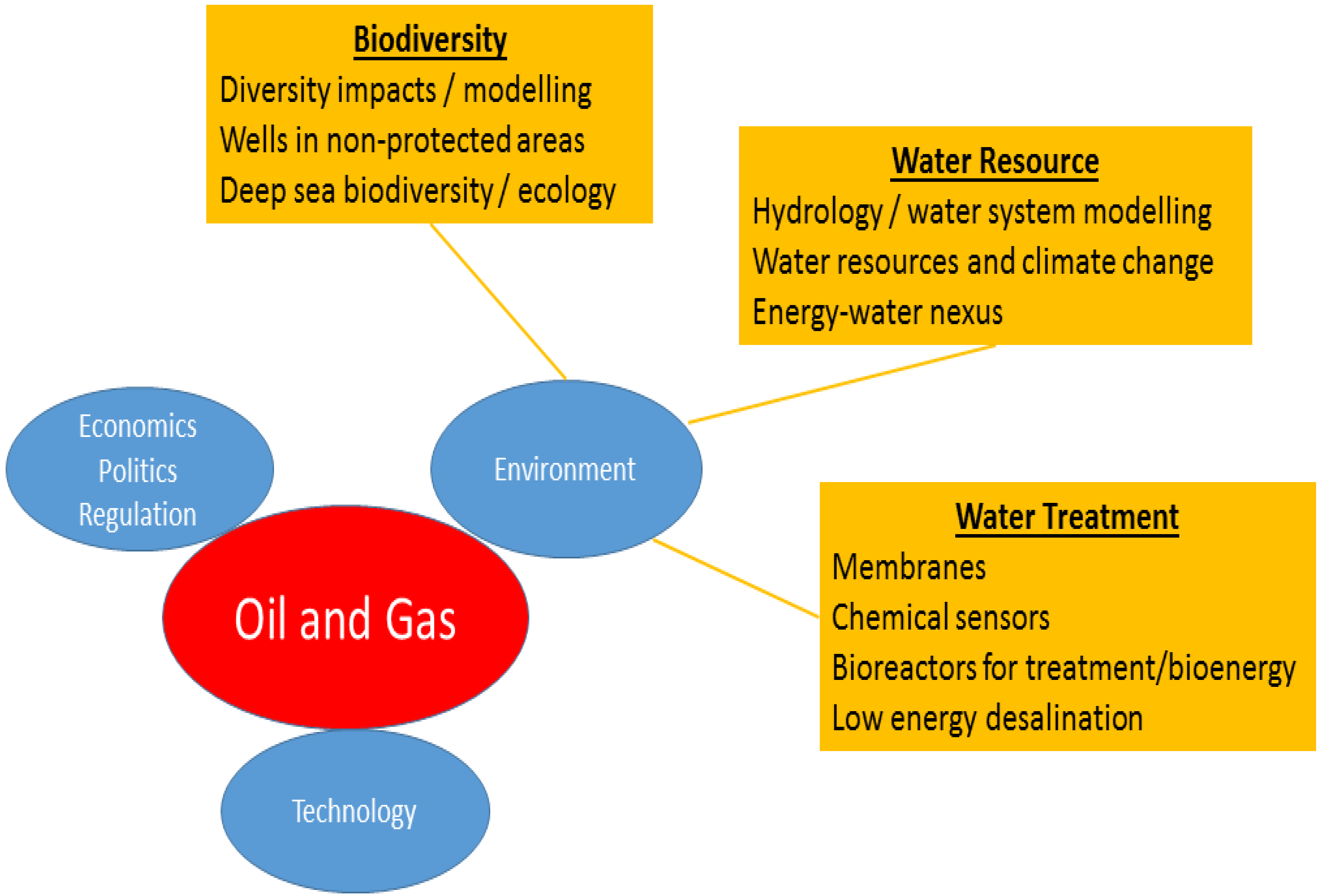


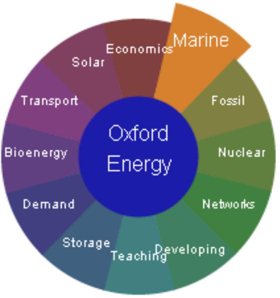

Oxford's Technical Expertise Related to Oil and Gas
Big Data
Data security/IT system management
Data architecture
Wireless communications
Information analysis/interpretation
Machine learning
Robotics
Economics
Politics
Regulation
Environment
Oil and Gas
Technology
Products
Combustion measurement
Additives in fuels/lubricants
Biofuels
Resource Identification
Geology formation / modelling
Carbon-rich sediments
Seismic data interpretation
Seismic processing
Arctic exploartion
Bio-fuel production
Plant production
Bio-catalysts
Structures
Offshore Foundations
Pipeline/seabed interaction
Wave/structure interaction
Refining
Multi-criteria risk analysis
Catalysts/colloidal interfaces
Materials/surface characterisation
Extraction
Enhanced oil and gas recovery
Hydraulic fracturing
Three phase flow measurement
Well re-use
Porous flows in CCS
Monitoring leakage

Oxford's Oil and Gas Related Expertise in Markets, Politics, Economics, Law, Regulation and Low Carbon Energy Futures



Oxford's Environmental Expertise Related to Oil and Gas



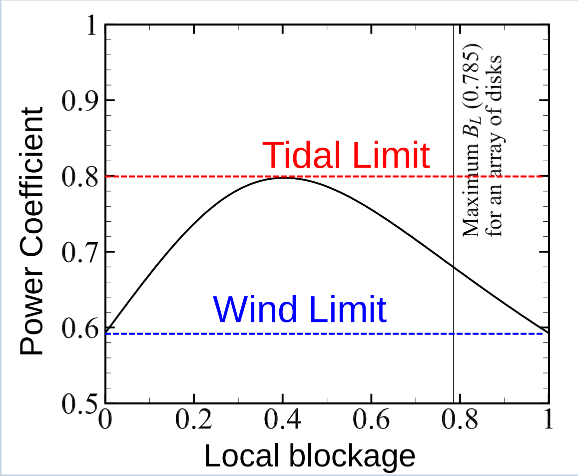


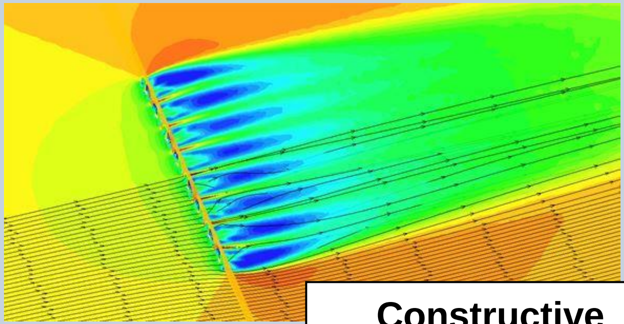
Marine

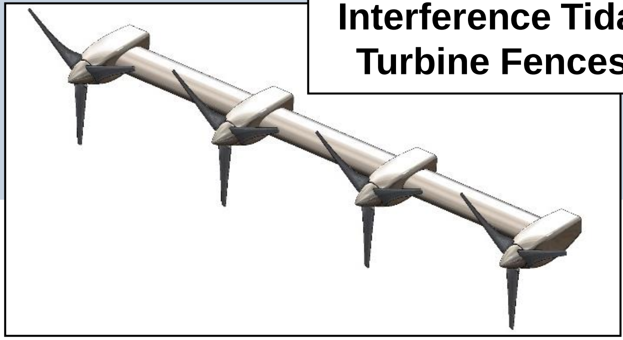
- **Tidal Energy -** device design and analysis; device-device interactions and tidal array design; large (basin) scale hydrodynamics and resource estimation. Performance enhancement through blockage effects; new energy extraction limits to replace Betz for tidal fences. (Spin-out Kepler).
- **Wave Energy -** dynamics and statistics of waves, and interaction with wave energy devices.
- **Offshore Structures -** robust designs to support off-shore structures, including wind turbines.
- **Ecological impacts -** assessment of human impacts on coastal and offshore marine ecosystems; mapping and assessment of biodiversity and ecosystem services (terrestrial and marine) using GIS and satellite technologies.

Tidal Turbines – *Design for Constructive Interference*

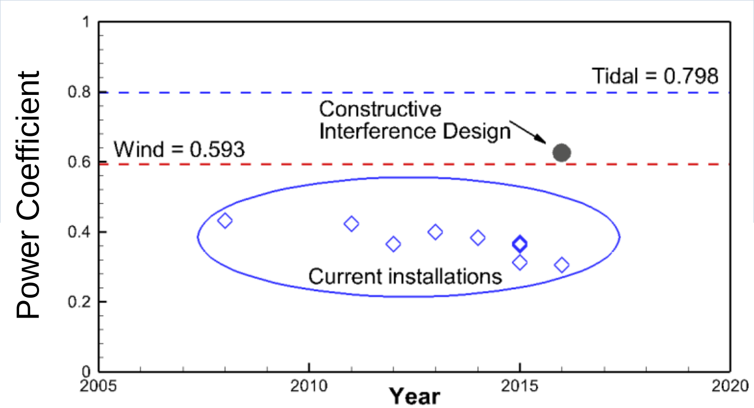
- **New theoretical limit** for a tidal turbine fence partially spanning a wide channel shown to be 79.8% (Nishino & Willden) (c.f. Betz 16/27 = 59.3% wind)
- Neighbouring rotors "support" each other using **constructive interference** (self-blocking).
- Oxford rotors designed using **bespoke coupled Analytical – CFD methods, outperform** conventionally designed rotors **by circa 25%.**
- Exploitation of constructive interference will lead to **significant reductions in LCOE** ... 10-20%.
- **Lab prototyping** through EPSRC Supergen & Fellowship (Willden), Altantis, EOn, NSFC (China), FAPESP (Brazil).
- Whole farm resource analyses through basin models.







Constructive Interference Tidal Turbine Fences



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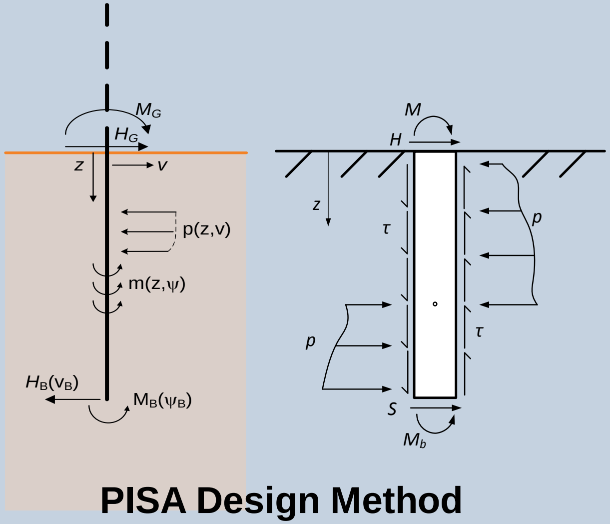
Offshore Wind – *New Geotechnical Design Methods*

- **PISA Project** – 2.5 year £3.5m industry funded project
  - New design methods for offshore wind turbine monopiles embedded in North Sea sands and clays
  - Savings of up to 30% on steel (~£300k) for each wind turbine monopile foundation
- **PISA2** – Industry funded project on application of new PISA methods for more complex soil profiles
- **ESPRC ALPACA** – £1.5m project on offshore pile design in chalk likely to lead to significant savings
- **E.ON/HR Wallingford** funded project on the effects of scour on offshore wind turbine performance
- Significant ongoing collaboration with **Ørsted**
  - rapid design calculations for suction caissons
  - cyclic loading of monopiles
- **EPSRC REMS CDT** - Renewable Energy Marine Structures
  - Oxford (Geotechnics) & Cranfield (Structural Integrity)
  - Atkins, E.ON, Fugro, HR Wallingford, Mott MacDonald, Ørsted

PISA Field Testing



PISA Design Method

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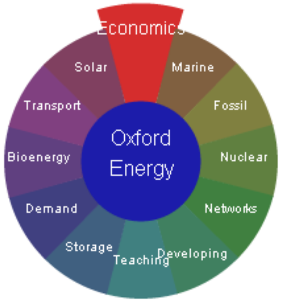
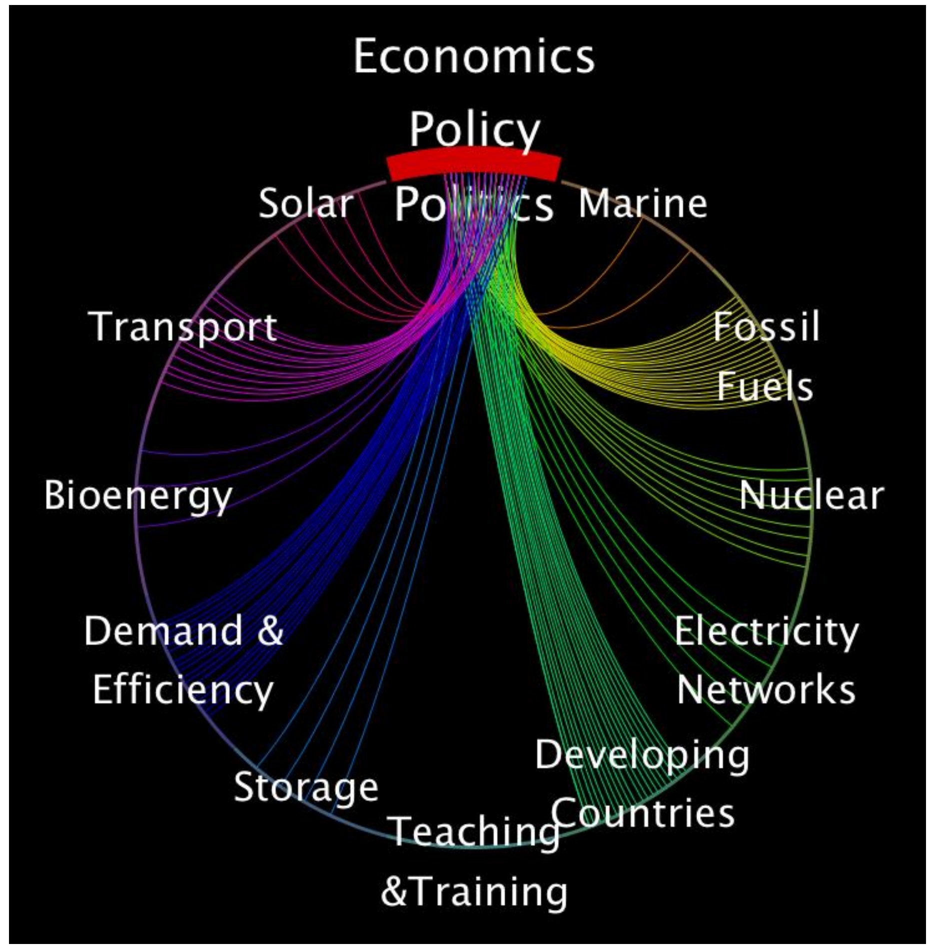


Economics, Policy, Politics, Law and Regulation

Work in Law, Politics and International Relations, Economics, Philosophy, Overseas Development and others + Blavatnik School of Government, the Low Carbon Futures Unit, the Oxford Centre of the Analysis of Resource Rich Economies, the Oxford Institute for Energy Studies*, the Said Business School, the Institute of New Economic Thinking, the Smith School of Enterprise and the Environment, and the Transport Studies Unit -some part of the work of the Oxford Martin School.

**Ranked the world's number 1 Energy and Resources Think Tank by the University of Pennsylvania in 2013, 2014 and 2016*

Note overlapping interests:



Economics, Policy, Politics, Law and Regulation

A few examples of topics:

Energy policy and market reform - bases for trade-offs, and the policies and legal and regulatory structure to give them effect. Advice on high-level government panels in the UK and abroad.

Energy resources and the next generation - questions of discounting and intergenerational justice related to energy resources and natural capital, with implications for current international negotiations and national accounting.

Energy system transitions - the political economy of energy, and economics and policies support innovation to accelerate the transition to an affordable clean energy system.

Recent work (much under the umbrella of Integrate)on: Border Carbon Adjustments; Peer to Peer Energy Trading; Stranded Assets; Climate change policy after Brexit; Encouraging Innovation that Protects Environmental Systems; Inducing and Accelerating Clean Energy Innovation with 'Mission Innovation' and Evidence-Based Policy Design; Reforming the EU ETS: Where Are We Now?… + Two Nature opinion pieces by Cameron Hepburn (Make carbon pricing a priority; Prove Paris was more than paper promises) + **numerous OIES papers** (sample of titles on next page)

Three examples →

OIES Publications form 1 October to 13 November 2017

- Assessing Kuwaiti Energy Pricing Reforms
- Completion Design Changes and the Impact on US Shale Well Productivity
- Local content and procurement requirements in oil and gas contracts: Regional trends in the Middle East and North Africa
- Gas and Taxes: The Impact of Russia's Tinkering with Upstream Gas Taxes on State Revenues and Decline Rates of Legacy Gas Fields
- Electricity market design for a decarbonised future: An integrated approach
- The Council Legal Service's assessment of the European Commission's negotiating mandate and what it means for Nord Stream 2
- Brexit Energy Security Enquiry
- Economic Adjustment and Reform in the Context of a Rentier State

Oxford Energy Forum

Four issues published so far this year. Issue 110, published 25/9/17:

Searching for Natural Gas Demand in the Next Decade

Is this the end of conventional wholesale electricity markets?

Niall Farrell, Cameron Hepburn, John Rhys, Jacquelyn Pless

Abstract: An important debate has emerged as to whether conventional wholesale energy markets alone can effectively guide electricity decarbonisation. In this paper we argue that capacity payments and/or long-term contracts will be required in most cases. Many renewable electricity technologies are intermittent; this increases price volatility and risk in inflexible systems. We show that current system structures create excessive risk in many markets, prohibiting adequate investment. **Capacity payments or long-term contracts will therefore be required to guide investment**. Wholesale energy markets will remain important for guiding allocative efficiency in operational decisions. Storage, interconnection and other flexibility services can offset much of this risk but the abundant quantities required are unlikely to transpire in the short to medium term.

Large Dams

Atif Ansar, Bent Flyvbjerg , Alexander Budzier, Daniel Lunn Energy Policy 2014

One in four came out on or under budget, *but 75% overran – on average by 96%; median 27%*

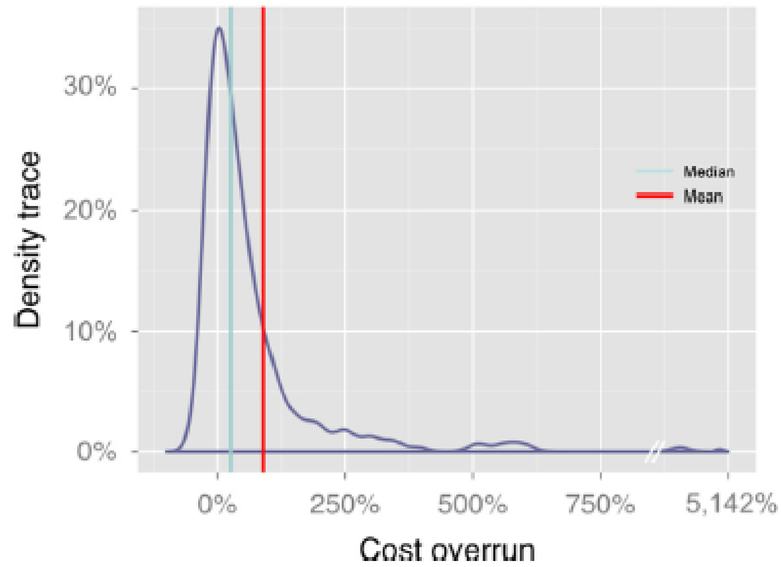


Fig. 2. Density trace of actual/estimated cost (i.e. costs overruns) in constant local currency terms with the median and mean ($N = 245$).

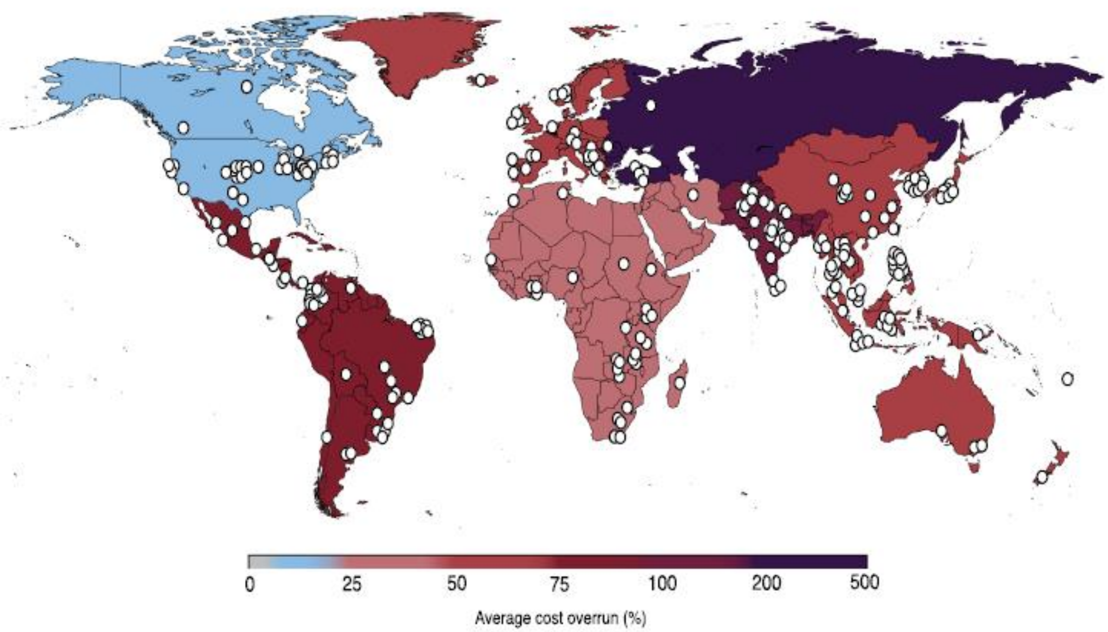


Fig. 3. Location of large dams in the sample and cost overruns by geography.

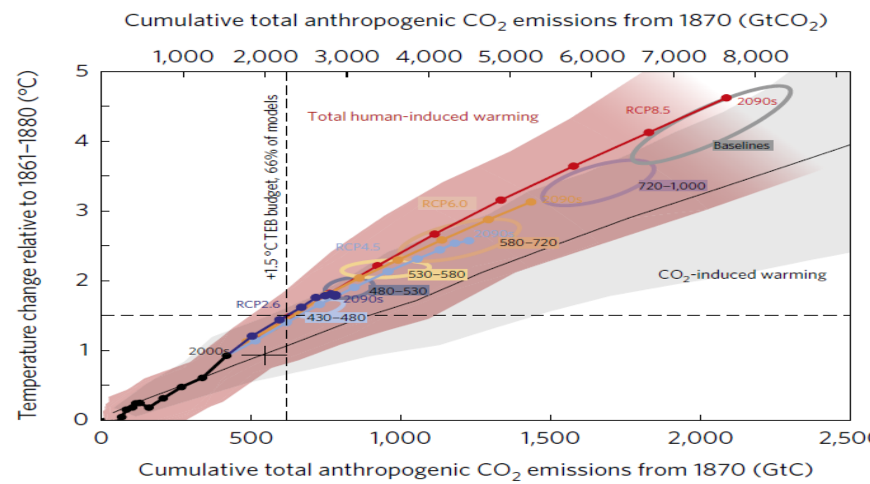
Recent Oxford work on climate change 1

Millar & Allen + others elsewhere; Pfeiffer, Caldecott, Hepburn, Vogt-Schilb in preparation

Millar et al note that observed warming is less than previous median estimate given carbon so far emitted

(although within errors)

→ **headroom for emitting CO2, while limiting climate change, bigger than thought**



In 66% of models, budget for emission of carbon since 1870 while keeping below

+ 1.5 C was thought (IPCC) to be 2,250 Gt CO2 of which 2,000 Gt CO2 emitted → room for 250 Gt CO2 more

*revised (Millar et al) to room for **750*** Gt CO2 more*

+ 2.0 C** was thought (IPCC) to be 2,900 Gt CO2 of which 2,000 Gt CO2 emitted → 900 Gt CO2 left

revised (Millar et al) to *room for **1,500**** Gt CO2 *more*

* Could be more depending on assumptions about forcings

** Climate feed-back uncertainties obviously increase with warming

Recent Oxford work on climate change 2

But Pfeiffer et al find that power generation, which currently contributes some 30% of CO_2 emissions, is on course to emit *much more* than 30% of the headroom:

-currently operating power generators* will → **308** Gt CO_2 **= 41% [21%]** of Millar et al's headroom in 1.5 C [2.0 C] case

-generators in pipeline* would *add* **271** Gt CO_2 **= 36% [18%]** of Millar et al's headroom in 1.5 C [2.0 C] case

* unless closed prematurely, underutilized or retro-fitted with CCS

reducing the very tight headroom for other *(much harder to decarbonise)* sectors and other GHGs

The Energy Network has

- Ensured calls for grant applications go to the right people

- Established and maintained the **web site** www.energy.ox.ac.uk (launched November 2013): 26,083 (different) visitors in the last 12 months - used as a resource for materials, events, research updates, by external partners to find key academics, and has attracted graduate student applications.

- Established an **Energy Steering Committee** (six members from MPLS; five from Social Sciences) – met twice/year: *needs to be revived, with external members*

- Convened **cross-divisional meetings** to assess/coordinate capabilities on topics of interest to members of many departments (energy demand, energy in developing countries, energy storage, batteries, the smart grid, bio-energy, solar PV biosynthesis for energy). These meetings - *which need to be revived* - have and positioned Oxford to respond to new funding opportunities, and led to new collaborations, grant applications, and programmes, e.g.

    WICKED (Working with Infrastructure, Creation of Knowledge, and Energy Strategy Development) - involves 5 Departments (Maths, Engineering, Law, Computer Science, ECI) + 7 external partners - would not have happened (or been as strong) without the network

    INTEGRATE - the Oxford Martin programme on integrating renewables; involves researchers from Materials, Engineering, SSEE, INET, ECI + various external partners. The Energy Network initiated and steered the bid.

- Fostered new **international collaborations**, e.g. through hosting Delegations from the Joint Centre for Energy Research (Argonne), Korean funding agencies (KETEP, KIER, KERI), the Chinese National Oil Corporation, Mexico, Brazil,... Helped Professor Kim identify expertise of interest to Samsung and Korean Funding Agencies and organised meetings which led to funding for some 15 groups (in 6 Departments).

- Convened cross university meeting to identify **Global Challenge Research Funding** opportunities

- Worked to strengthen **industrial links and support** in collaboration with the MPLS Business Development Manager for Energy, leading to substantial new support from companies new to Oxford (Samsung, Siemens, Systems, Upside, Hitachi…) while maintaining and strengthening on-going relationships with BP, Shell, British Gas, Schlumberger, EDF,… (see the web site for lists of industrial partners and Oxford energy spin-outs).

- Compiled overviews of Oxford's expertise related to

- **oil and gas** (spanning technology, policy, economics, markets & environmental impacts, used talking to majors) - in preparation for a major meeting with Shell (attended by members of 12 Departments), and
- **Electricity Networks** (spanning infrastructure, big data, markets, customer concerns, etc.); used talking to National Grid and Distribution Network Operators

EVENTS

The network organises **events** designed to spread knowledge, bring people together, create a sense of community, and strengthen external and internal visibility and engagement:

- Regular cross-divisional **Colloquium series (s**ince October 2014): attracts high profile speakers (Chief Economist, BP; Head of Scenarios, National Grid; former CEO of RWE, Head of eMobility, Siemens; European Commission, Executive Director of international Energy Agency,…); typically attract 50-100 people
- Annual Oxford Energy Day →
- Expert meetings in London →

Annual Oxford Energy Day

Open to all at Oxford, alumni and friends of Oxford energy; over 250 people typically sign up; costs covered by asking those working in the energy sector to pay if they can and sponsorship by Nature Energy; the meetings contribute to the energy debate and help foster a sense of community in Oxford and good relations with our collaborators.

- 2012 Can Renewable Energy Deliver?
- 2013 UK Energy Policy
- 2014 Transformative Change
- 2015 Integrating Renewables
- 2016 Energy Systems
- 2017 Energy in Growing Economies

Ideas for future topics?

Biannual invitation-only **Meetings** in London, under the Chatham-House-rule, **for senior stakeholders** (MPs, government, industry, media), since December 2013

Meetings (typically 60 attendees) contribute to energy debate and are a show-case for Oxford's expertise. Introductory talks + anonymised reports posted on web

- Shale Gas: Game Changer or Side-show? *Hosted by RBS*
- Who Should Decide the Energy Mix in a Central Buyer Market? *Held in House of Lords, courtesy John Krebs*
- The Future of Nuclear Power in the UK. *Hosted by BlackRock*
- UK Energy Efficiency Policy What Next? *Hosted by M&S*
- Energy Storage: Why, What, When? *Hosted by BP*
- Decarbonising Heat. *Hosted by the National Grid*
- The Future of Road Transport. *Hosted by Arup*

Ideas for future topics?

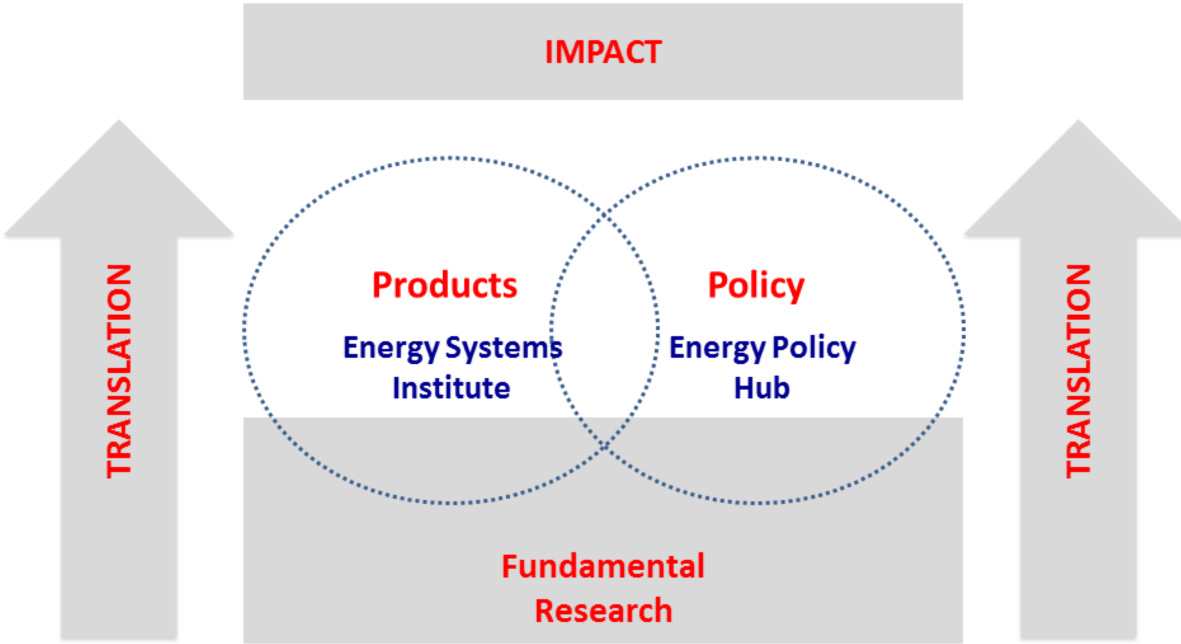
- Supported Estates in implementing the **Oxford Carbon Innovation Programme** created links between academics and estates; facilitated events, hosted website, produced promotional material, including video – *need to create web pages on local engagement*

- Created **mailing lists of nearly 1000 subscribers** (including 200 senior researchers, 200 RAs and Post Docs) plus 750 alumni, and established a **data base of alumni** who work in energy related industries, and a Linked-in group – *is it used?*

- Produced three editions of the Oxford Energy Newsletter - defunct: *should it be revived?*

- With MPLS **Development** Office, have generated some funding for DPhils. Drafted (but not used) an Energy Development Plan, which described the case for establishing/filling Chairs in areas that would strengthen energy work across several Departments, supporting NEST, funding studentships, and pump-priming funding for novel/highly multi-disciplinary research – revive/Update?

Future Plans/Wishes



Structural: Create **Energy systems Institute**, strengthen **Policy Hub** – pull together with network

New leadership posts: Bioenergy, Energy Economics, Energy Policy, Power Engineering, Vehicular Mobility, Integrated transport

Graduate scholarships + **new doctoral learning programme**

Energy Opportunities Fund

Group of **Friends of Oxford Energy**

Teaching

- The network was involved in establishing the **energy DTC-lite** and the **NEST**@Oxford programme.
- Now strongly supporting the proposed **MSc in Energy Systems**

Outreach

I (and others) have used my participation in energy meetings round the world to develop useful contacts to Oxford/promote Oxford Energy* + as advisor to the new World Energy Council-UK Foundation, established/strengthened links (at CEO level) with many of the UK's major energy companies

* energy talks 2011-17: 46 internal + 17 UK + 37 international

Key Benefits of the Network

- **Intellectual** – linked people with different disciplinary skills who are addressing common or related problems, which has enhanced their work and led to new collaborations; the energy colloquium is improving energy expertise among faculty and students, who have appreciated NEST. Meetings have increased Oxford's impact on national energy debate

- **Reputational -** raised Oxford's profile and reputation as a centre of broad excellence in energy research, according to comments by many Alumni and contacts in industry and other universities. After a meeting (organised by the Network) between the EPSRC energy team and 40-50 Oxford researchers, to discuss their and our strategy and help them prepare input for the then next spending review, EPSRC stated that 'Cambridge is four years behind Oxford in joining up energy'.

- **Recruitment.** The web site attracts DPhil students and post-docs.

- **Tangible.** Hard to quantify (some initiatives the network has fostered might have happened anyway; delay in tangible impacts of reputation; pointing to Oxford's strong/joined-up energy programme strengthens grant applications, but not possible to know if it changed the outcome,) but there are a number of identifiable hits (some of which I have mentioned)

Future Plans (some need new coordinator in place)

- Continue Colloquia, Energy Day, London Meetings,… *other events?* Web – update, add local connections,… *other ideas?*
- Renew/re-activate spokespersons for each sector of the wheel
- Convene subject meetings, in conjunction with spokespersons
- Renew Steering Committee, with externals members
- Review relations with industry: new round of meeting with major companies
- Review (up date list of) international links
- Support MSc
- Revive NEST (as part of MSc?)
- Revive Newsletter?
- Review mailing list
- Try to get better list of post-docs and DPhil students
- Keep Energy on Development Office's Agenda. Revisit Development Plan?

Serendipity!