Technology Strategy Board

Driving Innovation

Energy Harvesting: Watts Needed? Workshop

Royal Society, Carlton House Terrace, London

13 September 2011

Contents

You can read this record in five minutes – just scan the headlines

Executive summary

- Delegates met to discuss how the Technology Strategy Board could best develop an energy harvesting technology (EHT) industry in the UK
- They
  - listened to presentations on EHT from academic and industrial perspectives
  - identified and characterised commercial opportunities (from the niche to the mass market)
  - identified component-, system- and application-level challenges facing EHT
  - discussed potential interventions at length, and voted for their choice of intervention type
  - built a directory of UK EHT capability
- The TSB gained valuable insight into the ways in which it could help the industry, which may include
  - Fostering multi-disciplinary R&D to overcome specific basic challenges
  - Helping to establish demonstrators (possibly built round “grand challenges” in a few promising application areas)

Process – what happened

John introduced the agenda and key question for the day …

- Delegates introduced themselves – there was a mixture of academics and industrials as well as TSB and KTN members

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Question for today...

How can we accelerate the development and growth of this industry area in the UK ?

...where are the commercial opportunities?

...and in what ways can the TSB *best* enable, support and promote commercialisation?

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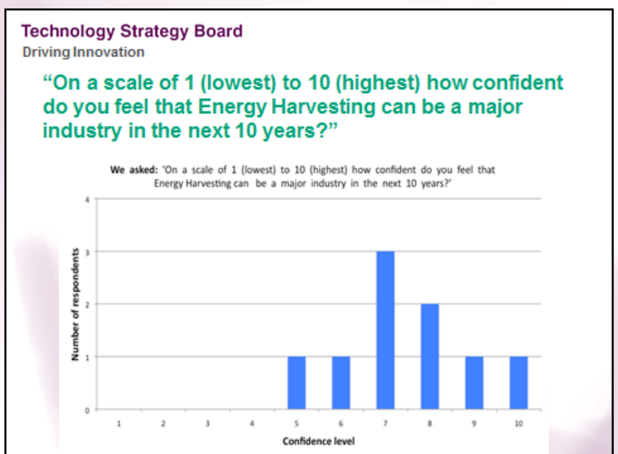
Agenda

Time	Activity
09:00	Arrival and registration.
09:30	Welcome and orientation from the Technology Strategy Board The Emerging Technologies & Industries Programme Some initial feedback from our general question
09:50	Thought-provoking presentations from: Douglas Paul, Glasgow University Simon Aliwell, Zartech Ltd Steve Turley, Perpetuum Ltd Martin Kemp, Nano KTN Steve Burrow, Bristol University
11:20	Short break.
11:40	Identifying the most significant opportunities, challenges and barriers
13:10	Lunch
13:50	Prioritising the opportunities and challenges; identifying what needs to be done to address them and the best approaches to take

… and explained how the TSB had decided that energy harvesting was important

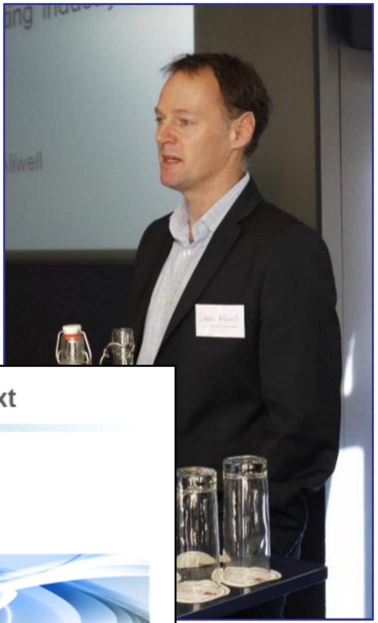
- John explained the role of the TSB and how it worked to stimulate emerging technology industries in the UK
- John talked about the aim of the programme – and the rigorous process it had used to arrive at a short list of four technologies to focus on
- He referring to a pre-event survey finding about confidence in building the industry



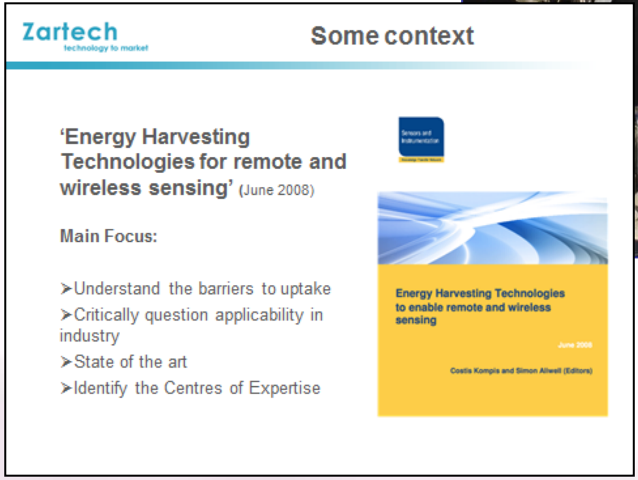
Slides from John's presentation are in the Annex – slides 49-62

Simon Aliwell gave his perspectives on the energy harvesting industry

"In the last three years there's been an explosion of interest from end users, but it's the same companies active in the space, and apart from smart buildings and condition monitoring there is not much evidence of actual take-up"



"Managing expectations was important to the industry three years ago, and it is now: what can realistically be done with energy harvesting – is it about managing and extending battery life?"

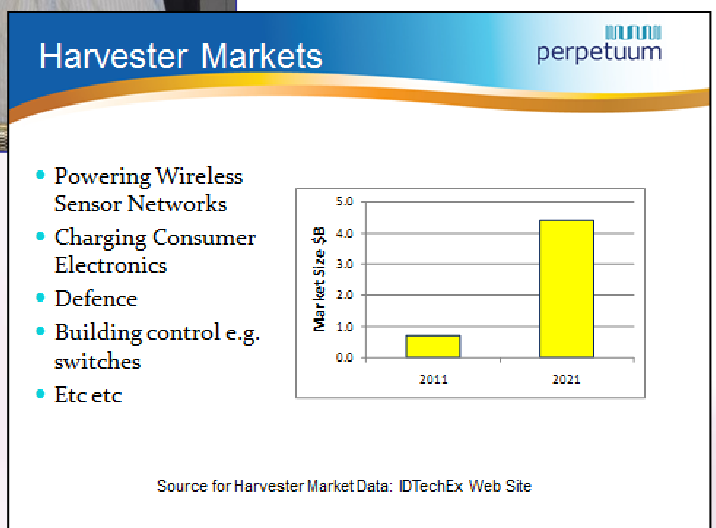


Slides presented and notes are in the Annex – slides 63-74

Steve Turley presented on EH technologies, and vibration in particular

"Battery technology is very important – a reliable rechargeable battery opens things up for EHT very substantially"

"In the industrial market, working with the big system providers like Emerson, GE, Honeywell, and Siemens is very important in building credibility"



"Field trials within the UK community, enabled by TSB and involving component and system makers and end users are incredibly useful in moving things forward (eg in the rail industry)"

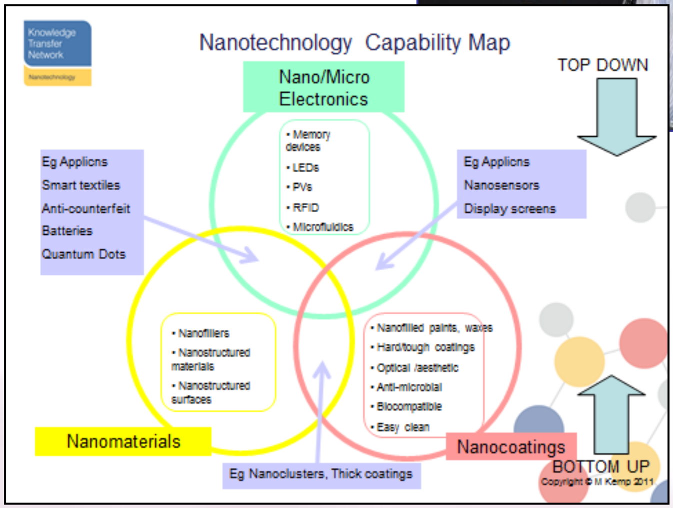
Slides presented and notes are in the Annex – slides 75-93

Martin Kemp explained the significance of manufacturing for different EH technologies

"Nano and microtechnologies offer a new toolkit for making things, and there are synergies from mixing and matching manufacturing processes"

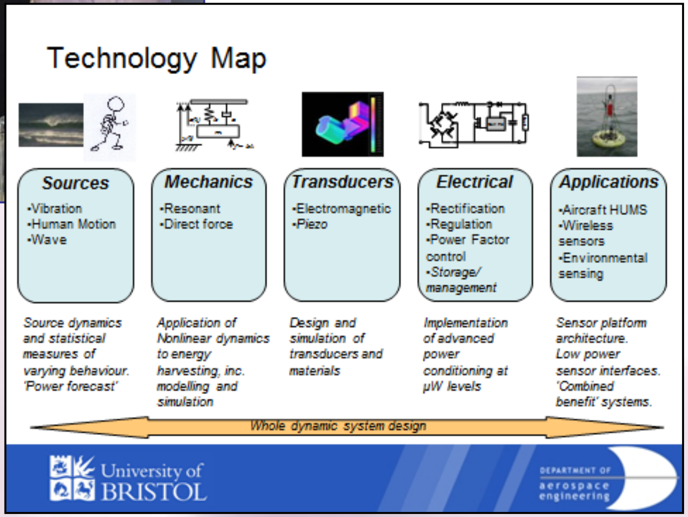
"Storage and EH should be co-developed because they are intrinsically linked"

"Energy harvesting should target end uses, supported by a strong business case – otherwise it'll be technology looking for a solution"



Slides presented and notes are in the Annex – slides 94-116

Steve Burrow summarised academic research in each component of an EHT map



"In the EH field, academic research in the UK tends to have an electrical focus; in the US it has more of a mechanical focus"

"The technology map shows stovepipes that are broad enough to satisfy academics, but EH R&D needs to be considered more broadly for commercial success - cross-disciplinary R&D is required here; there are all sorts of trade-offs to juggle"

"Applications can have combinations of benefits – such as vibration reduction for rucksacks or helicopters – as well as electricity generation"

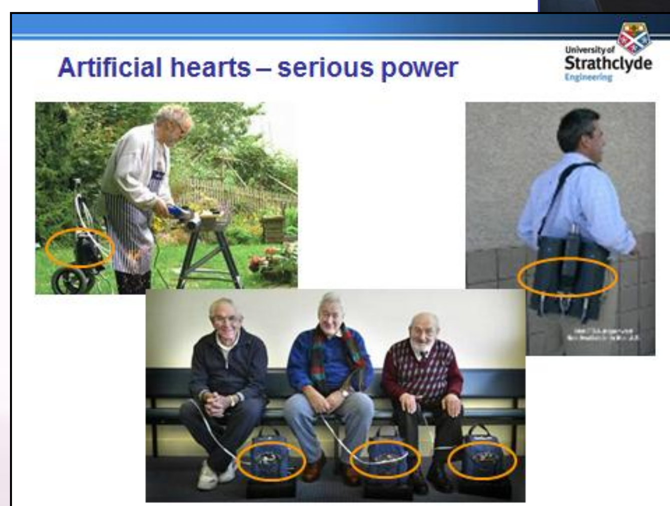
Slides presented and notes are in the Annex – slides 117-131

Martin Judd spoke briefly about medical opportunities for energy harvesting

"There are many advantages to EH for implanted devices, an opportunities, such as insulin pump power"

"There are lots of 'gadget' things that can be done – harvesting energy from clothing or sound…"

"The heart is very demanding from a power perspective – it needs serious power and is probably a step too far for EH"



Slides presented are in the Annex – slides 132-137

Douglas Paul presented on thermoelectrics and work at Glasgow

"Impedance matching is a critical engineering challenge"

"Peltier coolers are currently very inefficient but the could be made much more efficient"

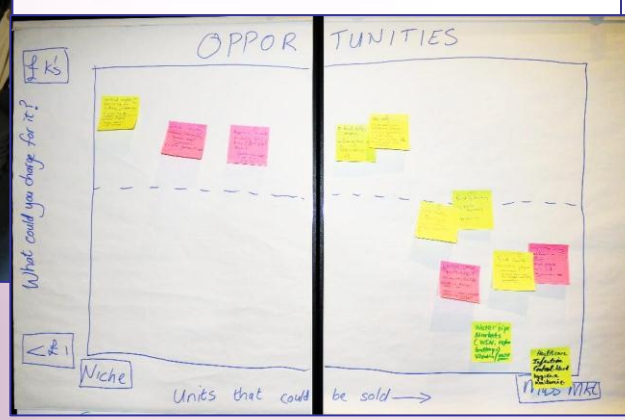
"Thermoelectrics can use a ubiquitous, static energy source; and at small scale can have good efficiency compared with thermodynamic engines"

"Replacing Tellurium with Si, Si/Ge and other exotic materials could increase efficiency and make use of current manufacturing processes"

Notes are in the Annex – slides 139-141

Delegates characterised potential applications and fed back their best ideas

- Simon gave some examples – aerospace application to save weight and power, or medical applications (high-value devices); tyre-pressure monitoring for cars, to replace batteries (low-value, high-volume devices)
- He also encouraged delegates to complete the flip chart of UK EH capabilities



Results of this exercise are in the Outputs section – slides 18-26

Delegates then considered challenges at component, system and application levels

- "Bear in in mind the opportunities just presented, and think about the challenges – some challenges will be application specific – others will be generic across applications"

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Challenges/barriers

Component level	System level	Application level
What & why?		

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Results are collected in the Outputs section – slides 27-31

After lunch John explained the interventions available to the TSB …

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TSB Interventions – John Collins

1. **Invest in Technology Demonstration**
   - Technology Demonstrators
   - Application Demonstrators
   - Market Demonstrators
2. **Build Critical Mass**
   - Additional Innovation & Knowledge Centres (IKCs)
   - Other methods (Clusters, SIGs, other?)
   - Help identify early adopters: SBRI, Innovation Platforms

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TSB Interventions – John Collins

3. **Create a Coordinated Programme**
   - For the entire UK
   - Bring together partners / funding agencies
   - Prioritise core high potential ET & their Industries
   - Emerging Technologies & Industries Steering Group (ETISG); challenges, technology and investment
4. **Build and Nurture Capacity**
   - Identify & nurture skills & entrepreneurship
   - Monitor effectiveness & modify / shape programme

… and the whole group considered which made most sense, then voted with dots

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What should we do to make a difference?

Discussion-framing questions:

- How might it work?
- What would it achieve that isn't already happening?
- How should it be focused?
- Who should be involved?
- What is missing?

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You are the investor…

- You have 5 votes (sticky dots) to distribute amongst the various interventions
- Spread them or concentrate them, its up to you
- We want to see what interventions have most support

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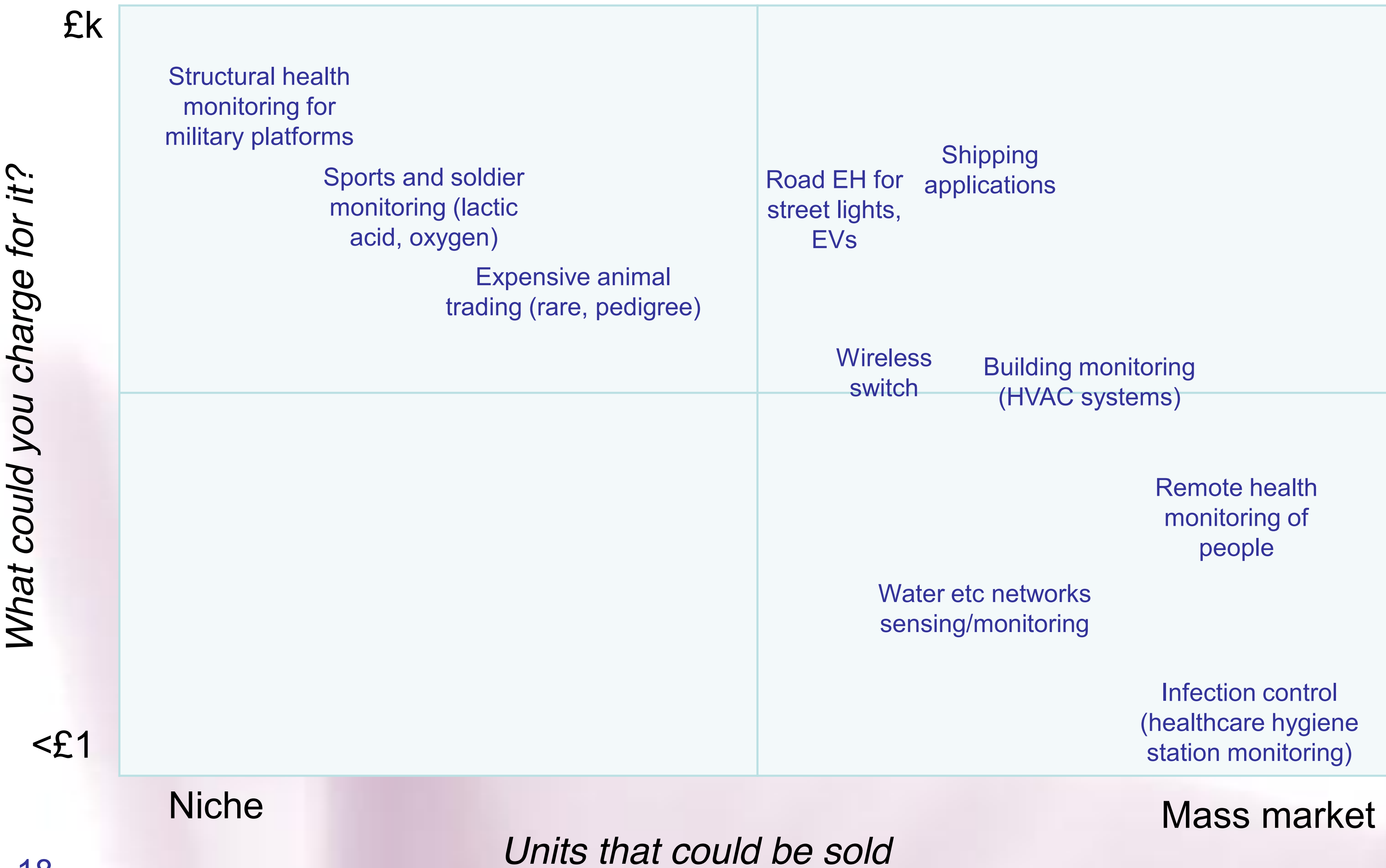
- John then wrapped up, thanking delegates for the their efforts during the day. He said the TSB would rapidly review the workshop output and get back to delegates

Voting and discussion notes are in the Outputs section – slide 32-45

Outputs – what was created

Opportunities (best)



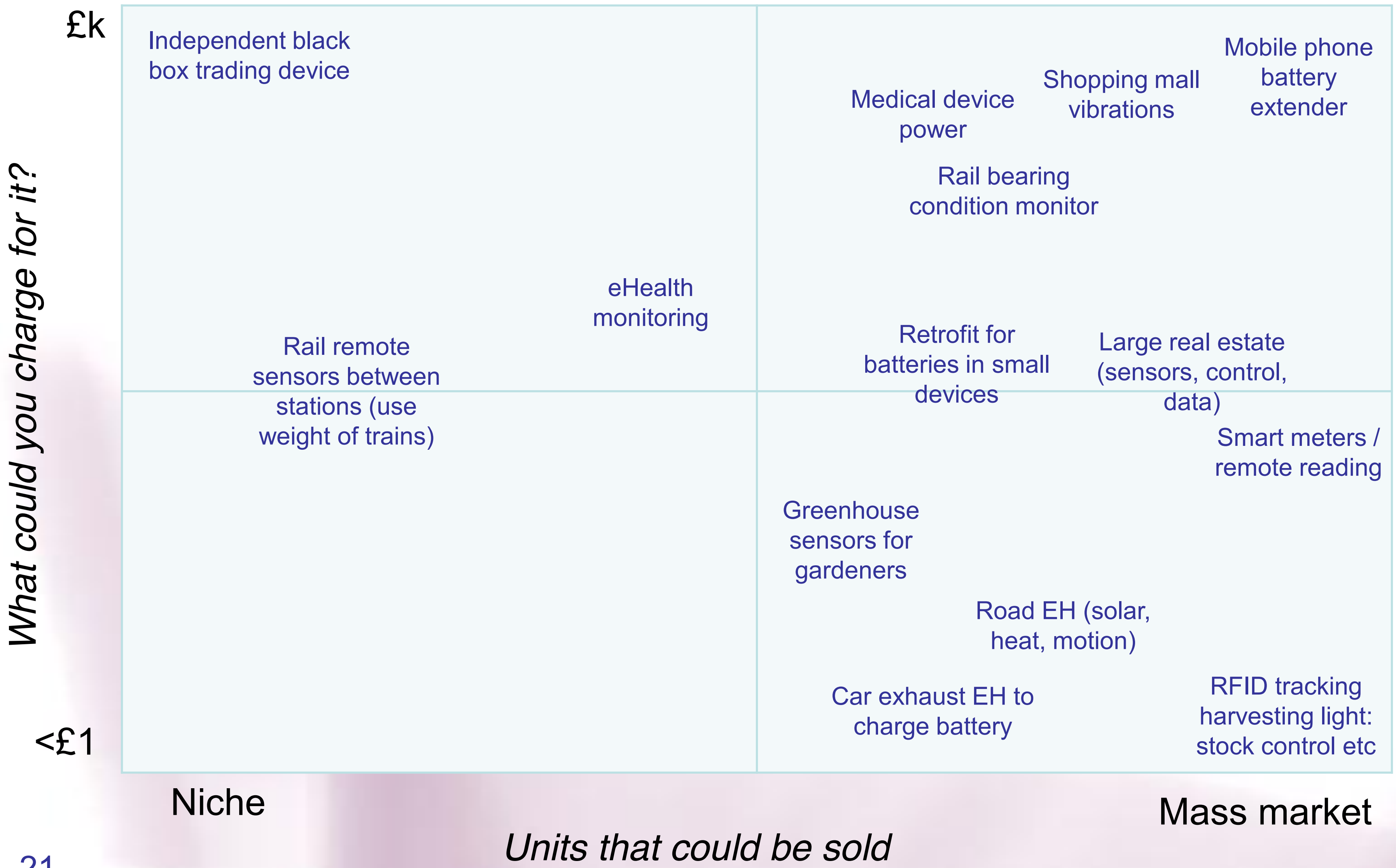
Presentations back of best opportunities [1]

- Sports monitoring, and monitoring soldiers' vital signs (two apps here for same tech)
  - Defence and sports (high-value in elite sports to work out when you pull off your best player)
  - Same tech could also be used in healthcare market (much bigger but needs more capital)
  - Build up your business in a niche market then transfer to bigger market where clinical trials are required
- Building monitoring (energy and smart buildings) – we are thinking about aircon ducts where there is wired infrastructure, but more can be done to make easy-to-fit and use monitoring systems with EH (no solar options etc)
- EH from roadways (streets) – need for more smart road infrastructure for monitoring and traffic lights etc. Lots of stuff needs to be installed where there isn't mains power – so EH works well here (no digging, disruption)
- Got to go into places where access is hard to change batteries – or it's a convenience thing: so – healthcare (remote health monitoring of people – granny monitors and diabetes monitors etc) – where people aren't capable of recharging or it's inconvenient
- Wireless switch for heritage housing (retrospective wiring)

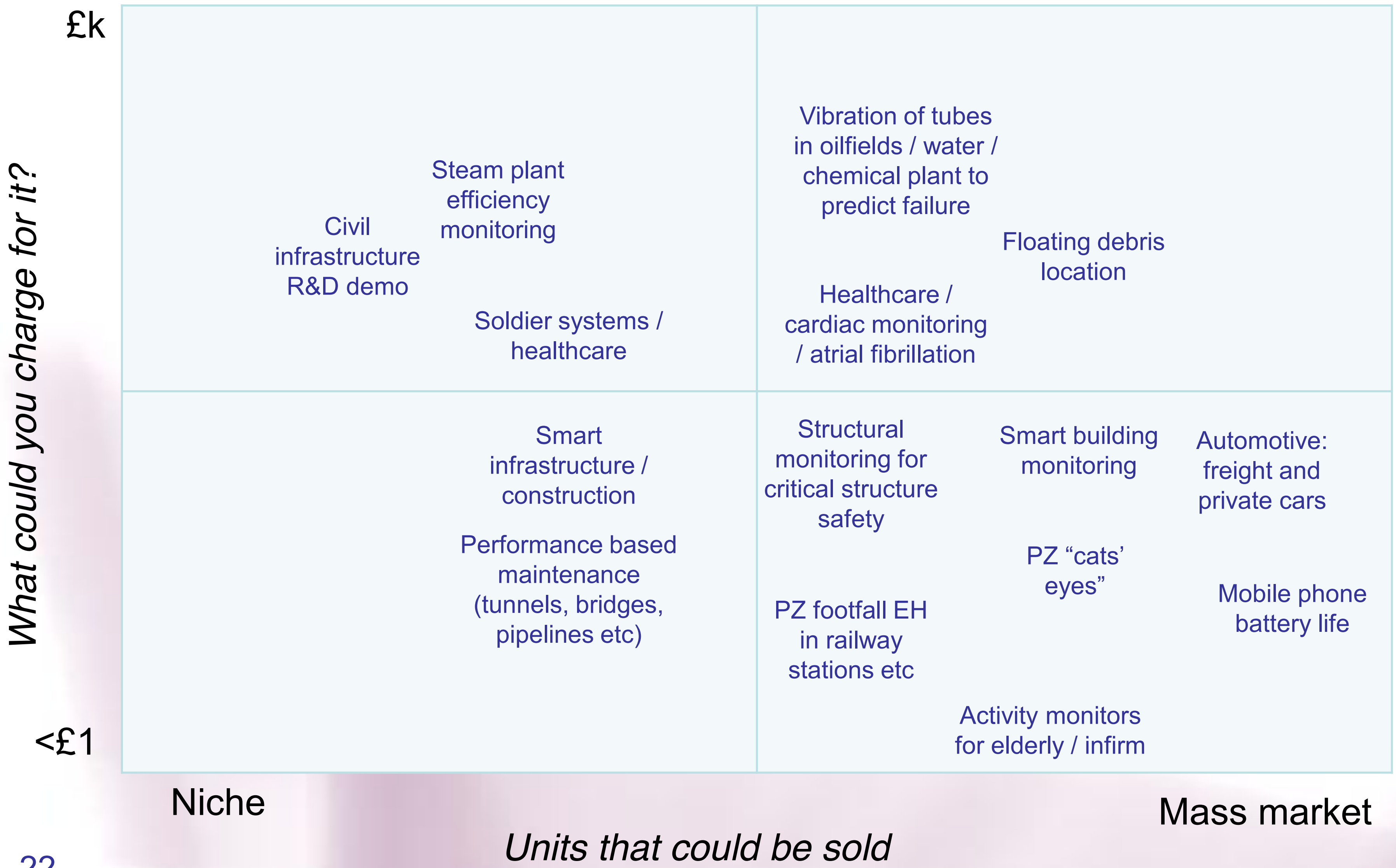
Presentations back of best opportunities [2]

- Shipping – no scope for grid power, and can't store enough for big voyage, and there is increasing pressure on energy efficiency: so there's potential for EH here – not just for monitoring purposes, but everything except motive power – will pay lots here (at least price per watt) – large industry
- Health monitoring for the military (use of EH to monitor soldier health and position and position of vehicles)
- Sensors in soap and gel dispensers – can build up picture of health compliance – a niche app, but pilots are already running
- Vibration for megastructures (oil rigs, nuclear power plant etc). The market is big – and instrumentation and control is something the UK is very good at (mass market / low cost)
- Smart meters – legislation requires deployment – but also can be used for leak detection instrumentation
- Expensive-animal tracking: rare horses, pets, pedigree stock – high value but not necessarily v large – could be extended to other tracking apps eg of food

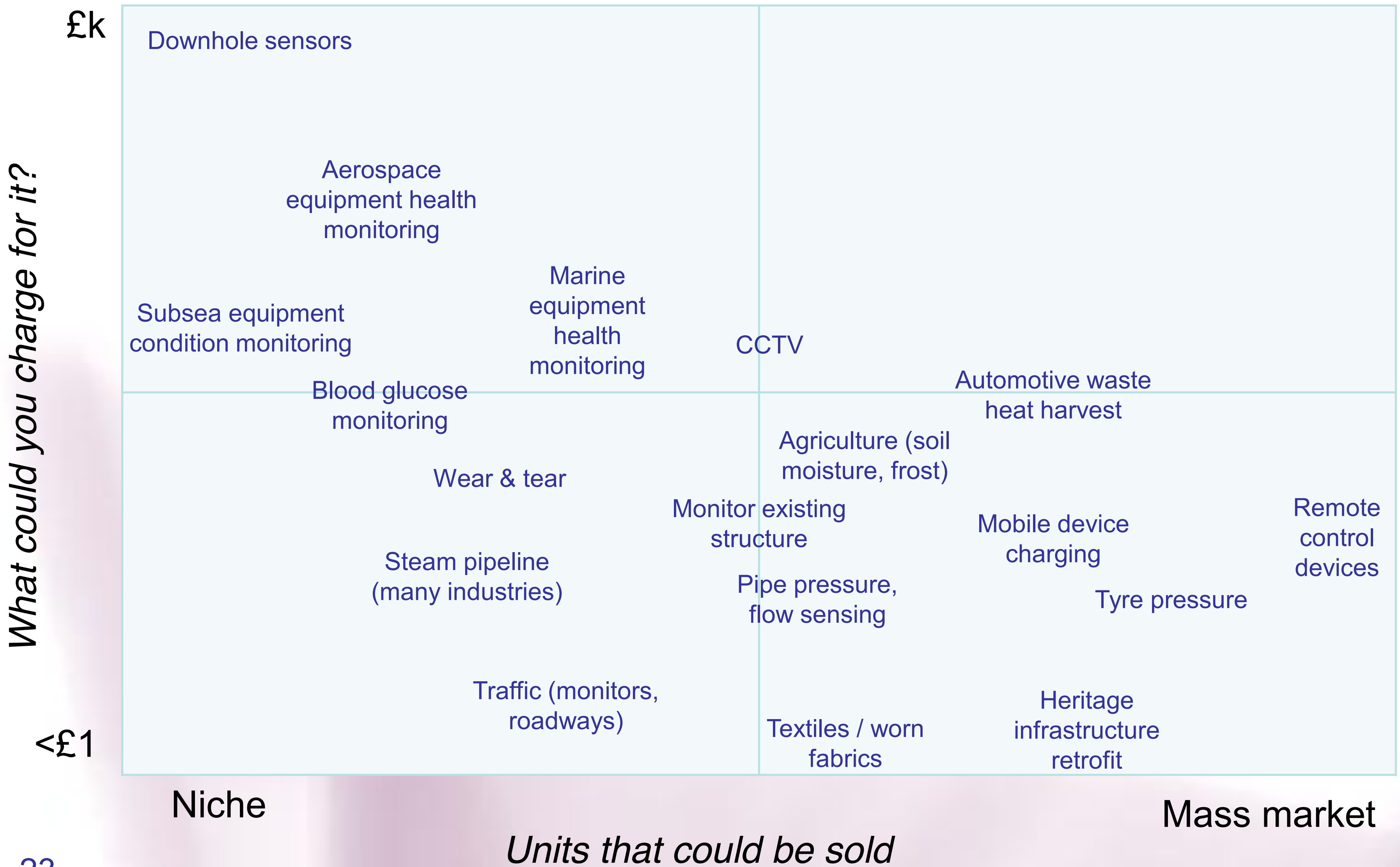
Opportunities (rest – table A)



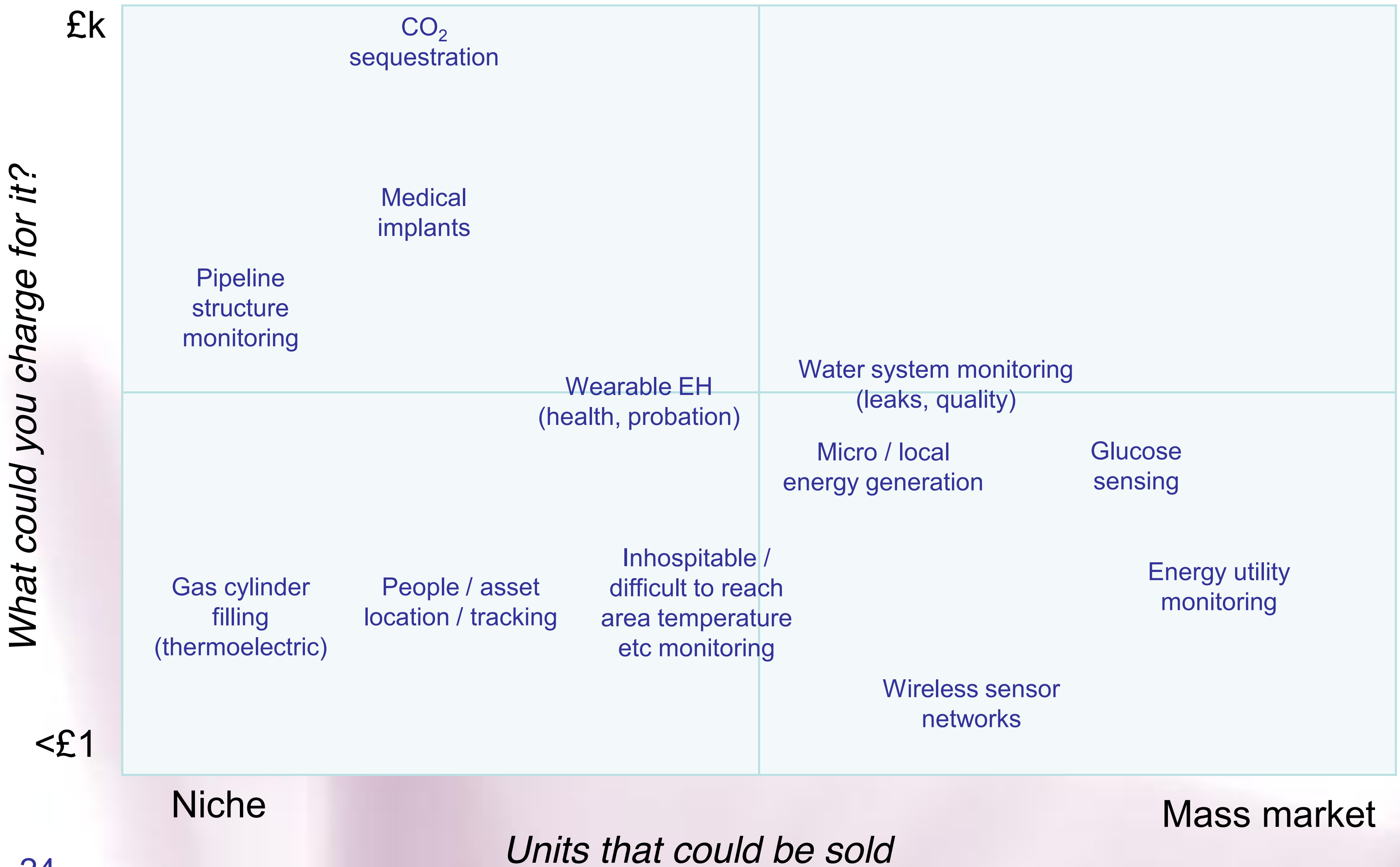
Opportunities (rest – table B)



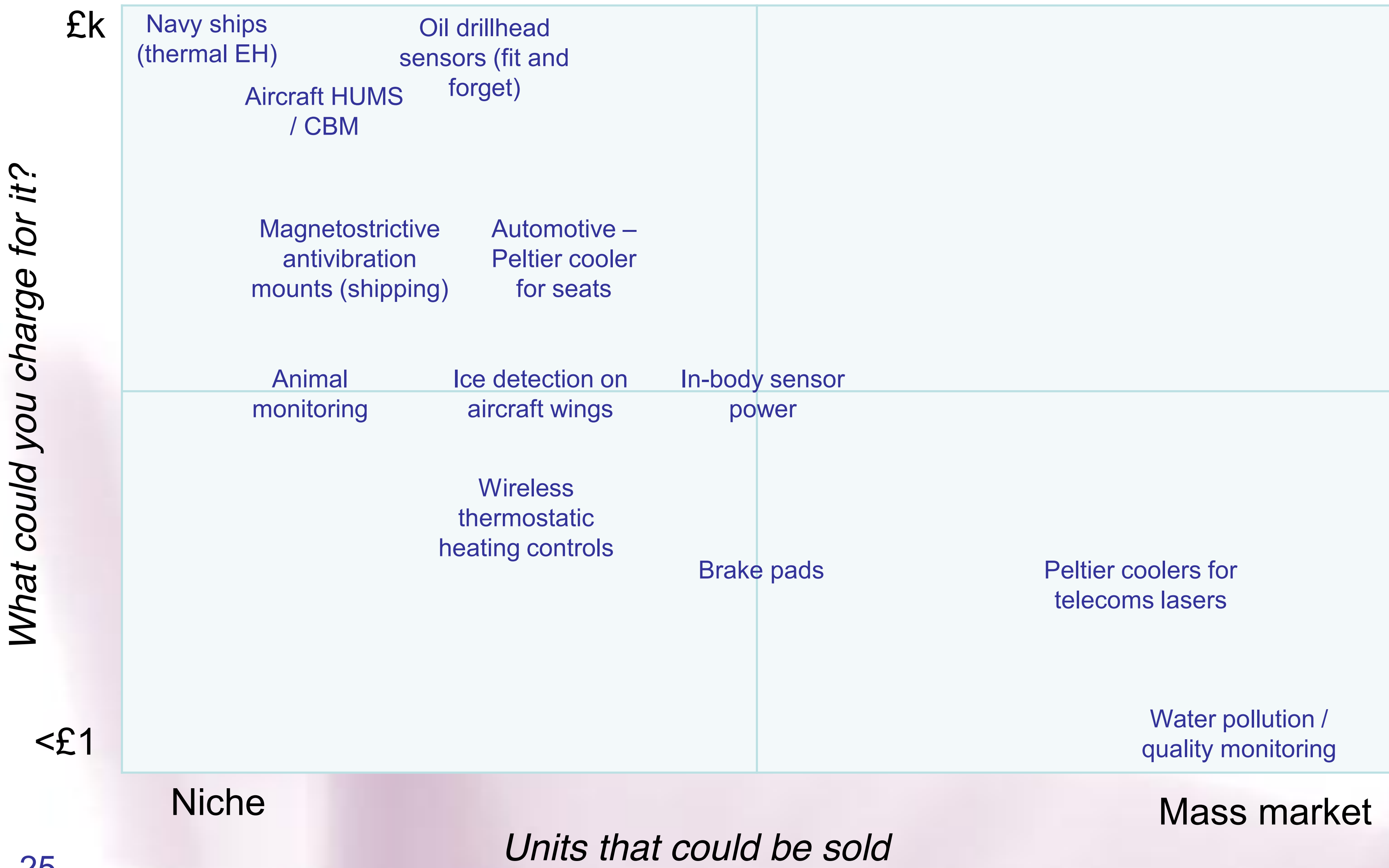
Opportunities (rest – table C)



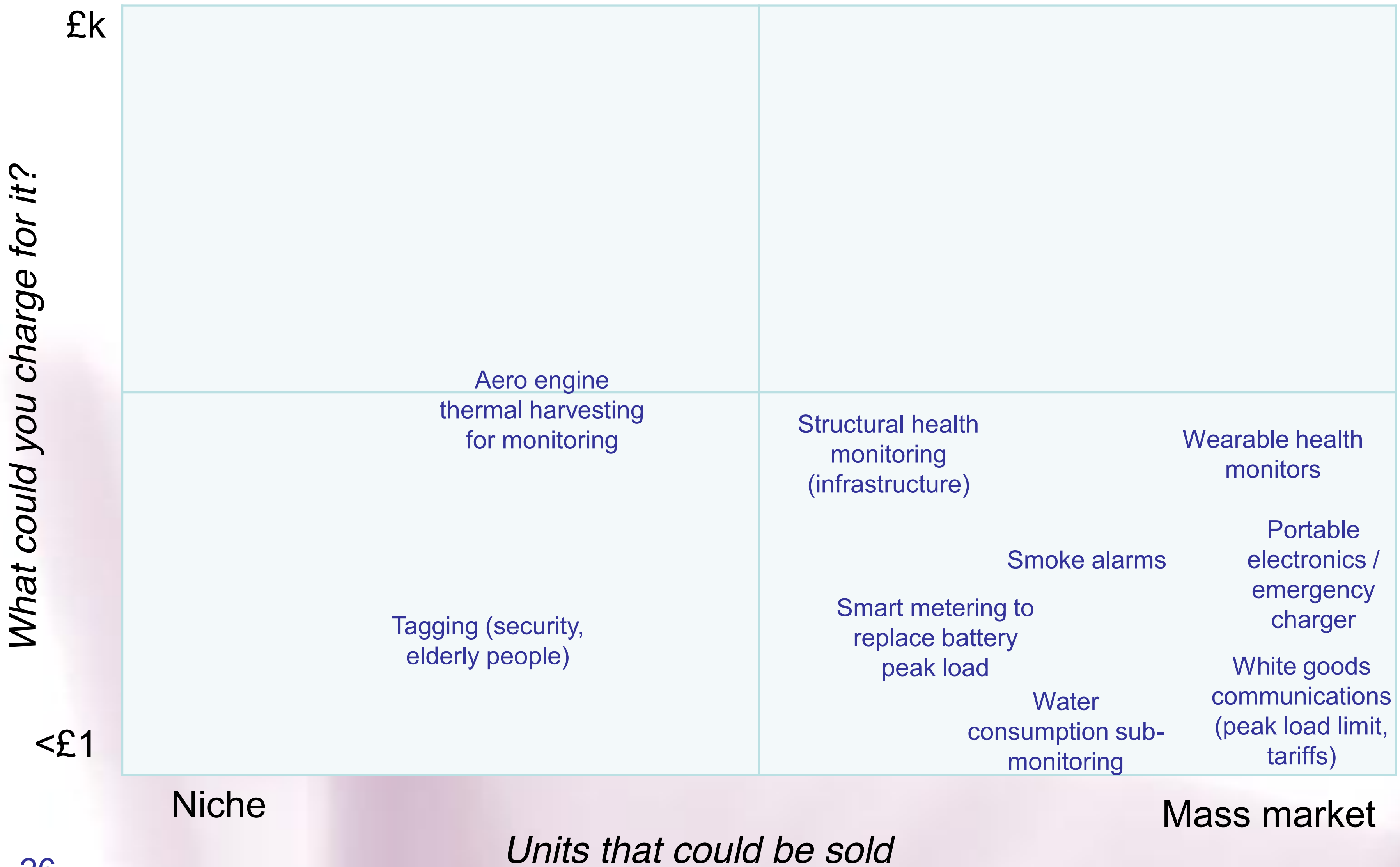
Opportunities (rest – table D)



Opportunities (rest – table E)



Opportunities (rest – table F)



Component-level challenges (aggregated, deduplicated and grouped)

- Rare-earth element supply / sustainable materials (especially if EH goes mass market)
- Materials substitution (Pb, Bi, Te) and exotic materials (cost, availability, legislation)
- Disposal, recycling
- Flexible materials (fabrics, threads)
- Availability of components, materials
- Reduce cost of active materials
- Improving energy conversion efficiency of thermoelectric generators
- Device efficiency improvement
- Maximising component life (low energy)
- Extending battery / supercap life
- Energy storage (capacitors, batteries)
- Size, energy density
- Antenna size for communications
- Sensors: availability, novel types, efficiency, power requirements
- New physics
- Component integration (on to one chip)
- Durability / hostile environment
- Manufacturing techniques
- Energy lifecycle (extraction -> reuse)
- “Start-up” electronics problem
- Cost / benefit

System-level challenges (aggregated, deduplicated and grouped) [1]

- Integration (inc sensor and storage, and power generation and storage – matched device)
- Impedance matching for energy extraction
- Reliable charge / release of energy (battery, capacitor)
- Harvested energy storage
- Better power management
- Power output / cost
- Low-power electronics
- Electronics / storage for scalable networks
- Scalability
- Retrofitting for circuits developed with batteries
- Form factor (overcoming the battery standard)
- Broadband connection
- Communications protocols are not low-power
- Limits on power and distance in communications
- Self-tuning (wideband)
- Innovative sensing (indirect measurement)
- Total energy (sum of parts)
- Generic solutions
- Holistic design
- Break the status quo in system design
- Institutional culture

System-level challenges (aggregated, deduplicated and grouped) [2]

- International approvals
- Rapid solution deployment
- Technology reuse (cross-domain)
- Protection and retention of IP (software a big challenge)
- How to do hybrid energy harvesting
- Measuring energy harvesting potential per location
- Lack of engineering tools for simulation without building a demonstrator
- Standards for performance comparison
- Robustness, inc housings (extreme climates, human treatment) and reliability of EH
- Funding models
- Concept demo and verification

Application-level challenges (aggregated, deduplicated and grouped) [1]

- Cost per watt
- Power requirement and consumption
- Low-power sensing and communications
- Up-front costs (requirement for legislation)
- Demonstration (who takes risk of demo investment; generating track record on performance)
- Reducing cost and proving RoI
- Business model
- Mass marketing approaches (Apple AppStore model)
- Time and route to market
- Finding common denominator among multiple applications that warrants development cost
- Real-life demonstrators and system monitoring trials for long-term (> 1 year)
- Government incentives
- Legislation (eg in healthcare) / regulation / certification
- Standards (for comparison, compatibility)
- Education, training, skills, knowledge, experience
- Attitudes / aptitudes
- Long-term reliability and robustness
- Retrofit capability
- Small enough to fit; simple enough to forget – “simple fit”
- Operating environment
- Specific solutions for infrastructure
- Soldier applications (healthcare)

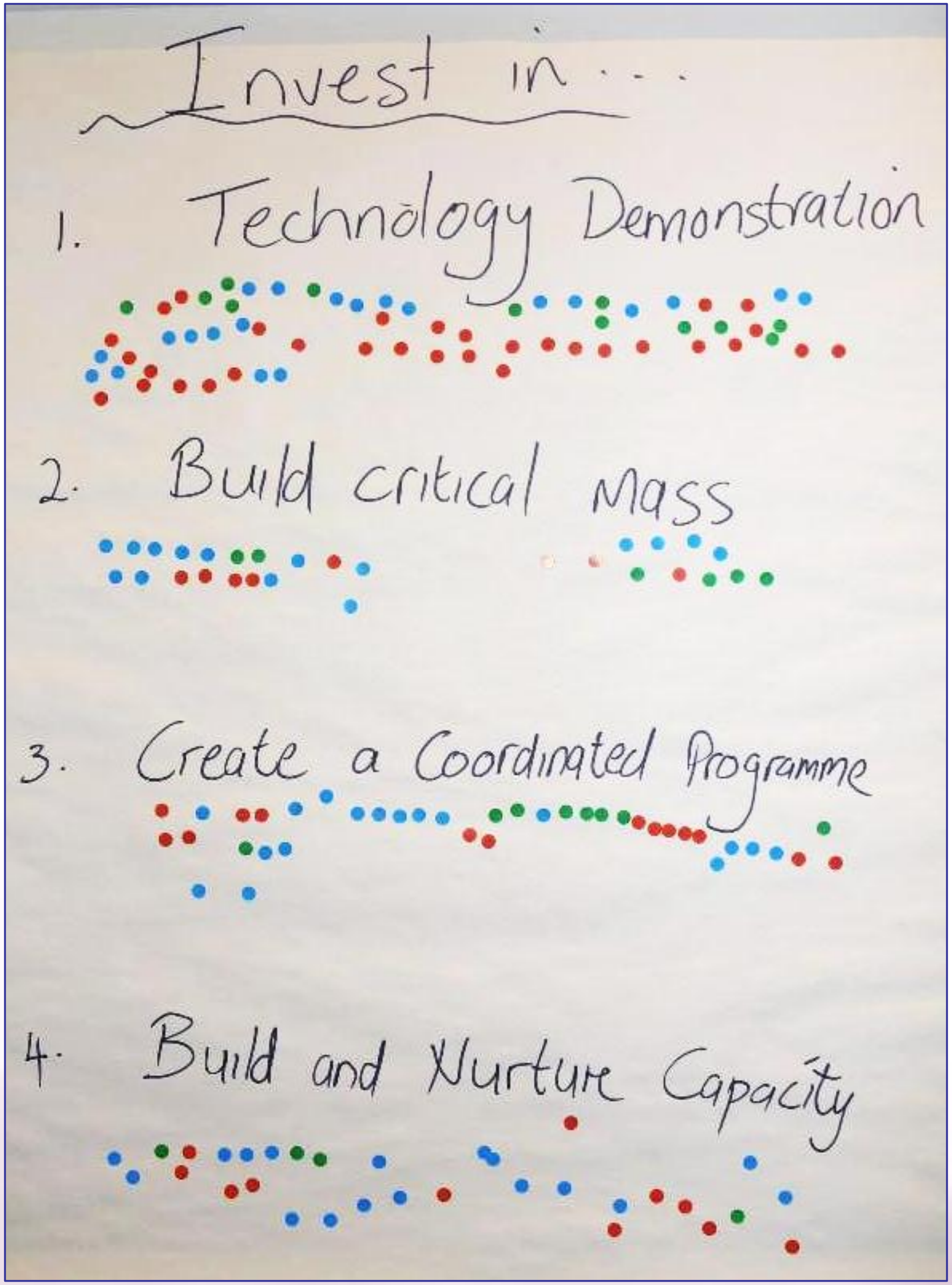
Application-level challenges (aggregated, deduplicated and grouped) [2]

- Lack of awareness from end users
- Public perception and convenience
- Misinformation from hype
- Consumer confidence in non-constant energy source
- More development kits
- Multi-disciplinary design teams

Voting for interventions

Note:

- *Academic* (red)
- *Industry* (blue)
- *Public sector (mostly TSB)* (green)



Discussion of interventions [1]

Invest in demonstrators

- There is a lot of potential for a "sector demonstrator" – for a sector where there's a clear demand (eg condition monitoring in aerospace) – it would be appropriate for TSB and research councils to invest in a physical test facility (hosted at an academic campus) for universities and others to use to test and compare their technologies (it's not putting money to a single company – it's a UK facility). I'm not sure what the sectors should be – there may be better examples that aerospace
- There is this type of organisation already – the health design and technology institute in Coventry serves the healthcare industry, but they're not aware of energy harvesting – so perhaps we should let them know about what they could do
- So this would help in building a coordinated programme
- At the other end of the scale, kits is a good idea – it would be great to have some available. I'm talking eg about a piezoelectric EH kit (I bought one, but it wasn't very user friendly). Something you could buy that you could retrofit into an application to test feasibility. I think it could be based on existing technology to help spread the message as technologies are moving forward
- There's a lack of capability on mechanics in the UK; a demonstrator could help. These should be available in a way that allows academics and others to dismantle existing technology; also earlier-stage demonstrator kits would be useful

Discussion of interventions [2]

Invest in demonstrators (cont'd)

- Idea of a demonstrator plant is a good one – but it would have to be two separate ones – aerospace could apply to other sectors too, but not to all. So for instance, healthcare sector isn't as hardware-intensive as say aerospace or automotive – so perhaps two demonstrators
- We can build some demonstrator kits and supply them to people who want them
- From the pre-event survey, I remember that people would like some case studies, to encourage end-user awareness of possibilities. Other thing was putting money into small companies that are developing devices to get them to try out non-core-market applications (so pushing out into new sectors. Any views?
- Yes – classic problem of bridging the gap between R&D and commercial development of a new type of harvester for a specific end use. It will be expensive and hard to develop, say 20 different demonstrator devices – if there were money to help that would be good
- One of or European counterparts used iPhone accelerometer to demonstrate concept / potential. [This was considered not serious from an engineering perspective but good from a message getting-across perspective]
- At Royal Society family fun day, there was a MPL stand that Raider of the Lost Amp – lots of interest from kids in energy harvesting

Discussion of interventions [3]

Invest in demonstrators (cont'd)

- Public's perspective of energy harvesting is that it can already be done! It might be that different levels of demonstrator that provide something the public can latch on to would be better than something that's lab-level – so a "grand challenge" would be appropriate
- From the IKC in Cambridge we are already doing demonstrations, and there is strong demand – we want to see if there is real, strong demand for this type of technology
- Q: Should money be put into doing a "quick and dirty" project, or something large scale and expensive (like the helicopters project) – what's the appropriate scale?
- I like the idea of the "grand challenge" – like the UK defence one recently – competing teams, and a competition with a nominal prize – can this be done for EHT that TSB could facilitate? This allows demonstrator money to be spread out among worthy groups and to get publicity – if you can get the right topic?
- What would the challenge be? I don't know.
- If you go back to the market value / niche-mass – then a demonstrator for niche it should be with those individual companies. The trick is for the mass market – that's where the demonstrator concept works best
- But someone has to sell something to somebody – and the accelerator programme is the demonstrator

Discussion of interventions [4]

Invest in demonstrators (cont'd)

- The generic thing is the "micro battery" for sensor apps – this would be an interesting integrated battery – if it could be built it could be sold into a multitude of sensor applications. The issue with EH is that there are so many applications
- Why a battery demonstrator? Specification would be "non-lithium, energy density > x etc"; a micro-scale battery (incorporating EH) would be a good challenge – and a significant one. But achievable through a variety of EH techniques
- I think some kind of storage device (battery, supercap) would be essential in this type of demonstrator (or generally) because that's what's needed by most applications
- I think the idea of a demonstrator being larger-scale and not company-specific is sound. A centre where people can go and say "I think EH can help me with this challenge, but I need to know where to go and what to do. We know we need two different EH technologies…" – a facility that could enable different providers to show their solution would be good – to pull things together from multiple providers
- You can define a fairly clear problem that you want to monitor some data (eg people living in their own homes, there are lots of problems – interference etc) – this has an impact on several other problems – there are lessons to learn from this type of demonstrator (Whole System Demonstrators for assisted living)

Discussion of interventions [5]

Invest in demonstrators (cont'd)

- Self-powered soldier being linked to other domains (like healthcare)
- I like the idea of a grand challenge – what about smart roads? A power-autonomous sensor system for the road network? We could challenge other technologies (PV etc)
- EC pilot challenge is 10mW/cm^2 is the target (any technology) – none of them gets there. Is it a challenge too far?
- No. Solar PV is getting there, but there are problems (when sun doesn't / can't shine)
- Does this interface to a battery system? If so, then it can be done now
- Yes, but they want a lifetime of 10-20 years
- We should look at whether we have capability to respond to some of the opportunities and challenges we identified this morning and see who could respond.
- Any demonstrator MUST be done in a realistic environment
- Energy harvesting people cannot do this on their own – the application areas are vey challenging in their own right – eg machine condition monitoring – there are significant sensor accuracy challenges, sampling frequencies etc as well; so we need to look at the wider system here – EH devices are not going to be developed in isolation from the system

Discussion of interventions [6]

Invest in demonstrators (cont'd)

- This has implications for who should be involved in the demonstrator – it's not just the EHT people
- Where should a demonstrator project be led from? Or should it be a consortium-led approach?
- Yes – a consortium led by an SI, with TSB contracting directly with participants (not with SI)
- Identify 3 demonstrators: machinery (and structures); healthcare sensors; micro-level – definitely need more than one (because of difference in scale and purpose)
- Need to be very aware of not following EU framework model. Because we can't turn EU frameworks into exploitable technologies (TSB is better from this perspective)
- There's a lot of technology push here. We should try to rebalance the "industry" towards industry pull
- I'm struggling to see (except in a few niche areas where changing batteries is really hard) why it isn't better to put in a battery. Where are the real opportunities?
- Because of the cost of lithium – the price could be greatly raised (x3). If we could develop non-lithium battery/EH technology this would insulate us from problems
- And the "dual use" thing – like the vibration-source comfortable backpack – it's the extra benefit
- Energy burden: the demand for rechargeable batteries and power for them is growing globally very fast and we need to keep this big picture in mind

Discussion of interventions [7]

Invest in demonstrators (cont'd)

- Most extreme example is the dismounted soldier (carrying 30kg of batteries that lasts two weeks)
- Effort to monitor with hand-held sensors is big – this could be eliminated with continuous monitoring – much more efficiently
- Also – remember that the markets don't have to be huge in volume terms if they are big in value terms
- Batteries will be the appropriate technology in many cases (eg TV remote controls) but there are many industrial environments where it is awkward and expensive to change the battery especially if you don't know when they are going to fail; eg underneath a train; in an oil refinery
- Condition monitoring case is an interesting one in its own right – battery problems put people off doing condition monitoring in the first place – so this isn't a replacement example – you need to think more flexibly about how things will be done in future using EHTs
- I agree that what we're considering is making the battery's life a little easier (dealing with crazy peaks) etc. Remember the smart meter opportunity – 100 million meters with batteries, in households, and that's a big problem. That's why we want to look at EH for smart meters
- And there are smoke alarms / detectors – people don't change them because it's awkward – so EH could work here (there are 20 million). Couple it with legislation to force people to have one. And a reliable rechargeable battery, of course

Discussion of interventions [8]

Building critical mass

- How to get more involvement from business (at the moment, it's mostly academic)
- Multi-disciplinary research groups could usefully be put together [by the TSB]
- We had a challenge on sensor technology – and the best way to build critical mass is to put large amounts of money into a research chair!
- Can you help us to "self form" these groups? Perhaps through a "grand challenge" – or challenges that were self-generated – you would specify what composition was required in order to bid for the challenge
- Choice of ideas being open would enable radical approaches – a call for activity shouldn't specify too much – just define the problem and realistic expectations
- Make sure you have some real potential customers in the groups so you understand the problem that really needs to be solved (not what you think needs to be solved) – because this shapes what solutions come out of it
- The Cambridge Smart Infrastructure / Construction IKN is a complex group of 34 organisations. The lead is Laing O'Rourke. As an example, this perhaps works at least in part. But we shouldn't reinvent it

Discussion of interventions [9]

Building critical mass (cont'd)

- There are at least two big international defence SIs who want to diversify into healthcare – we might be able to help them get them past a tipping point (with TSB investment). Note DALLAS (designing assisted living lifestyles at scale). UK is well ahead of US in this
- We have identified three different requirement sets – transport, built environment, human – this sounds like three critical masses – or communities around these three challenge areas. Is it communities or projects?
- Is it worth putting things on to existing entities? Approach DALLAS etc and tackle energy harvesting through this?
- Could DALLAS expand its scope (eg to military).
- Absolutely, EH will be a part of DALLAS – but EH solutions will be only a part of their solutions.
- Does DALLAS have open-call mechanisms?
- Find the consortiums and become part of their supply chains. TSB might be able to help point you in the right direction. (And anyone can apply to lead or be part of a consortium for existing challenges)
- MoD had a tech centre research initiative in four areas – they all had their own challenge areas – could TSB's consortia do something similar?

Discussion of interventions [10]

Building critical mass (cont'd)

- The consortia do what they want with their own money. And there are non-sector-specific funds for R&D available
- Care should be taken with MoD-type challenges – they are almost all application-driven, not research-driven (though they do give a driver to the research)
- Referring to DALLAS – it's been very sensibly organised on three trials – seems to be market pull, not technology push
- Existing IKCs could be a good bridge to link industry with end user companies
- There is a Swansea-based IKC that looks at coatings for steel – some have potential for EHTs – perhaps we could suggest that they look at this

Discussion of interventions [11]

Create a coordinated programme

- John explained what he meant by this – it's UK-wide, involving different partners (eg behavioural psychologists to understand why people leave their mobile phone plugged in a recharging when they don't need to; would they be prepared to pay for superior power performance) and the people that can fund this – including other government departments. So, which different agencies and industries would be interested in growing this industry in the UK? Food Standards Agency looking at self-powered food packaging?
- NHS has funding for various challenge-led projects – some of that could be put into EH
- Yes – everyone understands questions of life and death, and conflict. In the UK we're really good at both (!) so we should link military applications with healthcare applications
- T27 EV project has lots of different types of technologies (gearbox, power train …); you could have a demonstrator that addresses sensing, communicating and being self-powered – lots of organisations could feed into this (RFID, EH, comms …) – people working in a cluster towards some objective – this concept pulls a lot of your ideas together – the end uses could be healthcare monitoring, or water monitoring etc.
- You could have same devices that are self optimising could also be communicating to a larger system. This could be self-powered, becoming an integrated system is there advantage is working across industry boundaries. Would this work?

Discussion of interventions [12]

Create a coordinated programme (cont'd)

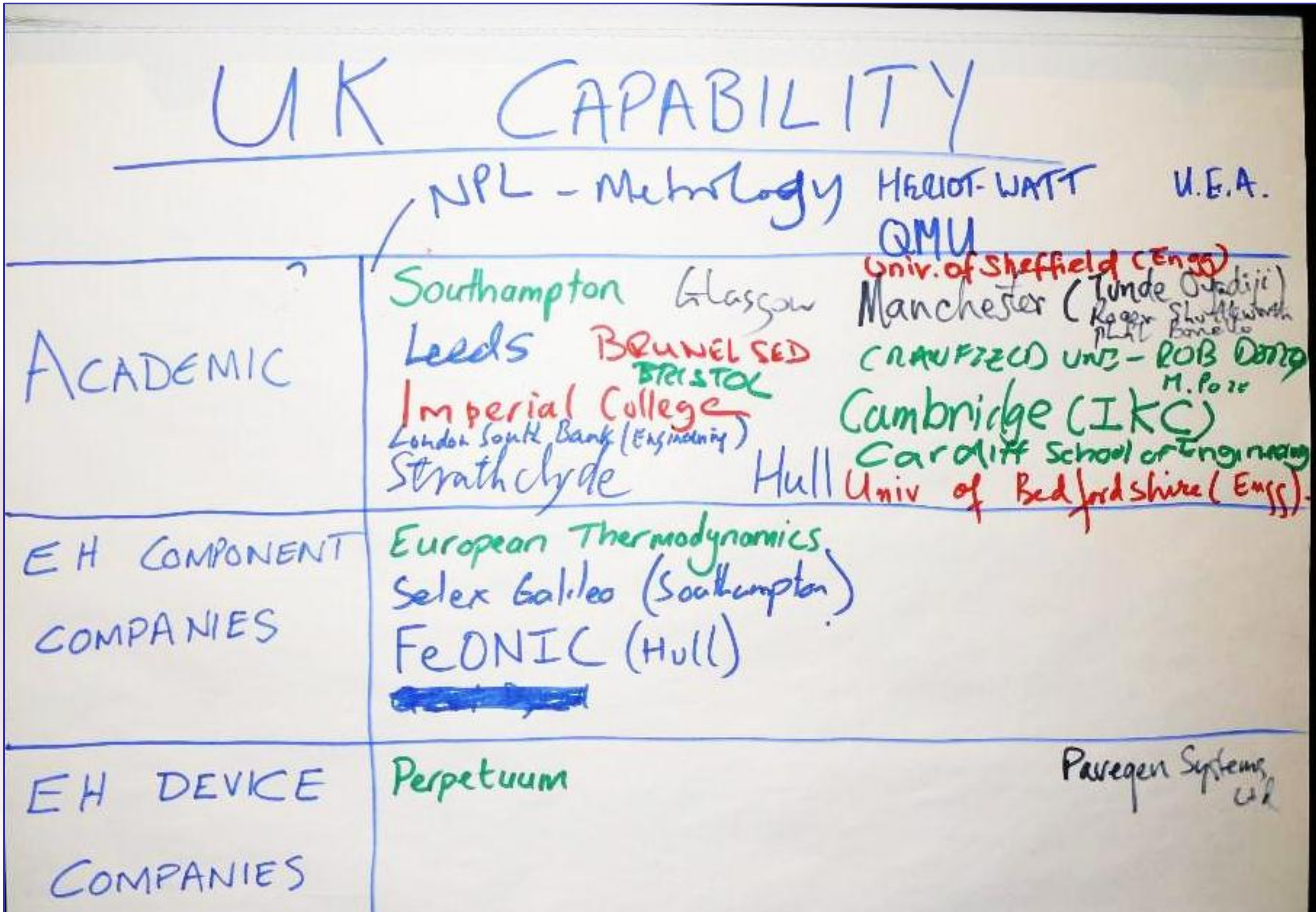
- It's a bit like the ASIC concept – it brought multiple disciplines together in a focused way
- It sounds like government drive to (huge) Smart Cities / Future Cities – that's all integrated. (No clue who's driving this, though). EHT already plays to multiple parts of a smart city (transport, building technology etc. And "Internet of Things" is relevant here – because everything is connected. There are demonstrators (eg in Portugal) to put sensors all over a city
- Cities seem to hold many opportunities for EH at small scale and large scale (eg cameras, sensors …) – maybe some of these are "killer applications"
- What you are talking about is distributed remote networks

Discussion of interventions [13]

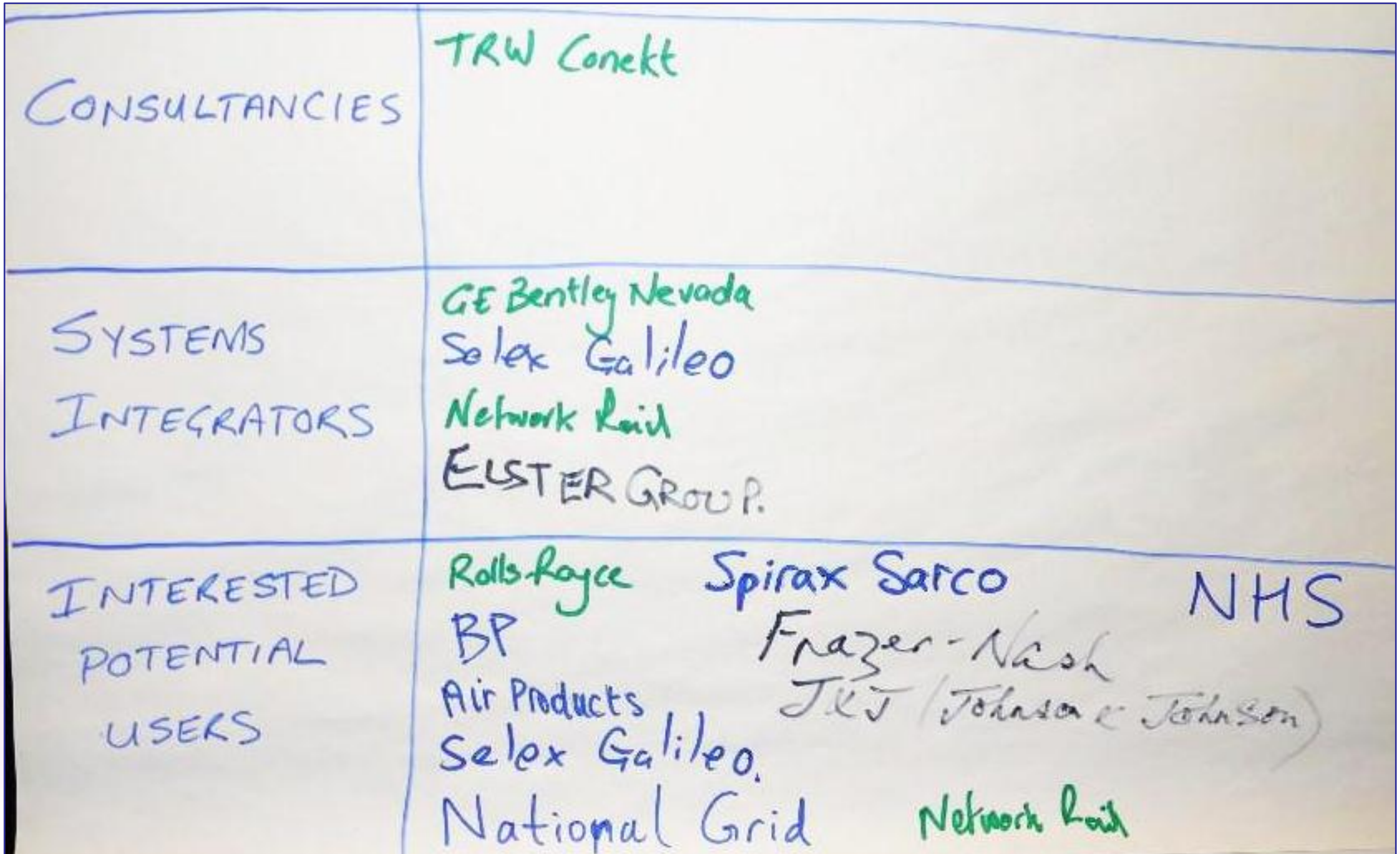
Build and nurture capacity

- What about skills? This is an interdisciplinary area – there are people working at the edge of their comfort zones, and there's a well-recognised need to bring more people into EH. What should be done?
- Because of the pace of technology change, we should stick to what we are good at – maritime and offshore engineering, microelectronics, wireless, instrumentation and control. This will encourage entrepreneurs. Encourage schools to produce physicists
- It's about influencing curricula – TSB can't do it, but we know people that can
- Think about the imbalance between academic and commercial sides in the map of UK EH capability. We should think about how to address this
- This builds on the issue of "understanding the problem"
- But we're looking at emergent technologies, so we don't necessarily need to rely on the existing strengths of the UK
- We need to look forward to try and understand what's going to be required for future EH technologies – so not just for now, but for the future. Please let me know afterwards

Directory of UK capability [1]



Directory of UK capability [2]



Annex: Presentation slides and notes / Q&A / discussion

John Collins - Technology Strategy Board

- The UK’s National Innovation Agency
- Goal to accelerate economic growth by stimulating and supporting business led innovation
- We understand business
- Rapidly, effectively and sustainably create wealth and enhance quality of life supporting businesses which apply technology

John Collins – Emerging Technologies and Industries Programme

- **Our vision: to turn the emerging technologies of today into the industries of tomorrow**
- **Energy Harvesting is one of those technologies**
- **And why?**
  - We’ve refined and ranked 140 emerging technologies

Technology Strategy Board

Driving Innovation

The Emerging Technologies & Industries Programme

John Collins

Lead Technologist

Emerging Technologies & Industries

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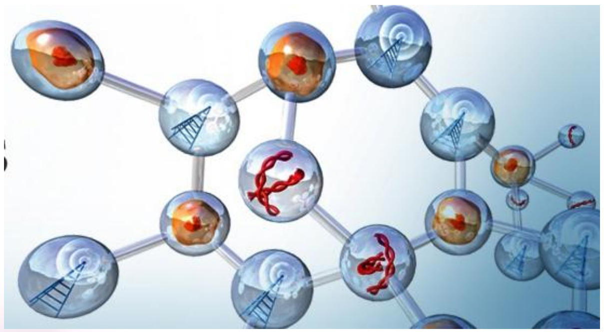
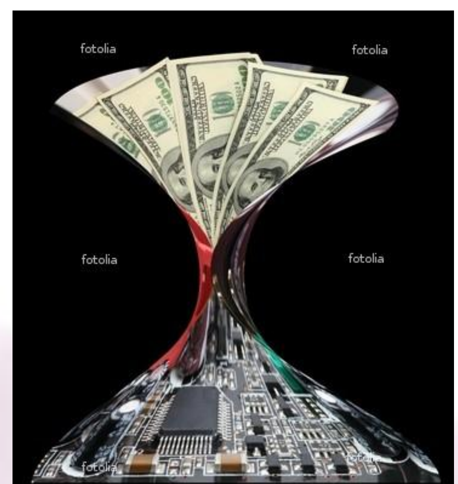
Our aim is to:



Turn today's emerging technologies into tomorrow's industries

Create at least one or two new £bn industries in the UK within 10 years



We have:

- Data transmission
- Reduced Energy Computation
- Augmented reality
- Novel composites
- Bioremediation
- Synthetic Biology
- Nuclear (Fusion)
- Scale-up manufacturing processes
- Deep well technologies
- Novel electronic devices & materials
- Novel carbon-based materials
- Photonic materials
- Power scavenging systems
- Energy storage
- Novel propulsion systems
- Novel sensors
- Nanomaterials with novel properties
- Smart materials
- New fuels
- Novel combustion
- Geothermal technologies
- Novel water power
- Inductive (vehicle) charging technologies
- Systems Biology
- Novel Imaging
- Quantum technologies
- Nanoshapes
- GM
- Photovoltaics
- '…omics'
- Carbon negative construction products
- Internet of things
- Autonomous transport
- Genomics
- Industrial Biotechnology
- Low impact building
- Genomics
- Industrial Biotechnology
- Low impact building
- Nanomaterials
- Stratified medicine
- Carbon capture & storage
- Transport systems integration
- Brain-computer interfaces
- Advanced software technologies & Intelligent systems
- Manufacturing continuous reactors for process industries
- Novel biomaterials
- Large & complex data sets
- Automated virtual manufacturing
- Wastewater treatments
- New spectrum technologies
- Cloud computing
- New paradigm computing & assured software
- Gaming
- Near net shape technology
- Advanced coatings
- Lab-on-a-chip
- Enzyme technologies
- Data & network security
- Grid & distributed computing
- Fuel cells & hydrogen
- Nuclear technologies
- Nanofabrication
- Wave & Tidal Power
- Intelligent grid
- New Display technologies
- Electric & hybrid vehicles
- Regenerative therapies
- Microfabrication/MEMS
- Offshore Wind power
- Crop protection & Novel pesticides
- Nanofabrication

Built a long-list of emerging technologies and put them into groups ('meso-technologies')

Shown if and where these fit with existing Technology Strategy Board programmes

- Data transmission
- Reduced Energy Computation
- Augmented reality
- Novel composites
- Bioremediation
- Synthetic Biology
- Nuclear (Fusion)
- Novel electronic devices & materials
- Novel carbon-based materials
- Photonic materials
- Power scavenging systems
- Energy storage
- Novel propulsion systems
- Transport systems integration
- Brain-computer interfaces
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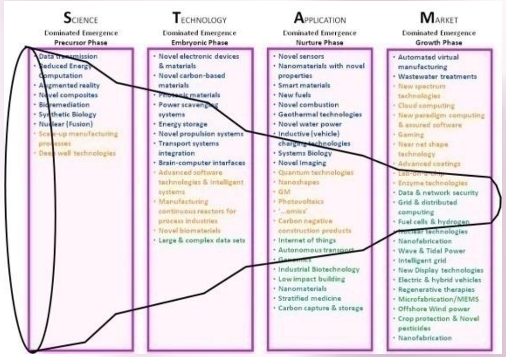
- Fuel cells & hydrogen
- Nuclear technologies
- Nanofabrication
- Wave & Tidal Power
- Intelligent grid
- New Display technologies
- Electric & hybrid vehicles
- Regenerative therapies
- Microfabrication/MEMS
- Offshore Wind power
- Crop protection & Novel pesticides
- Nanofabrication
- Nanomaterials
- Stratified medicine
- Carbon capture & storage
- Large & complex data sets



Shown where they fit on our 'emergence funnel'

Technology Strategy Board

Driving Innovation

Phases of Emergence
All the Meso-Technologies

SCIENCE Dominated Emergence **Precursor Phase**	TECHNOLOGY Dominated Emergence **Embryonic Phase**	APPLICATION Dominated Emergence **Nurture Phase**	MARKET Dominated Emergence **Growth Phase**
• Data transmission • Reduced Energy Computation • Novel composites • Bioremediation • Synthetic Biology • Nuclear Technologies (Fusion) • Scale-up manufacturing processes • Deep well technologies	• Novel electronic devices & materials • Novel carbon-based materials • Photonic materials • Power scavenging systems • Energy storage • Novel propulsion systems • Transport systems integration • Brain-computer interfaces • Advanced software technologies & Intelligent systems • Manufacturing continuous reactors for process industries • Novel biomaterials • Large & complex data sets	• Novel sensors • Nanomaterials with novel properties • Smart materials • New fuels • Novel combustion • Geothermal technologies • Novel water power • Inductive (vehicle) charging technologies • Systems Biology • Novel Imaging • Quantum technologies • Nanoshapes • GM • Photovoltaics • '…omics' • Carbon negative construction products • Internet of things • Autonomous transport • Genomics • Industrial Biotechnology • Low impact building • Nanomaterials • Stratified medicine • Carbon capture & storage	• Automated virtual manufacturing • Augmented reality • Wastewater treatments • New spectrum technologies • Cloud computing • New paradigm computing & assured software • Gaming • Near net shape technology • Advanced coatings • Lab-on-a-chip • Enzyme technologies • Data & network security • Grid & distributed computing • Fuel cells & hydrogen • Nuclear Technologies (Fission) • Nanofabrication • Wave & Tidal Power • Intelligent grid • New Display technologies • Electric & hybrid vehicles • Regenerative therapies • Microfabrication/MEMS • Offshore Wind power • Crop protection & Novel pesticides • Nanofabrication

Blue – TSB not active   Amber– TSB invested in some areas   Green – TSB active

We have:

ET&I Technologies Selection Process Opportunity Analysis Score — ELECTRONICS, PHOTONICS & ELECTRICAL SYSTEMS

Axis	Scoring	NOVEL ELECTRONIC DEVICES & MATERIALS	NOVEL SENSORS	NEW SPECTRUM TECHNOLOGIES	QUANTUM TECHNOLOGIES & PROCESSES	NOVEL IMAGING	NOVEL DATA TRANSFER TECHNOLOGIES
	Emergence phase leading edge	T	A	M	A	S	S
	Scope	Those materials whose properties can be exploited to produce novel electronic devices (e.g., biological electronics, high temperature electronics. Nanoelectronic implants)	Those sensors which are constructed from novel materials and offer greater sensitivity, resolution and discrimination than those currently available (e.g. Diamond-based sensors, matter wave sensors, quantum nanosensors, nanobiosensors, compressive sensing)	Predominantly terahertz radiation technologies but also includes multi-spectral LIDAR and UH Speed WiFi/GigaHertz WiFi. Terahertz radiation is non-ionizing submillimeter microwave radiation and shares with microwaves the capability to penetrate a wide variety of non-conducting materials. Terahertz radiation can pass through clothing, paper, cardboard, wood, masonry, plastic and ceramics. It can also penetrate fog and clouds, but cannot penetrate metal or water. It is used in medical imaging, security, spectroscopy, sensing & imaging.	Processes and devices which rely on quantum effects to operate; these include quantum IT, quantum electromechanical systems, coherent quantum electronics, quantum optics, quantum cryptography and coherent matter technologies. Fields include: Spintronics, quantum clocks, Qubits, Quantum Key distribution, quantum entanglement and QE devices and optical lattice simulators.	New technologies to create images or process images (e.g. Coded aperture imaging, photonic microcells, nanoscale imaging)	New ways to transmit data at ultrahigh speeds and wirelessly with minimal data loss and degradation.
	Markets	Energy, Healthcare, Manufacturing, Control systems, Environment	Energy, healthcare, Environment, Manufacturing, Control Systems, Digital Systems	Healthcare, manufacturing, Transport, Creative Industries	Healthcare, IT, Financial Services, Manufacturing, Control Systems, Transport, Entertainment, Digital Systems	Healthcare, Control systems, Visualisation, Manufacturing	Energy, Healthcare, Environment, Manufacturing, Control Systems, Entertainment, Communications, Financial Services, Digital Systems
Is there a large market opportunity? (L=0-10; M=11-20; H=21-30)	**GLOBAL IMPACT**						
What is the size of the global market opportunity in 10 years? L=<£10bn; M=£10-£50bn; H=>£50bn	L=2; M=4; H=6	6	6	2	4	4	6
Will it create value in the UK? (GVA) L=<£10bn; M=£10-£50bn; H=>£50bn	L=5; M=10; H=15	10	5	5	5	5	5
Will technology & innovation in one company or sector transfer or spill over to others, boosting overall returns?	L=3; M=6; H=9	9	9	6	9	9	3
	IMPACT TOTAL	**25**	**20**	**13**	**18**	**18**	**14**
How well positioned is the UK to capitalise on the opportunity? (L=0-10; M=11-24; H=25-40)	**UK CAPACITY**						
What is the UK Capability? (Low=6; Med=13; High=20)	L=6; M=13; H=20	13	13	13	20	13	13
Capability: In the science base; In publications & patents; In the number of businesses, specialist departments or centres; The global strength of UK industry (based on size, global rank)	Publications Number of Businesses In global top....	5-9% 10-40 Top 20	5-9% 10-40 Top 20	10+% 30+ Top 10	9% 10-40 Top 10	5-9% 10-40 Top 20	5-9% 10-40 Top 20
What's the time to market? (S(<5yrs)=10; M(~10yrs)=6; L(=15+yrs) =2)	L=10; M=6; H=2	6	10	10	6	6	10
What are the barriers to growth; to bringing the technology to market? (Low/Few=10; Med=6; High/Many=2)	L=10; M=6; H=2	10	10	10	10	10	6
	UK CAPACITY TOTAL	**29**	**33**	**33**	**36**	**29**	**29**
Can a national ET&I Programme make a difference? (L=0-10; M=11-20; H=21-30)	**ADDED VALUE**						
Is there a clear TSB role? Can we add value?	L=2.5; M=5; H=7.5	7.5	7.5	2.5	7.5	5	5
Can we bring partners or programmes together to create critical mass?	L=5; M=10; H=15	10	15	10	15	10	10
Will our investment promote sustainability and quality of life?	L=2.5; M=5; H=7.5	7.5	7.5	2.5	2.5	5	5
	ADDED VALUE TOTAL	**25**	**30**	**15**	**25**	**20**	**20**

Devised and stress-tested a scoring process

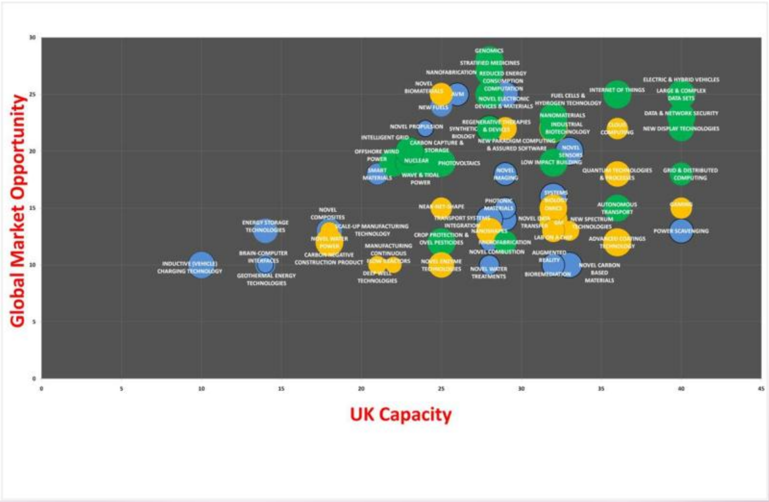
Scored all the meso-technologies

Plotted these as

UK Capacity

Vs

Global Market Opportunity



We have stress tested the output:

- We accept that the meso-technologies fall in the right place

- We are happy to use the results of this to guide the design of the programme

- We have devised an ‘attractiveness measure’ and ranked the technologies by attractiveness

Technology Strategy Board

Driving Innovation

All by Attractiveness

SCIENCE PHASE

ATT	MESO-TECHNOLOGY	2020 ($bn)
38	Reduced energy Consumption Computation	50
36	Synthetic biology	100
34	Bioremediation	20
32	Novel data transfer	440
31	Nuclear Technologies (Fusion)	0
23	Deep well technologies	2
22	Scale-up manufacturing	15
22	Novel composites	2

TECHNOLOGY PHASE

ATT	MESO-TECHNOLOGY	2020 ($bn)
47	Large & complex data sets	50
42	Power scavenging	4
41	Advanced software technology & intelligent systems	20
38	Novel electronic devices & biomaterials	150
34	Novel carbon-based materials	5
34	Manufacturing continuous flow reactors	5
33	Photonic fibres & crystals	40
33	Novel propulsion systems	200
31	Transport systems integration	200
29	Novel biomaterials	250
19	Energy storage	10
17	Brain computer interfaces	6

APPLICATION PHASE

ATT	MESO-TECHNOLOGY	2020 ($bn)
44	Internet of things	400
40	Quantum technologies & processes	10
39	Autonomous transport	65
39	Stratified medicines	200
39	Industrial biotechnology	250
39	Nanomaterials	100
39	Novel sensors	100
37	Low impact building	400
36	Systems biology	16
36	Regenerative therapies & devices	180
35	Omics	12
35	GM (livestock))	150
35	New fuels	250
34	Novel imaging	50
32	Genomics	95
31	Photovoltaics technology	100
31	Nanoshapes	10
30	Novel combustion	60
28	Smart materials	18
22	Carbon negative construction products	20
22	Novel water power	1
17	Geothermal energy	1
14	Inductive (vehicle) charging	12

MARKET PHASE

ATT	MESO-TECHNOLOGY	2020 ($bn)
47	Electric & hybrid vehicles	80
46	Data & network security	15
46	New display technologies	25
44	Grid & distributed computing	10
43	Gaming technologies	30
42	Cloud computing	150
39	Fuel cells & hydrogen	26
38	Advanced coatings	10
38	Nanofabrication	50
36	New paradigm computing & assured software	55
36	Automated virtual manufacturing	60
35	New spectrum technologies	10
35	Lab on a chip	6
34	Augmented reality	15
31	Carbon capture & storage	120
31	Microfabrication	20
31	Nuclear technologies (fission)	400
30	Intelligent grid technology	40
30	Wave & tidal power	100
30	Novel water treatments	50
29	Near-net-shape technologies	25
29	Offshore wind power	160
28	Crop protection technologies & novel pesticides	50
27	Novel enzymes	4

Those technologies which scored under 30 were removed

We are left with 17 meso-technologies...

...simply listed

Energy Efficient Computing
Assured Software Engineering
Synthetic Biology
Energy Harvesting
Advanced Software Technology and Intelligent Systems
Advanced Coatings
Novel Biomaterials (biosensors or biological electronics)
Bioremediation
Novel Carbon-based Materials
Quantum Technologies & Processes
Novel Sensors & Novel Imaging
Novel Electronic Devices and Materials
Systems Biology
-omics
Gaming Technologies
Cloud Computing
Novel Data Transfer

And we discussed these with our TSB colleagues and others to get their overview to reduce these to 4 technology domains...

The 4 technologies we propose to support:

Att.: 36 **SYNTHETIC BIOLOGY** 2020 ~$100bn

Att.: 36 **ASSURED SOFTWARE ENGINEERING** 2020 ~$55bn

Att.: 38 **ENERGY EFFICIENT COMPUTING** 2020 ~$50bn

Att.: 42 **ENERGY HARVESTING** 2020 ~$4bn

John Collins – Emerging Technologies and Industries Programme

- **Our strategy:**
  - Invest in demonstrators
  - Build critical mass
  - Create a coordinated programme
  - Build & nurture capability

Zartech
technology to market

Some perspectives on the Energy Harvesting ‘industry’

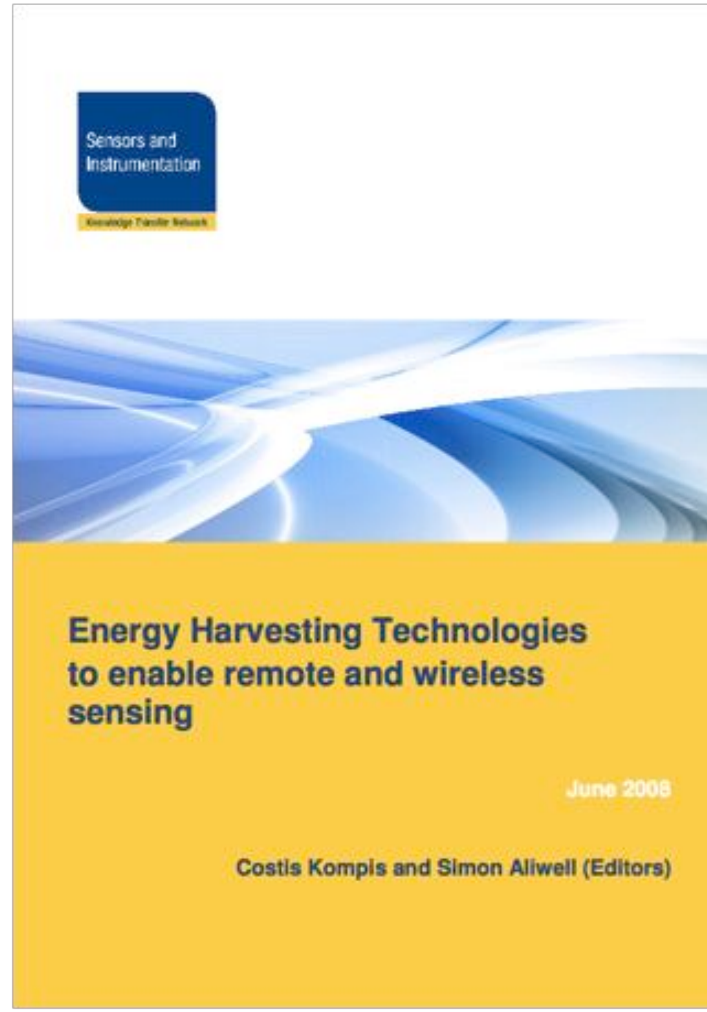
Simon Aliwell

Some context

'Energy Harvesting Technologies for remote and wireless sensing' (June 2008)

Main Focus:

- Understand the barriers to uptake
- Critically question applicability in industry
- State of the art
- Identify the Centres of Expertise



Zartech technology to market

Key industry questions

1. Power consistency & impedance matching to load required
2. Absolute minimum power - 200μW (excl. any losses)
3. Communications standards – too power hungry? Need new standards?
4. Efficient power storage – supercaps, rechargeables?
5. Harvesting type synergies – extend operating window of sensor

Zartech
technology to market

Key industry questions

6. Graceful degradation – detect impending failure? Reliability?
7. Health & safety – handling, disposal?
8. Cost of ownership – cost vs. batteries
9. Matching expectations with capability – intermittency affects sensing strategies
10. Integration of devices and expertise – complex range of technical skills and optimisation required

Zartech
technology to market

So what has changed in 3 years?

- An explosion of interest from potential users (and increased user awareness)
- Lots more academic groups
- More systems level thinking
- Standards work (comms and device comparison)
- Hype more under control
- Increased US commercial activity (catching up?)
- EH community becoming more cohesive particularly around research (EH Network)

Zartech
technology to market

But…….

- In Europe it is still the same few companies offering EH e.g. EnOcean, Micropelt, Perpetuum etc. (all SMEs)
- Outside of smart buildings and condition monitoring there is not a lot of evidence of actual take-up
- Systems integrators still noticeably absent
- Industry-Academic collaboration is mostly through FP7 – no TSB opportunities yet

Zartech
technology to market

So what is holding things up?

- Too early for an emerging technology – just low hanging fruit addressed so far?
- Supply chain not working – where are the big boys?
- Not seeing the big markets?
- Users not yet convinced?
- Application specific nature of the technology to date?

Zartech
technology to market

Pre-workshop input

How to ensure that EHT becomes successful UK industry in 10 yrs:

- Double the output of current devices
- Systems design for more efficient load management
- Ultra-low power sensors
- Address EH cost issues (batteries cheap & energy dense)
- Encourage flexible thinking by users (new approaches)
- Be aware of the fundamental limits / scaling laws etc
- Find the opportunities that lend themselves to EH e.g. ‘internet of things’ – match applications with right technologies
- Develop systems solutions – holistic design – every application different

Pre-workshop input

- Funding support for SMEs to produce demonstrators
- Support to publicise the capabilities of EH to engage end users
- UK to lead standards development
- Strong & clear support from BIS, TSB, EPSRC for EH research and commercialisation
- Continued funding for networking activities
- Market research to identify UK's internationally competitive strengths
- Manage the hype
- Manage expectations – probably not Watts; battery life extension
- Power conversion, power management, storage – UK has world-leading expertise
- MEMs/Nanotech – mitigate scaling effects (UK capabilities)
- Continue rapid reductions in power consumption of electronics

Zartech
technology to market

Thanks for listening

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www.zartech.co.uk

www.eh-network.org

Notes from Simon Aliwell's presentation [1]

- Simon pointed out that energy harvesting had been of commercial interest for several years; a report from 2008 had looked at this sector, and Simon spoke about the ten issues that had been of most interest to industry when the 2008 report was compiled
- He discussed what had changed over three years …
  - There had been an explosion of interest among users; and more academic groups working in this area (UK is world leading)
  - Change in focus from components to systems; and there were standards being developed in some areas
  - Less hype; more reality in discussions
  - Increase in real US commercial activity
  - Creation of a community of interest such as the Energy Harvesting Network
- … and what hadn't changed – there hadn't been much interest from big companies (inc SIs) yet, and posed questions about what was holding back the industry
- Simon talked through the results of the pre-event survey about how people felt that energy harvesting technology could be developed
- He pointed out that batteries are cheap and energy-dense so there were cost considerations to take into account, and the need for end-user behaviour change

Notes from Simon Aliwell's presentation [2]

- Simon said that matching applications to technologies was important, and that the Internet of Things might potentially stimulate some EHTs
- Respondents had suggested what the TSB could do to support the emerging industry – managing expectations came up again

TSB Energy Harvesting Workshop

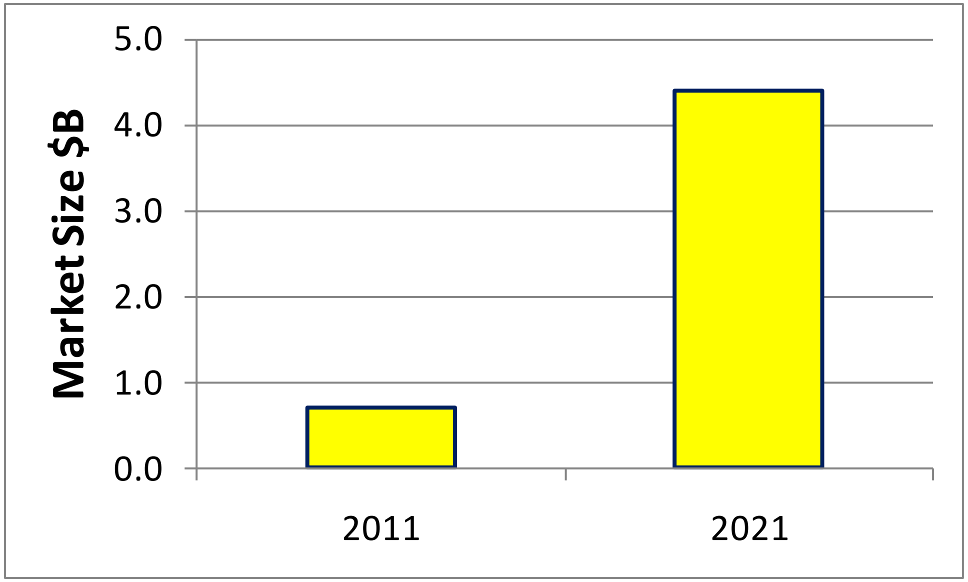
13th Sept 2011

Steve Turley, CEO Perpetuum

Harvester Markets

perpetuum

- Powering Wireless Sensor Networks
- Charging Consumer Electronics
- Defence
- Building control e.g. switches
- Etc etc



Source for Harvester Market Data: IDTechEx Web Site

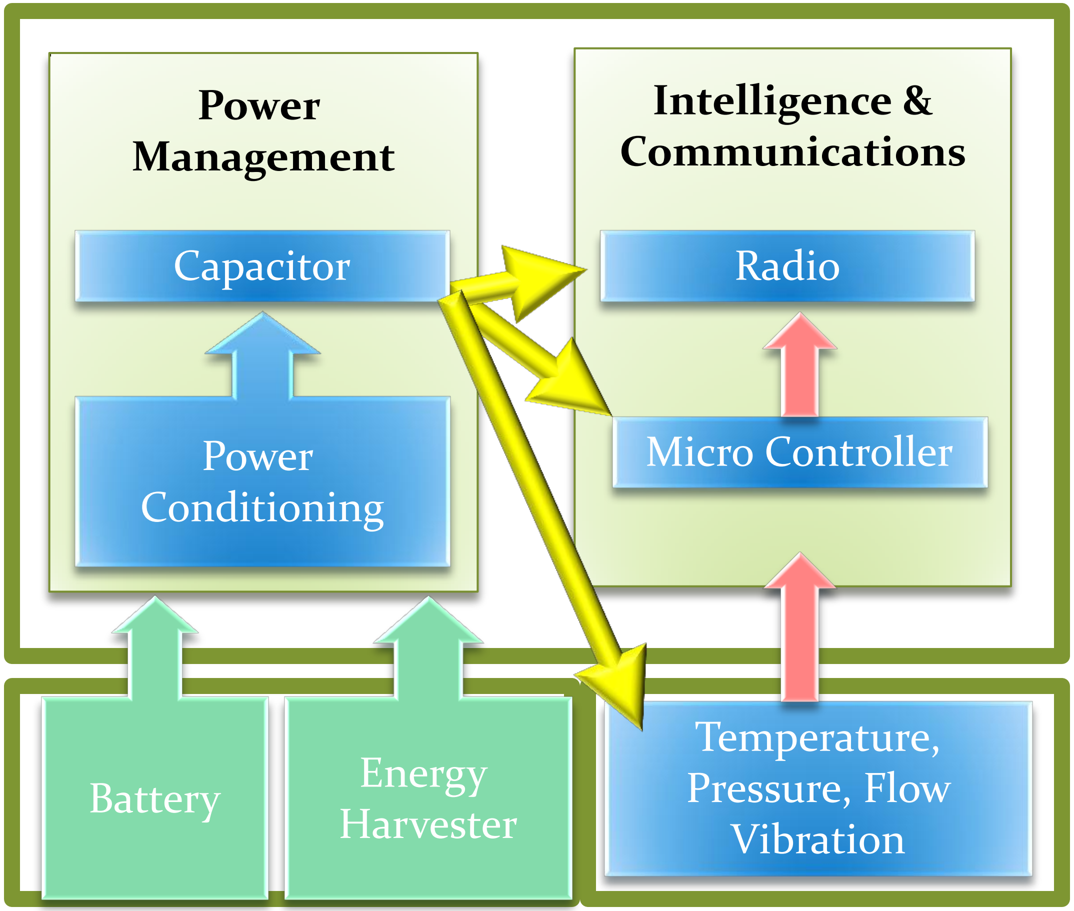
Harvesting Technologies

perpetuum

- Vibration
- Solar
- Thermal
- RF
- Shock
- Pressure
- Etc etc

Ecosystem

- Harvesting technologies
- Wireless technologies
- Applications & subsystems
  - Industrial
  - Transport
- Electronics to control
- Battery technology esp rechargeable



Perpetuum Overview:

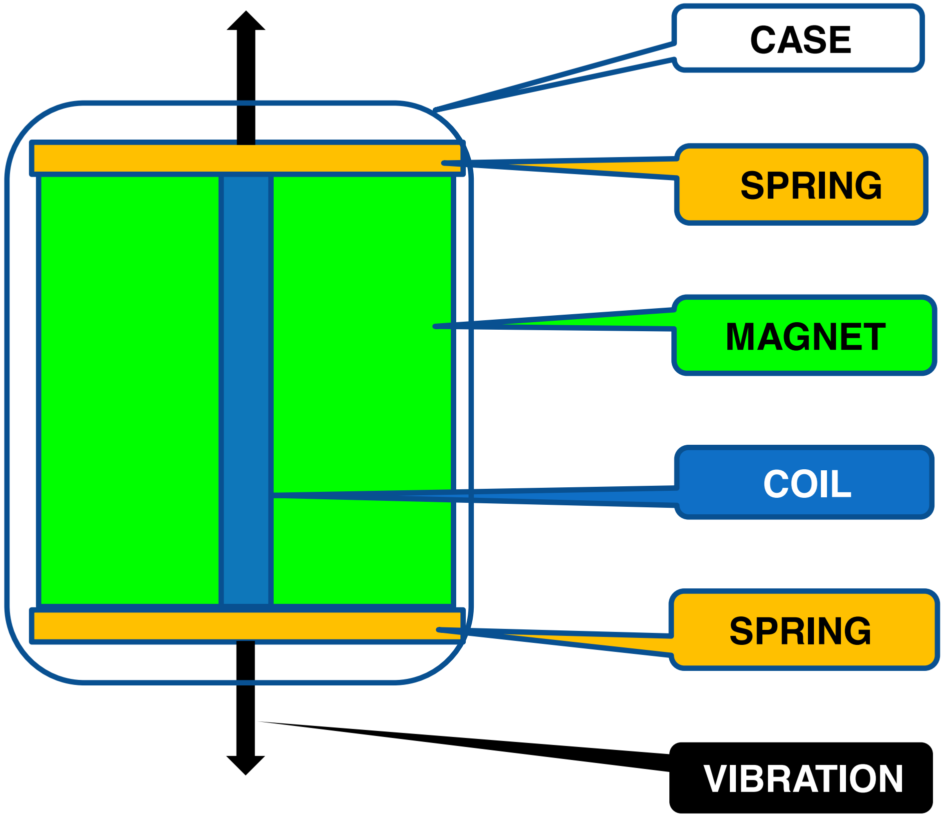
perpetuum

- Vibration Energy Harvester (VEH)
  - Converts waste vibration energy into electrical power for Wireless Sensor Nodes
- Technology spun out from Southampton University (2004)
  - 10 patents
- Key Product features
  - "Fit & Forget" power solution
  - Very good power harvesting capability
  - Industrially robust & reliable
  - Already in production phase
  - Certified safe in hazardous environments
  - Wide temperature range of operation

VEH Construction & Operation

perpetuum

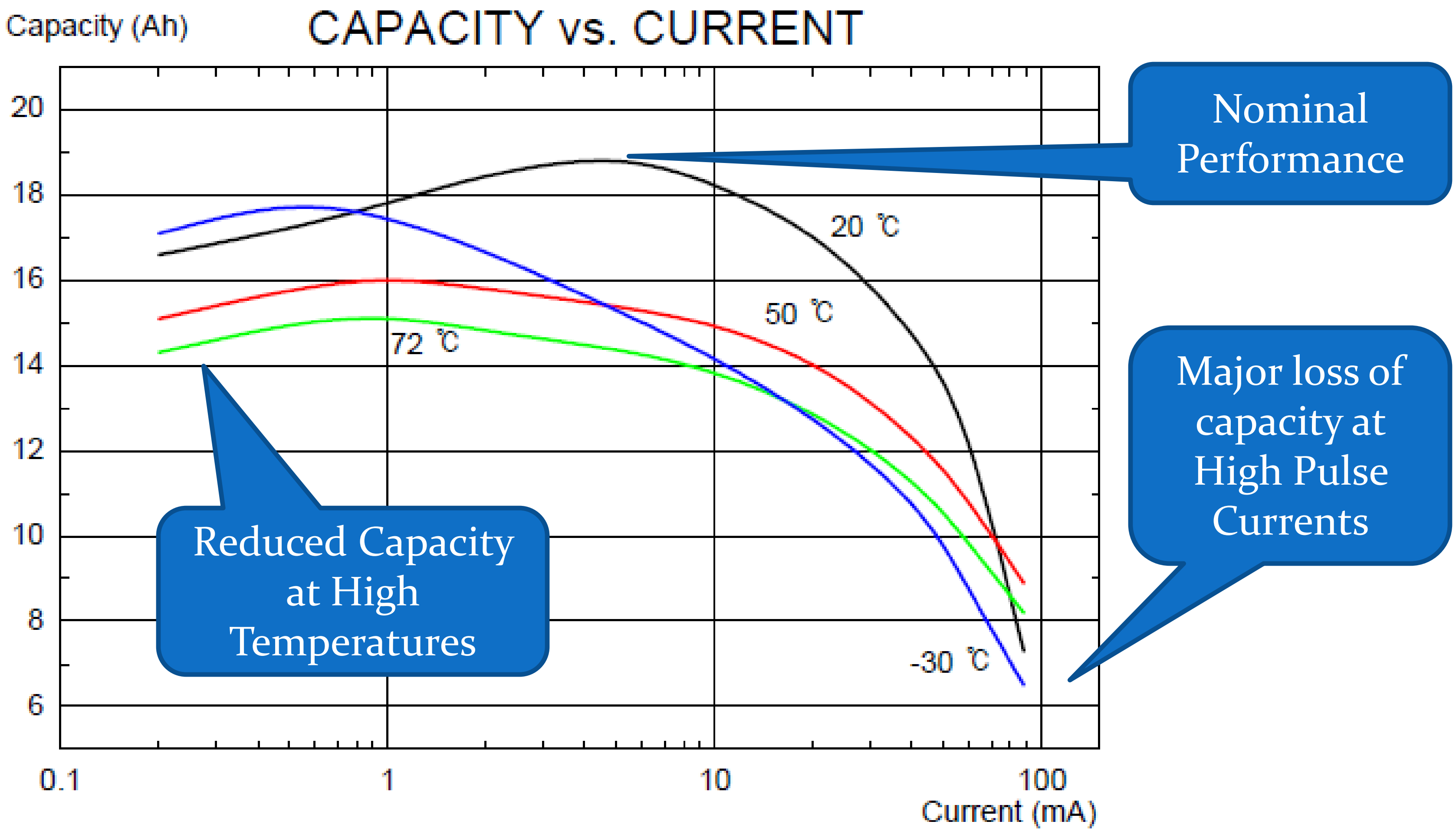
- VEH Construction:
  - Magnets, Coils & Springs
  - Power management
  - Temperature compensation
- Vibration moves magnet up and down relative to coil.
- Based on Faradays law, an AC current is generated
- AC current rectified to produce a DC output.



Basic Physics is Simple - IP is in controlling performance in an Industrial Environment

Battery Capacity Erosion

perpetuum

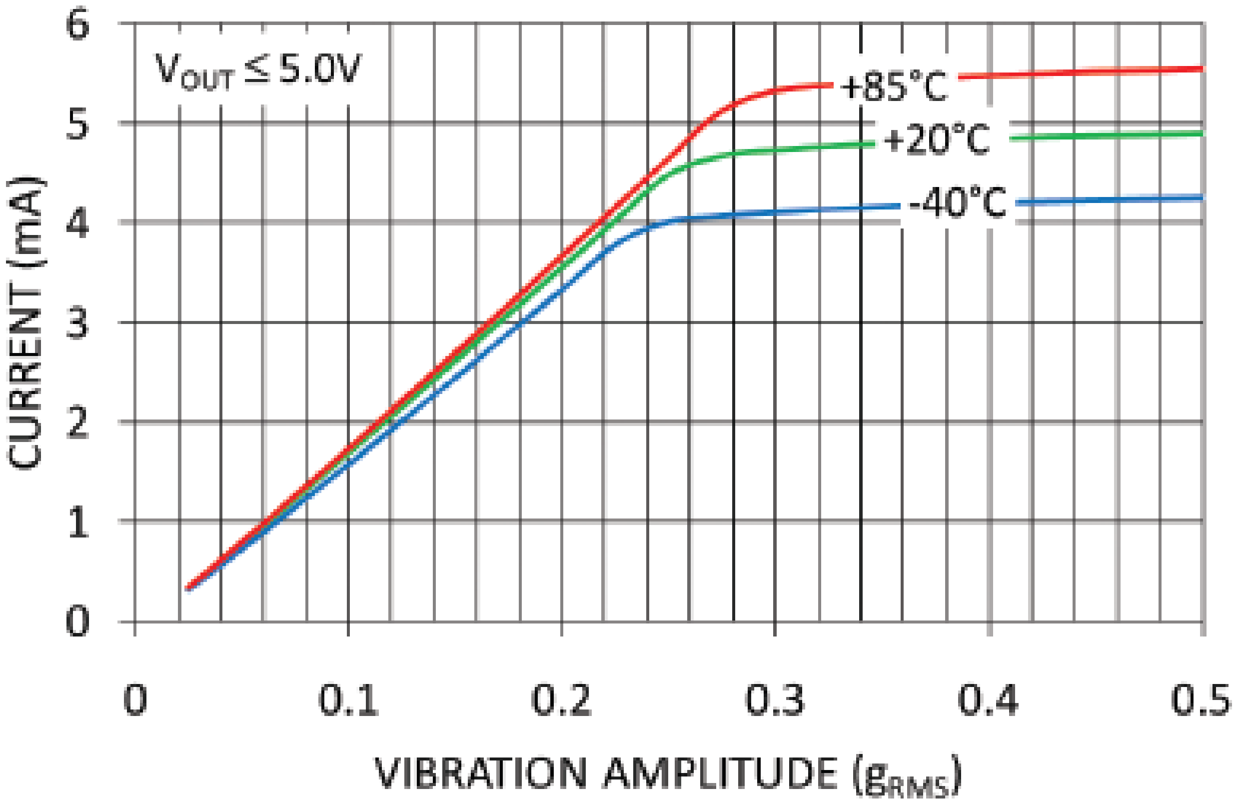


Data from Xeno datasheet

VEH Performance vs. Temp.

perpetuum

Figure 1. Centre-band current output



Perpetuum's Harvester delivers full operational performance from -40C to +85C

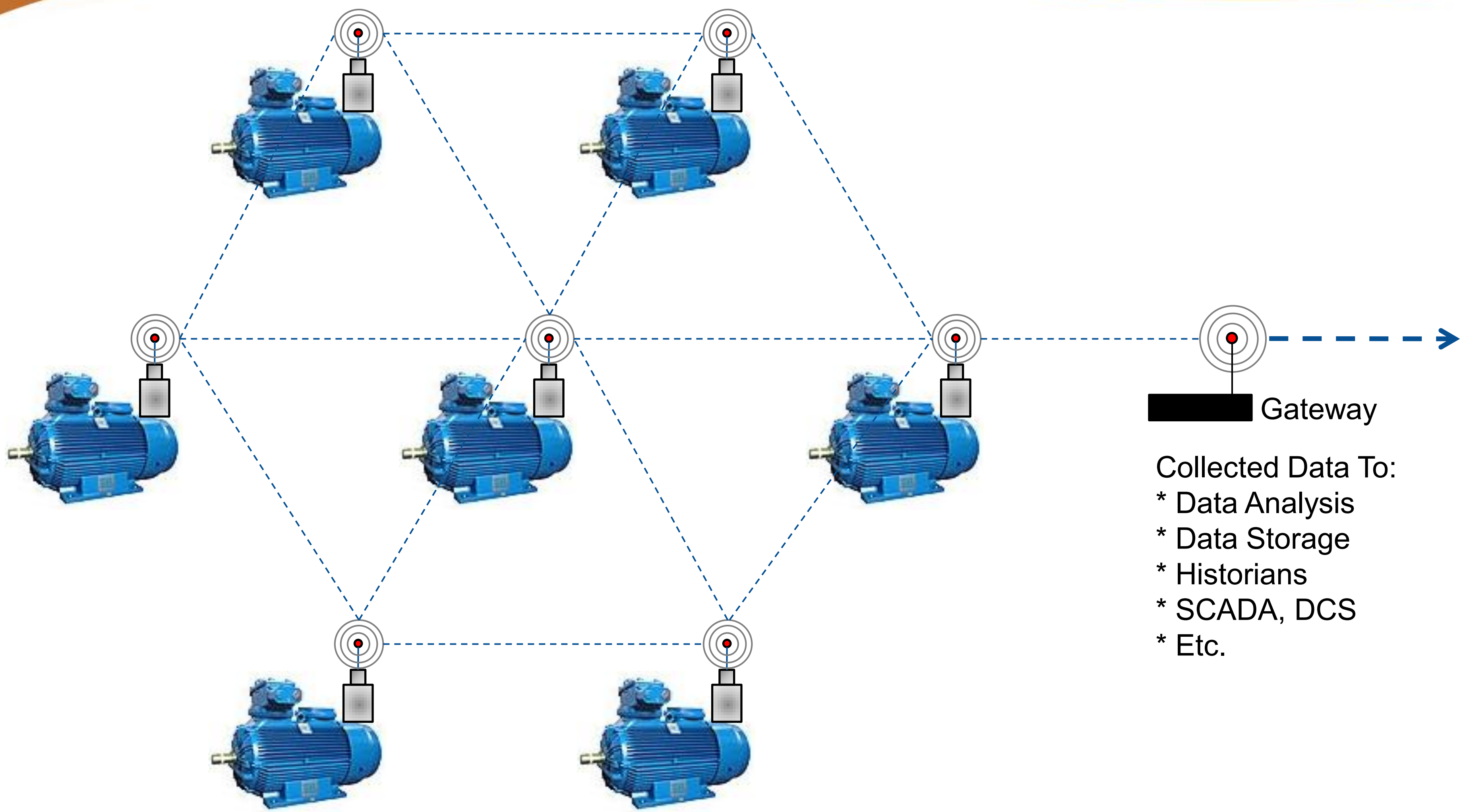
Perpetuum Markets

- Safety & Economics are key drivers in both Industrial (e.g. Oil & Gas) and Rail markets
- Machine Health Monitoring predicts failure
  - delivers both safety & cost benefit
- Wireless technology enables this to be deployed quickly and cost effectively
  - Wireless Sensor Networks (WSNs)
- Perpetuum provides a "Fit & Forget Power Solution"
  - Energy Harvester converts vibration energy to electrical energy

Target markets where clear value can be delivered

Industrial Market Deployments

WSN: Principle of Operation



Collected Data To:
* Data Analysis
* Data Storage
* Historians
* SCADA, DCS
* Etc.

Previously Orphaned Assets

Sensors Show, Chicago, June ’11

Credibility: Key OEMs publicly support Perpetuum

Rail Markets

Perpetuum's Wireless Sensor Node

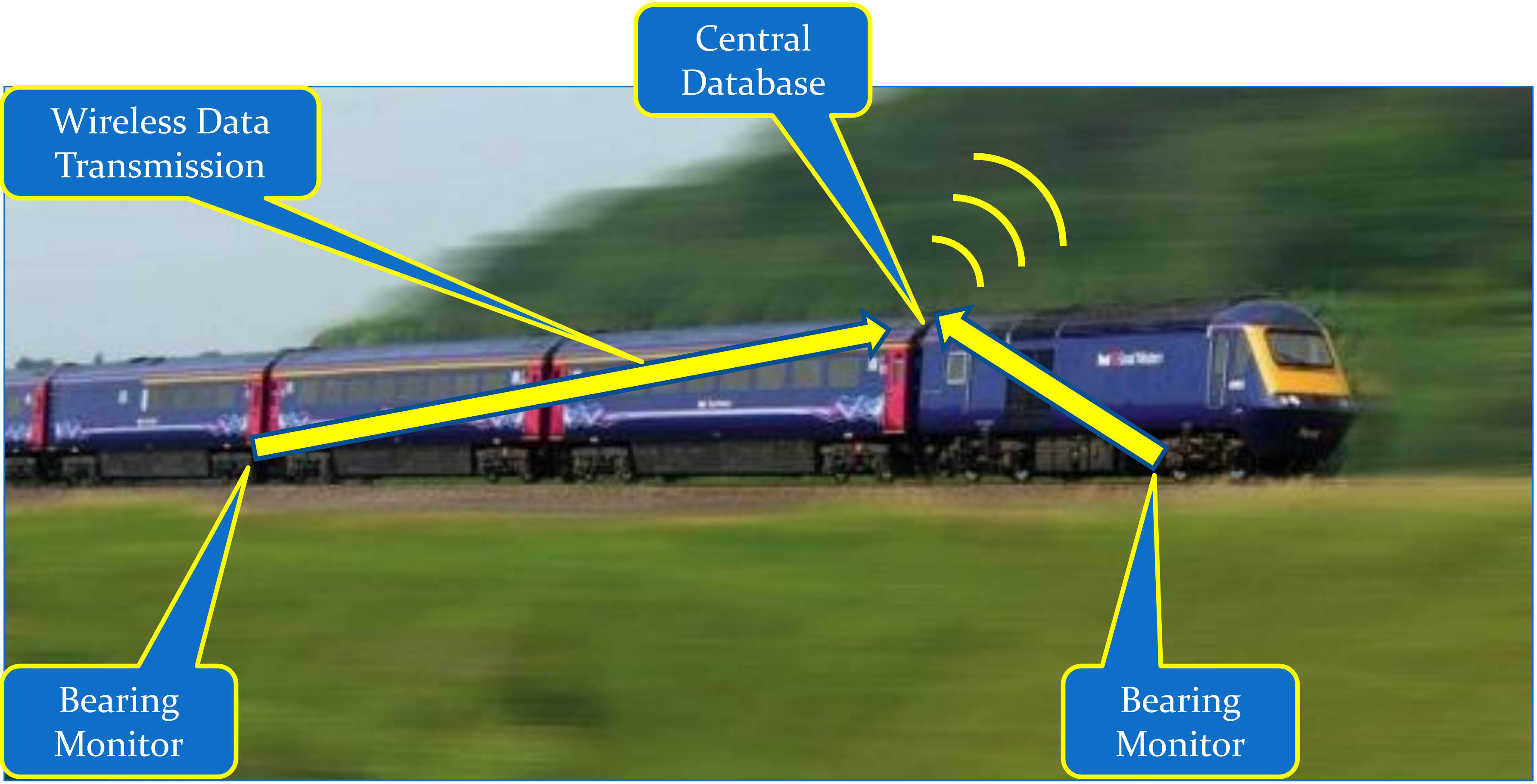
perpetuum

- Key Features:
  - ✓ Vibration & Temperature Sensors > Early Identification of Failure
  - ✓ Microprocessor > Simple Measure of Bearing Condition
  - ✓ Wireless Communication > No Wires
  - ✓ Energy Harvester > No batteries
  - ✓ Robust design for harsh environments

Uses Techniques Already Widely Deployed in Industrial Environments

Wireless Data Transmission

perpetuum



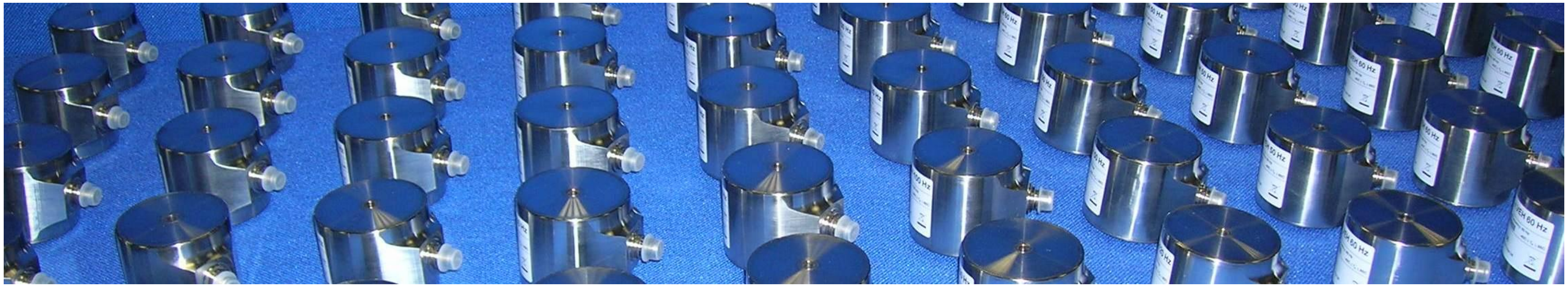
Key Challenges

perpetuum

- Strong Patents and other IP
  - Ensure IP is not dissipated by early publication
- Early stage funding
  - e.g. SBIR in US
- Fast to market
  - Fast decision making process
- Field trials
  - demonstrates credibility for market and supplier
- Employment security
  - E.g in Si Valley its not a problem due to the high # of early stage companies
  - How do we encourage talented people to take the risk of a start up

Vibration Energy Harvesters

perpetuum



The ***Evolution of Power*** for Wireless Sensing & Automation

Notes from Steve Turley's presentation [1]

- Steve presented a view on the size of the energy harvester market and ran through the types of harvesting technologies
- He spoke about ecosystems of technologies that were required – this is a way to expand the potential market for EHT: he said that much of what Perpetuum does is related to wireless technologies (inc battery-operated wireless sensors)
- Steve said that battery technology is very important – a reliable rechargeable battery opens things up for EHT very substantially
- He gave a brief introduction to Perpetuum, its technology (vibration) and core markets (wireless sensors for industrial and rail transport safety-related machine health monitoring applications) – and its aim to enable a fit-and-forget power solution – he said the market was expanding into process control as well as machine monitoring
- He mentioned the importance of protection of IP to Perpetuum
- He said that batteries are complex, and lifetime in different situations is unpredictable – EHT can make battery life more reliable and output more reliable and consistent

Notes from Steve Turley's presentation [2]

- Steve said that Perpetuum's strategy in the industrial market was to work with the big providers of systems – Emerson, GE, Honeywell, Siemens etc – this is very important in building credibility
- In rail, the application and strategy is different – it's creating new ways to detect failure (eg in train wheel bearings) and this has economic benefits for scheduling of maintenance; hard wiring for power in / communications out is difficult: wireless technologies can make the system self-contained, more reliable and quicker to install, so EHT can deliver value in many ways
- Steve identified a number of important issues, including IP/patents, early-stages funding, speed to market, field trials and employment security (making it worth taking the risk of working for a startup)
- **Q: Perpetuum has succeeded because it's identified a niche that is the right size – is this the case?**
- A: yes – there are large EH markets, but our niche is manageable *and* has sufficient potential

Knowledge Transfer Network

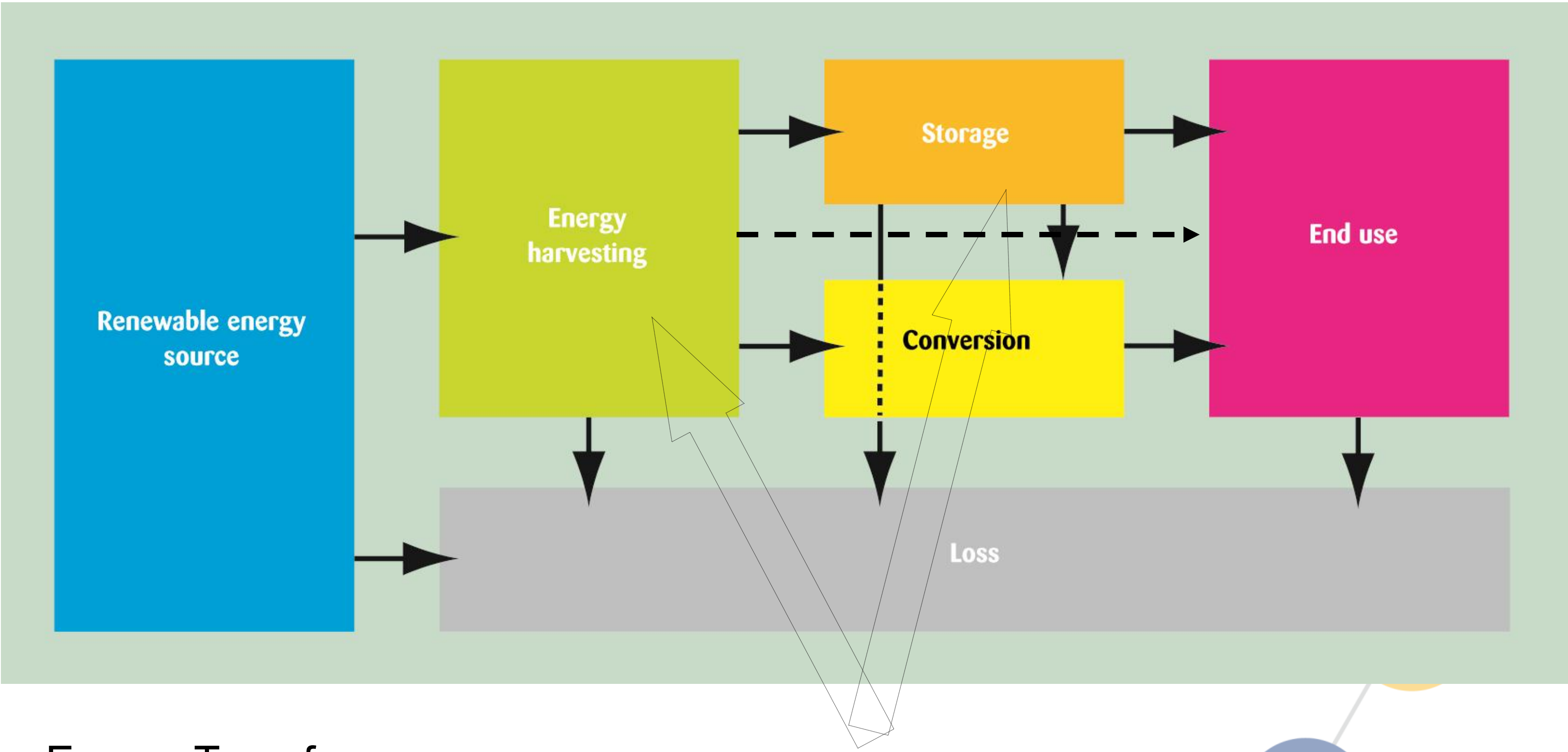
Nanotechnology

NanoEnabled Energy Harvesting

Dr Martin Kemp
Theme Manager Engineering Applications
Nanotechnology KTN

Energy Harvesting –Watts Needed? 13th Sept Roy Soc

Clean Energy Processes



Energy Transfer

Knowledge Transfer Network
Nanotechnology

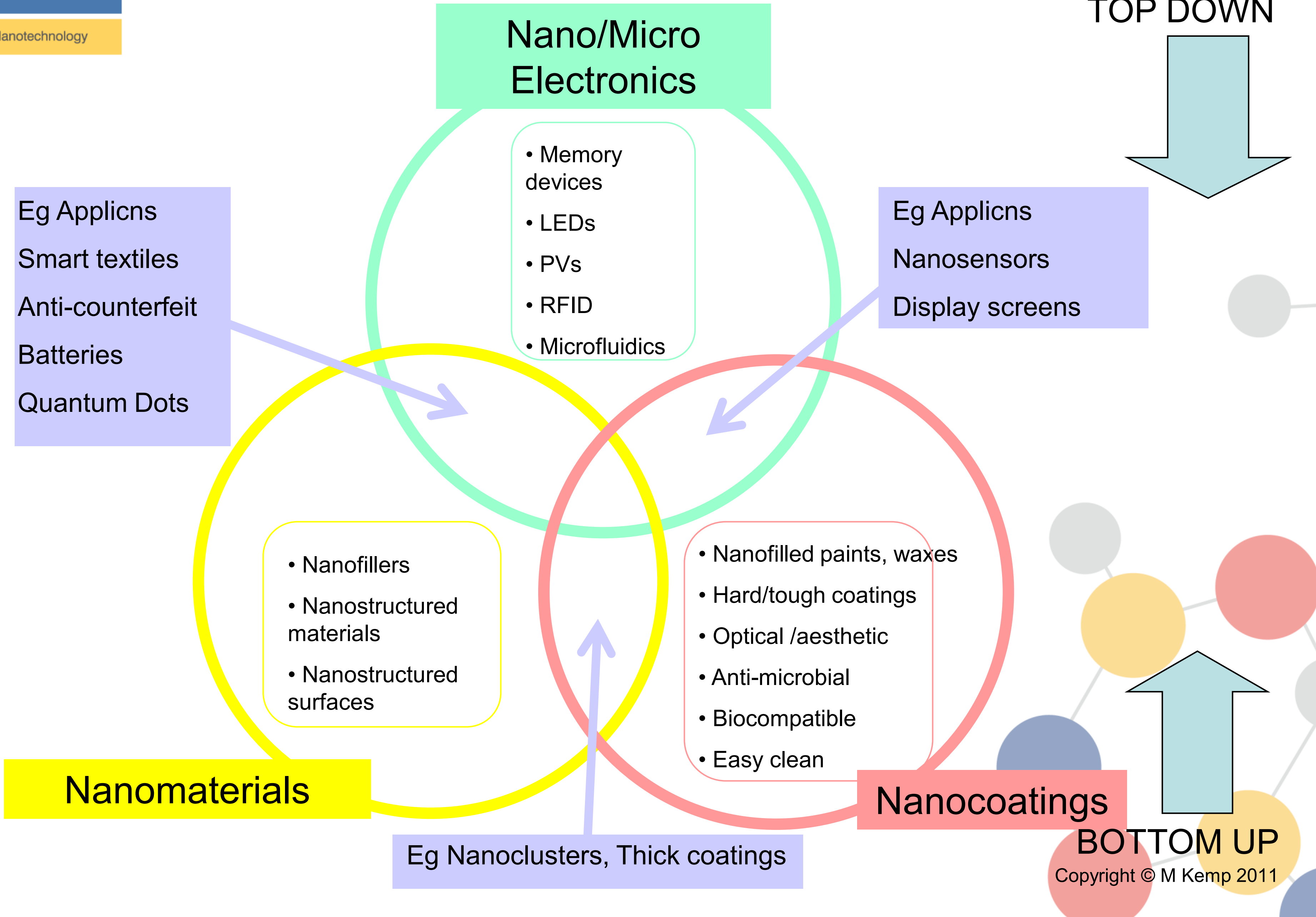
A Vision –
Ubiquitous Energy Harvesting

Nanotechnology Perspective

- Nano and micro technologies offer an expanding ‘toolkit’ providing new approaches to develop disruptive solutions

- Synergy from ‘mix and match’ of combining innovative processes

Nanotechnology Capability Map



Knowledge Transfer Network
Nanotechnology

Nano/Micro Manufacturing Routes

Nano/Micro Electronics

- Silicon wafer processing
- Clean room technologies
- Focussed Ion Beam etching
- Epitaxial growth
- Nanoimprinting

Nanomaterials

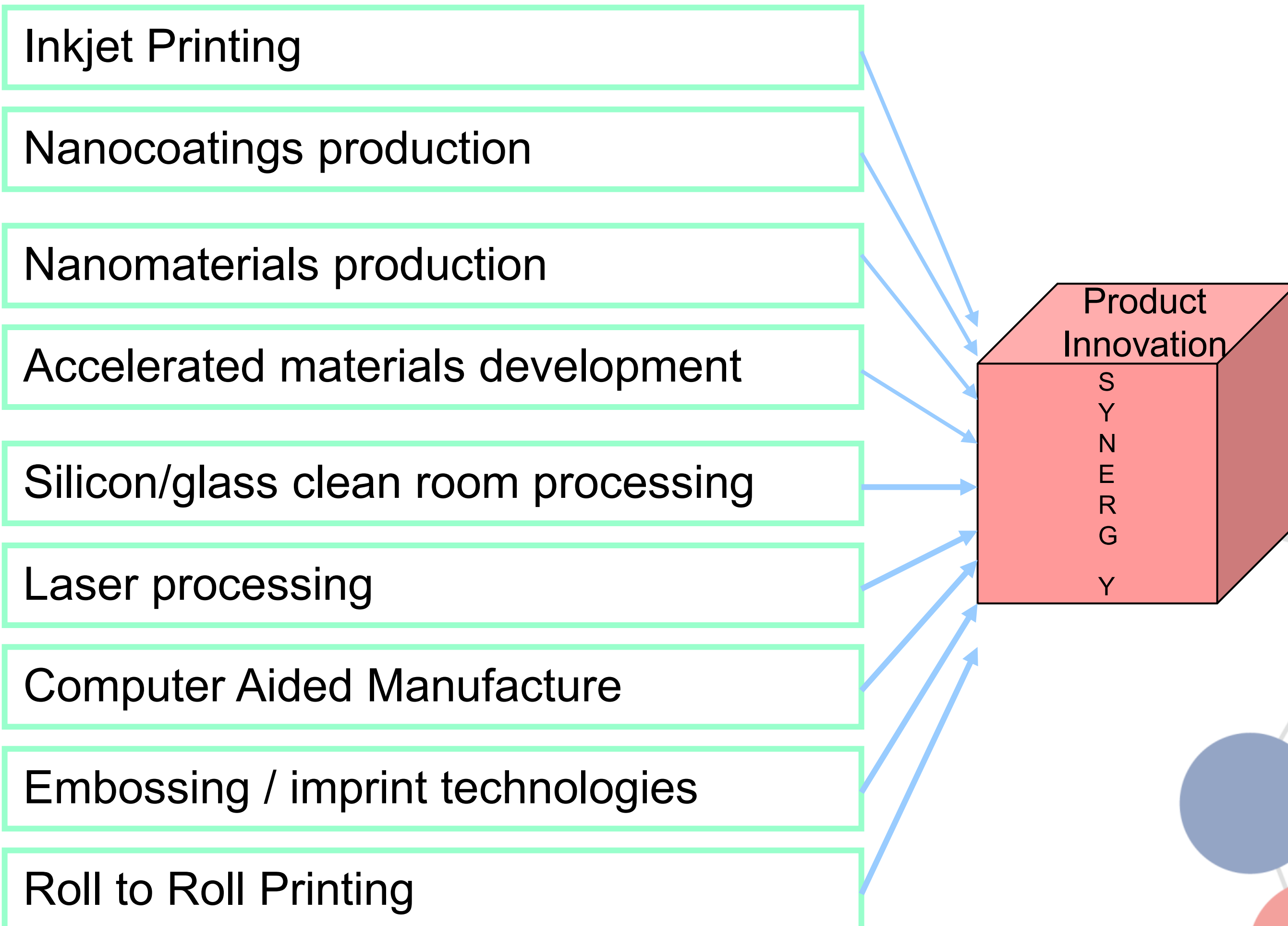
- Colloid chemistry
- Physical vapour deposition
- Chemical vapour deposition
- Hydrothermal synthesis
- Flame spray pyrolysis
- Laser ablation
- Gasification + Processing
- Mechanical processes eg ball milling

Nanocoatings

- Atomic Layer Deposition
- Physical Vapour Deposition
- Chemical Vapour Deposition
- Laser etching
- Water / Solvent based
- Plasma / Sputtering
- Spin coating

Knowledge Transfer Network
Nanotechnology

Confluence Effect of Technology Developments



Knowledge Transfer Network
Nanotechnology

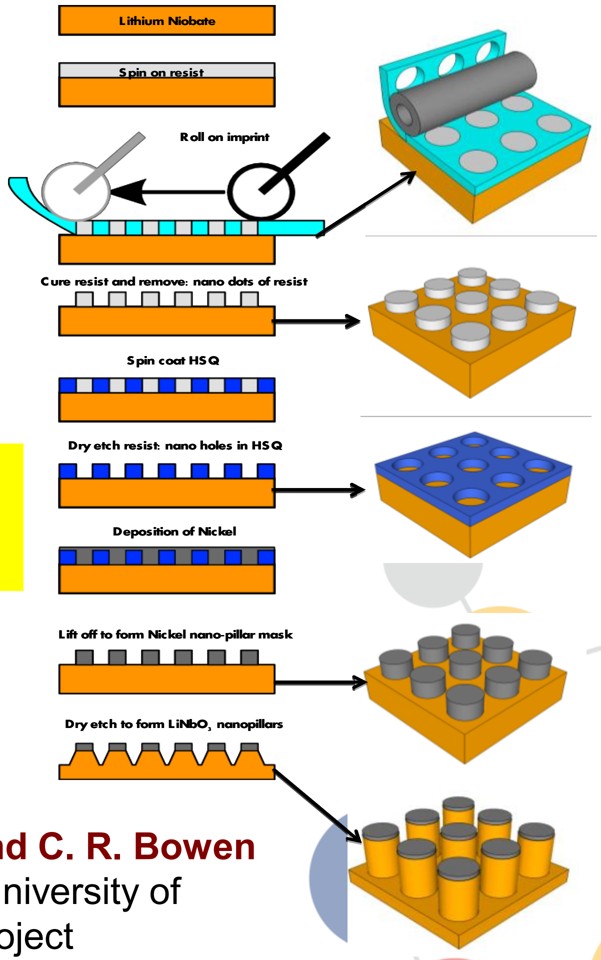
Nano-enabled Clean Energy - Opportunities

1. Piezoelectrics
2. Thermoelectrics
3. Batteries

Knowledge Transfer Network
Nanotechnology

1. Piezoelectrics

- Case Study: Nanoimprinting - Fabrication of highly ordered Nickel mask with dry etching of $LiNbO_3$ to form nano-rods



PZ energy materials using advanced manufacturing technique

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Rhodri W. C. Lewis*, D. W. E. Allsopp, P. Shields, A. Šatka and C. R. Bowen
*Materials Research Centre, Dept. of Mechanical Engineering, University of Bath, E-mail: *R.W.C.Lewis@bath.ac.uk

* EPSRC funded project

Knowledge Transfer Network
Nanotechnology

PZ Technical Drivers

- Replace toxic or scarce materials (eg Lead zirconate titanate (PZT))
- Improve conversion efficiency using nanotechnology
- Reduce cost by using high throughput manufacturing techniques

PZ Market Opportunities

- Energy harvesting
  - pavements, roads
  - clothing
  - Tyres / kinetic applications
- Cross-Market Applications
  - Mechanical Sensing
  - Actuation (eg smart actuators for aerodynamics, medical)

2. Thermoelectrics

- Harvesting heat energy currently focuses on high temperatures where existing materials are more efficient (eg Bismuth Telluride)
- Current global market is $300m. If technical challenges can be overcome, the potential market is $billions
- Significant activity in automotive

T/E Technical Drivers

- Improve conversion efficiency
  - Harvest low grade heat (lower temperature devices)
  - Improve heat transfer efficiency
  - Optimise device geometry and design
  - Improve thermoelectric efficiency (zT)
- Reduce cost
  - Alternatives to scarce materials (eg Tellurium)
  - Materials scale-up

T/E Market Opportunities

- Heat energy harvesting eg:
  - Transport: Auto / HGV / Rail / Aerospace
  - Industrial plants (scavenging, eg to power sensors)
  - Energy generation (eg power stations)
  - Geothermal
  - Solar
- Cross-Market Applications
  - Peltier cooling for autos, clothing, buildings etc

3. Batteries

Size	Applicn
Large Scale	Grid buffering
Medium	Automotive
Small	Laptop/mobiles
Micro	Medical
Nano	Sensors

Energy source for harvesting is rarely continuous, hence the need to store energy

Nano/Micro/Small cells:

Existing UK business:

- in smart cards, medical devices, defence apps

Future Business:

- Medical devices, Smart clothing, sensors, RFID, track&trace, intelligent ticketing, water grid monitoring etc

Technical Drivers

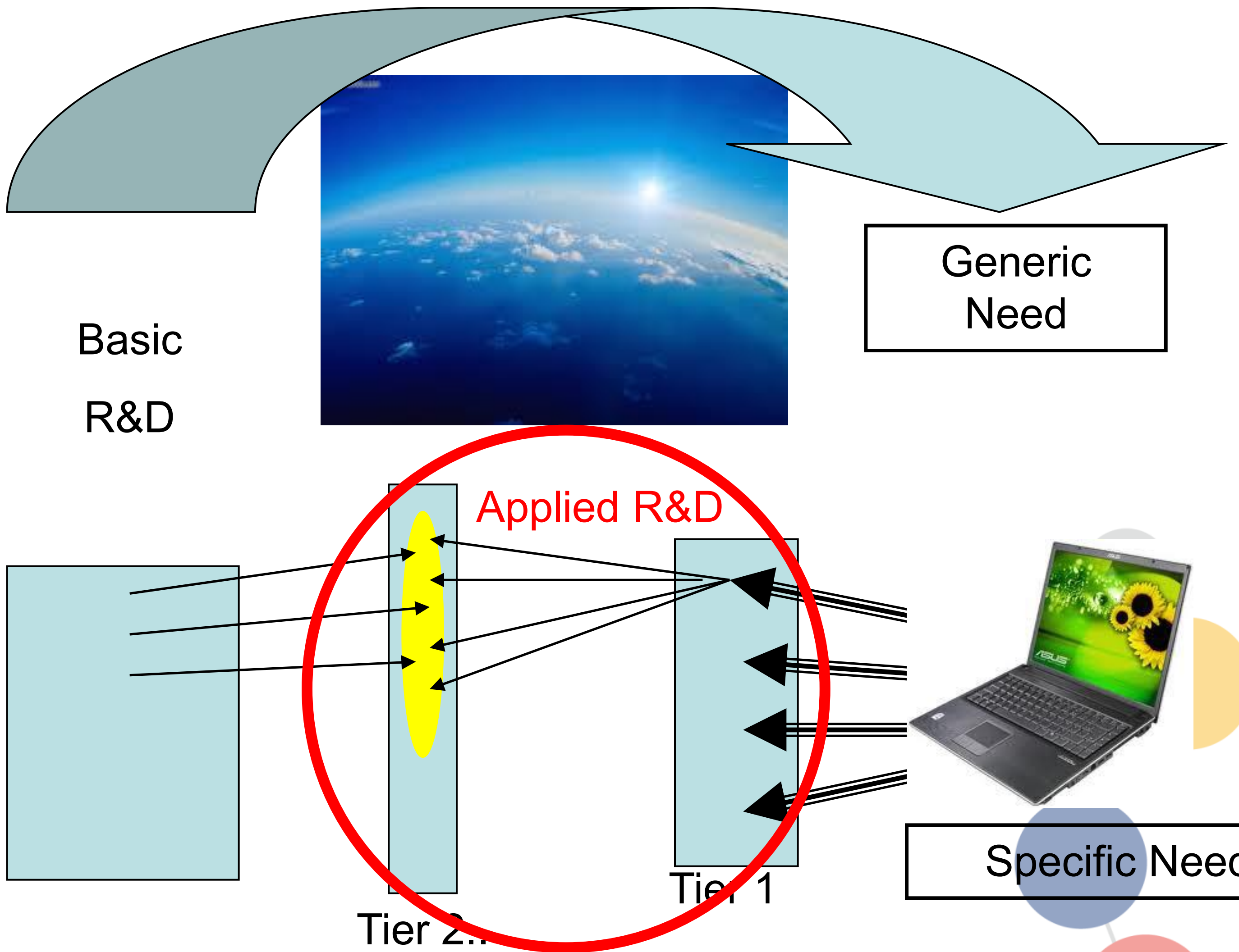
- Alternative materials to scarce or controlled resources such as Lithium
- Novel cell design –eg solid state electrolyte
- High energy density – reduce weight/size
- Hybridise with supercapacitor for rapid charge

Knowledge Transfer Network
Nanotechnology

Market Opportunities (Nano/Micro/Small Batteries)

- Medical
  - Eg In-eye implanted nanobattery to power artificial retina (Sandia Labs 2006)
- Personal IT
  - Distributed energy in a device, back-up memory
- Sensors
  - wide area grids eg water
  - Environmental monitoring
  - E-medicine
- Actuators
  - Powering of ‘smart’ micro structures
- Cross Market Applications
  - Potential to scale-up a cell for use in larger scale battery (ie new market opportunities)

Funding Strategies



Knowledge Transfer Network
Nanotechnology

Key Discussion Points

- Energy storage is key component of energy harvesting
- Energy storage and harvesting devices should be co-developed
- Prototype manufacturing processes should be a key element to project
- Device design & manufacture should be a key element (& project leader?)
- Energy harvesting should target end uses supported by strong business case

More information or to join the NanoKTN: www.nanoktn.com

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Notes from Martin Kemp's presentation [1]

- Martin presented the vision of ubiquitous energy harvesting – but asked "who's paying" for this harvest? It's difficult if it's society; if it's an individual, then it's easier to see who will pay
- Two key messages:
  - Nano/microtechs offer new toolkit for making things
  - There are synergies from mixing and matching manufacturing processes
- He showed a nanotechnology capability map – and illustrated the synergies that started to emerge form overlaps in the map
- He talked through the manufacturing techniques that had been developed and gave some examples of how this had been used, eg in printing, to create product innovation
- Turning to EHTs, he systematically discussed the drivers and opportunities of various technologies
- In **piezo**, he talked through a case study: nano-imprinting to form nano-rods of $LiNbO_3$ – a scalable process, and said that replacement of toxic materials, and cost reduction were among the drivers of development

Notes from Martin Kemp’s presentation [2]

- The piezo market opportunities including pavements, clothes, and also actuators for cross-market apps
- In **thermoelectrics** he spoke about harvesting heat energy at lower temperatures with new materials – the automotive sector was important here as a major potential user (harvesting exhaust heat)
- Technology drivers included low-grade heat capture; improved heat transfer efficiency and thermoelectric efficiency (zT) – new materials can improve this significantly (could save 2.5 mpg in automotive applications); reducing cost; and eliminating scarce materials like Tellurium
- There were opportunities in transport (road, rail and air); industrial plant inc steel making; geothermal energy; solar; space – also Peltier cooling (air conditioning, clothing etc
- Martin spoke about storage and batteries saying that in the UK the focus has been on medium-scale (automotive) batteries; but we have technology in small polymer cells
- Martin said there were plenty of future opportunities, eg in sensors of various kinds

Notes from Martin Kemp's presentation [3]

- Technology drivers of the market include the fact that Lithium is a controlled resource (only 4 mines worldwide) so there is interest in non-Li-based batteries; also in solid-state electrolytes; increasing energy density and speed of charging; hybrid battery / supercapacitor devices
- There were very many opportunities including in the medical sphere, personal IT; sensors and backup power
- Martin said it was important to note that batteries and EH are closely linked
- He said that here drivers were societal needs, funding strategy should be direct to university research; and where there was an industrial need, funding should flow back through the supply chain to research. He felt that there was a mid-way point that the TSB could help with
- Summing up, Martin said storage and EH should be co-developed because they are intrinsically linked; prototyping manufacturing processes, and device design and manufacture, should be key elements of any project and that EH should target end uses, supported by strong business case (who's going to pay for it) – otherwise it'll be tech looking for a solution

Energy Harvesting Research – vibration, oscillatory motion

Steve Burrow

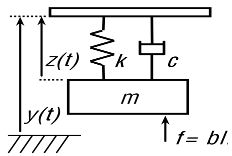
University of BRISTOL

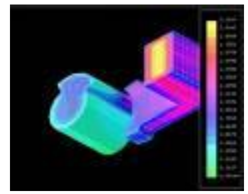
DEPARTMENT OF aerospace engineering

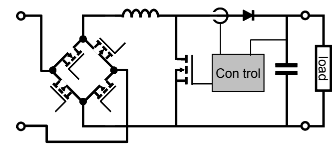
Overview

- Component technologies
- EPSRC funding
- Research challenges
- A few examples
- Personal thoughts on DTI project

System components







Sources

- Vibration
- Human Motion
- Wave

Mechanics

- Resonant
- Direct force

Transducers

- Electromagnetic
- *Piezo*

Electrical

- Rectification
- Regulation
- Power Factor control
- *Storage/ management*

Applications

- Aircraft HUMS
- Wireless sensors
- Environmental sensing

EPSRC grants with ‘Energy harvesting’ in title

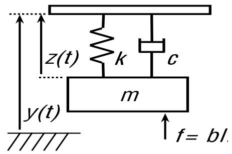
- **Energy Harvesting Materials for Smart Fabrics and Interactive Textiles**
- **Next Generation Energy-Harvesting Electronics - holistic approach**
- **Energy Harvesting Network**
- **Energy Harvesting: vibration powered generators with non-linear compliance**
- **Mobile Energy Harvesting Systems**
- **Nanostructured Functional Materials for Energy Efficient Refrigeration, Energy Harvesting and Production of Hydrogen from Water**
- **Enhanced solar energy harvesting in dye sensitized solar cells using nanophosphors and nano-structured optics**
- ***Highly-efficient thermoelectric power harvesting***
- ***Distributed Health Monitoring with Autonomous Power Generation***
- ***Self-Powered Wireless Sensors for Fixed Wing Aircraft***

Research areas

Sources

- Vibration
- Human Motion
- Wave

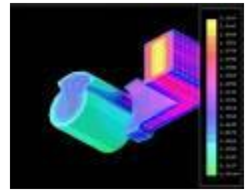
Source dynamics and statistical measures of varying behaviour. 'Power forecast'



Mechanics

- Resonant
- Direct force

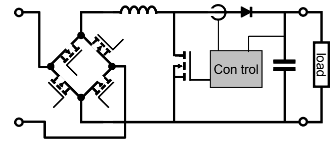
Application of Nonlinear dynamics to energy harvesting, inc. modelling and simulation



Transducers

- Electromagnetic
- *Piezo*

Design and simulation of transducers and materials



Electrical

- Rectification
- Regulation
- Power Factor control
- *Storage/ management*

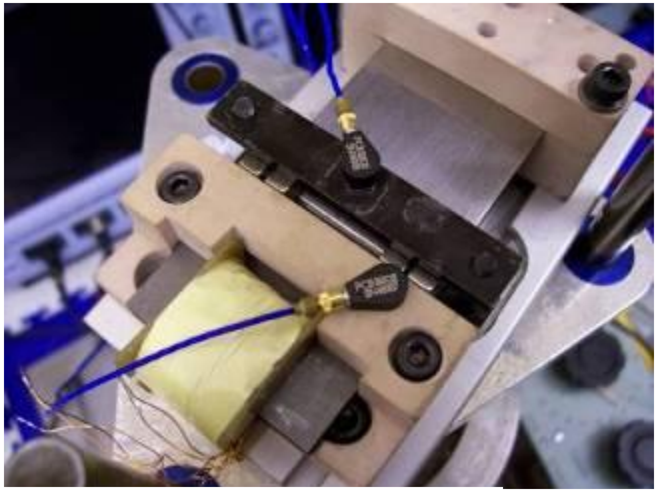
Implementation of advanced power conditioning at μW levels

Applications

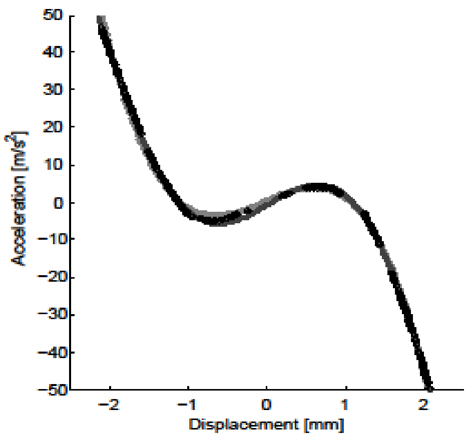
- Aircraft HUMS
- Wireless sensors
- Environmental sensing

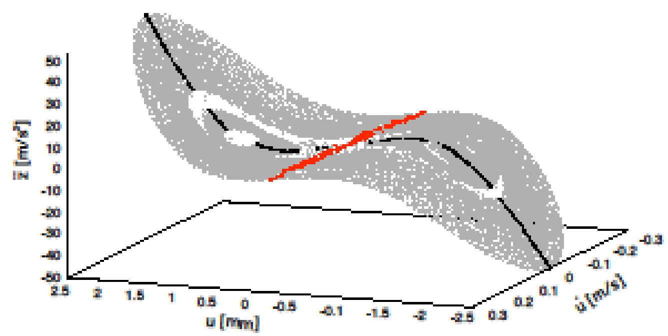
Sensor platform architecture. Low power sensor interfaces. 'Combined benefit' systems.

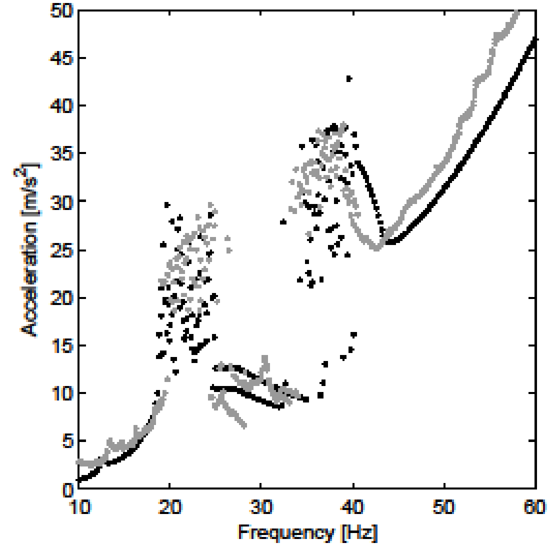
Mechanics



- Many vibration energy harvesters use resonant mechanical amplifiers with narrow frequency response.
- Non-linearity can be exploited to modify frequency response.



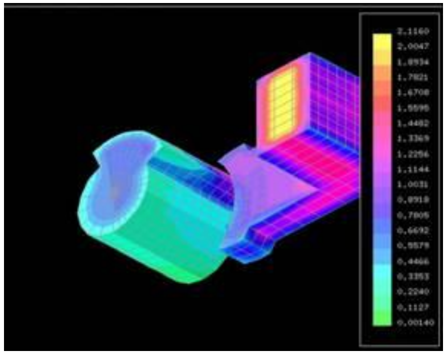




Behaviour of bistable harvester

Transducers

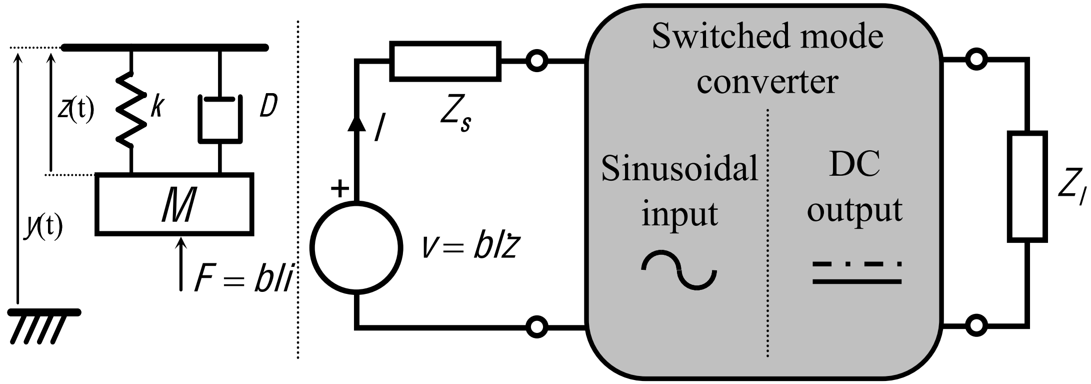
Composite with embedded magnetic material



FEA analysis of reluctance transducer

- Transducers typically become less efficient as scale reduces.
- Manufacturing is more complex, simpler mechanisms (e.g. reluctance, electrostatic) incur losses due the lack of excitation.
- Solid-state materials are desirable, with significant research into new materials and structures.

Electronics



Simple schemes are very sub-optimal. Many research challenges exist;

•Stability of regulation schemes

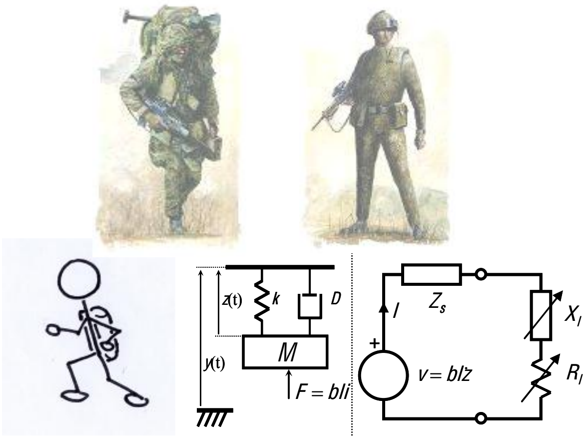
•Compensation for transducer impedance

•Implementing complex schemes - unity power factor, power tracking – all at low power

•Implementation over a wide range of low powers: uW - mW levels

Applications: Combined benefit

Rucksack harvesting

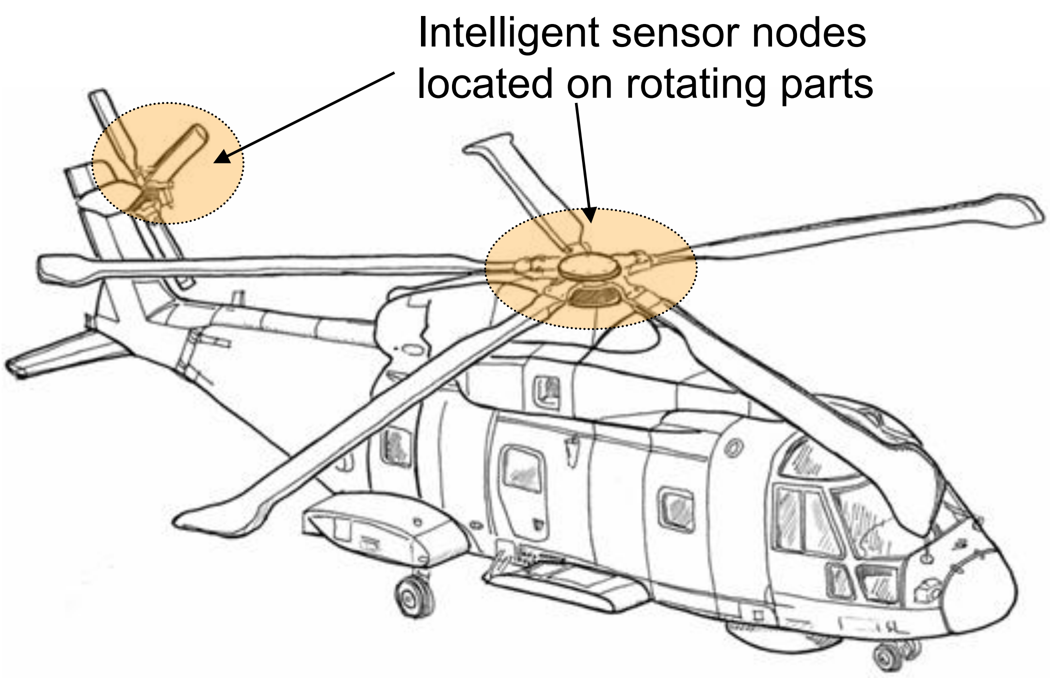


- The rucksack harvesting concept is treated as vibration isolation problem.
- System is adaptive through electrical load.
- Can reduce load on wearer – which may be more important than energy harvesting

Vibration isolation

- In some applications where EH is proposed, structures already exist to damp vibrations.
- Power generation and damping can be combined to develop active systems, providing new functionality.

Review: Rotorcraft HUMS



- The WISD project sought to advance HUMS
- Exploiting the high-vibration environment for power harvesting
- Using feature extraction techniques to estimate actual usage or detect damage
- Locating processing power at remote nodes to reduce power

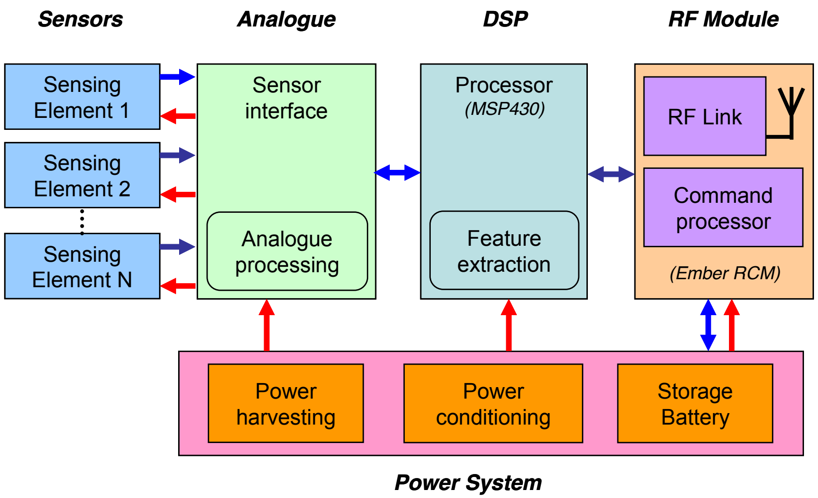
S·E·A

conekt powered by TRW

University of BRISTOL

AgustaWestland

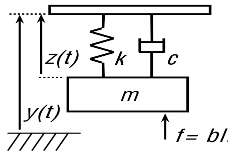
Review: Rotorcraft HUMS

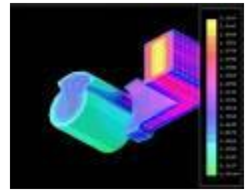


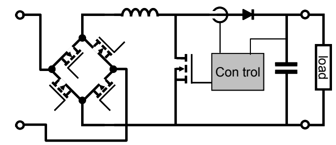
- Ultra low power sensor interfaces, mixed analogue/digital processing and radio link demonstrated to tethered flight trial.
- Energy harvesting demonstrated on bench.

- Energy harvesting couples individually complex systems, linking engineering disciplines and requiring buy-in from each to achieve success.

Technology Map







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Design and simulation of transducers and materials

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Implementation of advanced power conditioning at μW levels

Applications

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- Wireless sensors
- Environmental sensing

Sensor platform architecture. Low power sensor interfaces. 'Combined benefit' systems.

Whole dynamic system design

Notes from Steve Burrow's presentation [1]

- Steve gave a research perspective, starting with a map breaking down EH systems into component parts (making the point that in the UK, EH has an electrical focus; in the US, it has a mechanical focus) and said academics tend to present their research results in this area in specific ways because of their particular interests
- He looked at how funding had been given for EHTs and what had been published for each of the components in his map, and gave examples of types of academic work in each component, including
  - Energy sources
  - Mechanics (structural dynamics research)
  - Transducers (new materials; loss minimisation; scale issues)
  - Electrical/electronics (simple schemes are very sub-optimal and there are many research challenges here – stability of regulation, transducer impedance, requirement to cover many power ranges – uW and mW)
  - Applications (combined benefits – eg rucksack that extracts power through vibration and increases comfort, similar vibration isolator in helicopters or cars)
- He then spoke about work he had been involved with – helicopter Rotorcraft HUMS (which had included energy harvesting)

Notes from Steve Burrow's presentation [2]

- He showed how an EH would interact with vibration reduction system on a helicopter – challenges include increase in complexity
- He said that R&D stovepipes existed (shown in his map), that were broad enough to satisfy academics, but that for commercial success, EH needed to be considered more broadly
- **Q: The helicopter example shows why EH is difficult – where energy can be harvested best isn't necessarily the place where measurement can best be done – so there are difficulties in implementation**
- A: Yes – this is exactly right – in UK academia we may have ignored structural dynamics – so cross-disciplinary R&D is required here; there are all sorts of trade-offs to juggle

INSTITUTE FOR ENERGY AND ENVIRONMENT

University of Strathclyde Engineering

Lifelong Power for Bioengineered Implants

Prof. Terry Gourlay, Bioengineering

Dr Martin Judd, Electrical and Electronic Engineering

Technological Opportunities

University of Strathclyde Engineering

- Implanted systems and body components that adapt to an individual's growth.
- Eliminate need for young patients to undergo repeated major surgery.
- Lower costs, better prognosis, improved quality of life.

Requirements

University of Strathclyde Engineering

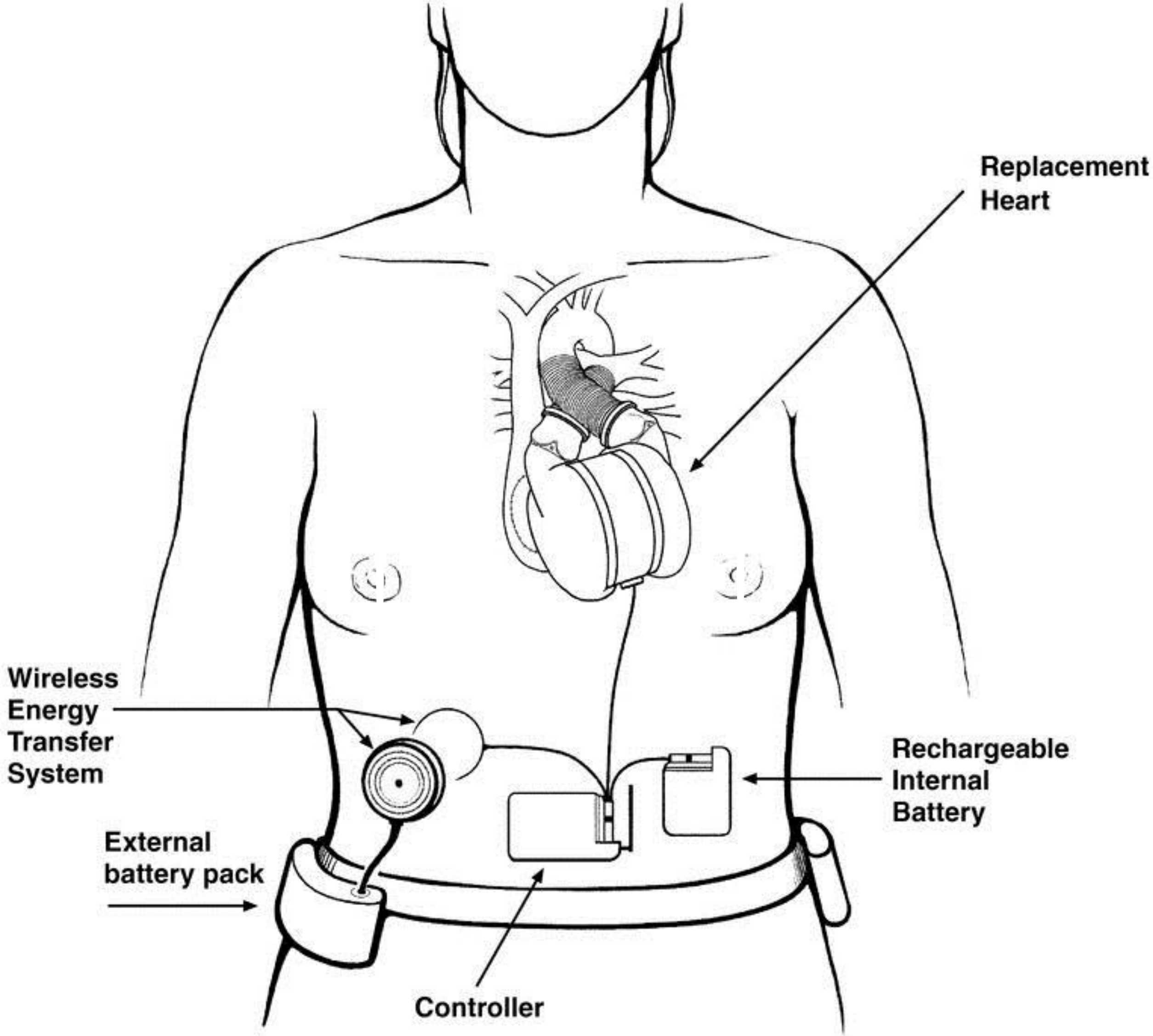
- Reliable, long term electrical power from the body itself.
- Unlike artificial heart, average power consumption may be very low.
- Harvesting from continuous power source, e.g., breathing.

Power sources

- To what extent can ‘gadget’ technology be applied within (or permanently on) the body?

Artificial hearts – serious power

Artificial heart – power delivery



Martin Judd's presentation was brief – significant points made are on slide 11

Notes from Douglas Paul's presentation [1]

- Douglas introduced the physics of the Seebeck Effect and how the effect could be used in practice, including how the efficiency of the effect changed with temperature
- He said that impedance matching is a critical engineering challenge – but it is possible to address; you need to build modules with series electric, parallel thermal configurations
- He showed comparisons of thermodynamic efficiencies with other power generation technologies, and discussed what happens when things are scaled down electrically (here thermoelectrics became much more efficient)
- In practice, the uses would be in cars (in exhaust gases you can use T deltas of 1000K); Peltier coolers (every telecom laser uses this); Gunn diodes; RF modules – all use Peltier coolers – currently Peltier coolers are very inefficient, but could be made much more efficient. Douglas pointed out that in space applications, Voyager was still working after 34 years

Notes from Douglas Paul's presentation [2]

- Douglas listed other applications including – temperature control for carbon capture in power stations; smart pills (legislation says they currently must be powered by batteries!); autonomously powered (biomedical) sensors for example for telecare / remote care
- He then spoke about a research project he was working on ("GREEN Silicon") in response to problems with use of Tellurium in thermodynamic EHT – looking at the use of Si and Ge
- He said that current Te modules are not particularly efficient (in terms of thermoelectric coefficient); Si/SiGe and more exotic materials can be much more efficient (but only in the lab at the moment)
- The research was European-funded, and covered research into thermal and electrical impedance matching, and the construction of components and complete generators
- There is a lot of use of current manufacturing processes (similar to Te-based processes)

Notes from Douglas Paul's presentation [3]

- Douglas explained what the James Watt Nanofabrication Centre in Glasgow could do, and who it had worked with
- He then explained current issues with the GREEN Silicon project (eg, accurate thermal measurement)
- Douglas finished by showing where the potential was for better thermoelectric materials and devices was and how it compared with what was commercially available at the moment, and summarised what his team was doing
- He believes that thermoelectrics have the following advantages: ubiquitous, static energy source; efficiency good compared with thermodynamic engines at small scale; but that there are some challenge to be overcome to their commercial use
- He introduced the "Zero-power.eu" group

For more information…

www.innovateuk.org

For even more information and online networking…

www.innovateuk.org/connect