EPSRC Engineering and Physical Sciences Research Council

EPSRC Workshop Report:

Photonic Systems Workshop
Tuesday 1st December 2009

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EPSRC

Contents

Background

Motivation for the workshop

Individually in photonics, software, communications and electronics, UK research is world class. (This perception came out of the ICT theme days in Communications, Electronics, Computer Science and Photonics.) Technology associated with these disciplines is increasingly converging as all aspects of data input, information processing and transmission become embodied in a single ICT system. It is apparent that this 'systems' approach to ICT is not well represented within the individual ICT disciplines in a way as to maximise the benefit and impact of UK research.

Photonics is, and will increasingly be, a key enabling technology in ICT. Part of the discussions at the photonics theme day[#] revolved around how photonics fits into ICT themes and its future relationship with electronics, software, and communications networks. Subsequent dialogue with the research community identified an interest to explore a holistic approach to ICT, centred on opportunities and challenges for photonic systems.

EPSRC are endeavouring to facilitate this opportunity by bringing together the appropriate research communities. At this early stage this workshop will assess the disciplines involved, scope future developments in this area, gain the views of potential users and industrial collaborators and also endorse goals and challenges. It is hoped to build a coherent vision for photonics systems research, so that the community can take this vision forward and manage activities in this area in the future.

Key outputs of the Photonics theme day (June) were:

- There is a community view that photonics is all pervasive, underpins lots of science and technology areas and has the ability to address contemporary issues.
- There are concerns that boundaries between Photonics & ICT disciplines are not being crossed, increasing global competitiveness and the lack of national strategy for applications of Photonics.
- There exists an opportunity to define a holistic approach to multidisciplinary working. This can also deliver a competitive advantage in global market place.
- The future of photonics research relies of open communication, systems integration and strategic funding.
- Key technology areas beyond 2010: Optical wireless convergence; photonic-electric integration and end-to-end photonics and enabling systems.

Objectives of the workshop

- Promote a dialogue between members of the ICT community and identify a common vision for the future of photonic systems research.

- Gain views from industry and other stakeholders on key messages and priorities.
- Investigate potential economic benefits of a photonic systems approach.
- Explore mechanisms for encouraging research in these areas

Delegate selection

Delegates were invited to submit an expression of interest to attend the workshop through an open call on the EPSRC website. A mailing list consisting of all invitees of the ICT theme days were particularly encouraged to apply. The selection of accepted applicants was subsequently made by the ICT programme to ensure a breadth of expertise (across ICT disciplines), institutional representation and academic/industry background. Members of the ICT strategic advisory team were also invited to the workshop.

A full list of attendees (including EPSRC staff) is given in Appendix I.

Agenda

The workshop was held on Tuesday 1st December at The Montague on the Gardens Hotel, London. The agenda was as follows:

Time	**Item**
1000	Registration
1030	Welcome and Introduction
1040	Icebreaker
1100	Setting the scene: An Industry View Talk by John Bagshaw (BAE Systems)
1130	Session 1: Vision Identification
1245	Lunch
1345	Session 2: Vision Exploration
1515	Break
1530	Session 3: Vision Realisation
1615	Next Steps
1630	Finish

Workshop outputs

Icebreaker

The workshop began with an icebreaker to set the scene for the day and to introduce delegates to each other. The premise for the icebreaker activity was that

"Photonics is becoming increasingly ubiquitous and has made an impact across all sectors. But just how ubiquitous is Photonics in our world today (and potentially in the future)? "

Delegates were allocated into groups of 3 or 4 and asked to randomly select a theme. For each theme, the attendees were asked to brainstorm where photonics had an impact in that particular theme.

Output from posters:

Crime

Now	**Future**
CCTV	Terahertz sensor
Spectroscopy	Widespread IRIS recognition (2D-3D)
Number plate recognition	Thought detection
Speed Camera	Optical pattern recognition
Face recognition	Fire detector
mm wave radar	Object detection
IRIS recognition (bibliometric)	Cloak of invisibility (sensor hiding)

Transport

Now	**Future**
Scanners-barcodes	Pilot-less vehicles
Displays	Increasing role of sensors/ security systems.
Datacams (in vehicle)	Failure prediction + detection
Head up displays	Automatic payment- mobile POS
Pattern recognition (e.g number plate)	Optical wireless
Security (biometrics)	

AV systems	
Simulators	

Banking and Finance

Now	**Future**
Optical networks	Investment return on photonics
Anti-counterfeiting	Photonic-enabled money production/ security
Displays-ATM-Trading	Optical storage
ID cards reading and writing	Quantum cryptography
Home banking	Virtual teller/ bank manager
	Secure photonic enabled ID cards
	Data centres and Networks for resilience, power consumption

Home and Household

Now	**Future**
ADSL- Copper wire	Fibre to the home
Plasma LCD TV/ HD/ Sat	Interactive
PDA	UHD-fibre
Limited connectivity	Displays – wall projection
Fluorescent lighting	Multiple wireless devices
None-few	Hundreds of sensors
	Remote healthcare working
	LED lighting + smart homes

Leisure

Now	**Future**
Cinema + data projection	Centralised cinematic network
Cell phones for cameras, navigation Augmented reality	Spec-free 3D Fibre to the home enabler

LCD now	‘Wallpaper’ display
	Active contact lenses (photonic projection onto retina)
	Super GoogleMap: superposition of data on real view

Media and the Arts

Now	**Future**
Cameras (digital imaging)	Advertising based on personal/subjective identification
Displays (decorative & imaging)	Whole body tracking
Wearable garments + interference data transfer	Interactive learning/ entertainment
Interactive media	3D displays
Virtual reality	Optical data processing
Fluorescent clothes and pigments	
Data storage (DVD, CD etc…)	
Watermarking	
Painting examination	

Sport

Now	**Future**
Stadium displays	Security/ screening – mm & THz
Racing cars – sensors	Optical networks. Connections – simulation, interactive crowd participation
HAWKEYE	Virtual stadia – 3D venues, broadcasting and visualisation
LED & Laser shows	Increased analysis and prediction
Drag/flow analysis (windtunnels)	Collaborative training
Comms	Improved health analysis
Lighting	

Security (badges, ticketing)	
Anti-counterfeiting	
CCTV & crowd control	
Timing/ Imaging	
Thermal imaging + environment monitoring	
Medical/ health diagnosis of blood pressure/ flow	
Drug analysis (spectroscopy)	
Laser vibrometry (e.g. cars, sporting equipment)	

Agriculture

Now	Future
Satellite Monitoring/ remote sensing	Satellite monitoring
Artificial lighting	Artificial lighting
Mechanism of photosynthesis	Fluorescence –based quality control (freshness monitoring)
Air quality monitoring	Marker plants to monitor field crop health
Barcode scanners	THz scanning for quality control/ imaging
UV light in pollination (guiding insects)	Photonics in GM and synthetic biology.
Fluorescence microscopy	

Military

Now	Future
Laser sensing – LIDAR, Designators	3D profiling of targets, vibrometry remote chemical sensing
Displays – HUDs, CRTs, touchscreen	Crew out of vehicle (Immersive remote displays, 3D)
IR + VIS imaging (night vision)	THz + image integration

Within vehicle comms	Freespace opto long reach
Lighting	LED lighting covert IFF
IR countermeasures	Laser Dew
Camouflage	Active camouflage
Safety	Quantum cryptography – computational imaging
CCD	
X-Ray imaging	
Nuclear imaging	

Construction

Now	**Future**
Laser	Efficient Lighting
Theodolites	Home networks info + sensors
LED lighting	Fibre to the home
FBG sensors	Wireless optical home security networks
Geosurvey	Intelligent info systems for construction
Laserline of sight	PV (BIPV)
Security systems	Light conditioning
	Laser machining
	ALM
	Thermal monitoring
	Robotics

Setting the scene: An Industry View

John Bagshaw (member of ICT SAT) gave a talk to set the scene entitled 'Photonics: An Industry View'. The key messages are reiterated below:

The state of photonics:

- Photonics is a key enabling technology for many industries

- Application is very broad and pervasive (telecomms, medical, defence, energy, lighting etc…)

Historical importance of photonics

- Engendered in UK by collaborative R&D over 25 years
- Supported by government and research council funding.
- Large industrial labs and SME's, working with universities
- Universities are essential to the establishment of technology in the UK
- Very significant funding and strong European dimension
- Part of the fifth industrial revolution (information and telecoms) huge relevance economically.

Significant change in the last 20 years

- Disappearance of 'the great' industrial labs and a growing importance of SMEs.
- Characteristic industrial R&D has changed significantly over 10 years
- Within industry there is more emphasis toward development (shorter product lifestyles)
- Engineers use photonics as a means to an end (rather than as specialists)
- Universities will need to engage with users who are no longer expert at a fundamental level

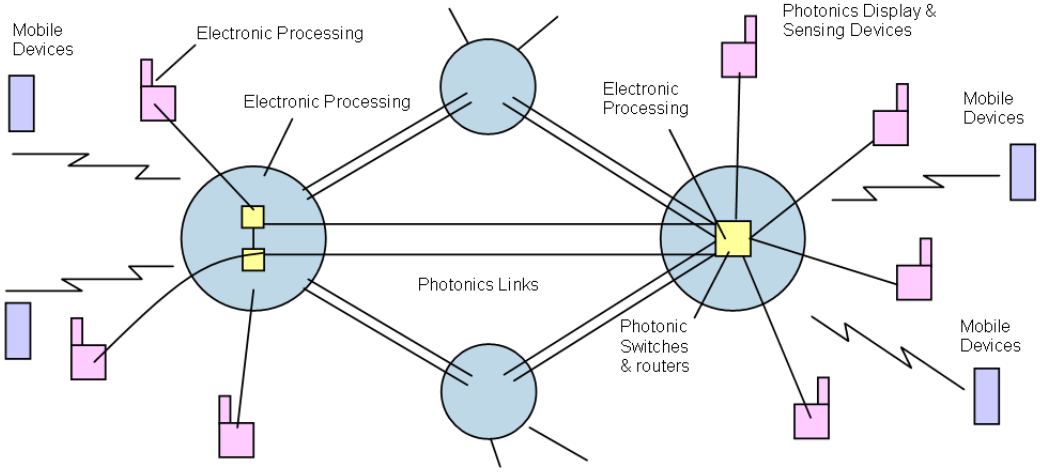
What should be Universities' role?

- There is an increasing importance of university research
    - Universities need to be more engaged and user friendly (this is both an opportunity but also a threat to research independence)
- Academic independence and excellence are still key
- Despite economic downturn and budgetary pressures, university research essential to the engine of economic recovery
- Should universities step into gaps vacated by large industrial research labs?
- Should universities identify areas which are societally relevant?

Photonics and ICT disciplines

- Bring these together to offer more than the sum of the parts academically and economically

- Develop a strategy for Photonics and ICT
- Only the research community can do this for itself
- Solicit contributions & support from users, industry, TSB, KTNs etc…
- Requirement for university research to move ‘up-system and be integrated & multi-disciplinary.
- Develop role of photonics and ICT in the sixth industrial revolution?
    - Cleantech and biotech
    - Rise of mobile systems / cloud computing
    - All optical switched networks, high efficiency
    - Software/ algorithms/ efficient electronics photonics and algorithms / data security
    - Green networks
    - Growth of aging population/ medical applications



Budgetary and impact considerations

- Industry ‘switches off’ research in areas which look unfruitful, or where technology is superceded, and places funding elsewhere.
- Should there be a mechanism to realign university funding of areas which look unlikely to find application?
- Academic community to develop, review and apply research strategy above the peer review process? Actively restrict some areas even though rated academically excellent?

Session 1: Vision Identification

The objectives of session 1 were to explore holistic approaches to ICT, identify key societal issues and where photonic systems can contribute and identify the ambitious, overarching visions to take forward into following sessions.

To help create a vision, the delegates were divided into groups containing a mixture of academic and industry expertise in order to answer one of five questions (listed below). Each of the questions were posed to extract a coverage of ideas on future technology, research areas and applications relevant to photonic systems, whilst aligning towards an overarching vision.

Key outputs were:

1. In the future, what major societal problems will need to be overcome?

Themes included:

- Energy
- Environment
- Security
- Healthcare (+ aging population)

(Many of the themes identified here were absorbed into subsequent sessions and not captured separately).

2. In the future, what technology will we have that we do not have now?

- Interaction (that is not keyboard/ screen related)
- The universal factory?
- Immersive video – towards object conferencing 3D Polaroid transmission
- 3D interactive displays
- Smart surfaces, including clothing
- New detectors, new image systems and new storage techniques
- Enabling technologies
- Networking and transmission current future data storage and transmission needs
- Realistic many-photonic technologies

3. In the future, what new research areas will there be?

- Security –detection, image recognition

- 100GH+ high frequency free space communications
- Bio-imaging, surgery, diagnostic therapy
- (Optical) access networks- broadband high data rates
- Integrated power photonics systems for manufacturing
- Systems view of network power consumption – hardware/ software
- Coherence – links with electronics
- Diagnostic platform for optimal network performance (cross layer)
- On chip photonic systems – integration
- Interconnects
- Sensing technologies
- User experience (including AI methods)
- Sharing of infrastructure

And what opportunities would there be for Photonic Systems?

- End to end comms and Apps (inc RF)
- Green technologies
- Sensing technologies and networks (big, security)
- Manufacturing
- Healthcare
- Space applications
- Only way to link component to application
- Need to understand disciplines and communities involved
- Requires other communities to be involved

4. In the future, which problems should photonics be addressing?

- Accessibility
- Education
- Fun things, basic physics
- System integration of PV, lighting, storage
- Ultra low-cost PV systems
- Discipline integration

- Games
- Nonlinear photonics
- Systems approach (optimised designs of novel nonlinear photonic systems to efficiently generate and deploy around different scales of optical networks, but important to understand the basic physics behind the “Ware-particle” duality of nom state particularly in the pre-state of a “random” distribution of O2Ds)
- Nanophotonics
- System 2D and 3D holographic vision systems/displays
- Photonic hardware for human machine interfaces – VR – 3D – Mice
- High power laser machining
- Wearable photonic materials (signage and fashion)

And how could a systems approach help?

- If done right can focus the pure research
- Essential because each device is reliant on more than one technique
- Things (parts of the project) rely on each other – interdependent
- New fields e.g. medical imaging
- Need to solve more than one thing at a time
- Closer engagement with industry getting faster results
- Academics can be seen in more areas (career)
- Technology alone is not sustainable
- More attractive to industry but would result in less funding
- Exposure to other areas – becoming aware of problems/issues in other areas
- Identify weaknesses
- 1 year post PhD follow on project into industry

5. In the future, which applications should drive photonics research?

- Security
- Entertainment
- Home entertainment (high speed connectivity, cable and free space)

- 3D viewing experience
- Cinema experience (CIN NET, centralised distribution of films to cinemas and houses)
- Ubiquitous sensing (data overload, more distributed data)
- Information small holding

And how could a systems approach play a part?

- Bringing in new physics – taking it thru to application
- Link photonics to silicontech people
- Holistic approach hard soft – both have to be done
- Bringing people together – cross fertilisation
- Start with applications
- Finding out what users need (i.e. working together, awareness of funnelling, future)

Session 2: Vision Exploration

The objectives of session 2 were to explore and expand the 'visions' identified in the previous session in more detail.

To do this, outputs from the five questions in session 1 were clustered underneath common themed areas and displayed on large posters. These common themes were identified as:

- Sensing
- Connected World (enabling communications)
- Security & Defence
- Energy
- Manufacturing and Healthcare

Using these themes as potential visions for the future, the first part of this session relied on randomly-assigned groups to 'blaze a trail' within each theme and explore future scope (between 1 – 20 years) with the aid of supporting issues/ ideas from the outputs of session 1. A number of questions to highlight the added value of a systems approach were posed to encourage discussion around these themes (i.e. who should be involved, major barriers, key research questions and economic/ social impacts).

Following this initial 'trailblazing' phase, group members were free to change or remain with their chosen theme to continue to develop the visions. There was also an opportunity to suggest new themes that were

not identified through the output of session 1. At this stage, additional themes were identified as

- Photonic VLSI

The final stage of this session allowed the delegates to select (using sticky dots) certain ideas, concepts or themes that they would like to endorse or would be interested to develop further (either in the final session of the workshop or beyond the workshop). The motivations for endorsing the vision (or tasks within each vision) were based around the following questions:

- Is it something that is realistic and doable?
- Should it have community/ industry buy in?
- Is the vision ambitious enough?
- Is it something the UK should be focussing on?

All outputs from this session are displayed on the charts in Appendix II. Here, the number of individual endorsements for each theme are captured by a superscript number next the theme title. Those ideas individually endorsed/supported are denoted by red type.

Towards the end of this session, the delegates were invited to help develop or 'champion' any of the supported themes/ concepts/ ideas in the final session of the day.

Session 3: Vision Realisation

The objective for session 3 was to derive next steps to help realise the most supported/endorsed visions and ideas from session 2.

Each idea (be it a theme or focussed research idea) would require a 'champion' to lead the initial realisation exercise during this session and ideally pursue further actions to develop the ideas beyond the workshop. However, it was noted that at this stage there was no initial obligation to continue to scope these visions beyond the workshop.

The session began with a call for volunteers (within the delegates) to champion any of the themes/ ideas explored in the previous session. A number of 'champions' were identified, who then gave a short pitch on what vision they were hoping to build in order to rally support to help develop the idea during this final session. The delegates were then invited to accompany the vision champions to discuss the vision and develop next steps to aid its realisation.

Using a proforma as a prompt for realising these visions, the groups were encouraged to identify what the community need to do to build critical mass, take the research ideas forward and construct a convincing feasibility case for economic, social, academic, industrial benefit (i.e. added value) to the UK.

Towards the end of the session, each champion was then asked to present the outcomes of this initial scoping exercise to all attendees and rally further support to continue development of these themes beyond the workshop.

Outputs from the session are reproduced below:

Safety / Security (from 'Security & Defence' vision)

Question	**Output**
What is the vision?	Safety/security. *Taking a systems approach* "A safe, secure world" 10 years → 20 years. Fill capability gaps (Network security)
How to proceed developing the vision beyond this workshop?	Get the "right" people involved (Politicians, scientists (us etc), Home Office, MOD etc) Obtain security clearance to do this
Who else to bring in to scope vision? (i.e. colleagues not attending the workshop)	DSTL and security services and companies such as QinetiQ. MOD ICT Centre
What involvement should industry have?	From start to pull through to market place (in an advisory capacity at beginning, development and later)
What existing funding mechanisms are available (and appropriate)?	EPSRC, MOD, Home Office (HOSDB) TSB EC security programme …. Significant funding over a longer term than annually
I'd like to help to develop this vision (please supply name and email)	roger.green@warwick.ac.uk D.Paul@elec.gla.ac.uk G.S.Buller@hw.ac.uk d.h.foster@manchester.ac.uk g.y.tian@ncl.ac.uk tim.holt@strath.ac.uk john.bagshaw@baesystems.com

Other comments/ notes:	Continuity of funding and charging of departmental structures etc Need to put together long term strategy not subject to whims of MOD/reorganisation etc

Connected world (enabling communications)

Question	**Output**
What is the vision?	Limitation in today's comms → what is the next BIG thing (no incremental) – Drive new research in all net layers and network segments
How to proceed developing the vision beyond this workshop?	Engage with stakeholder (identify the technical and non technical communities we should talk to) i.e. Government, ofcom, net operators, new service providers, content providers
Who else to bring in to scope vision? (i.e. colleagues not attending the workshop)	User communities Mobile VCE ICT communities Physics …..
What involvement should industry have?	Involve industry to define their long term technology Value proposition to industry
What existing funding mechanisms are available (and appropriate)?	TSB funding (access mainly) – digital Britain Define managed program → cross council Possibly through "Ideas Factory" process to create an appropriate community forum → Clear strategy for a funded program

I'd like to help to develop this vision (please supply name and email)	Udsimeo@essex.ac.ukU HUdnp@orc.soton.ac.ukU HUa.seeds@ee.ucl.ac.ukU HUh.haas@ed.ac.ukU HUs.yu@Bristol.ac.ukU HUN.J.Gomes@kent.ac.ukU Ian and Ian
Other comments/ notes:	Create a working doc. And wiki workspace

Diagnostic Systems (from 'Healthcare' vision)

Question	**Output**
What is the vision?	(all on post its) Non-invasive diagnostics systems Photonic scanners – low cost; safe; in GP Surgeries Multi modality – system/devices Data fusion registration Personal diagnostic scanners
How to proceed developing the vision beyond this workshop?	Identify sub themes – Neural imaging; cancer; diagnostic, therapy; Nano photonic medicine National international network – identify/contact Move towards meeting/workshop of academics/clinicians (IPEM)/medical physicists/industry
Who else to bring in to scope vision? (i.e. colleagues not attending the workshop)	Clinicians – identify from above Patient representative

What involvement should industry have?	Evaluating importance of applications Collaborative research Funding for specific projects Pharmaceutical – drug delivery etc
What existing funding mechanisms are available (and appropriate)?	EPSRC NIHS (MRC?) Europe FP7 Industry – TSB Welcome Trust
I'd like to help to develop this vision (please supply name and email)	b.hamilton@manchester.ac.uk martin.tillin@sharp.co.uk h.dehghani@cs.bham.ac.uk s.yu@Bristol.ac.uk N.J.Gomes@kent.ac.uk
Other comments/ notes:	

Energy

Question	**Output**
What is the vision?	50 years solar will be dominant Energy efficient architectures, photonics enabled Low coast PV Match generation/consumption - smart lighting
How to proceed developing the vision beyond this workshop?	Smart Grids Sensors Long term feasibility studies

Question	Output
Who else to bring in to scope vision? (i.e. colleagues not attending the workshop)	Architects/designers look good PV Planners Big generation/consumers Material scientists Software/control/systems
What involvement should industry have?	Construction/regulations Manufacturing
What existing funding mechanisms are available (and appropriate)?	Need “system level” funding Focussed call Energy community TSB Carbon Trust
I’d like to help to develop this vision (please supply name and email)	ngb@orc.soton.ac.uk dominic.obrien@eng.ox.ac.uk mark.leeson@warwick.ac.uk ihw3@cam.ac.uk michael.robertson@ciphotonics.com a.wilson@ppektn.org martin.tillin@sharp.co.uk John.Lincoln@sepnet.net
Other comments/ notes:	Need research Challenges

Platform Technology

What is the vision?	Platform technology for design and fab of complex circuits systems Design and validation toolbox/design rules Integration of photonics/electronics

	Enables: more highly functional pics; widens access to non expert users; reduces cost of photonic systems (incl SEMS etc)
How to proceed developing the vision beyond this workshop?	"Outline Call" – challengers, technologies etc. Roadmap Funding Routes Engage with EU programmes Workshop?
Who else to bring in to scope vision? (i.e. colleagues not attending the workshop)	Glasgow, IC, St Andrews, Sheffield, Southampton, Edinburgh, Warwick, H-W, Leeds, Surrey, Bristol, UCL, Manchester, Glamorgan, Cambridge, Cardiff, City, Nottingham, Strathclyde Functions: Modelling/design rules, material/wafers fab. Houses, users/designers, packaging applications
What involvement should industry have?	Foundries: Oclaro, CST, CIP, Intense, IQE, Qinetiq Users: Large numbers but incl. Kemelian etc Across Disciplines: Medicine sensing, Bio-photonics, comms, interconnects MPC
What existing funding mechanisms are available (and appropriate)?	EPSRC: Programme Grant? Collaborative grant TSB: Involve industry!! RDAS/KTNS EU Framework
I'd like to help to develop this vision (please supply name and email)	g.reed@surrey.ac.uk s.yu@Bristol.ac.uk a.seeds@ee.ucl.ac.uk sobayya@glam.ac.uk s.chakraborty@manchester.ac.uk rvp11@cam.ac.uk

Other comments/ notes:	

At the conclusion to this session, it was emphasised that it was up to the community to now take ownership of these visions beyond the workshop (either with or without the existing champion). At this stage, EPSRC would help to facilitate and support the development of these ideas, but would not preferentially promote any specific area.

Summary and Conclusions

A number of outcomes arose from the workshop that specifically aligned with the objectives for the workshop (defined in section 1.2). These outputs, as perceived by EPSRC are described below;

- **Promote a dialogue between members of the ICT community and identify a common vision for the future of photonic systems research.**
    - The workshop brought together a diverse range of members of the ICT community (photonics, electronics, communications) to open a dialogue on the future of photonic systems research.
    - The first (icebreaker) session explored the ubiquitous nature of photonics in our world today as well as its potential application in the future, through a number of generic sectors.
    - In session 1 (vision identification), a number of key societal themes were identified through a discussion of how and where a systems approach to photonics could contribute to future technology and research.
    - Coherence towards a common vision(s) was evidenced by collective interest around several of these themes in session 3 (vision realisation).
- **Gain views from industry and other stakeholders on key messages and priorities.**
    - John Bagshaw presented an industrial perspective of photonic systems research and highlighted the important contribution that universities can have in the future of this discipline.
    - As well as support from individual academics (who were willing to champion the development of the key themes at the workshop), there was input from industrial and user-group participants in scoping these themes.
- **Investigate potential economic benefits of a photonic systems approach.**

- In session 2 (vision exploration), discussion within the key themes included consideration of economic benefits of a systems approach.

- **Explore mechanisms for encouraging research in these areas**

  - In session 3, theme champions were identified to gain support around selected themed areas and aid the development and realisation of these themes.

  - Methods to build critical mass, promote research and to take each themed vision forward in partnership with EPSRC were suggested.

At the conclusion to the workshop, EPSRC encouraged the workshop participants to take these outputs forward and respond to community need for photonic systems research for the benefit of the UK research base.

Since the workshop, three of the themed areas (Connected World, Safety & Security and Diagnostic Systems) have continued to build community support following the workshop. Dialogue within the community continues in order to develop the research within these areas of interest.

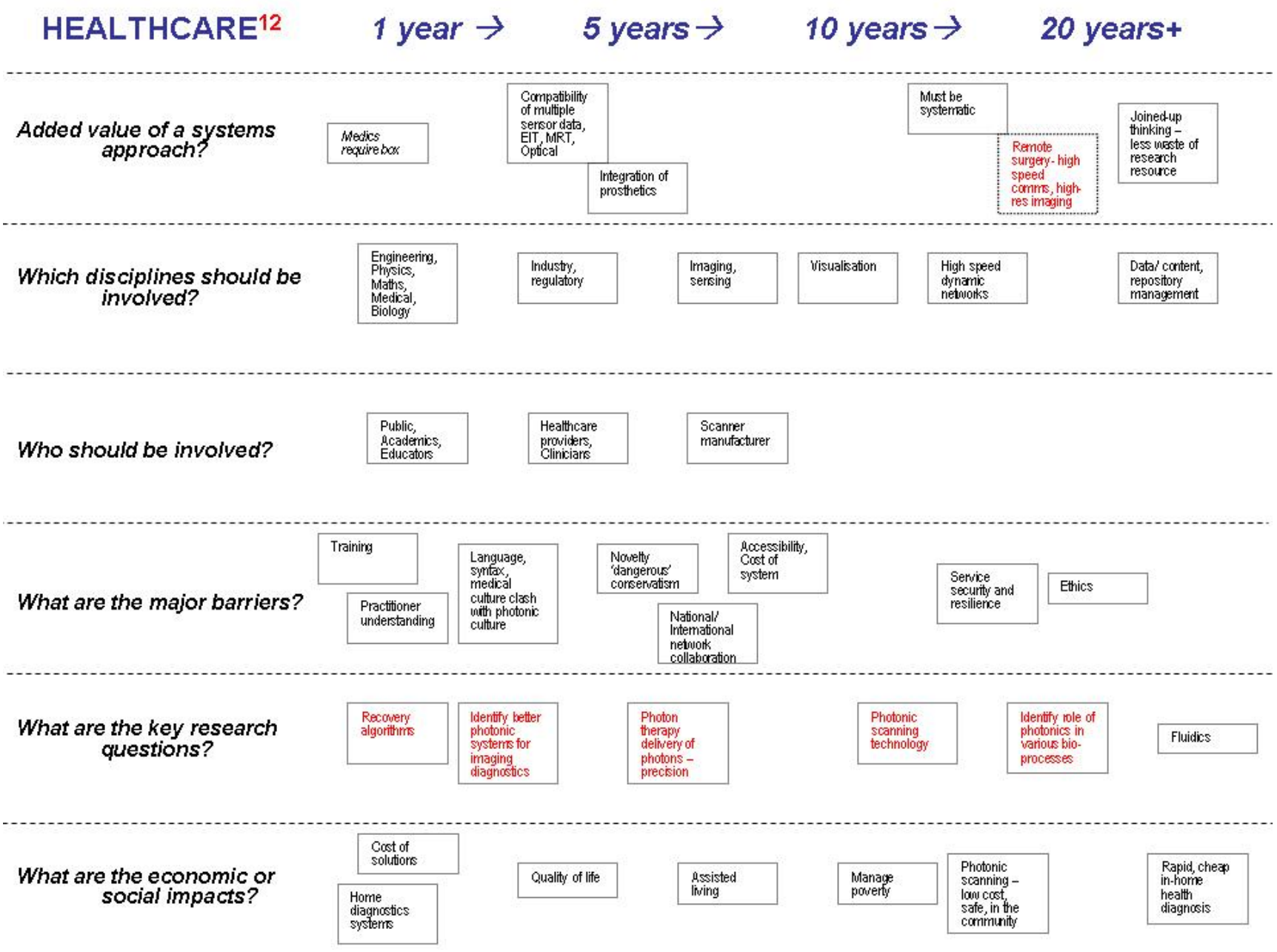
Appendix 1: Delegate List

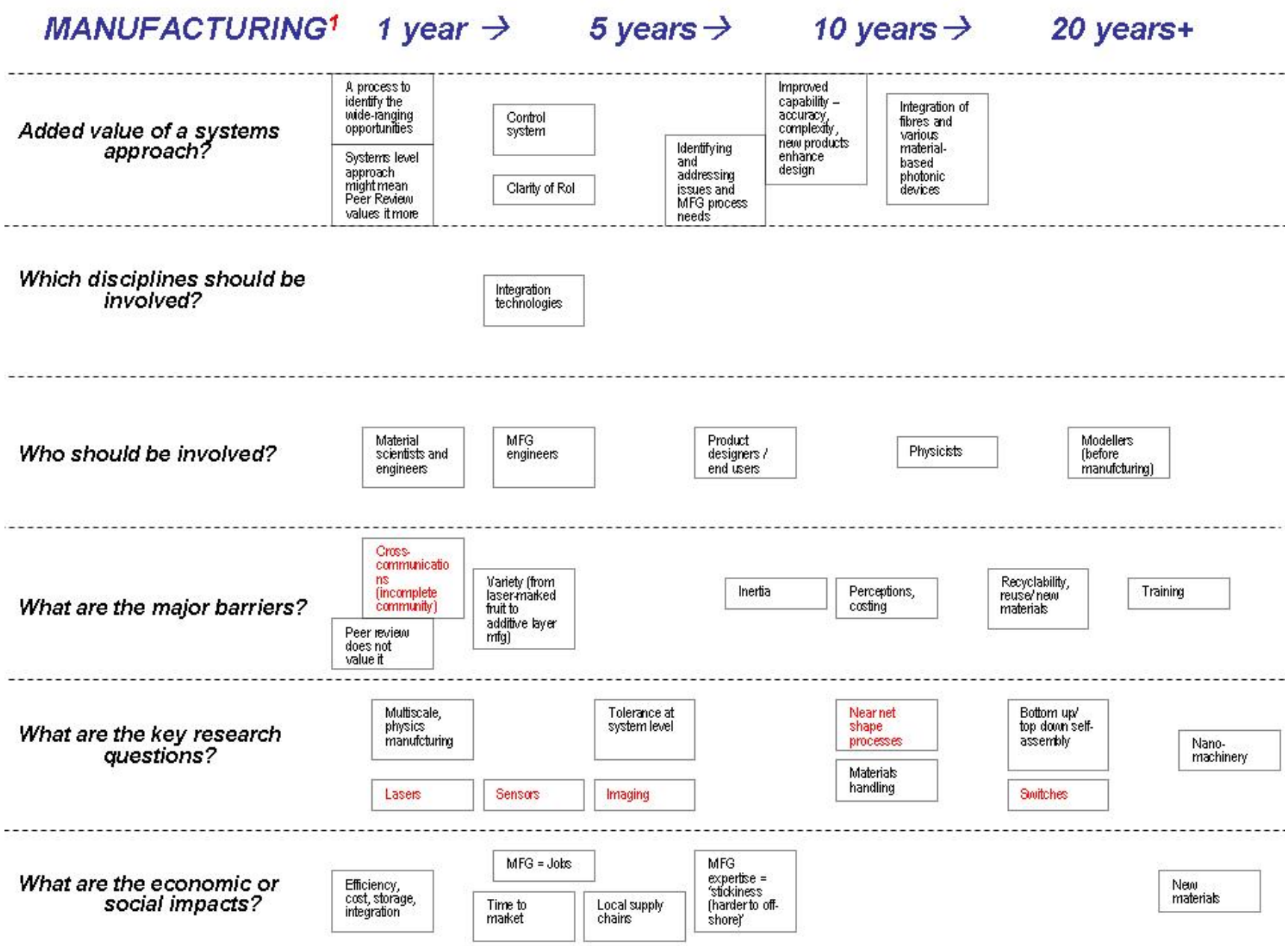
First name	Surname	Organisation
Ivan	Andonovic	University of Strathclyde
John	Bagshaw	BAESystems / ICT SAT
Mike	Biddle	TSB
Neil	Broderick	University of Southampton
Gerald	Buller	Heriot-Watt University
Subhasish	Chakraborty	University of Manchester
Nigel	Copner	University of Glamorgan
Martin	Dawson	University of Strathclyde / ICT SAT
Hamid	Dehghani	University of Birmingham
David	Foster	University of Manchester
Nathan	Gomes	University of Kent
Roger	Green	University of Warwick
Bruce	Hamilton	University of Manchester
Harald	Hass	University of Edinburgh
David	Heatley	BT
Ian	Henning	University of Essex / ICT SAT
Tim	Holt	University of Strathclyde
Mark	Leeson	University of Warwick
John	Lincoln	South East Photonics Network
Wei	Loh	University of Southampton
Salah	Obayya	University of Glamorgan
Dominic	O'Brien	University of Oxford
Douglas	Paul	University of Glasgow
David	Payne	University of Southampton
Richard	Penty	University of Cambridge

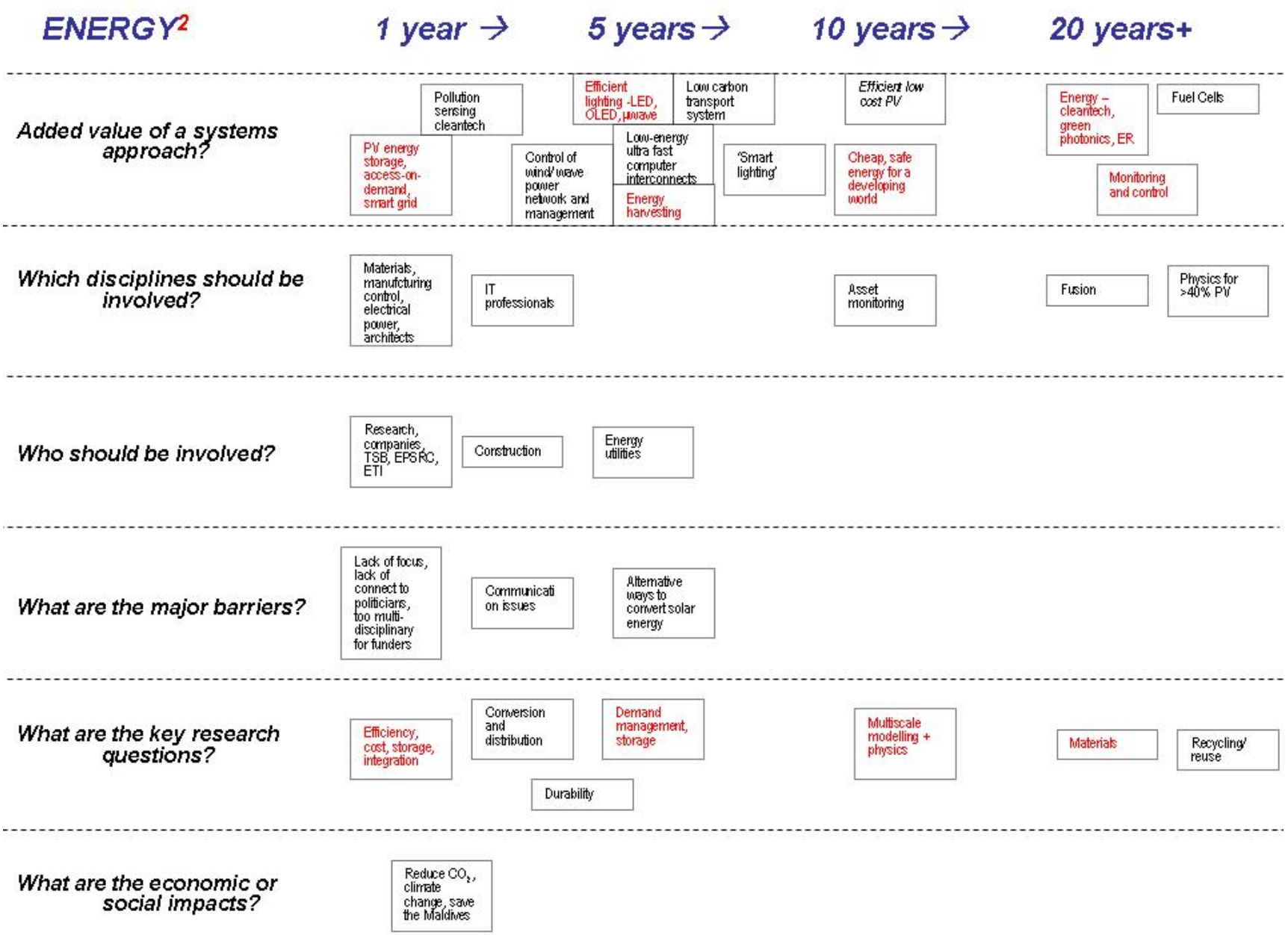
Periklis	Petropoulos	University of Southampton
Graham	Reed	University of Surrey
Michael	Robertson	Centre for Integrated Photonics
Alwyn	Seeds	University College London
Dimitra	Simeonidou	University of Essex
Gui Yun	Tian	Newcastle University
Martin	Tillin	Sharp / ICT SAT
Deepak	Uttamchandani	University of Strathclyde
Ian	White	University of Cambridge
Alastair	Wilson	Photonics KTN
Siyuan	Yu	University of Bristol
Andy	Lawrence	EPSRC
Matthew	Ball	EPSRC
Liam	Blackwell	EPSRC
Katie	Blaney	EPSRC
Denise	Dabbs	EPSRC
Tom	Headen	EPSRC

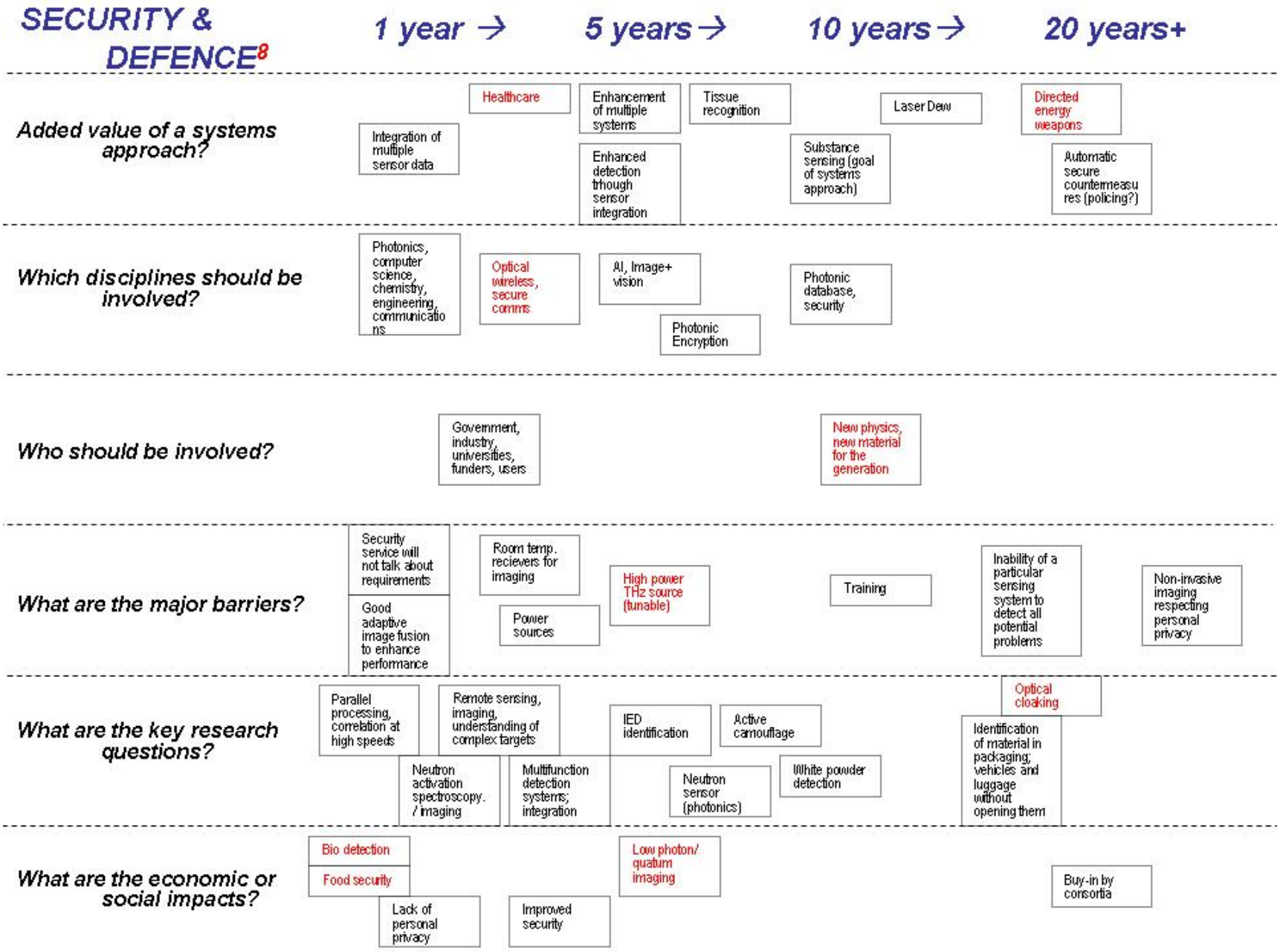
Appendix 2:
Outputs from session 2 (Vision Exploration)

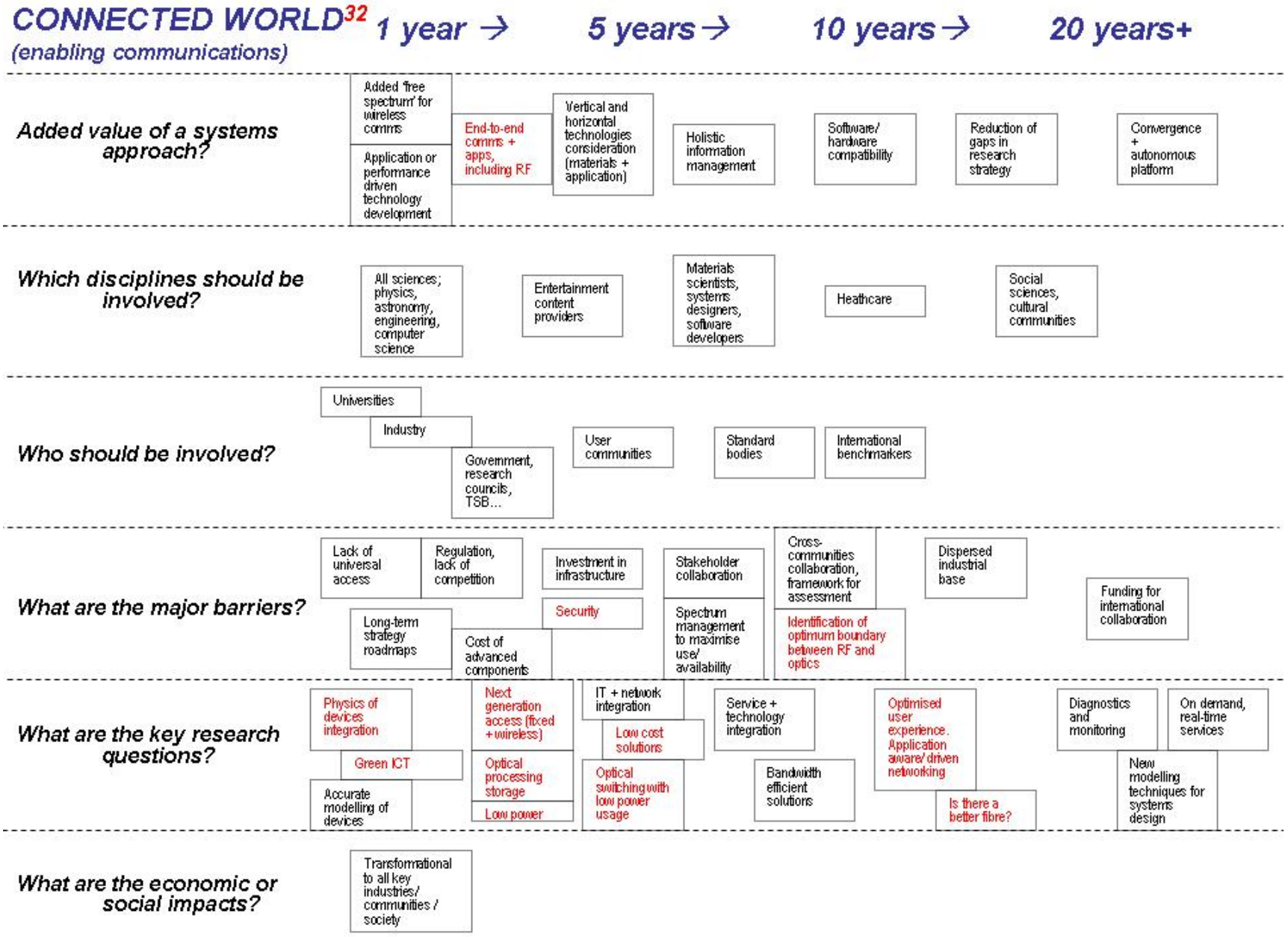
(red type indicates endorsement/ support of ideas & themes by the workshop by attendees)


HEALTHCARE[12]
1 year →
5 years →
10 years →
20 years+
Added value of a systems approach?
Medics require box
Compatibility of multiple sensor data, EIT, MRT, Optical
Integration of prosthetics
Must be systematic
Remote surgery - high speed comms, high-res imaging
Joined-up thinking – less waste of research resource
Which disciplines should be involved?
Engineering, Physics, Maths, Medical, Biology
Industry, regulatory
Imaging, sensing
Visualisation
High speed dynamic networks
Data/ content, repository management
Who should be involved?
Public, Academics, Educators
Healthcare providers, Clinicians
Scanner manufacturer
What are the major barriers?
Training
Practitioner understanding
Language, syntax, medical culture clash with photonic culture
Novelty 'dangerous' conservatism
National/ International network collaboration
Accessibility, Cost of system
Service security and resilience
Ethics
What are the key research questions?
Recovery algorithms
Identify better photonic systems for imaging diagnostics
Photon therapy delivery of photons – precision
Photonic scanning technology
Identify role of photonics in various bio-processes
Fluidics
What are the economic or social impacts?
Cost of solutions
Home diagnostics systems
Quality of life
Assisted living
Manage poverty
Photonic scanning – low cost, safe, in the community
Rapid, cheap in-home health diagnosis


MANUFACTURING[1]
1 year →
5 years →
10 years →
20 years+
Added value of a systems approach?
A process to identify the wide-ranging opportunities
Systems level approach might mean Peer Review values it more
Control system
Clarity of RoI
Identifying and addressing issues and MFG process needs
Improved capability – accuracy, complexity, new products enhance design
Integration of fibres and various material-based photonic devices
Which disciplines should be involved?
Integration technologies
Who should be involved?
Material scientists and engineers
MFG engineers
Product designers / end users
Physicists
Modellers (before manufcturing)
What are the major barriers?
Cross-communications (incomplete community)
Peer review does not value it
Variety (from laser-marked fruit to additive layer mfg)
Inertia
Perceptions, costing
Recyclability, reuse/ new materials
Training
What are the key research questions?
Multiscale, physics manufcturing
Lasers
Sensors
Tolerance at system level
Imaging
Near net shape processes
Materials handling
Bottom up/ top down self-assembly
Switches
Nano-machinery
What are the economic or social impacts?
Efficiency, cost, storage, integration
MFG = Jobs
Time to market
Local supply chains
MFG expertise = 'stickiness (harder to off-shore)'
New materials

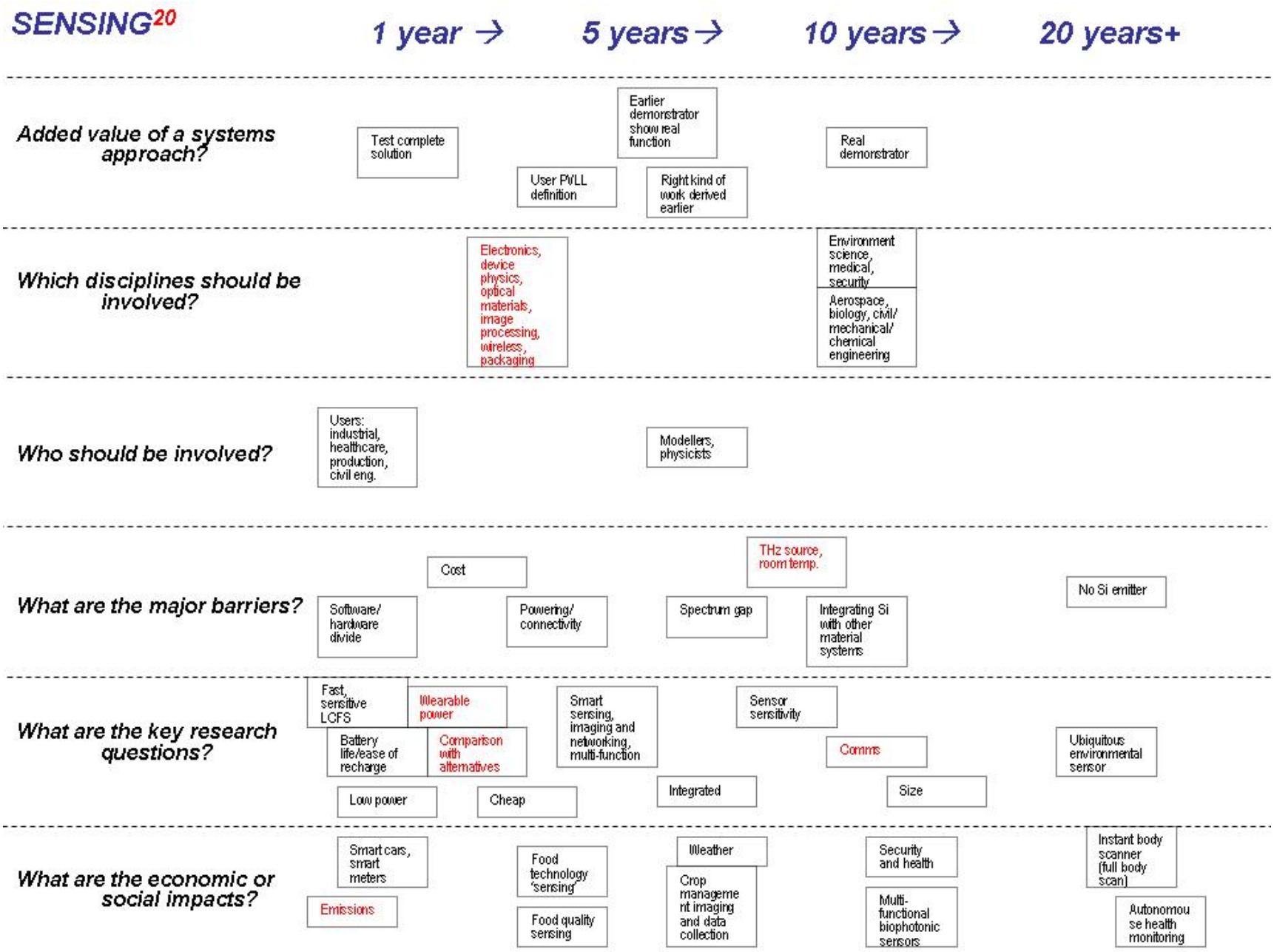

ENERGY²
1 year →
5 years →
10 years →
20 years+
Added value of a systems approach?
Pollution sensing cleantech
PV energy storage, access-on-demand, smart grid
Control of wind/ wave power network and management
Efficient lighting -LED, OLED, µwave
Low-energy ultra fast computer interconnects
Energy harvesting
Low carbon transport system
'Smart lighting'
Efficient low cost PV
Cheap, safe energy for a developing world
Energy – cleantech, green photonics, ER
Fuel Cells
Monitoring and control
Which disciplines should be involved?
Materials, manufcturing control, electrical power, architects
IT professionals
Asset monitoring
Fusion
Physics for >40% PV
Who should be involved?
Research, companies, TSB, EPSRC, ETI
Construction
Energy utilities
What are the major barriers?
Lack of focus, lack of connect to politicians, too multi-disciplinary for funders
Communicati on issues
Alternative ways to convert solar energy
What are the key research questions?
Efficiency, cost, storage, integration
Conversion and distribution
Demand management, storage
Durability
Multiscale modelling + physics
Materials
Recycling/ reuse
What are the economic or social impacts?
Reduce CO_2, climate change, save the Maldives


SECURITY & DEFENCE[8]
1 year →
5 years →
10 years →
20 years+
Added value of a systems approach?
Integration of multiple sensor data
Healthcare
Enhancement of multiple systems
Enhanced detection through sensor integration
Tissue recognition
Substance sensing (goal of systems approach)
Laser Dew
Directed energy weapons
Automatic secure countermeasures (policing?)
Which disciplines should be involved?
Photonics, computer science, chemistry, engineering, communications
Optical wireless, secure comms
AI, Image+ vision
Photonic Encryption
Photonic database, security
Who should be involved?
Government, industry, universities, funders, users
New physics, new material for the generation
What are the major barriers?
Security service will not talk about requirements
Good adaptive image fusion to enhance performance
Room temp. recievers for imaging
Power sources
High power THz source (tunable)
Training
Inability of a particular sensing system to detect all potential problems
Non-invasive imaging respecting personal privacy
What are the key research questions?
Parallel processing, correlation at high speeds
Remote sensing, imaging, understanding of complex targets
Neutron activation spectroscopy. / imaging
Multifunction detection systems; integration
IED identification
Neutron sensor (photonics)
Active camouflage
White powder detection
Optical cloaking
Identification of material in packaging; vehicles and luggage without opening them
What are the economic or social impacts?
Bio detection
Food security
Lack of personal privacy
Improved security
Low photon/ quatum imaging
Buy-in by consortia


CONNECTED WORLD[32]
(enabling communications)
1 year →
5 years →
10 years →
20 years+
Added value of a systems approach?
Added 'free spectrum' for wireless comms
Application or performance driven technology development
End-to-end comms + apps, including RF
Vertical and horizontal technologies consideration (materials + application)
Holistic information management
Software/ hardware compatibility
Reduction of gaps in research strategy
Convergence + autonomous platform
Which disciplines should be involved?
All sciences; physics, astronomy, engineering, computer science
Entertainment content providers
Materials scientists, systems designers, software developers
Healthcare
Social sciences, cultural communities
Who should be involved?
Universities
Industry
Government, research councils, TSB…
User communities
Standard bodies
International benchmarkers
What are the major barriers?
Lack of universal access
Regulation, lack of competition
Investment in infrastructure
Security
Stakeholder collaboration
Spectrum management to maximise use/ availability
Cross-communities collaboration, framework for assessment
Identification of optimum boundary between RF and optics
Dispersed industrial base
Funding for international collaboration
Long-term strategy roadmaps
Cost of advanced components
What are the key research questions?
Physics of devices integration
Green ICT
Accurate modelling of devices
Next generation access (fixed + wireless)
Optical processing storage
Low power
IT + network integration
Low cost solutions
Optical switching with low power usage
Service + technology integration
Bandwidth efficient solutions
Optimised user experience. Application aware/ driven networking
Is there a better fibre?
Diagnostics and monitoring
On demand, real-time services
New modelling techniques for systems design
What are the economic or social impacts?
Transformational to all key industries/ communities / society

PHOTONIC VLSI[12]

	1 year →	5 years →	10 years →	20 years+
Added value of a systems approach?	Standard device set	Huge global industry		
Which disciplines should be involved?	Physics, quantum information processing Materials science	Computer science		
Who should be involved?	IT architects, fabrication, electrical engineering			
What are the major barriers?	Light emitting Silicon	Photonics to/ on the chip/ interconnect Lower power than electronics		
What are the key research questions?	What materials system?	Plasmonics, nanophotonic	Programmable/ reconfigurable Electronic/ photonic integration	Optical buffer
What are the economic or social impacts?				


SENSING20
1 year →
5 years →
10 years →
20 years+
Added value of a systems approach?
Test complete solution
Earlier demonstrator show real function
User P/LL definition
Right kind of work derived earlier
Real demonstrator
Which disciplines should be involved?
Electronics, device physics, optical materials, image processing, wireless, packaging
Environment science, medical, security
Aerospace, biology, civil/ mechanical/ chemical engineering
Who should be involved?
Users: industrial, healthcare, production, civil eng.
Modellers, physicists
What are the major barriers?
Cost
THz source, room temp.
No Si emitter
Software/ hardware divide
Powering/ connectivity
Spectrum gap
Integrating Si with other material systems
What are the key research questions?
Fast, sensitive LCFS
Wearable power
Smart sensing, imaging and networking, multi-function
Sensor sensitivity
Battery life/ease of recharge
Comparison with alternatives
Comms
Ubiquitous environmental sensor
Integrated
Size
Low power
Cheap
What are the economic or social impacts?
Smart cars, smart meters
Emissions
Food technology 'sensing'
Food quality sensing
Weather
Crop management imaging and data collection
Security and health
Multi-functional biophotonic sensors
Instant body scanner (full body scan)
Autonomous health monitoring