IfM Education and Consultancy Services

UNIVERSITY OF CAMBRIDGE

EPSRC Centre for innovative manufacturing in ultra precision

REPORT

on the

Roadmapping Workshop for the EPSRC Centre for Innovative Manufacturing in Ultra Precision

Reel-to-Reel Platform

The Workshop was sponsored by EPSRC

15 May 2014

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EPSRC Pioneering research and skills

1. Executive Summary

The EPSRC Centre for Innovative Manufacturing in Ultra Precision organised a roadmapping workshop for the Reel-to-Reel (R2R) technology platform with input from nine participants from industry and academia in the UK. Its aim is to:

- Identify key industrial drivers and needs
- Identify which applications are emerging in ultra precision engineering that would benefit from the technological advancements made in the R2R platform.
- Explore the best applications, their value for UK businesses and the best route for their commercialisation.
- Develop a preliminary business plan for the selected applications.

This workshop followed on from a previous workshop that took place in October 2011 for the whole EPSRC Centre in Innovative Manufacturing in Ultra Precision and explored in more detail the R2R platform. The workshop took place on 15 May 2014 at Cranfield University.

The **key market and industry drivers** identified were the following:

1. **Reducing manufacturing and operating product costs**. Industry needs to respond to continuous pressure for reducing manufacturing costs for both components and overall systems, and reducing the operating costs for products.
2. **Increasing range of consumer electronic devices.** There is an on-going demand for increasing the range and functionality of consumer electronic products and their sub-components.
3. **Increasing speed of manufacturing**. There is pressure to increase the speed of manufacturing, enable rapid volume scale up and have a faster turn-around of products.
4. **Renewable energy generation and storage**. There is a global driver for increasing the generation and storage of renewable energy.

The **priority future applications** identified were predominantly around the development of technology for machine control applicable to a variety of products and industries. These were:

1. **Registration** information on 3 axis (x, y, z) better than or equal to 1 µm to enable the development of multi layer functional devices, e.g. TFT for logic or smart packaging on thin glass, plastic or paper.
2. **R2R handling** of thin glass and plastics including tension and precision position for single web. Lamination is included. This can facilitate the development of multiple printed and aligned layers e.g. OLED/lighting or photovoltaics as well as printed and/or flexible circuit boards and large scale, programmable displays.
3. **Small format R2R** flexible tool to facilitate development of R2R processes and products. The tool can be used for small sheet/width roll in a flow process to enable the transfer of processes and products from lab to volume by offering a pre-production capability.

After exploring these applications in detail, applications 1 and 2 were considered to be addressing similar issues and were summarised together.

The most important **R&D priorities** to deliver these applications were:

1. Modelling of materials and processes
2. Fiducial design especially in 3D
3. Incorporating in-process metrology
4. Demonstrate 1 µm control
5. Designing friction free spindles
6. Control system
7. Sensors and measurements
8. Substrate development
9. Spray coat precision
10. Vacuum gate technology

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2. Methodology

The methodology used to develop the roadmap consisted of three parts: a **Design and Pre-work** part, the **Workshop** and the **Analysis and Client Report**.

1. The **Design and Pre-work** consisted of the following activities:

(a) confirmed with the workshop sponsors the key aims and desired outputs from the workshop;

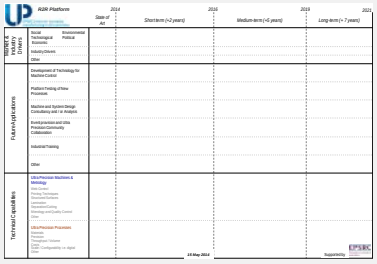
(b) designed the appropriate roadmap architecture and group templates;

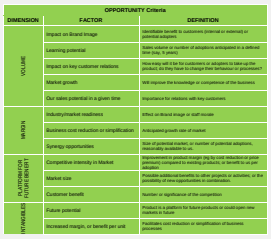
(c) Designed suitable pre-work templates that resembled the roadmap architecture to collect input from the participants. These were sent to 12 people from both industry and academia in advance of the workshop to collect their input on the future applications they considered the most important. Six people contributed content for the roadmap in advance of the workshop and independently of others; all participants contributed additional content during the workshop;

(d) Circulated to the participants in advance of the workshop pre-defined lists of Opportunity and Feasibility criteria that could be used to assess each future application. Each person was asked to independently select (vote on) the criteria they considered key for assessing each application. All votes were collected and consolidated. The criteria that received the most votes were used during the workshop to prioritise the various applications;

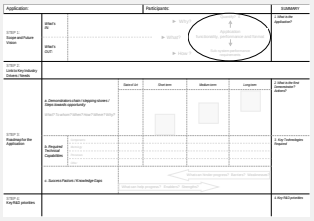
(e) received and clustered all input;

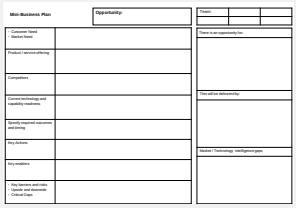
(f) designed the workshop process and required collateral material for the workshop (facilitation slides, participant handouts etc).





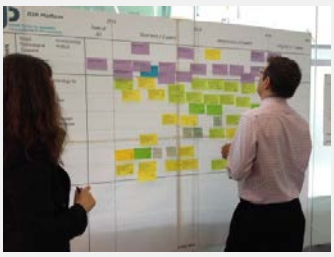
DIMENSION	FACTOR	DEFINITION
VOLUME	Impact on Brand Image	Identifiable benefit to customers (internal or external) or potential adopters
	Learning potential	Sales volume or number of adoptions anticipated in a defined time (e.g. 5 years)
	Impact on key customer relations	How likely will it be for customers or adopters to take up the product, do they have to change their behaviour or processes?
	Market growth	Will improve the knowledge or competence of the business
	Our sales potential in a given time	Importance for relations with key customers
VALUE	Industry/market readiness	Effect on Brand image or staff morale
	Business cost reduction or simplification	Anticipated growth rate of market
	Synergy opportunities	Size of potential market, or number of potential adoptions, reasonably available to us.
EXPERIENCE / REPERTOIRE	Competitive intensity in Market	Improvement in product margin (eg by cost reduction or price increase) compared to existing products, or benefit to an per solution
	Market size	Possible additional benefits to other projects or activities, or the possibility of new opportunities in combination
	Customer benefit	Number or significance of the competition
STRATEGIES	Future potential	Product is a platform for future products or could open new markets in future
	Increased margin, or benefit per unit	Facilitates cost reduction or simplification of business processes

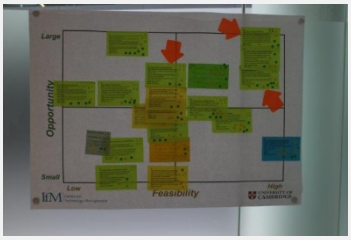




2. The one-day **Workshop** brought together 9 participants from industry and academia. The workshop aims were to:

(a) present each participant's input on the future applications in ultra precision for R2R;
(b) prioritise the applications using the pre-defined selection criteria;
(c) select the most suitable manufacturing applications to explore further;
(d) explore the shortlist of manufacturing applications in groups and determine the desired technology development plans and collaboration opportunities and identify the most important R&D priorities;
(e) determine the common research themes emerging from the shortlisted laser-based manufacturing applications.





3. The final part consisted of the transcription of all output from the workshop into an electronic format, content analysis and the drafting of the **Client Report**.

The report can be used by the workshop sponsors for setting research priorities and, if appropriate, communicating these with academic, industrial or public sector stakeholders.

3. Background and Previous Work

The EPSRC Centre for Innovative Manufacturing in Ultra Precision undertakes early stage production research to establish new processing technologies needed for the effective production of emerging products, with global outreach. The Centre was established in 2011 and in October 2011 it conducted a workshop to roadmap the market and industry drivers and future applications in ultra precision.

The Centre conducts research in three technology platforms; Nano-FIB, Meso and R2R. The initial workshop mapped all three platforms in parallel, reviewed key trends and drivers and identified future applications, which could result in novel Production Machines and Products and enabling technologies to support these.

The original roadmap developed for the Centre is shown below:

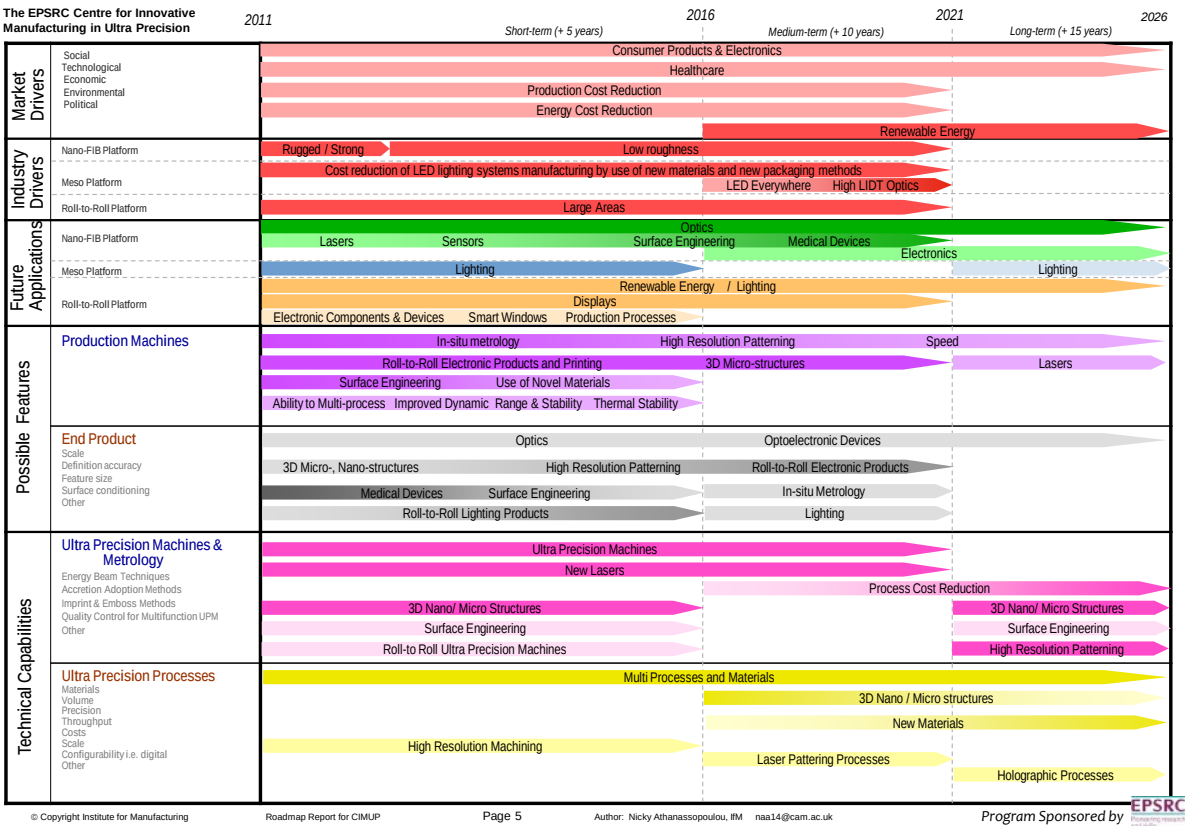


Figure 1 *– Original Roadmap for the EPSRC Centre in Ultra Precision (Oct 2011).*

The three technology platforms were also explored in more detail during that workshop to establish required targets, technology developments and knowledge gaps, enablers and drivers. The summary plan derived for the R2R platform is shown below.

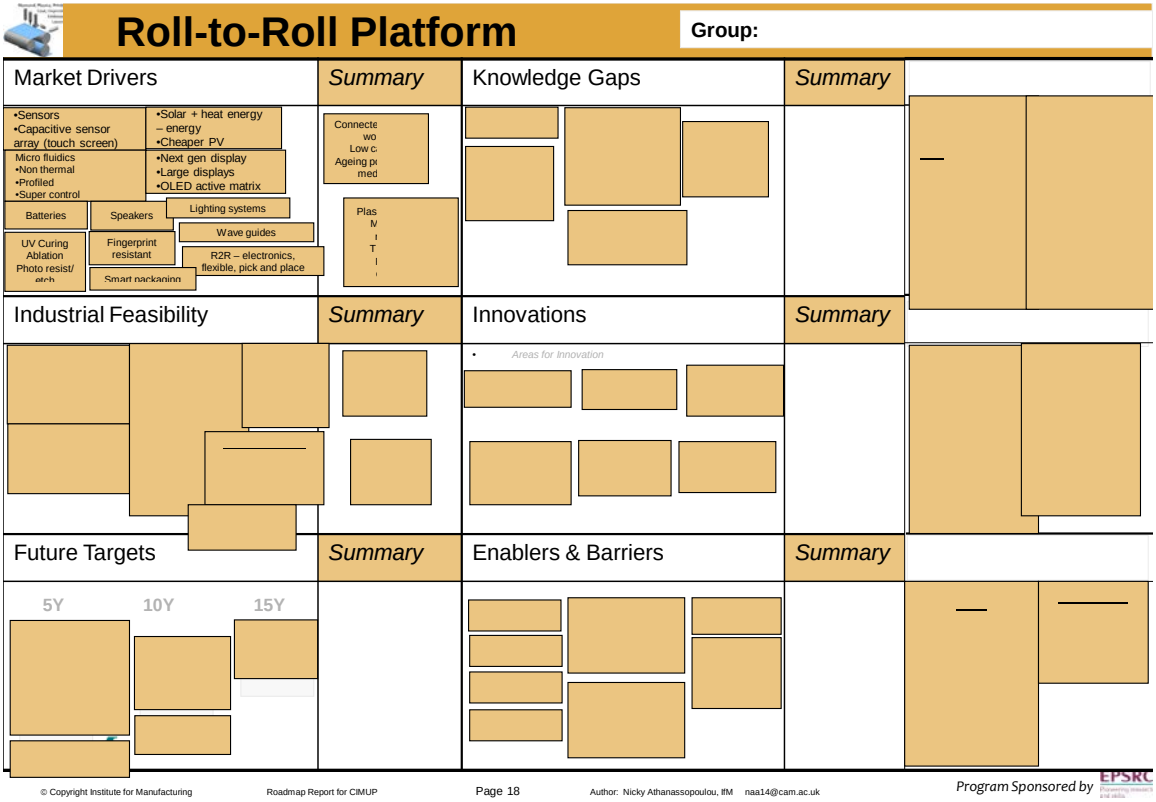


Figure 2 *– Original exploration of R2R technology platform for the EPSRC Centre in Ultra Precision (Oct 2011).*

Considerable technological development has taken place since then. The Centre now wants to develop innovation roadmaps for each of its technology platforms. The first one organised was for the R2R platform.

4. R2R Roadmap Summary

The roadmap covers three time periods: the short term (+2 years i.e. up to 2016), the medium term (+5 years i.e. up to 2019) and the long term (+7 years i.e. up to 2021). Nine people in total from both industry and academia contributed with content for its creation.

The roadmap includes three broad layers; (1) Market and Industry Drivers, (2) Future Application and (3) Technical Capabilities. The **Market and Industry Drivers** were further subdivided into the following layers:

1a. Macroeconomic drivers such as Social, Technological, Economic, Environmental and Political;
1b. Industry Drivers;
1c. Other.

In total, 20 market and industry drivers were identified. These were distributed mainly in the short and medium term. Most were relating to industry drivers.

The **Future Applications** were also subdivided into the following layers:

2a. Development of Technology for Machine Control;
2b. Platform Testing of New Processes;
2c. Machine and System Design Consultancy and/or Analysis;

2d. Event provision and Ultra Precision Community Collaboration;
2e. Industrial Training;
2f. Other

In total, 41 future applications were identified. Approximately 90% of those were in the short and medium term. The applications were well distributed between the different layers.

The **Technical Capabilities** were subdivided into the following layers:

3a. Ultra Precision Machines and Metrology
3b. Ultra Precision Processes

In total, 21 technical capabilities were identified during the workshop. These were well distributed from the short to the long term and between the two sub-layers.

A schematic of the roadmap is shown below.

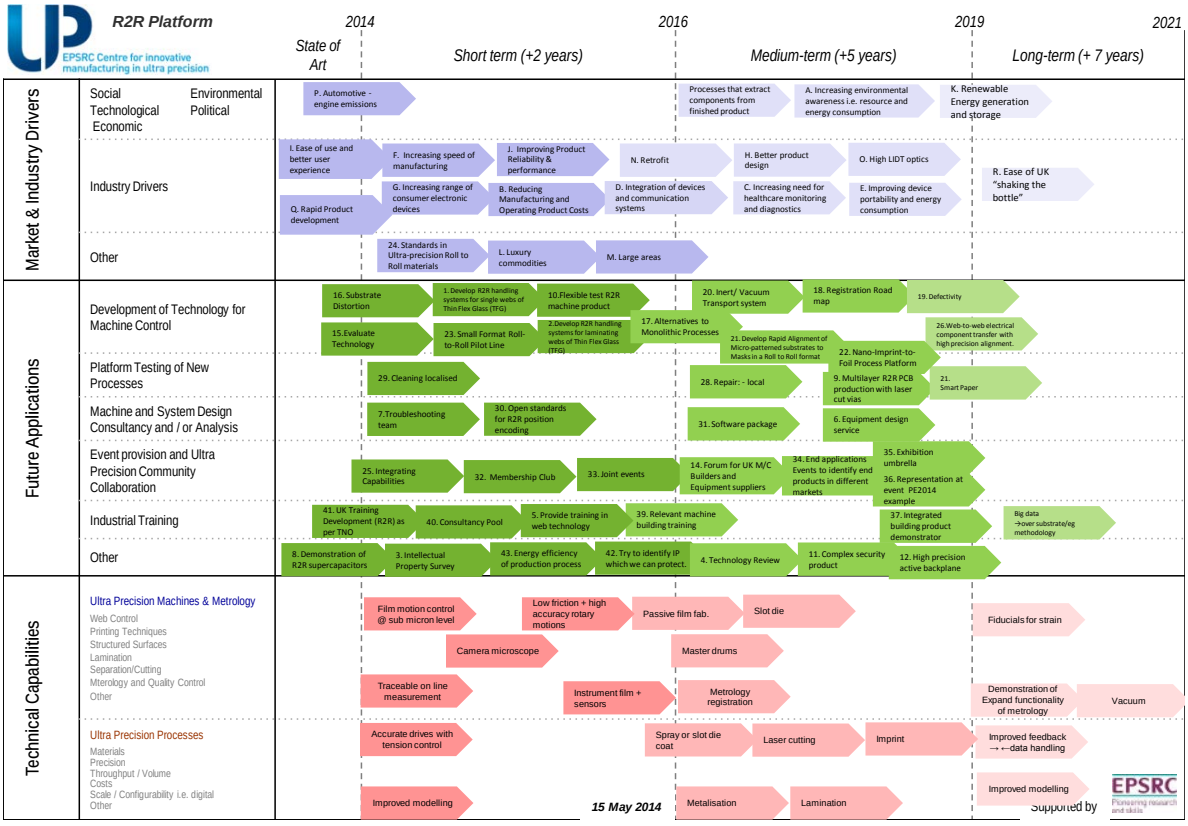


Figure 3 *– Roadmap for the ultra precision R2R platform.*

5. Market and Industry Drivers

The list of Market and Industry drivers developed in the original workshop was collected and used as input for the R2R platform. The participants were given the original list and asked during the exploration of the three priority applications (group work) to assess which ones were relevant for the particular application under consideration. The prioritised list of drivers that emerged is shown in the table below. Four new industry drivers were added to the original list, namely: U.) *Ease of UK "shaking the bottle"*; V.) *Rapid Product Development*; S.) *Standards in Ultra-Precision R2R Materials* and T.) *Processes that Extract Components from a Finished Product*. The full list of drivers is shown in Appendix 4.

	Driver	Description	Ranking
B	Reducing manufacturing and operating product costs	Pressure for reducing manufacturing costs for both components and overall systems, and reducing the operating costs for products	3
G	Increasing range of consumer electronic devices	Increasing range and functionality of consumer electronic products and their sub-components	3
F	Increasing speed of manufacturing	Increasing speed of manufacturing, rapid volume scale up and faster turn-around of products	2
K	Renewable energy generation and storage	Increase the generation and storage of renewable energy	2
A	Increasing environmental awareness i.e. resource and energy consumption	Designing and producing eco-friendly products, systems and services; promoting low carbon energy production and transport; incorporating renewable energy production; reducing resource utilisation	1
C	Increasing need for healthcare monitoring and diagnostics	Introducing new or improved methods for point-of-care diagnostics and health monitoring; reducing healthcare costs; increasing the speed of healthcare monitoring and diagnostic methods	1
D	Integration of devices and communication systems	Information exchange between different devices aided by the internet; better integration of communication systems and a better connected mobile world	1
H	Better product design	Better product designs; design freedom; improved size, weight and cost	1
L	Luxury commodities	Increase of demand for luxury commodities	1
M	Low roughness	Requirement for low roughness of specific surfaces	1
R	Ease of UK “shaking the bottle”		1
Q	Rapid product development		1

Table 1 *– Prioritised market and industry drivers for the ultra precision R2R platform.*

The top four market and industry drivers were:

1. **B. Reducing manufacturing and operating product costs**. Industry needs to respond to continuous pressure for reducing manufacturing costs for both components and overall systems, and for reducing the operating costs for products.
2. **G. Increasing range of consumer electronic devices.** There is an ongoing demand for increasing the range and functionality of consumer electronic products and their sub-components.
3. **F. Increasing speed of manufacturing**. There is pressure to increase the speed of manufacturing, enable rapid volume scale up and have a faster turn-around of products.
4. **K. Renewable energy generation and storage**. There is a global driver for increasing the generation and storage of renewable energy.

This is consistent with the market and industry drivers identified originally: Production Cost Reduction, Energy Cost Reduction, Renewable Energy and Consumer Products & Electronics.

6. Prioritisation of the Future Applications

Each of the 41 applications put forward during the workshop was assessed using two different and broadly separate considerations: Opportunity and Feasibility. Opportunity was defined as the magnitude of the opportunity plausibly available to an organisation. Feasibility was defined as how well-prepared the organisation is to grasp the opportunity.

For both Opportunity and Feasibility, a list of factors was provided to all participants in advance of the workshop. Each participant independently selected the ones he/she considered to be the most appropriate for assessing the applications. The factors are shown in the green and yellow tables below.

DIMENSION	FACTOR	DEFINITION
VOLUME	Market size	*Size of potential market, or number of potential adoptions, reasonably available to us.*
	Our sales potential in a given time	*Sales volume or number of adoptions anticipated in a defined time (say, 5 years)*
	Synergy opportunities	*Possible additional benefits to other projects or activities; or the possibility of new opportunities in combination.*
	Customer benefit	*Identifiable benefit to customers (internal or external) or potential adopters*
	Competitive intensity in Market	*Number or significance of the competition*
MARGIN	Increased margin, or benefit per unit	*Improvement in product margin (eg by cost reduction or price premium) compared to existing products; or benefit to us per adoption*
	Business cost reduction or simplification	*Facilitates cost reduction or simplification of business processes*
	Industry/market readiness	*How easy will it be for customers or adopters to take up the product; do they have to change their behaviour or processes?*
PLATFORM FOR FUTURE BENEFIT	Market growth	*Anticipated growth rate of market*
	Future potential	*Product is a platform for future products or could open new markets in future*
INTANGIBLES	Learning potential	*Will improve the knowledge or competence of the business*
	Impact on Brand Image	*Effect on B rand image or staff morale*
	Impact on key customer relations	*Importance for relations with key customers*

***Table 2** – Opportunity factors used to assess the various future applications.*

DIMENSION	FACTOR	DEFINITION
CHARACTERISTICS OF THE PRODUCT	Product differentiation	*How well the product is differentiated from those of major competitors*
	Sustainability of competitive advantage	*Our ability to sustain our competitive position (eg IPR, Brand strength etc)*
	Technical challenge	*How confident are we that the proposed product is technically feasible?*
	Market knowledge	*Our understanding of size and requirements of the market*
CAPABILITY	Technical capability	*Do we have the required technical competence to design the product?*
SUPPORTING BUSINESS PROCESSES	Fit to sales and/or distribution	*Fit to our sales competences and/or distribution chain*
	Fit to manufacturing and/or supply chain	*Ability to manufacture or supply the product*
	Finance	*Availability of finance for the project*
ORGANISATIONAL BACKING	Strategic fit	*How well does the proposal fit our company strategy?*
	Organisational backing	*Level of staff or management backing at an appropriate level*

***Table 3** – Feasibility factors used to assess the various future applications.*

All the votes received were consolidated in advance of the workshop. The total number of votes received for each factor is shown in the figures below.

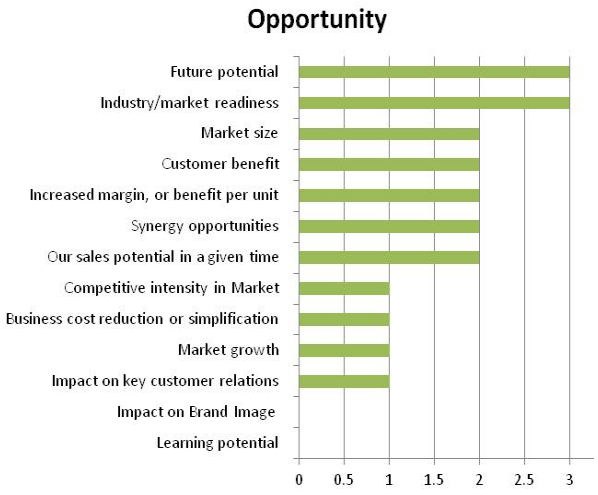


Figure 4a *- Total votes received for all the Opportunity factors.*

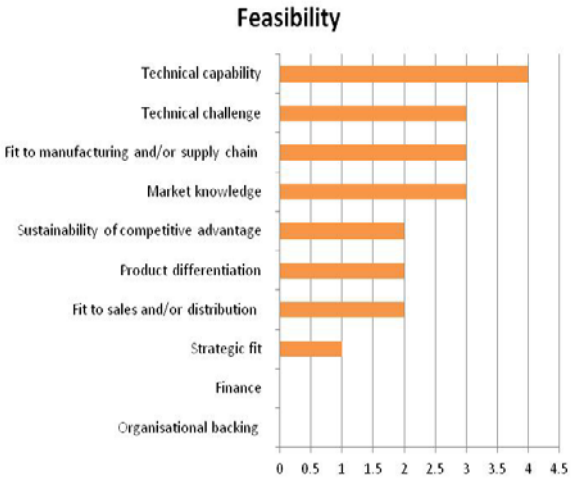


Figure 4b *- Total votes received for all the Feasibility factors.*

The factors that received most votes for both Opportunity and Feasibility are shown in the figures below. These were used during the workshop to assess and prioritise all applications.

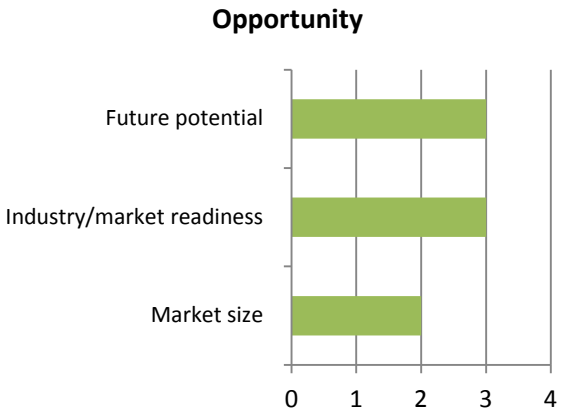


Figure 5a *-Top three Opportunity factors selected and used in the workshop.*

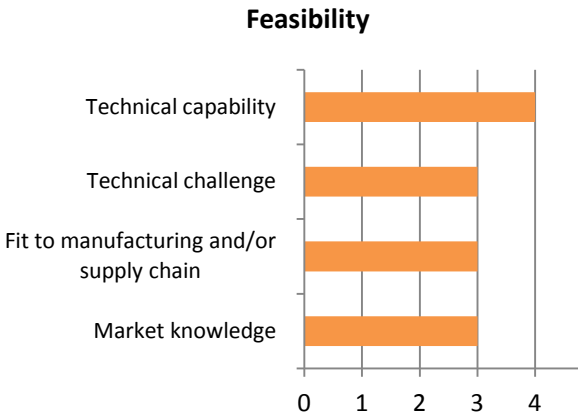


Figure 5b *- Top four Feasibility factors selected and used in the workshop.*

The assessment process had two parts. Firstly, each participant was asked to review the 41 applications and independently select four to eight of them, based on the three Opportunity factors. Participants were discouraged to vote for the applications they had contributed unless they were part of bigger group or cluster.

In the second step, participants were asked to consider only applications that had already been selected using the opportunity factors. Each participant was then asked to independently select four to eight applications of these based on the four Feasibility factors.

A shorter list of 20 applications was thus derived and considered further during the workshop. This shorter list contained mainly applications for the ***Development of Technology for Machine***

Control or for the ***Platform Testing of New Processes*** layers of the roadmap. The shortlist of applications is shown in the Table below.

Application	Feasibility	Opportunity
26. Web-to-web electrical component transfer with high precision alignment	7	3
23. Small Format R2R Pilot Line	6	6
18. Registration Roadmap	6	5
16. Substrate Distortion	5	3
40. Consultancy Pool	4	5
20. Inert/ Vacuum Transport system	4	4
8. Demonstration of R2R supercapacitors	3	3
13. Collate Specification of Roll2Roll process requirements	3	3
19. Defectivity	3	3
41. UK Training Development (R2R) as per TNO	3	2
5. Provide training in web technology	3	1
10. Flexible test R2R machine product	3	3
21. Develop Rapid Alignment of Micro-patterned substrates to Masks in a Roll to Roll format	2	6
32. Membership Club	2	2
6. Equipment design service	2	4
9. Multilayer R2R PCB production with laser cut vias	2	2
17. Alternatives to Monolithic Processes	2	1
2. Develop R2R handling systems for laminating webs of Thin Flex Glass (TFG)	2	2
1. Develop R2R handling systems for single webs of Thin Flex Glass (TFG)	2	2
22. Nano-Imprint-to-Foil Process Platform	1	4

Table 4. *Shortlisted applications including the Feasibility and Opportunity votes received for each.*

The shortlist was transferred onto a 2x2 matrix with Opportunity shown on the vertical axis and Feasibility on the horizontal axis (see figure below). This was to facilitate decision making and the selection of the most appropriate applications to explore during the workshop. Applications placed on the top right quadrant (High Feasibility and High Opportunity) were of immediate interest. Applications on the top left quadrant (Low Feasibility / High Opportunity) may represent possible long-term opportunities. Applications placed on the bottom quadrants (Low / High Feasibility and Low Opportunity) are not automatically dismissed as they might enable other applications or support longer-term prospects.

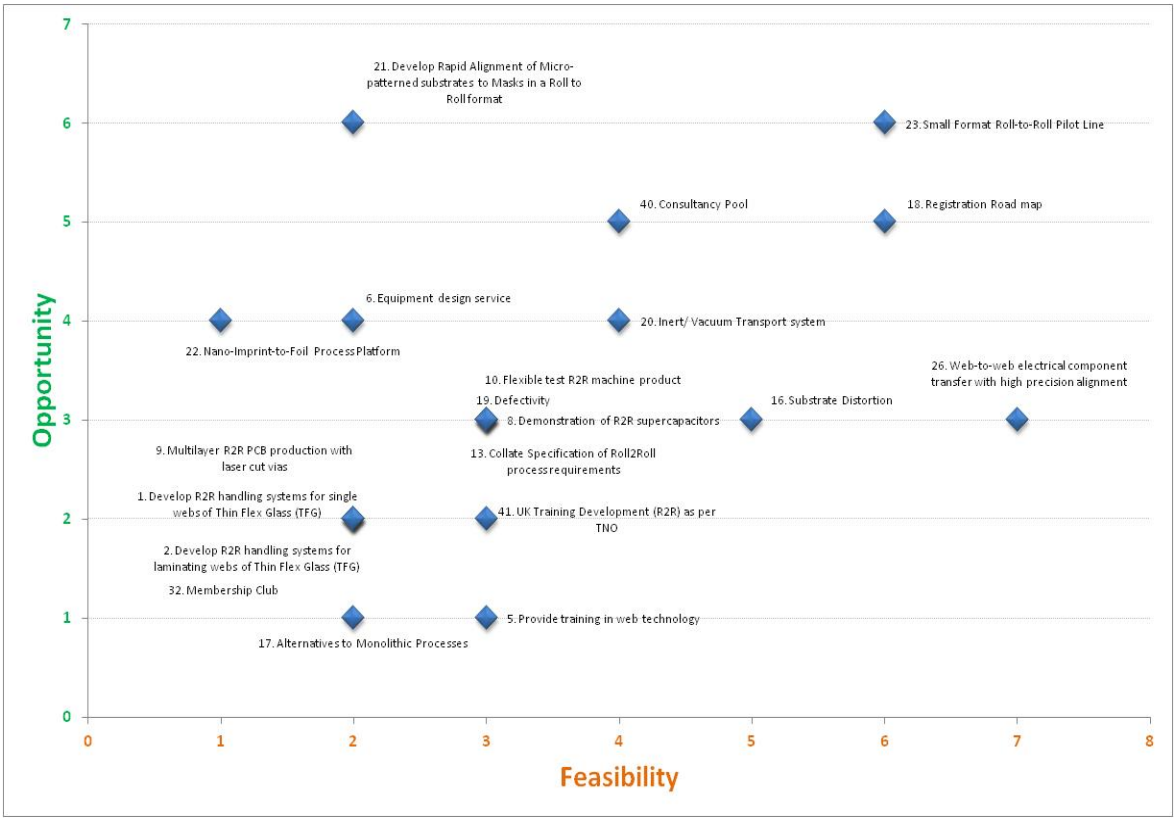


Figure 6 *– Application prioritisation chart using Feasibility-Opportunity axis.*

All participants were involved in choosing which of the applications were most appropriate to take forward. Some applications were synergistic and were grouped together. These were:

- *1. Develop R2R handling systems for single webs of Thin Flex Glass (TFG)* and *2. Develop R2R handling systems for laminating webs of Thin Flex Glass (TFG)*
- *10. Flexible test R2R machine product* and *23. Small Format Roll-to-Roll Pilot Line*

Three applications were selected using a consensus-based process that took into consideration the following aspects to achieve a balanced selection:

- relative scores of each application and their position onto the 2x2 chart
- the timeline of the application (short, medium or long-term)
- the specific expertise of the workshop participants

The following three applications were selected for further exploration:

1. **R2R handling** of thin glass and plastics including tension and precision position for single web. Lamination is included. This can facilitate the development of multiple printed and aligned layers e.g. OLED/lighting or photovoltaics as well as printed and/or flexible circuit boards and large scale, programmable displays. (Applications 1& 2)

2. **Registration** information on 3 axis (x, y, z) better than or equal to 1 µm to enable the development of multi layer functional devices, e.g. TFT for logic or smart packaging on thin glass, plastic or paper. (Application 18)

3. **Small format R2R** flexible tool to facilitate development of R2R processes and products. The tool can be used for small sheet/width roll in a flow process to enable the transfer of processes and products from lab to volume by offering a pre-production capability. (Applications 10 & 23)

A summary roadmap for the ultra precision R2R platform indicating priority Market and Industry Drivers, Future Applications and Technical capabilities is shown below.

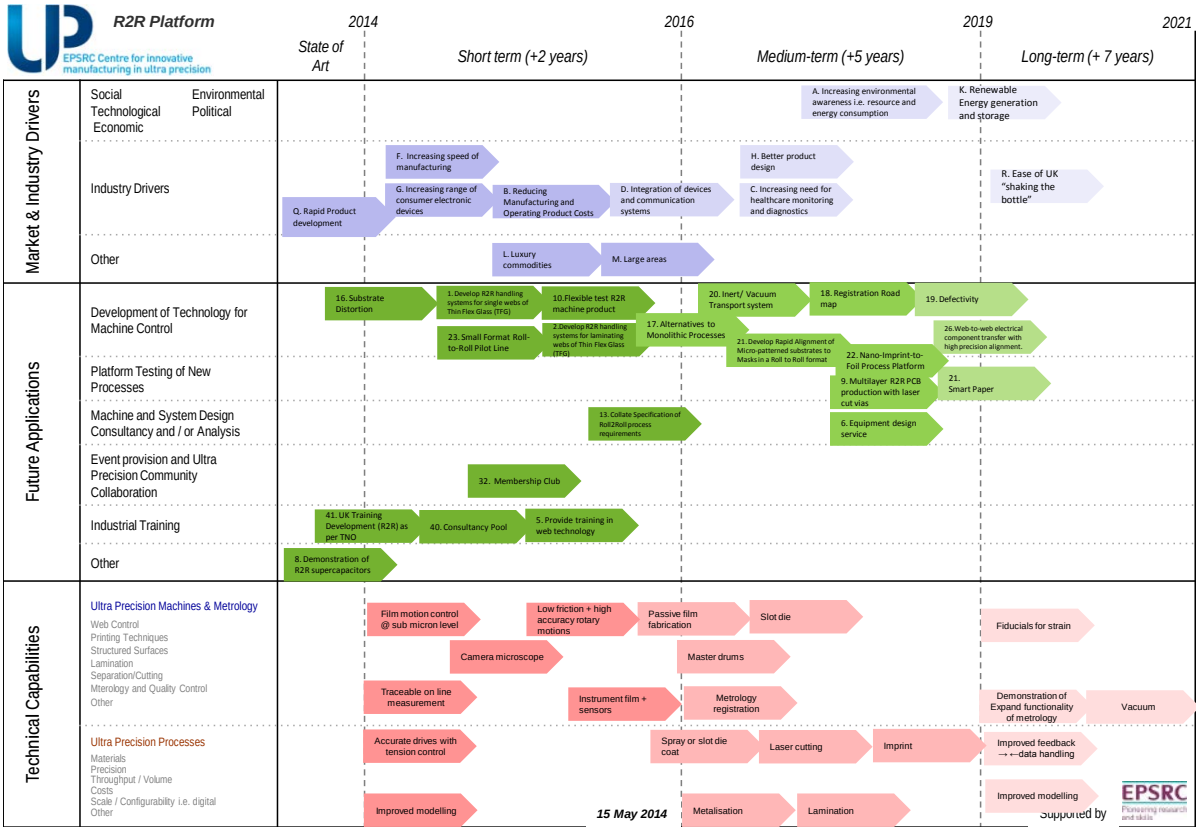


Figure 7 *– Roadmap showing the prioritised Market and Industry Drivers, Future Applications and key Technical Capabilities for the ultra precision R2R platform.*

7. Exploration of the Three Future Applications

Each application was explored in four steps. Initially, the scope and boundaries of the application were considered as well its long-term goal and vision. Then its links to the market drivers and needs were discussed. The technical feasibility was subsequently explored in detail especially in terms of the required machines, metrology and processes, any success factors and knowledge gaps and the milestones that need to be put in place to realise the final vision. Finally, the key R&D priorities were summarised.

The participants were split into four groups, each exploring one application. The following people participated in each group:

Registration	R2R Handling thin glass and plastics	Small format R2R
Liam Blunt John Lampett Paul Streatfield	Dilwyn Jones Paul Shore Nick Walker	Neil Davies Cliff Joilliffe Martin O'Hara

***Table 5** – List of attendees participating in the exploration of the three selected applications.*

Each of these applications can potentially address many different markets from instrumentation to healthcare, flexible electronics and sensors.

Collectively, the three applications can cover all the top four market and industry drivers and adequately address the rest. The links of the three applications to the market and industry drivers are shown below.

			Registration	R2R Handling thin glass and plastics	Small format R2R
DRIVERS AND INDUSTRY NEEDS	**B**	Reducing Manufacturing and Operating Product Costs	■	■	■
	G	Increasing range of consumer electronic devices	■	■	■
	F	Increasing speed of manufacturing		■	■
	K	Renewable Energy generation and storage		■	■
	A	Increasing environmental awareness i.e. resource and energy consumption	■		
	C	Increasing need for healthcare monitoring and diagnostics			■
	D	Integration of devices and communication systems			■
	H	Better product design		■	
	L	Luxury commodities		■	
	M	Large areas		■	
	R	Ease of UK "shaking the bottle"			■
	Q	Rapid Product development			■

***Table 6** – Links of the most important market drivers and needs to the three selected future applications.*

The high-level roadmaps and summary mini-business cases derived for each of the applications are shown below. These include a more detailed specification for the application defining the boundaries, the long-term vision, the desired future performance characteristics, the milestones necessary to achieve the vision, specific technical capabilities for each milestone and desired research priorities.

The Registration and R2R handling thin glass and plastic shared the same business case as it became clear that they are fundamentally very similar.

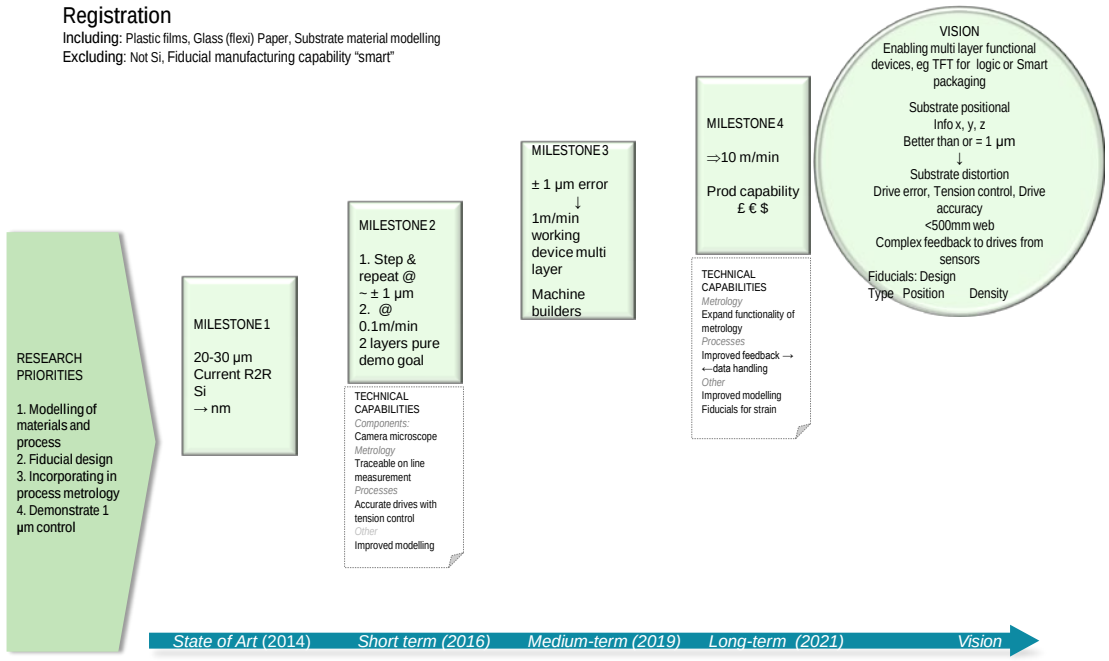


Figure 8 *- Roadmap for the Registration application.*

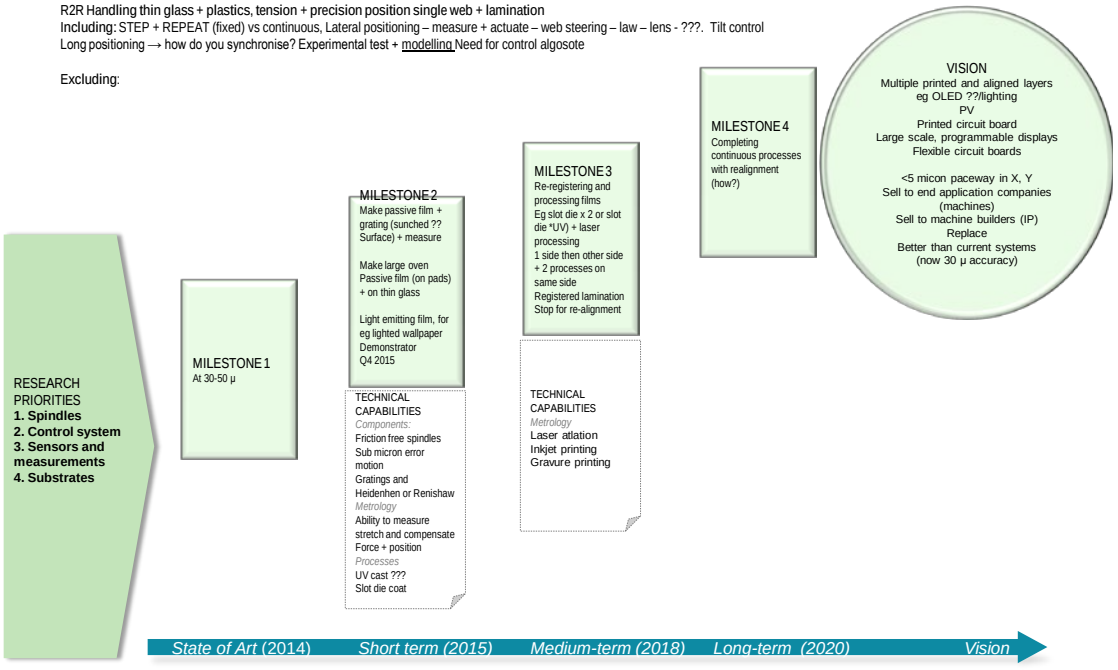


Figure 9 *– Roadmap for the R2R handling of thin glass and plastics application.*

Mini-Business Plan	Opportunity: Active film business + R&D Opportunities
• Customer Need • Market Need	
Product / service offering	**Passive film → active film → products** **→ Adv. → [large scale mould fab]** **Machine building cap**
Competitors	**TNO → VDL flow** **Fraunhofers** **Samsung** **3M**
Current technology and capability readiness	**LAE → contacts → new device ideas** **MET → EU projects → contacts → Measuring solutions** **Mend/fix awareness** **UP → build positioning of stable 'parts'**
Specify required outcomes and timing	**By 2016 → passive film → income** **Cred** **justification of renewal**
Key Actions	***Establish passive film fab capability**
Key enablers	**As per registration summary**
• Key barriers and risks • Upside and downside • Critical Gaps	**International comp + speed of their development funding 'stops'**

Team:		

There is an opportunity for:

+ active films **Packaging**
Displays
Branding
+ M/C builders ←supply chain [TSB]
+ CPI → partners
+ new businesses

This will be delivered by:

EPSRC Funding
Metrology
Large area electronic
Ultra precision
CPI/Catapult/New businesses

Market / Technology intelligence gaps

Up positioning of films.
Films Awareness
Data

Figure 10 *– Mini-business plan for the Registration and R2R handling thin glass and plastic applications.*

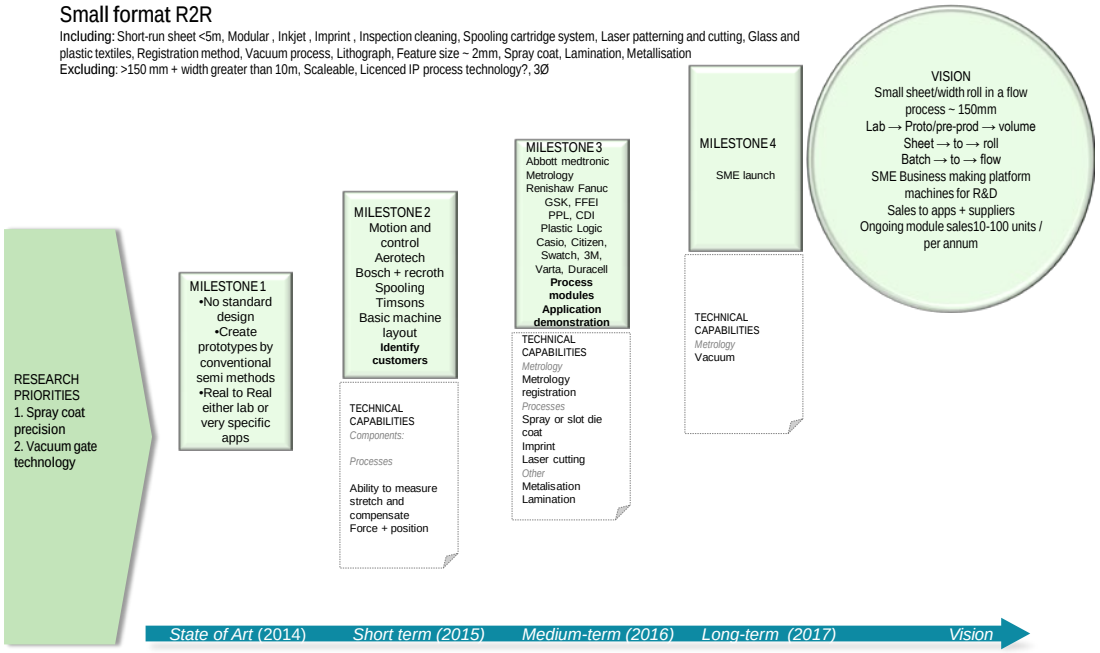


Figure 11 *– Roadmap for the small format R2R application.*

Mini-Business Plan	Opportunity: Small format R2R	Team:	Neil Davies	Cliff Joliffe
			Martin O'Hara	

• Customer Need • Market Need	**Small scale flexible tool to facilitate development of R2R processes and products** **Mid step from lab scale to volume (ie prototype/pre production)** **Prove of sheet-to-roll and batch-to-flow**
Product / service offering	**Modular roll processing machine** **Low consumable cost (low volume processes)**
Competitors	**Sheet based lab & custom built roll processing (all 'one-off')**
Current technology and capability readiness	**Use current state-of-art roll-to-roll machine capabilities** **Process modules can be adapted from existing 3rd parties**
Specify required outcomes and timing	**Identify potential customer + market size within 12 months** **Have operating spool-to-spool within 12 months** **Identify demonstrator + fabricate by 24 months** **Determine vacuum feasibility by 24 months** **SME launch 36 months**
Key Actions	**Build business case** **Identify funding source**
Key enablers	**TSB or Horizon 2020 funding** **Industrial sponsor**
• Key barriers and risks • Upside and downside • Critical Gaps	**Wider industry not interested (lab → vol)** **Could lessen move to large scale volume** **Lowers barrier of entry for other companies** **Vacuum processes + feasibility in-line?**

There is an opportunity for:
Instrumentation, plastic electronics + machine builders **Small volume applications to realise cost benefits** **New business creation without high production costs**
This will be delivered by:
New UK SME **CIM in UP → technology** **Existing paper/label equipment manufacturers**
Market / Technology intelligence gaps
Market size + understanding (is UK big enough?) **Suitability of vacuum processes** **Has it already been done overseas?**

Figure 12 *– Mini-business plan for the small format R2R application.*

8. R&D priorities

The following R&D activities were considered most important by the participants in delivering the selected applications:

1. Modelling of materials and processes
2. Fiducial design especially in 3D
3. Incorporating in-process metrology
4. Demonstrate 1 µm control
5. Designing friction free spindles
6. Control system
7. Sensors and measurements
8. Substrate development
9. Spray coat precision
10. Vacuum gate technology

			Registration	R2R Handling thin glass and plastics	Small format R2R
R&D Priorities	1	Modelling of materials and processes			
	2	Fiducial design especially in 3D			
	3	Incorporating in-process metrology			
	4	Demonstrate 1 µm control			
	5	Designing friction free spindles			
	6	Control system			
	7	Sensors and measurements			
	8	Substrate development			
	9	Spray coat precision			
	10	Vacuum gate technology			

***Table 7** – Link of R&D priorities to the three future applications.*

9. Knowledge Gaps and Enablers

All of the knowledge gaps identified were technical and related to specific processes, metrology or material understanding.

The enablers were predominantly centred around economic support or incentives, such as funding through national or European projects, or commercial, such as understanding specific markets, targeting large enough markets or accessing industrial partners to transfer technologies and know-how.

The table below summarises the knowledge gaps and potential enablers identified.

Knowledge Gaps
• Process effects • Accurate tension measurement • Understanding and modelling of processes and substrates • Substrate variability • Specifications • Vacuum processing
Enablers
• Market understanding • Market size • TSB and H2020 Project • Good OK SME base in plastic electronics • Paper and label business looking to diversify

***Table 8** – Knowledge gaps and enablers for the ultra precision in R2R platform.*

10. Conclusions

A roadmapping workshop organised and sponsored by the EPSRC Centre in Innovative manufacturing in ultra precision for the R2R platform in May 2014. The Centre aims to create ultra high precision manufacturing processes and tools that can make products with nanoscale precision. Furthermore, it aims to be a knowledge 'hub' and link academia with UK industry and other leading international organisations.

The workshop brought together 9 participants from industry and academia in the UK to understand the market and industry needs, prioritise relevant applications and assist in developing appropriate R&D priorities for the UK for the R2R platform.

Three future applications were selected as priorities due to their potentially widespread impact on a range of different markets and their relevance to the Centre's key objectives. These were:

1. Registration information on 3 axis (x, y, z) better than or equal to 1 µm
2. R2R handling of thin glass and plastics
3. Small format R2R flexible tool to facilitate development of R2R processes and products.

The key R&D activities necessary for delivering these applications were:

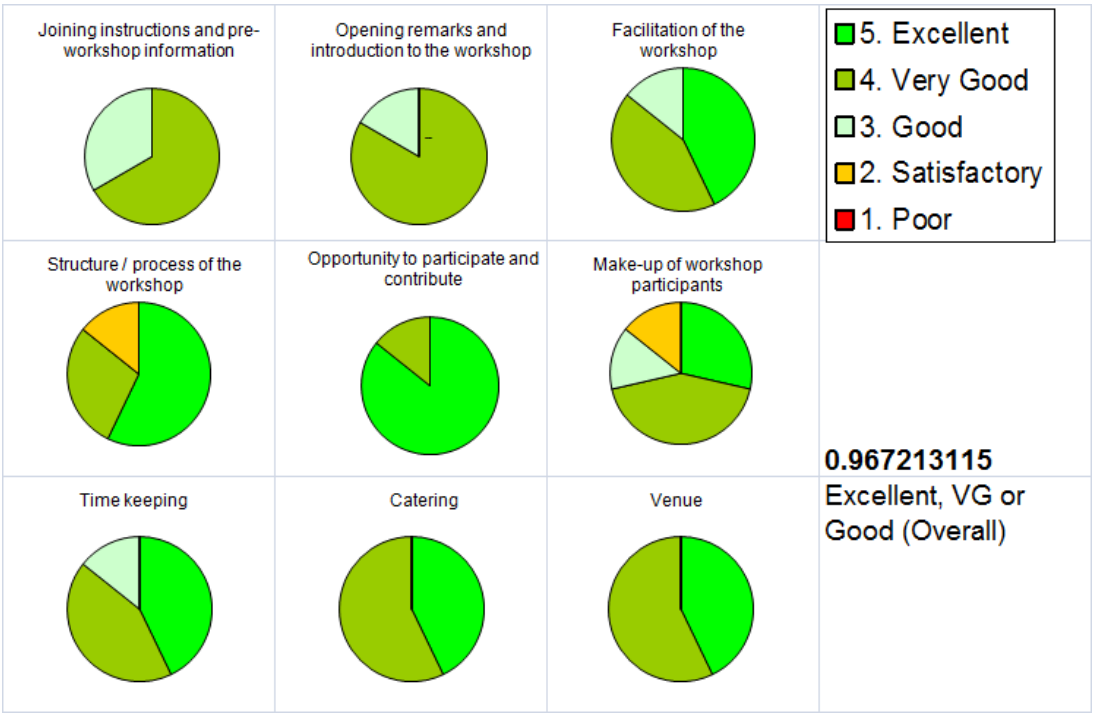
1. Modelling of materials and processes
2. Fiducial design especially in 3D
3. Incorporating in-process metrology
4. Demonstrate 1 µm control
5. Designing friction free spindles
6. Control system
7. Sensors and measurements
8. Substrate development
9. Spray coat precision
10. Vacuum gate technology

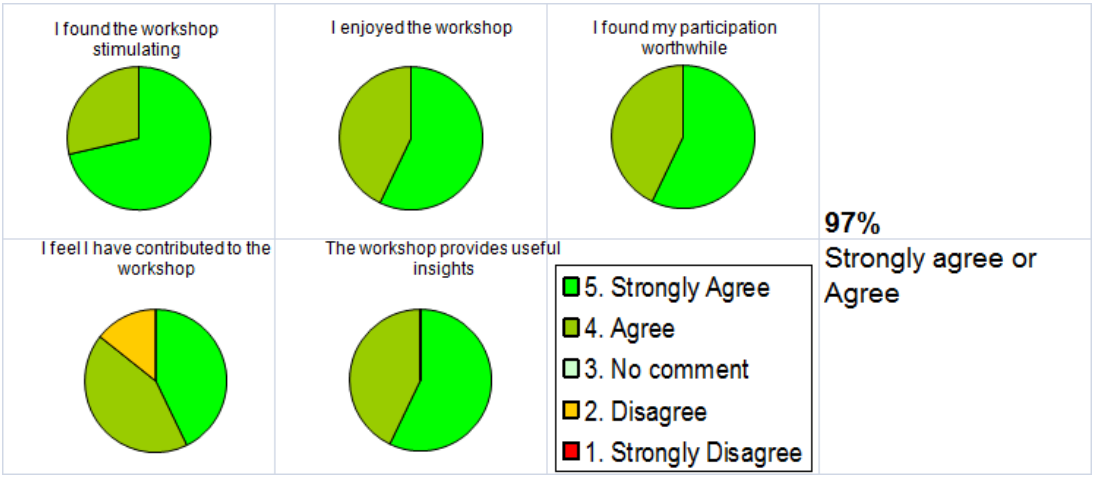
11. Appendix 1 – Participants List

NAME	ORGANISATION
Liam Blunt	Huddersfield University
Neil Davies	Pragmatic Printing
Enza Giaracuni	CIM - Facilitator
Cliff Joilliffe	Aerotech
Dilwyn Jones	Emral
John Lampett	CPI
Martin O'Hara	CIM - Facilitator
Paul Shore	CIM
Paul Streatfield	Bosch-Rexroth
Nick Walker	iXscient
Nicky Athanassopoulou	IfM ECS - Facilitator
Andi Jones	IfM ECS - Facilitator

12. Appendix 2 – Participant Feedback

Feedback was received at the end of the workshop from 7 participants. 97% considered the workshop to be Excellent, Very Good or Good as well as useful and stimulating. All considered their participation worthwhile. The detailed feedback is shown below.





13. Appendix 3 – Workshop agenda

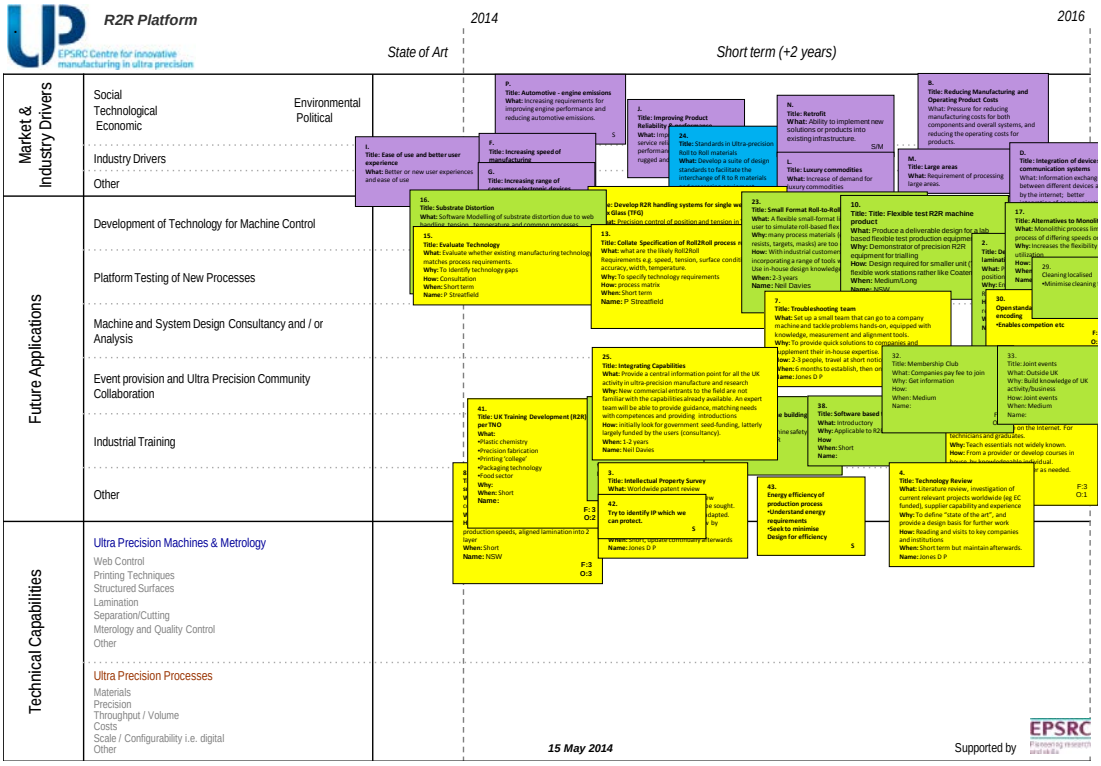
09.45	Arrival	
10.00	Welcome, Introductions and Overview	Prof. P. Shore
10.20	Individual presentations on Applications	All
11.40	Prioritisation of the most important applications	All
12.30	Selection of top 3-5 Applications	All
13.00	Lunch	
13.45	Break-out Group Work: Explore the selected applications	In Groups
15.30	Identify/Understand the technologies to be developed/integrated	In Groups
16.30	Feedback and Review	All
17.30	Close	

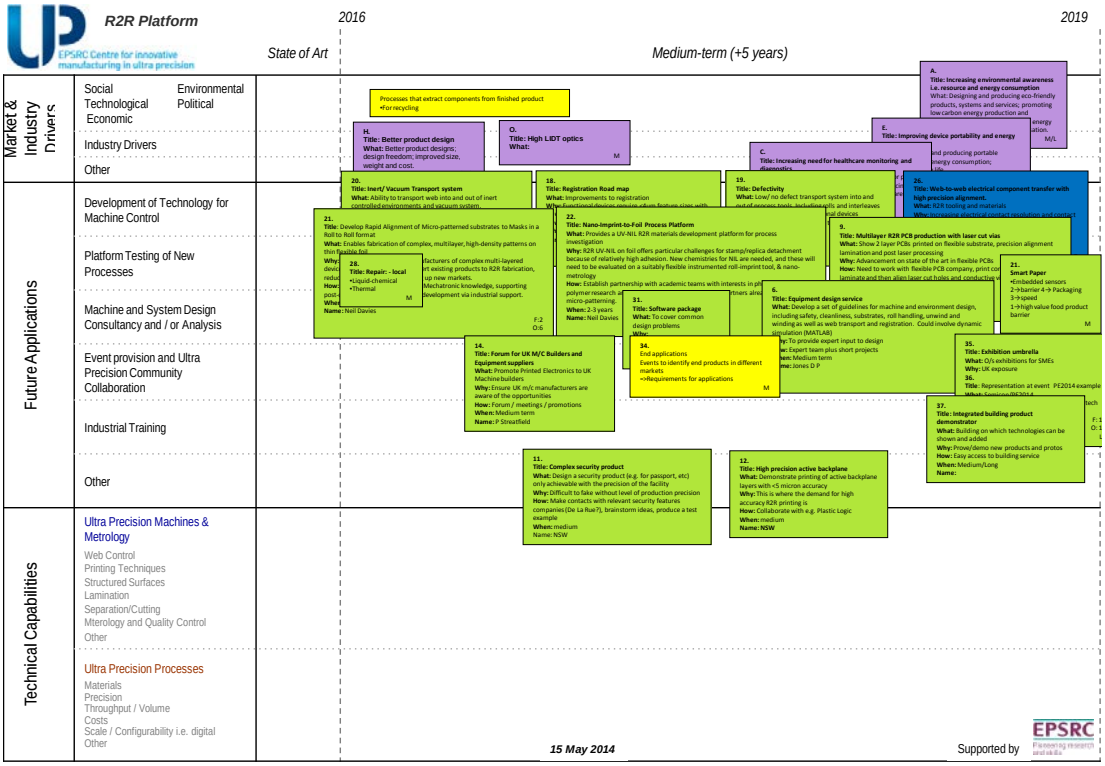
14. Appendix 4 – List of all Drivers and Industry Needs

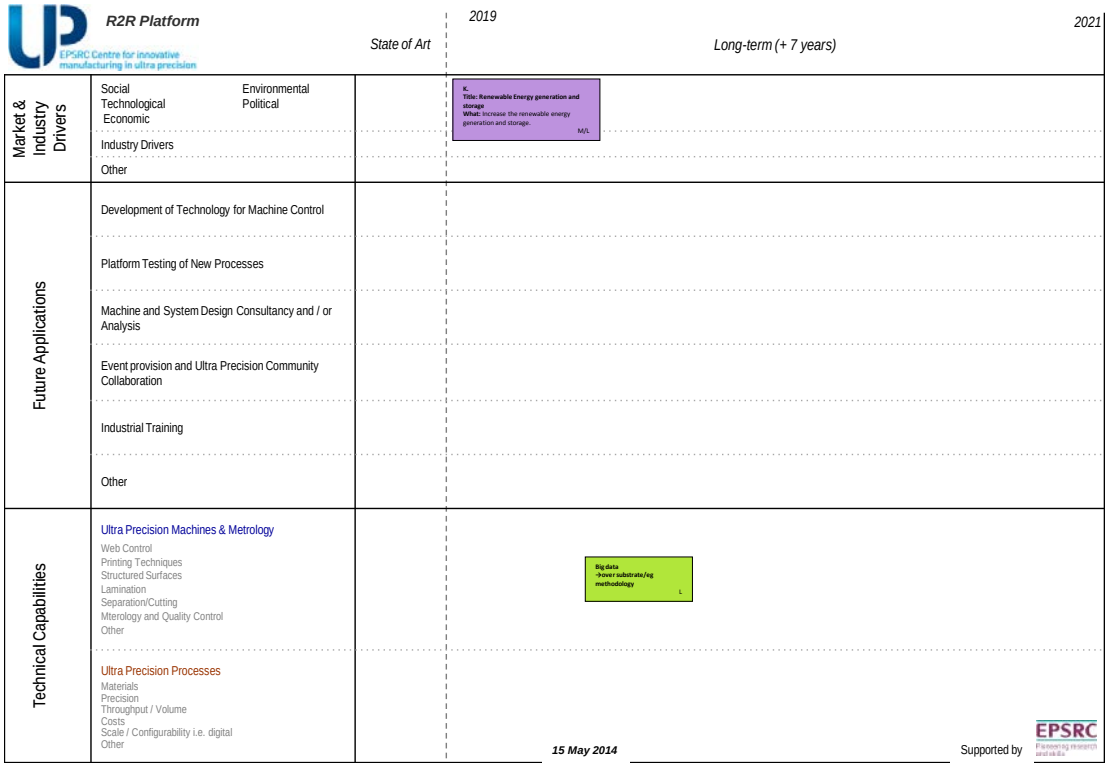
	Driver	Description	Ranking
A	Increasing environmental awareness i.e. resource and energy consumption	Designing and producing eco-friendly products, systems and services; promoting low carbon energy production and transport; incorporating renewable energy production; reducing resource utilisation	1
B	Reducing manufacturing and operating product costs	Pressure for reducing manufacturing costs for both components and overall systems, and reducing the operating costs for products	3
C	Increasing need for healthcare monitoring and diagnostics	Introducing new or improved methods for point-of-care diagnostics and health monitoring; reducing healthcare costs; increase the speed of healthcare monitoring and diagnostic methods	1
D	Integration of devices and communication systems	Information exchange between different devices aided by the internet; better integration of communication systems and a better connected mobile world	1
E	Improving device portability and energy consumption	Designing and producing portable devices with low energy consumption; Improving battery life	

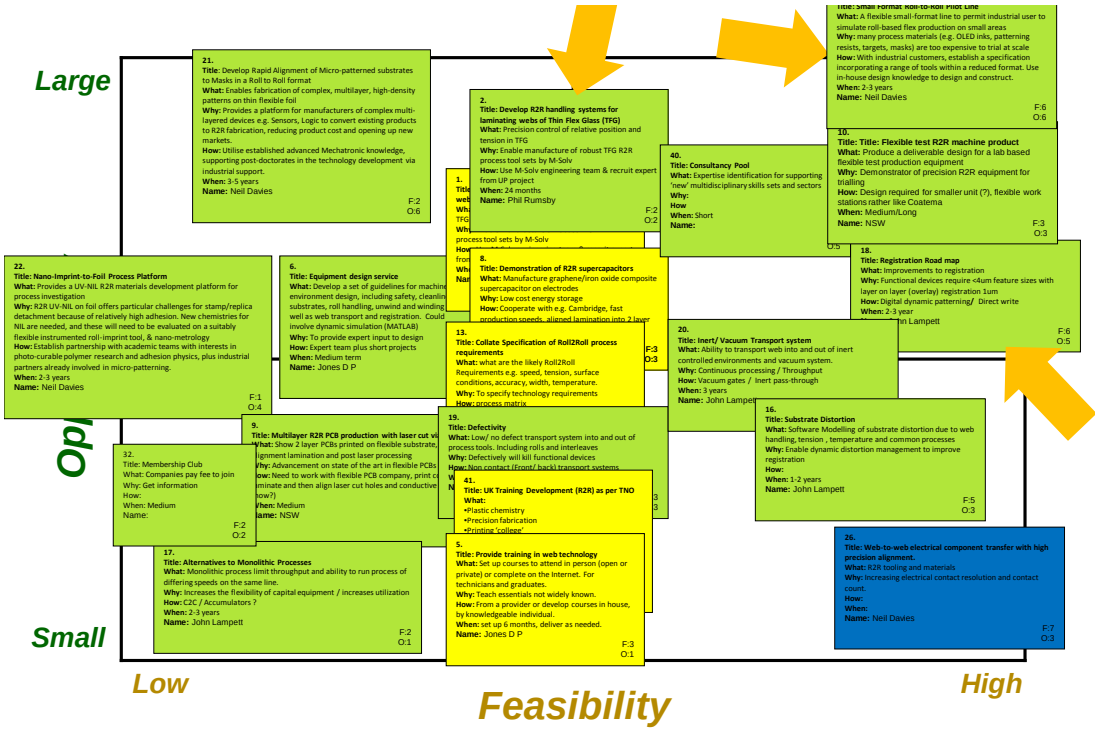
F	Increasing speed of manufacturing	Increasing speed of manufacturing, rapid volume scale up and faster turn around of products	2
G	Increasing range of consumer electronic devices	Increasing range and functionality of consumer electronic products and their sub-components	3
H	Better product design	Better product designs; design freedom; improved size, weight and cost	1
I	Ease of use and better user experience	Better or new user experiences and ease of use	
J	Improving Product Reliability & performance	Improving product and service reliability and performance; produce more rugged and stronger products	
K	Renewable energy generation and storage	Increase the generation and storage of renewable energy	2
L	Luxury commodities	Increase of demand for luxury commodities	1
M	Large areas	Requirement of processing large areas	1
N	Retrofit	Ability to implement new solutions or products into existing infrastructure	
O	High LIDT optics		
P	Automotive – engine emissions	Increasing requirement to improve engine performance and reduce automotive emissions	
Q	Rapid product development		1
R	Ease of UK “shaking the bottle”		1
S	Standards in ultra precision R2R materials		
T	Processes that extract components from finished product		

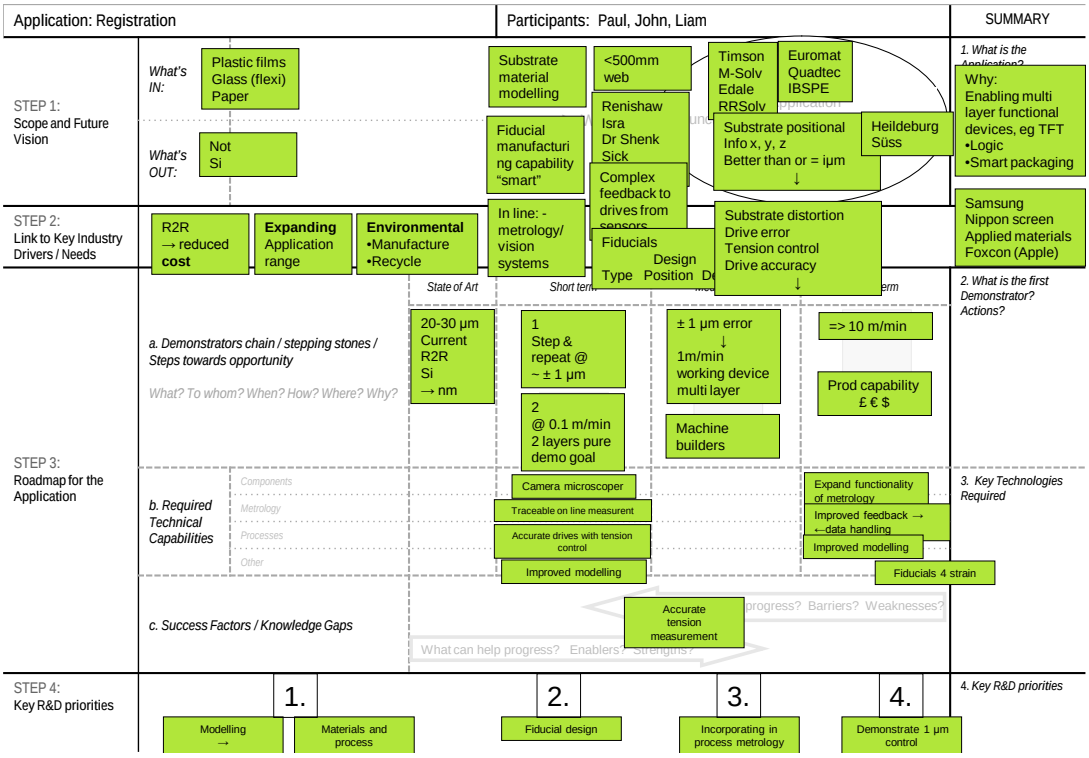
15. Appendix 5 – Electronic transcription of Workshop Outputs

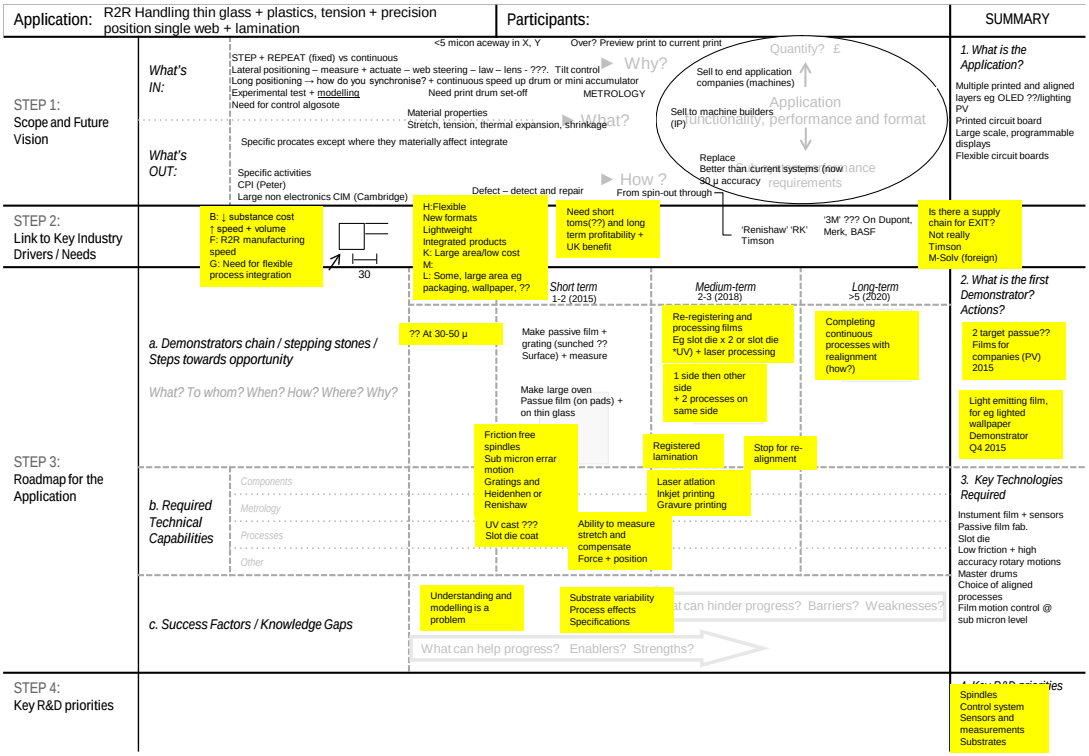

R2R Platform
EPSRC Centre for innovative manufacturing in ultra precision
2014
2016
State of Art
Short term (+2 years)
Market & Industry Drivers
Social
Technological
Economic
Environmental
Political
Industry Drivers
Other
Future Applications
Development of Technology for Machine Control
Platform Testing of New Processes
Machine and System Design Consultancy and / or Analysis
Event provision and Ultra Precision Community Collaboration
Industrial Training
Other
Technical Capabilities
Ultra Precision Machines & Metrology
Web Control
Printing Techniques
Structured Surfaces
Lamination
Separation/Cutting
Mterology and Quality Control
Other
Ultra Precision Processes
Materials
Precision
Throughput / Volume
Costs
Scale / Configurability i.e. digital
Other
15 May 2014
Supported by
EPSRC


R2R Platform
EPSRC Centre for innovative manufacturing in ultra precision
2016
2019
State of Art
Medium-term (+5 years)
Market & Industry Drivers
Social
Technological
Economic
Environmental
Political
Industry Drivers
Other
Future Applications
Development of Technology for Machine Control
Platform Testing of New Processes
Machine and System Design Consultancy and / or Analysis
Event provision and Ultra Precision Community Collaboration
Industrial Training
Other
Technical Capabilities
Ultra Precision Machines & Metrology
Web Control
Printing Techniques
Structured Surfaces
Lamination
Separation/Cutting
Mterology and Quality Control
Other
Ultra Precision Processes
Materials
Precision
Throughput / Volume
Costs
Scale / Configurability i.e. digital
Other
15 May 2014
Supported by
EPSRC


R2R Platform
EPSRC Centre for innovative manufacturing in ultra precision
State of Art
2019
Long-term (+ 7 years)
2021
Market & Industry Drivers
Social
Technological
Economic
Environmental
Political
Industry Drivers
Other
K.
Title: Renewable Energy generation and storage
What: Increase the renewable energy generation and storage.
M/L
Future Applications
Development of Technology for Machine Control
Platform Testing of New Processes
Machine and System Design Consultancy and / or Analysis
Event provision and Ultra Precision Community Collaboration
Industrial Training
Other
Technical Capabilities
Ultra Precision Machines & Metrology
Web Control
Printing Techniques
Structured Surfaces
Lamination
Separation/Cutting
Mterology and Quality Control
Other
Big data
->lower substrate/eg methodology
L
Ultra Precision Processes
Materials
Precision
Throughput / Volume
Costs
Scale / Configurability i.e. digital
Other
15 May 2014
Supported by
EPSRC


Large
Small
Low
Feasibility
High
21.
Title: Develop Rapid Alignment of Micro-patterned substrates to Masks in a Roll to Roll format
What: Enables fabrication of complex, multilayer, high-density patterns on thin flexible foil
Why: Provides a platform for manufacturers of complex multi-layered devices e.g. Sensors, Logic to convert existing products to R2R fabrication, reducing product cost and opening up new markets.
How: Utilise established advanced Mechatronic knowledge, supporting post-doctorates in the technology development via industrial support.
When: 3-5 years
Name: Neil Davies
F:2
O:6
2.
Title: Develop R2R handling systems for laminating webs of Thin Flex Glass (TFG)
What: Precision control of relative position and tension in TFG
Why: Enable manufacture of robust TFG R2R process tool sets by M-Solv
How: Use M-Solv engineering team & recruit expert from UP project
When: 24 months
Name: Phil Rumsby
F:2
O:2
40.
Title: Consultancy Pool
What: Expertise identification for supporting 'new' multidisciplinary skills sets and sectors
Why:
How
When: Short
Name:
What: A flexible small-format line to permit industrial user to simulate roll-based flex production on small areas
Why: many process materials (e.g. OLED inks, patterning resists, targets, masks) are too expensive to trial at scale
How: With industrial customers, establish a specification incorporating a range of tools within a reduced format. Use in-house design knowledge to design and construct.
When: 2-3 years
Name: Neil Davies
F:6
O:6
10.
Title: Title: Flexible test R2R machine product
What: Produce a deliverable design for a lab based flexible test production equipment
Why: Demonstrator of precision R2R equipment for trialling
How: Design required for smaller unit (?), flexible work stations rather like Coatema
When: Medium/Long
Name: NSW
F:3
O:3
18.
Title: Registration Road map
What: Improvements to registration
Why: Functional devices require <4um feature sizes with layer on layer (overlay) registration 1um
How: Digital dynamic patterning/ Direct write
When: 2-3 year
Name: John Lampett
F:6
O:5
22.
Title: Nano-Imprint-to-Foil Process Platform
What: Provides a UV-NIL R2R materials development platform for process investigation
Why: R2R UV-NIL on foil offers particular challenges for stamp/replica detachment because of relatively high adhesion. New chemistries for NIL are needed, and these will need to be evaluated on a suitably flexible instrumented roll-imprint tool, & nano-metrology
How: Establish partnership with academic teams with interests in photo-curable polymer research and adhesion physics, plus industrial partners already involved in micro-patterning.
When: 2-3 years
Name: Neil Davies
F:1
O:4
6.
Title: Equipment design service
What: Develop a set of guidelines for machine environment design, including safety, cleanline substrates, roll handling, unwind and winding well as web transport and registration. Could involve dynamic simulation (MATLAB)
Why: To provide expert input to design
How: Expert team plus short projects
When: Medium term
Name: Jones D P
8.
Title: Demonstration of R2R supercapacitors
What: Manufacture graphene/iron oxide composite supercapacitor on electrodes
Why: Low cost energy storage
How: Cooperate with e.g. Cambridge, fast production speeds, aligned lamination into 2 layer
13.
Title: Collate Specification of Roll2Roll process requirements
What: what are the likely Roll2Roll Requirements e.g. speed, tension, surface conditions, accuracy, width, temperature.
Why: To specify technology requirements
How: process matrix
F:3
O:3
20.
Title: Inert/ Vacuum Transport system
What: Ability to transport web into and out of inert controlled environments and vacuum system.
Why: Continuous processing / Throughput
How: Vacuum gates / Inert pass-through
When: 3 years
Name: John Lampett
19.
Title: Defectivity
What: Low/ no defect transport system into and out of process tools. Including rolls and interleaves
Why: Defectively will kill functional devices
16.
Title: Substrate Distortion
What: Software Modelling of substrate distortion due to web handling, tension , temperature and common processes
Why: Enable dynamic distortion management to improve registration
How:
When: 1-2 years
Name: John Lampett
F:5
O:3
9.
Title: Multilayer R2R PCB production with laser cut vi
What: Show 2 layer PCBs printed on flexible substrate
lignment lamination and post laser processing
hy: Advancement on state of the art in flexible PCBs
ow: Need to work with flexible PCB company, print c
minate and then align laser cut holes and conductive
ow?)
hen: Medium
ame: NSW
32.
Title: Membership Club
What: Companies pay fee to join
Why: Get information
How:
When: Medium
Name:
F:2
O:2
41.
Title: UK Training Development (R2R) as per TNO
What:
•Plastic chemistry
•Precision fabrication
•Printing 'college'
17.
Title: Alternatives to Monolithic Processes
What: Monolithic process limit throughput and ability to run process of differing speeds on the same line.
Why: Increases the flexibility of capital equipment / increases utilization
How: C2C / Accumulators ?
When: 2-3 years
Name: John Lampett
F:2
O:1
5.
Title: Provide training in web technology
What: Set up courses to attend in person (open or private) or complete on the internet. For technicians and graduates.
Why: Teach essentials not widely known.
How: From a provider or develop courses in house, by knowledgeable individual.
When: set up 6 months, deliver as needed.
Name: Jones D P
F:3
O:1
26.
Title: Web-to-web electrical component transfer with high precision alignment.
What: R2R tooling and materials
Why: Increasing electrical contact resolution and contact count.
How:
When:
Name: Neil Davies
F:7
O:3


Application: Registration
Participants: Paul, John, Liam
SUMMARY
STEP 1: Scope and Future Vision
What's IN:
Plastic films
Glass (flexi)
Paper
What's OUT:
Not
Si
Substrate material modelling
<500mm web
Timson M-Solv
Euromat Quadtec IBSPE
Renishaw Isra Dr Shenk Sick
Fiducial manufacturing capability "smart"
Substrate positional Info x, y, z Better than or = ıµm
Heildeburg Süss
Complex feedback to drives from sensors
In line: - metrology/ vision systems
Fiducials Design Type Position
Substrate distortion Drive error Tension control Drive accuracy
1. What is the Application?
Why: Enabling multi layer functional devices, eg TFT •Logic •Smart packaging
STEP 2: Link to Key Industry Drivers / Needs
R2R → reduced cost
Expanding Application range
Environmental •Manufacture •Recycle
Samsung Nippon screen Applied materials Foxcon (Apple)
State of Art
Short term
2. What is the first Demonstrator? Actions?
a. Demonstrators chain / stepping stones / Steps towards opportunity
What? To whom? When? How? Where? Why?
20-30 µm Current R2R Si → nm
1 Step & repeat @ ~ ± 1 µm
2 @ 0.1 m/min 2 layers pure demo goal
± 1 µm error ↓ 1m/min working device multi layer
Machine builders
=> 10 m/min
Prod capability £ € $
STEP 3: Roadmap for the Application
b. Required Technical Capabilities
Components
Metrology
Processes
Other
Camera microscoper
Traceable on line measurent
Accurate drives with tension control
Improved modelling
Expand functionality of metrology
Improved feedback → ←data handling
Improved modelling
Fiducials 4 strain
3. Key Technologies Required
c. Success Factors / Knowledge Gaps
Accurate tension measurement
What can help progress? Enablers? Strengths?
progress? Barriers? Weaknesses?
STEP 4: Key R&D priorities
1.
2.
3.
4.
Modelling →
Materials and process
Fiducial design
Incorporating in process metrology
Demonstrate 1 µm control
4. Key R&D priorities


Application: R2R Handling thin glass + plastics, tension + precision position single web + lamination
Participants:
SUMMARY
STEP 1: Scope and Future Vision
What's IN:
What's OUT:
<5 micon aceway in X, Y
Over? Preview print to current print
STEP + REPEAT (fixed) vs continuous
Lateral positioning – measure + actuate – web steering – law – lens - ???. Tilt control
Long positioning –› how do you synchronise? + continuous speed up drum or mini accumulator
Experimental test + modelling
Need for control algosote
Need print drum set-off
METROLOGY
Material properties
Stretch, tension, thermal expansion, Shrinkage
Specific procates except where they materially affect integrate
Specific activities
CPI (Peter)
Large non electronics CIM (Cambridge)
Defect – detect and repair
Why?
What?
How ?
From spin-out through
Quantify? £
Sell to end application companies (machines)
Sell to machine builders (IP)
Application
functionality, performance and format
Replace
Better than current systems (now
50 µ accuracy
requirements
'Renishaw' 'RK' Timson
'3M' ??? On Dupont, Merk, BASF
1. What is the Application?
Multiple printed and aligned layers eg OLED ??lighting PV
Printed circuit board
Large scale, programmable displays
Flexible circuit boards
STEP 2: Link to Key Industry Drivers / Needs
B: ↓ substance cost ↑ speed + volume
F: R2R manufacturing speed
G: Need for flexible process integration
30
H:Flexible
New formats
Lightweight
Integrated products
K: Large area/low cost
M:
L: Some, large area eg packaging, wallpaper, ??
Need short toms(??) and long term profitability + UK benefit
Is there a supply chain for EXIT?
Not really
Timson
M-Solv (foreign)
Short term 1-2 (2015)
Medium-term 2-3 (2018)
Long-term >5 (2020)
2. What is the first Demonstrator? Actions?
a. Demonstrators chain / stepping stones / Steps towards opportunity
What? To whom? When? How? Where? Why?
?? At 30-50 µ
Make passive film + grating (sunched ?? Surface) + measure
Make large oven
Passue film (on pads) + on thin glass
Re-registering and processing films
Eg slot die x 2 or slot die
*UV) + laser processing
1 side then other side
+ 2 processes on same side
Completing continuous processes with realignment (how?)
2 target passue?? Films for companies (PV) 2015
Light emitting film, for eg lighted wallpaper Demonstrator Q4 2015
STEP 3: Roadmap for the Application
b. Required Technical Capabilities
Components
Metrology
Processes
Other
Friction free spindles
Sub micron errar motion
Gratings and Heidenhen or Renishaw
UV cast ???
Slot die coat
Ability to measure stretch and compensate
Force + position
Registered lamination
Stop for re-alignment
Laser atlation
Inkjet printing
Gravure printing
3. Key Technologies Required
Instument film + sensors
Passive film fab.
Slot die
Low friction + high accuracy rotary motions
Master drums
Choice of aligned processes
Film motion control @ sub micron level
c. Success Factors / Knowledge Gaps
Understanding and modelling is a problem
Substrate variability
Process effects
Specifications
t can hinder progress? Barriers? Weaknesses?
What can help progress? Enablers? Strengths?
STEP 4: Key R&D priorities
Spindles
Control system
Sensors and measurements
Substrates

Mini-Business Plan	Opportunity: Active film business + R&D Opportunities
• Customer Need • Market Need	
Product / service offering	**Passive film → active film → products** **→ Adv. → [large scale mould fab]** **Machine building cap**
Competitors	**TNO → VDL flow** **Fraunhofers** **Samsung** **3M**
Current technology and capability readiness	**LAE → contacts → new device ideas** **MET → EU projects → contacts** **UP → build positioning of stable (partial)** → **Measuring solutions** **Metalfix awareness**
Specify required outcomes and timing	**By 2016 → passive film →** **income** **Cred** **justification of renewal**
Key Actions	***Establish passive film fab capability**
Key enablers	**As per registration summary**
• Key barriers and risks • Upside and downside • Critical Gaps	**International comp + speed of their development funding 'stops'**

Team:		

There is an opportunity for:

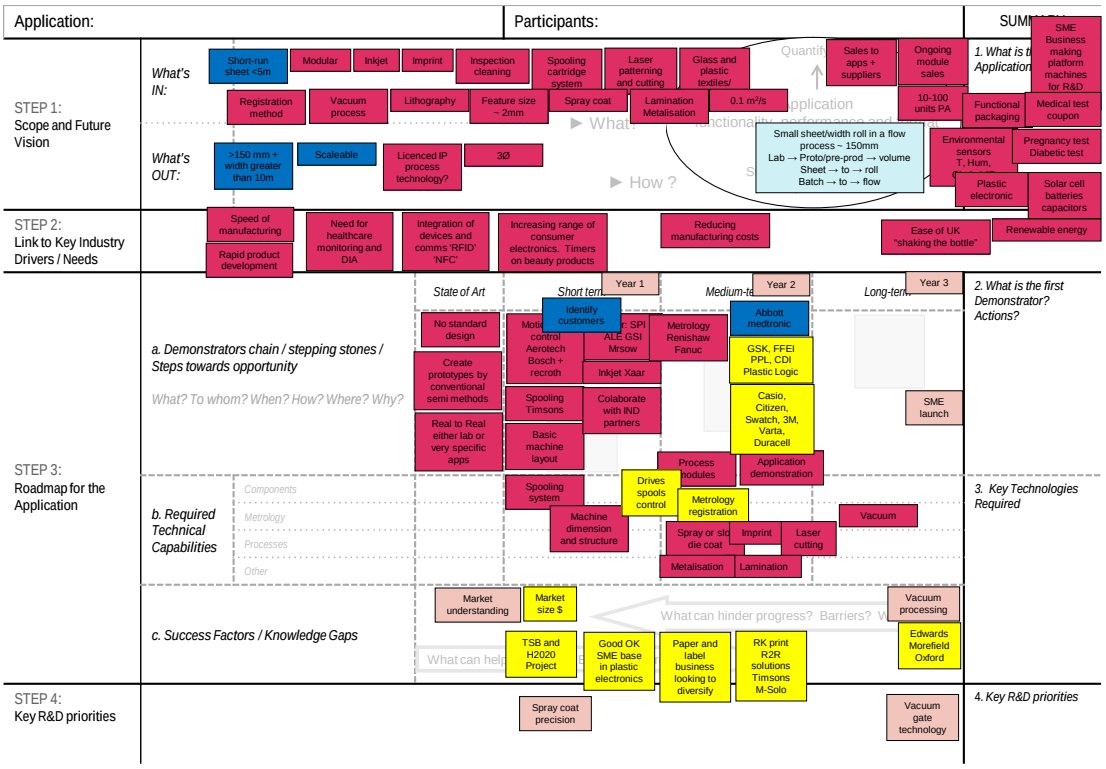
+ active films
Packaging
Displays
Branding
+ M/C builders ←supply chain
[TSB]
+ CPI → partners
+ new businesses

This will be delivered by:

EPSRC Funding
Metrology
Large area electronic
Ultra precision
CPI/Catapult/New businesses

Market / Technology intelligence gaps

Up positioning of films.
Films
Awareness
Data



Mini-Business Plan

Opportunity: Small format R2R

Team:	Neil Davies	Cliff Joliffe
	Martin O'Hara	

• Customer Need • Market Need	**Small scale flexible tool to facilitate development of R2R processes and products** **Mid step from lab scale to volume (ie prototype/pre production)** **Prove of sheet-to-roll and batch-to-flow**
Product / service offering	**Modular roll processing machine** **Low consumable cost (low volume processes)**
Competitors	**Sheet based lab & custom built roll processing (all 'one-off')**
Current technology and capability readiness	**Use current state-of-art roll-to-roll machine capabilities** **Process modules can be adapted from existing 3rd parties**
Specify required outcomes and timing	**Identify potential customer + market size within 12 months** **Have operating spool-to-spool within 12 months** **Identify demonstrator + fabricate by 24 months** **Determine vacuum feasibility by 24 months** **SME launch 36 months**
Key Actions	**Build business case** **Identify funding source**
Key enablers	**TSB or Horizon 2020 funding** **Industrial sponsor**
• Key barriers and risks • Upside and downside • Critical Gaps	**Wider industry not interested (lab → vol)** **Could lessen move to large scale volume** **Lowers barrier of entry for other companies** **Vacuum processes + feasibility in-line?**

There is an opportunity for:

Instrumentation, plastic electronics + machine builders

Small volume applications to realise cost benefits

New business creation without high production costs

This will be delivered by:

New UK SME

CIM in UP → technology

Existing paper/label equipment manufacturers

Market / Technology intelligence gaps

Market size + understanding (is UK big enough?)

Suitability of vacuum processes

Has it already been done overseas?