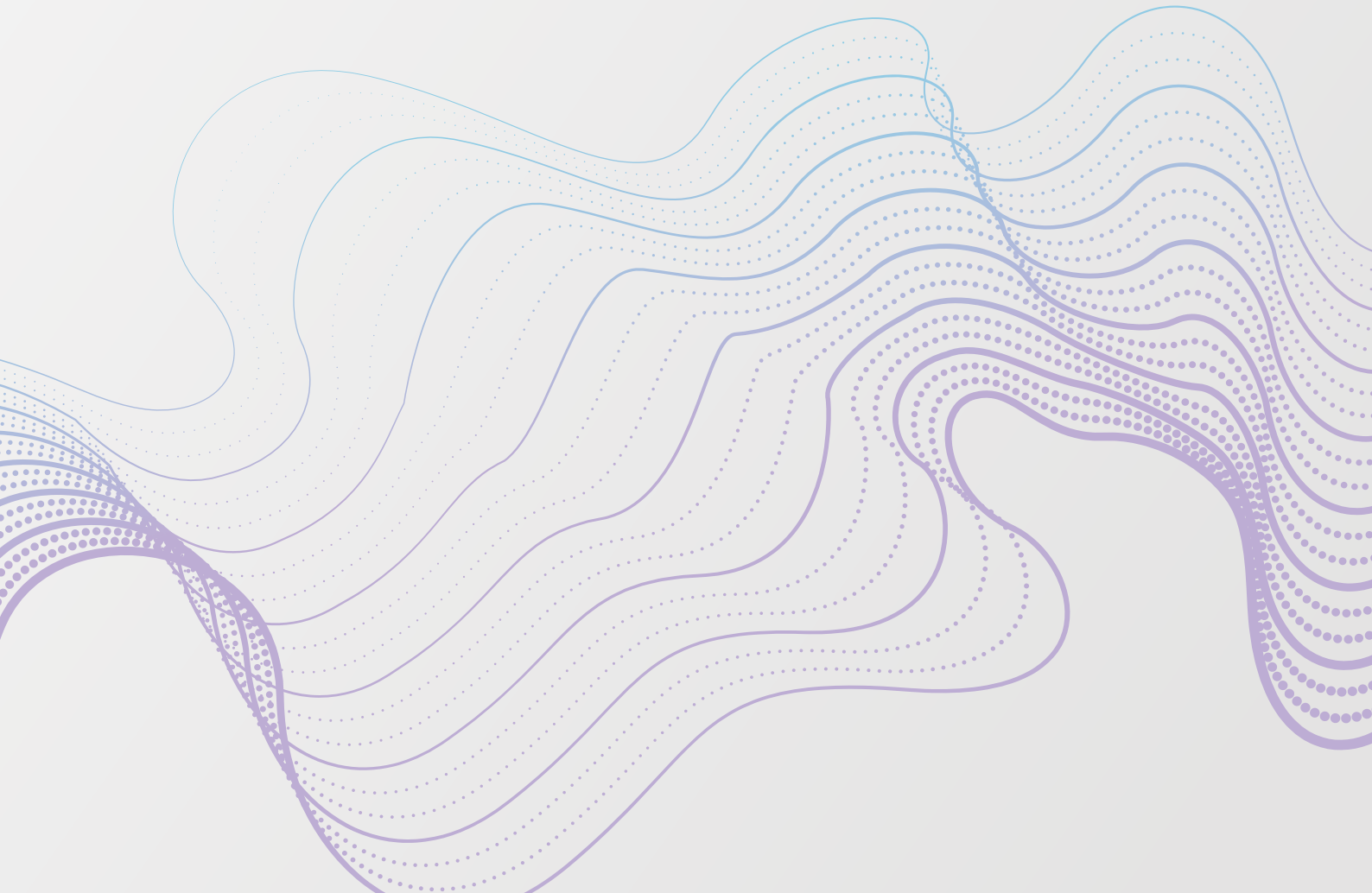
National Biofilms Innovation Centre

Biofilm Prevention

WORKSHOP REPORT

NOVEMBER 2021 – BIRMINGHAM UK



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NBIC WORKSHOP

Executive Summary

This workshop was aimed at exploring unmet industrial needs and resulting research questions in the field of biofilm prevention. NBIC partner organisations shared their experience and the 59 attendees worked in syndicates to discuss the key challenges and ways to overcome them.

The ability to control and prevent biofilms is central to some of the most urgent global challenges, which exert considerable economic impact across many industry sectors. The potential benefits of harnessing the power of biofilms are equally profound, offering significant opportunities for creating economic and societal benefits.

Biofilm prevention aims at limiting or preventing the early-stage microbial adhesion and colonisation events at surfaces. The remit of biofilm prevention spans multiple sectors for which avoiding biofilms altogether is a key goal.

The main needs that emerged were:

- There remain many areas in which continued **basic research** is needed: (i) the factors and interventions that promote or inhibit biofilm formation, (ii) the early colonisation mechanisms leading to biofilm formation, (iii) the heterogeneous nature of early stage biofilms and the resultant impacts on their behaviour, (iv) the spatial-temporal dynamics of bacterial strains in mixed early stage biofilms, (v) can and how microbes adapt to different surfaces?, (vi) use of advanced techniques to answer these fundamental questions, (vii) the need for interdisciplinary science to develop the knowledge base required to master prevention or early control of colonisation.

- **A continued focus on translation.** The block to progress is not solely the basic research gaps, but an inability to readily translate possible solutions into commercial practice due to challenges in upscaling technologies that are reliable, low-cost, robust and within regulatory guidelines.

- **A clearer focus on standards and regulations is required for the approval of products** aimed at preventing and controlling biofilms.

- **Overcoming the lag that occurs during new technology adoption into the market,** that can often put at peril the commercial survival of new technology.

- **A need for a more unified terminology** e.g. being clear on the distinction/overlap between stages of biofilm growth, with clear delineation of the early development phases that span adhesion to the onset of irreversible attachment.

- **Close and active collaborations in this field across and between academia and industry.**

Background: National Biofilms Innovation Centre (NBIC)

NBIC was formed in December 2017 as an Innovation Knowledge Centre (IKC), funded by BBSRC and Innovate UK, with a mission to harness the UK's industrial and academic strength in biofilms.

NBIC is the recognised UK hub for accessing biofilm expertise, capability, science and innovation capacity. Its central focus is catalysing growth in UK's scientific, technological and industrial expertise in biofilms with the goal of delivering:

- World class science and scientists
- Breakthrough innovations
- Economic and societal value

NBIC has created a community of researchers and industrial/commercial partners across the UK and internationally to progress all these elements.

NBIC's Industrial and Academic Engagement Strategy

A primary element of NBIC's engagement strategy with its industrial and academic community is the exploration of unmet industrial, scientific and societal needs in biofilms, including challenges they create or the opportunities they present. NBIC's market analysis estimated that biofilms have an economic significance in excess of $5000bn USD a year[1]. The needs driving these impacts are diverse. In the field of biofilm prevention, these include the development of surfaces and materials that prevent microbial attachment and formation of biofilms on the hulls of ships or medical implants, to the search for hand held systems for detecting early-stage biofilms in infection, to water treatment or food manufacturing plants (as also identified in our Biofilm Detection Workshop[2]). Many of these needs will be shared across industrial sectors and others may be unique to a particular context.

This Biofilm Prevention Workshop and its predecessors on Biofilm Detection (NBIC Report October 2018[2]), Biofilm Engineering (NBIC Report April 2019[3]) and Biofilm Management (NBIC Report April 2020[4]) are a key dimension in achieving these goals and have created a forum whereby academic experts and industrial practitioners have come together to explore, understand and solve unmet needs. Developing this understanding allows NBIC to better direct it's research and translational strategy, as well as facilitating and sharpening its industrial and academic engagement.

NBIC will, as it progresses into its second phase, continue to explore these 4 themes as well as focussing on narrower subject fields. Together, these multidisciplinary events deepen the collective understanding/consensus and influence future scientific and translational activity/funding. To aid this, NBIC in collaboration with our community have developed a Biofilm Ontology to build a common language.

PREVENT

Knowledge-based design of surfaces, interfaces and materials

DETECT

Innovative sensing, tracking and diagnostic technologies

MANAGE

Kill, remove or control established biofilms from exploiting their life cycle dynamics

ENGINEER

Control and direct complex microbial communities in process applications

Biofilms in Context

Microbial biofilms and communities collectively represent one of the largest biomass and activity centres on the planet, playing a major role in the biology of the environment (both natural and engineered) and in maintaining public health. Therefore, the understanding of biofilms is key to discovering, controlling and directing their behaviours to support a sustainable environment, different areas of engineering, public health and medical applications.

Biofilms are central to some of the most urgent global challenges and exert considerable economic impact across industry in many sectors. The potential benefits of harnessing the power of biofilms are equally profound, offering significant opportunities for creating economic and societal benefits. These areas and their impact are covered in depth in a recent NBIC publication[1].

In trying to both tackle and utilise biofilms, the industrial and research communities (led by BBSRC and Innovate UK) have defined 4 key interventional strategies:

- **Prevent:** To limit or prevent the early-stage microbial adhesion and colonisation events at surfaces. This requires the use of advanced techniques to create knowledge-based design of next-generation technologies[7] that can deliver advanced interventions via surfaces, materials and interfaces for specific and targeted actions on early-stage biofilm formation.
- **Detect:** To deliver a step change in the ability to detect biofilms directly, *in situ,* at the point-of-use in field-based contexts and close-to-patient care through accurate and quantitative biofilm detection and metrology across multiple scales.
- **Manage:** To destroy, remove or control established biofilms by understanding and exploiting their life cycle dynamics and development across a range of environments and levels of complexity. Also, to accelerate the development of successful treatments, which target the biofilm life cycle-dynamics and intricate structure, through the creation and use of biofilm models resembling real environments.
- **Engineer:** To harness the benefits of complex microbial consortia from knowledge of their composition, function, ecology and evolution. This exploits understanding at the boundaries with engineering and process applications. It includes improving engineered platforms and solutions e.g., wastewater, biotechnology, resource recovery from wastewater, microbial fuel cells, aerobic and anaerobic biorefinery. The scope for this theme also includes precision tools for microbial community engineering using synthetic biology.

During a KTN workshop in 2018[6], early in the life of NBIC, it was very clear that participants saw it as vital that NBIC should pay attention to the creation of a balanced view of biofilms addressing not only the problems that biofilms present but the opportunities which they offer. NBIC workshops aim to meet this goal.

This report covers a workshop held on the subject of biofilm prevention. A key strategy to achieve this is the knowledge-based design of surfaces, materials and interfaces. Research strategies are being considered and deployed for achieving this outcome in a wide range of sectors, such as health (e.g. infection), marine, drug delivery, personal care and the built environment. These strategies include:

- Prevention of early-stage microbial adhesion and colonisation events at surfaces e.g., via intrinsically anti-adhesion surfaces that rely on surface topography, surface functionalisation and smart delivery of antimicrobials via coatings and surface functionalisation.
- Advanced techniques for knowledge-based design of next-generation biofilm prevention strategies.

NBIC combines a wide range of surface and materials characterisation techniques with biological imaging and bioassays to create knowledge-based correlations. These were described in an opening presentation at the workshop by Professor Rasmita Raval (NBIC Co-Director and academic lead on biofilm prevention).

Biofilm Prevention Workshop

1.1 SETTING AIMS AND PROCESS

The workshop was held at Aston University Business School in Birmingham on 24 November 2021 starting at 10:00 and finishing at 16:00.

The stated goals of the workshop were to:

- Identify the unmet needs in relation to biofilm prevention across a range of sectors - commercial, industrial and clinical.
- Understand the problems with current approaches.
- Explore possible solutions and the way forward.

The intended outputs of the day were to:

- Establish the translational priorities which could influence funding calls and regulators.
- Identify current research gaps to address industry needs.
- Determine whether there are existing solutions available to address challenges.
- Identify collaboration opportunities.
- Generate a report for all attendees and for wider dissemination.

The meeting was open to all NBIC industry partners and affiliated research institutions, with 59 attendees in total, representing 27 organisations. A list of participating organisations is available in Appendix 3.

To provide input to the meeting, those who had registered to attend were asked to consider four questions in advance and submit these online, by email or by hand. Submissions were received from a wide stakeholder base (Appendix 1).

1. What do you see (from your perspective, company or interests) as the problems or needs in the prevention of biofilms? What are the problems with current approaches available to you?
2. In your view what should be done to address these needs/problems?
3. What do you think it would take to close these gap(s)? For example, in duration of time, level of expertise, specific capabilities and level of effort (e.g., in £/$ or people in full time equivalents)? Is this basic research, applied research, cross industry action?
4. Do you have any other thoughts, contacts, opportunities, ideas or proposals?

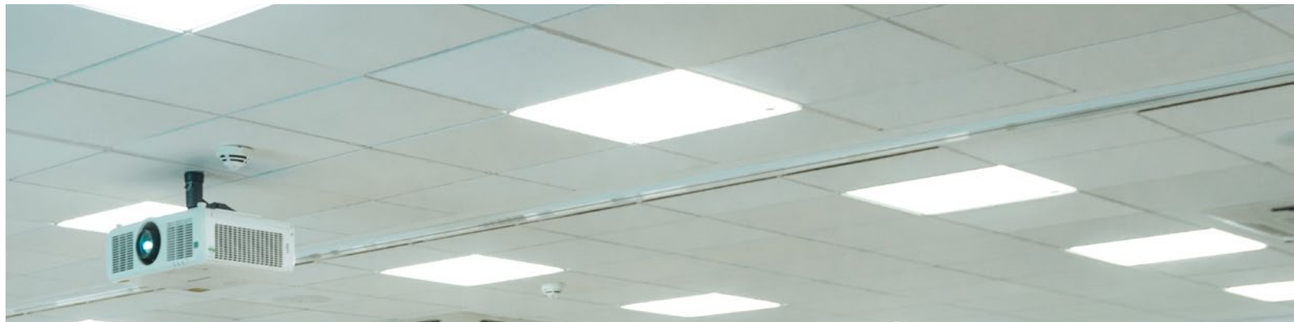
The meeting started with a plenary session, led by NBIC (Professor Rasmita Raval, University of Liverpool), summarising and discussing an outline scope of the needs, problems and opportunities in biofilm prevention.

1.2 SYNDICATE OUTPUTS

For the rest of the day, there were multiple industry/academia syndicate sessions (with mixes of sectors and expertise) discussing the four questions and with the aim to reach clear thoughts and recommendations.

The groups were reshuffled between sessions to enable discussions among a new set of people. The outputs from the syndicate session were captured on flipcharts and from individual feedback received during or after the meeting.

To finish off, there was final plenary session where participants had the chance to share and discuss the syndicate outputs. These were then used to prompt the whole syndicate discussions which mixed industry, academic institutions and business sectors. The outputs from the syndicate discussions are highlighted in detail in Appendix 2, and individual feedback is collated in Appendix 1.

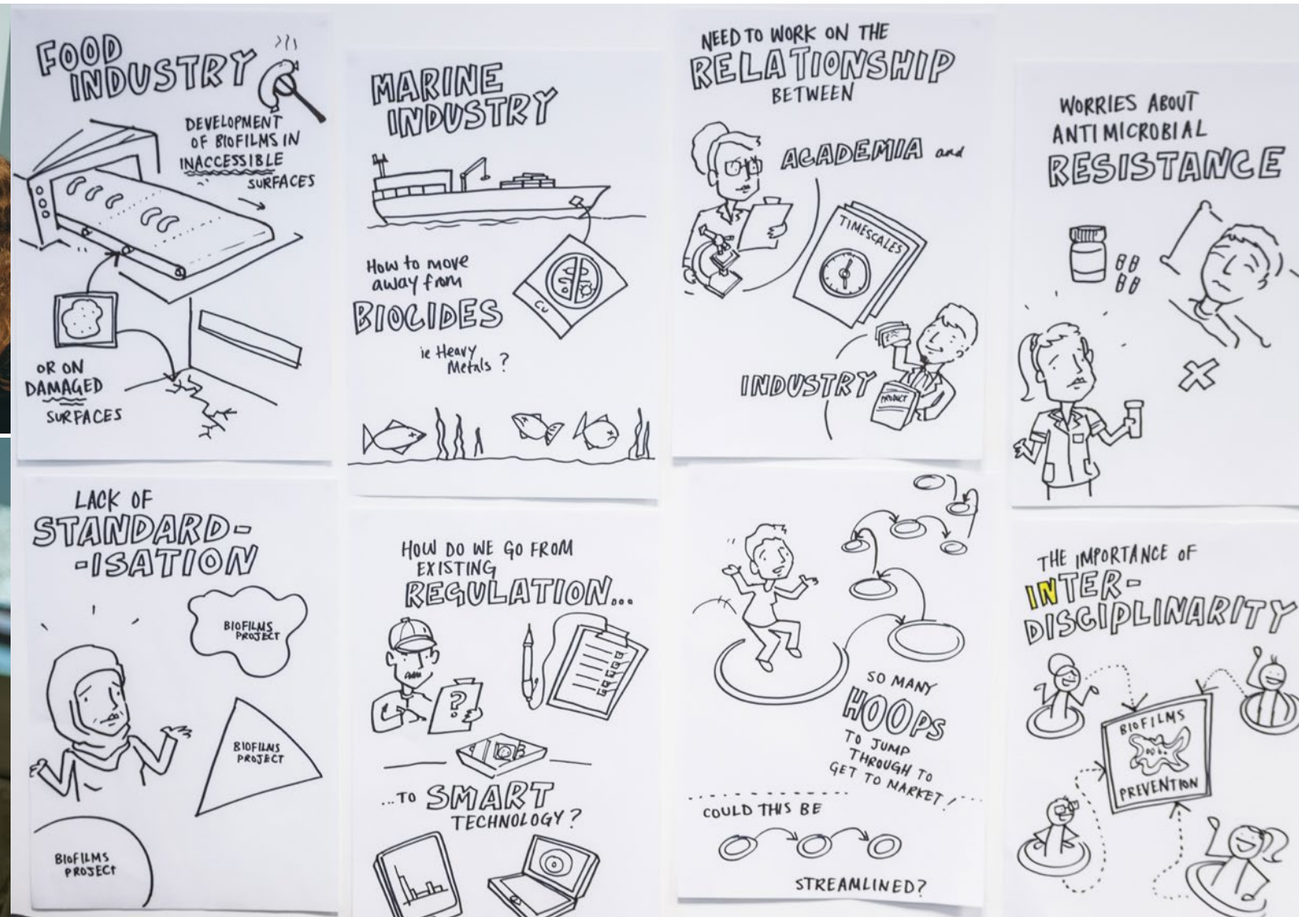


1.3 DISCUSSION AND CONCLUSIONS

The subject of biofilm prevention generated much interest and discussions between the attendees. It is demonstrably an area of ongoing industrial and academic attention as evidenced by NBIC's own project calls illustrated in Professor Raval's presentation[7].

Underpinning the discussions at the meeting was a plea to consider the problems and unmet needs of industry. There was a request for a continued academic focus on addressing these needs. It is apparent that there is a lack of joint understanding within industries and between academia and industry on the clear definition of industry problems/needs. NBIC has a critical role to play in bridging this gap.

Attendees were asked to think about the four questions, mentioned in Section 1.1, around what they see as the key problems and what would be ways forward. These were then consolidated with the workshop syndicate output to identify the key findings and actions from the meeting.



Prevention workshop illustrations by Tom Bailey.

The remit of biofilm prevention spans multiple sectors:

- **Health:** Biofilm prevention is a critical target in conditions such as cystic fibrosis and chronic infections of tissue and implants (e.g., orthopaedic devices, catheters, intravenous tubing, artificial valves and infections such as that of the prostate and wound). There is a strong link between biofilm prevention treatment and the alleviation of symptoms towards recovery.
- **Industrial processing:** Fluid flow is a feature of industry processes and the pipelines and equipment are prone to microbial colonisation, biofilm formation and can lead to product spoilage, reductions in process efficiency or direct risks to public health (water).
- **Marine:** The formation of biofilms on the hulls of ships presents a major economic and CO_2 emission problem[1] and there is a constant drive to find improved preventative approaches. Biofilms are also a major factor in the fouling and corrosion of internal systems such as water distribution, sea chests and fire suppression systems causing major safety issues for both civilian and military vessels. Biofilms and other organisms found within ballast tanks are also coming under increasing monitoring to combat the release of invasive species making prevention of biofilm formation within these systems a key area of interest.
- **Oral hygiene:** The prevention and reduction of microbial biofilms is arguably the key goal of dental care and hygiene aiming at prevention of plaque and avoiding gum disease and tooth decay.
- **Food and agritech:** *Listeria* remains the primary cause of fatal food poisoning in the UK and is often linked to formation of biofilms on food production surfaces or equipment. A key need in the food sector is to prevent and detect biofilms across the whole 'Farm to Fork' processes. In the wider agritech sector, the control of biofilm formation, both in food production and human GI tract, using pre-, pro-, post- and syn-biotics is an intense area of interest for impacting positively on human health.
- **Public areas and the built environment:** The Covid-19 pandemic has intensified awareness of the importance of establishing hygiene regimes for controlling microbial adhesion to high contact surfaces in order to prevent pathogen transmission. Biofilms in water distribution systems and cooling towers present a high risk of *Legionella,* with traditional methods of heating or chlorination coming with a high energy cost. Furthermore, biofilm formation in public leisure facilities such as swimming pools and hot tubs is a major concern to users, operators and manufacturers. These can develop in pumps, pipework and filters risking the health of users, reducing efficiency and increasing the use of biocides which require lengthy downtime.
- **Energy Sector:** Biofilm formation both in pipelines, storage tanks and static marine infrastructure is a major contributor to corrosion in both oil and renewable energy systems. Marine fouling of renewable assets, especially tidal plants, causes a reduction in efficiency and presents a requirement for a unique antifouling solution.
- **Heat exchangers and semiconductors:** The formation of biofilms, in open and closed water-cooling systems, reduces efficiency of both heat exchangers and semiconductors used in the nuclear power, industrial processing, energy and water sectors. These systems often release into the environment and are monitored, therefore the use of traditional biocides can prove challenging.

The discussion groups felt that there remain many areas in which continued basic research is needed to be able to achieve progress in the sectors listed above: (i) A fundamental understanding of the factors promoting or inhibiting biofilm formation and how this varies with species; (ii) Developing understanding of the mechanisms by which antimicrobials and other agents could act as biofilm preventers; (iii) How the heterogeneous nature of biofilms impacts on behaviour; (iv) Better understanding of the early colonisation mechanisms leading to biofilm formation e.g. the shapes of bacteria, their movement velocities and the fluid shears they experience can all affect how they approach surfaces, and therefore, the likelihood of biofilm formation; (v) Understanding how the spatial-temporal dynamics of bacterial strains in mixed biofilms affect cell-cell interactions. Large studies are needed mapping initial interactions for multiple species biofilms; (vi) Can, and how, do microbes adapt to different surfaces?

These are all complex questions and the subject of ongoing research. Many in the discussion groups felt that a major block to progress was an inability to readily translate possible solutions into commercial practice. These blocks include upscaling and economic production and processes. More funding is needed for this in order to aid the collaboration between academia and industry.

In common with the other interventional areas NBIC has explored (Detect[2], Manage[4] and Engineer[3]), the groups felt that a clearer focus on the standards and regulations required for the approval of products aimed at preventing and controlling biofilms would be aid the translation. Key points raised in relation to standards: (i) There are few that cover biofilms and "the ones that do, don't get used"; (ii) There is a lack of standard methods for testing or claims generation; (iii) There is also a difference between the approaches needed to achieve academic standards and those expected to develop international standards (e.g., ISO, CEN). It is important that the two work in cooperation to ensure progress in this area; (iv) There is also a clear need for better defined onward regulatory pathways to allow new and existing products to gain regulatory approval with clear product effectiveness claims; (v) There is currently a poor fit of biofilm prevention and control agents to the existing biocide regulations. "SMART" technologies also need to be anticipated in developing these pathways e.g., those with antimicrobial properties activated by the presence of pathogens or with sound/light/chemical switches.

Further headwinds to the translation of innovation that were discussed include overcoming the lag that occurs during new technology adoption into the market. This can often put at peril the commercial survival of new technology. This further emphasises that new technologies must be cost effective if they are to be adopted in the market. End-user participation in data generation from demonstrators will be critical in facilitating this outcome. It was felt, in some sectors, that people "don't want to pay for a problem that doesn't exist yet".

The environmental agenda and the grand challenge of 'net zero' is driving a move away from synthetic chemicals and heavy metals in a wide range of industrial and agritech applications. This offers a real opportunity for newer technologies. For example, some current biocidal coatings can be washed into the water and be harmful to the environment. Permanent coatings (that do not get released into the environment) or agents capable of preventing biofilms (e.g., phage, biopolymers and electrolytically produced dissolved ozone) all offer a promise of greener solutions. Attendees from consumer-based businesses reported an increasing consumer preference for more naturally derived products providing a further commercial driver.

In a wider discussion, it was also felt that there was a need for a more unified terminology e.g., clear distinction / overlap between microbiome and biofilm. This could help expand thinking around prevention based, for example, on the maintenance of an existing healthy microbiome / biofilm as a method to selectively prevent the attachment and growth of pathogenic organisms and the establishment of a dysbiotic microbiome.

It is very clear that biofilm formation and removal is a cycle (prevent, detect, and manage) and that in order to be certain that the formation of biofilms has been prevented then appropriate methods of detection[2] are needed.

A final collective area of discussion was around improving collaborations in this field across and between academia and industry. Examples of this included:

- Shared resources: Online sites to help people who want to find relevant information e.g., the development of a platform which could help share test methods between groups aiding reproducibility across industry groups and universities.
- Creation of a biofilm prevention working group.
- Industry/academic joint research on promising antibiofilm agents in the gap between bench research, and translation, e.g., into the formulation of product suitable for clinical trials.
- Developing a shared understanding between academia and industry of the issues and goals, the translation of lab to real-life, and joint funding of postdocs and PhDs.
- Problems are cross-sectorial and the need for change is shared. Hence, there could be pan-industry working groups (as at this workshop). This could drive collective outreach, lobbying and education to the government, regulatory authorities, policy makers funding bodies, charities, learned societies and the public.

References

1) Cámara, M., Green, W., MacPhee, C.E. *et al.* Economic significance of biofilms: a multidisciplinary and cross-sectoral challenge. npj Biofilms Microbiomes 8, 42. 2022.
2) NBIC Biofilm Detection Report. October 2018.
3) NBIC Biofilm Engineering Report. April 2019.
4) NBIC Biofilm Management Report. February 2020.
5) NBIC 2022 Annual Report. September 2022.
6) Identifying and Prioritising Industrial Challenges and Potential Solutions for the Prevention, Detection, Management and Engineering of Biofilms. May 2018.
7) R. Raval. 2020. Biofilm Prevention, NBICs Approach.

Appendix 1: Pre-submitted Input from Attendees

Delegate	What do you see (from your perspective, company interests or academic field) as the problems or needs in achieving the prevention of biofilm formation? What are the problems with current approaches?	In your view what priority activities and actions could and should be carried out to address these needs/ problems either in industry, academia or jointly?	What do you think it would take in terms of cost, time and effort to close these gap(s)? For example, time, expertise, capabilities, effort (£, FTE)?	Do you have any other thoughts, contacts, opportunities, ideas or proposals relating to Biofilm formation prevention?
1	Working in the academic field studying infections in cystic fibrosis, we often focus on biofilm associated mechanisms. One of the key elements of establishment of chronic biofilm infections is the early colonisation stages which are often aided by exotoxins and bacterial virulence both for the liberation of nutrients for colony expansion, but also for defence against host immune mechanisms. If we want to prevent the establishment of infections, we could look at focusing at these adjunctive methods which play important roles in biofilm establishment. Benefits of these approaches are that they don't necessarily act in a bactericidal way against the bacteria directly and therefore it is possible to mitigate high rates of resistance. Furthermore, these targets are often identified or at highlighted in existing studies looking at infection, but don't necessarily get associated with biofilms compared to just routine microbiological infection studies.	Jointly collaborating with existing companies or non-biofilm labs working on virulence or methods which investigate core microbiological challenges but could be applied to biofilms. Establishment of novel studies, multi institution studies, potentially focused on -omics approaches to identify mechanisms of virulence or methods of early infection and bacterial cell survival in chronic infections. This would be important in providing novel targets.	Initially this would have to be addressed with basic research - £1-4m over a number of years in collaborative research projects or consortium funding. BBSRC/MRC grant funding. Progression to cross collaboration with industry - £1m with some funding or in kind contributions coming from industry partners. Potential for clinical trials if any successful compounds are highlighted for medical applications. Mechanism to overcome government inertia regarding funding challenges, would be highlighting novel applications of existing research and methods which has been widely promoted in government policy in recent years. Particularly in light of the COVID-19 pandemic which saw this as a common strategy, at least initially, to tackle this healthcare challenge.	Development of a biofilm prevention - adjunctive therapies working group. Focused on looking at methods of biofilm prevention through inhibition of alternative mechanisms of early colonisation in infections and in industrial applications, eg. initial adherence to surfaces.
2	The very high susceptibility of some host sites (e.g. wounds) to colonisation by biofilm pathogens with extensive tolerance of/resistance to current antimicrobial agents.	Collaborative research in the gap between bench research on promising antibiofilm agents, and translation into a formulation or product suitable for clinical trials.	Applied research (Industry/ Academic collaboration over a few years). Collaborative funding of a post-doc position, with cost split between academic funder and industry, seems ideal to me.	
3	I am interested in biofilms in hot tubs in domestic settings, collaborating with hot tub chemical supplier companies. The domestic hot tub sector is booming, but not much is known about biofilm prevention/removal in this specific built environment setting.	More public engagement targeted at hot tub users/ owners; Health risk assessment; Set up and run an awareness program.	I've not costed my ideas. Some aspects are basic research, but all of the above options are pertinent. It is also cross-sector relevant, from domestic settings to commercial industries such as holiday lets where managers/owners are often not aware of commercial regulations on wet leisure activities, e.g. water sampling and analysis protocols as seen in swimming pools, but also relevant to the chemical industry (sanitizing chemicals), coatings and materials engineering, health and wellbeing, etc. Closing of gaps in knowledge and awareness is likely a multi £M effort, if all fronts are tackled.	Yes, I have several ideas on the broad topic of biofilms in hot tubs, seeking collaborators and funding suggestions to target.
4	I feel that our *in vitro* models we use to characterise biofilms are just not reflective of what happens in reality. Microtiter crystal violet assay for example is very useful and easy to do but think there is a lack of new biofilm models that can be used in research.	I think that most biofilm research, in a traditional academic approach where a biofilm assay forms part of a paper, means that assay development is not a priority. I would like to see more funding opportunities to focus on developing novel biofilm assays and linking this to a special edition of publications of these methods. I think that this should involve industrial partners so these novel assays can use samples and materials that are relevant	It would be good to have smaller grants to do this, but that these monies can be used to build work towards bigger funding like Innovate UK. I also think that these funds should be prioritised for ECR staff like postdocs to get to allow them the experience of running projects and getting funding. they could then be co-I on larger grants with their PIs and collaborators	Lots of great research published showing solid methods for biofilm prevention, like regular 30% acetic acid down hospital sinks. but this realistically is terrible for the environment and clinically would pose hazards using in large amounts. more "green" focus on safer prevention methods would be great to see.
5	Can we get away from so-called "shock treatment" in biofilm control, and move towards less environmentally damaging control through low dose application of non-harmful chemicals that avoid biofilm establishment? Less chemical firepower means less pollution and less embedded carbon.	Reassessment of the use of "cheap" (and nasty) chemicals e.g. hypochlorite, as an "easy" way to control biofilms, and more systemic control measures through making conditions less amenable to biofilms. Reducing chemicals like chlorine or quats, reduces the risk of toxic chemicals entering the food chain.	Let's not think about cost per se. Let's consider UK and global priorities this millennium i.e. net zero industries, less environmental damage, healthier food chains. These are all at the top of UK gov priorities. What price for what cost? Projects need the right partnerships (academia and industry) and funding at the right time, plus impetus to get successful solutions into the market to overcome the lag during new technology adoption.	Our company has developed zero chemical input processes for disinfection using electrolytically produced dissolved ozone. A powerful antimicrobial, produced from water and electricity, which reverts to oxygen if unreacted with microorganisms. The possibilities for industrial applications are huge, but we are a SME which needs to focus and grow without over-stretching our resources. Early POC work under NBIC funding will, we hope, capture the imagination of industry to trail potential applications in the field.

Delegate	What do you see (from your perspective, company interests or academic field) as the problems or needs in achieving the prevention of biofilm formation? What are the problems with current approaches?	In your view what priority activities and actions could and should be carried out to address these needs/ problems either in industry, academia or jointly?	What do you think it would take in terms of cost, time and effort to close these gap(s)? For example, time, expertise, capabilities, effort (£, FTE)?	Do you have any other thoughts, contacts, opportunities, ideas or proposals relating to Biofilm formation prevention?
6	Fundamental understanding of the factors promoting or inhibiting biofilm formation and how this various with species	Quantitatively demonstrating the benefit of (a) solution(s); demonstrating the link(s) to antimicrobial resistance; proof of concept data that demonstrates this isn't an insoluble problem and hence a blackhole for funding. The work needs to be carried out jointly	The range of activities above comprise a combination of basic and applied research and improving communication between academia, government and industry. A staged approach is probably the way forward - modest funding could provide the benefit analysis and proof of concept data. Implementation will take more resource.	Much could be learned from biological systems and the defence mechanisms they employ/features they have evolved
7	Acknowledgement of the contribution biofilm development plays in various disease states. Understanding of biofilm science (i.e. antibiotics or short-lived antiseptics on their own, may have limited effect). Contribution biofilm (tolerance, some resistance mechanisms) makes to wider issue of (phenotypic) antibiotic/antimicrobial resistance. Duration of anti-biofilm activity to be clinically useful. Active vs. passive mechanisms of biofilm prevention, and associated biocompatibility and regulatory challenges (release = therapeutic).	Publications presenting consistent messaging in the clinical, scientific and health care business literature. Messaging in the mainstream media with appropriate, easy-to-understand messaging. Companies presenting a unified and consistent front.	Applied collaborations between industry, academic, health care, government bodies - over many years, but needs to start now.	
8	One of the problems with developing new surfaces which can prevent biofilm formation is that they can work under laboratory conditions. When they are used in natural environments such as the human host or the marine environment, they get heavily conditioned losing in part their ability to prevent biofilm formation.	There is a real need to develop more self-cleaning surfaces where their conditioning can be removed and their natural anti-biofilm properties restored. This will required a joint effort between chemists, surface scientists, microbiologist, physicist and modellers.	The focus would have to be on a particular sector to start with but could then be extrapolated to others. The basic research required could cost in the region of £10M and a minimum of 5 years of collaboration between academics and industry.	There is also need for surfaces which antimicrobial properties get activated in the presence of specific pathogens i.e.. targeted towards them.
9	1) Understanding of the role of biofilm in health/disease and symptom resolution (i.e. link between biofilm prevention/treatment and alleviation of symptoms), boiling down to an understanding of to what extent do we need to prevent biofilm formation in consumer healthcare areas like oral health, nasal health, gut health etc. 2) Applicability/commercial application of academic research. eg. Toxicology/regulatory/cost of goods issues of new actives/anti-biofilm solutions and their consumer acceptability 3) Natural solutions in line with consumer trends. 4) Lack of standard methods for testing or claims generation. 5) Consumer perception of biofilm/microbiome - do they care enough or will "microbiome friendly"-type claims resonate enough with consumer to warrant investment.	Continued research into role of biofilm in health/disease (eg. marker of change or driver of change?). Closer alignment between academia and industry to facilitate commercialisation of applicable innovations. Rapid screening methods or industry standard methods for biofilm testing.	Combination of further basic research, applied research, closer ties between industry & academia. Application of new methods from other disciplines/cross disciplinary approaches to help drive change in areas where true innovation can be constrained.	
10	Biofilm prevention (as well as dispersal) has mainly focussed on chemical methods, using antimicrobials to reduce the likelihood of bacteria colonising on a surface. Use of antimicrobials, in a prevention context could be contributing to antimicrobial resistance and recalcitrance. There is also little known about the effectiveness and mechanisms by which antimicrobials can maintain a non-fouled surface as dead bacteria can form a barrier for subsequent bacteria colonisation. It would be beneficial to understand the mechanisms by which the antimicrobials act as biofilm preventers (which stage of formation do they effect, is the effect the same in all bacteria species or families, are there mechanisms to overcome the antimicrobial). There is also a lack of adequate models *in vitro*. All work needs to start *in vitro* but often fails to mimic the complexity of the intended environment. The lack of adequate models also leads to a mix of models being used between industry and academia which often lead to different results.	Priority should be on producing replicable and representative models of *in vivo* environments *in vitro*. These models should be usable both in industry and academia. To start building these models, the simplest models should first be used, and then adding in the various complexities.	For models, the various models should be made to be both reproducible and economically viable (otherwise they will not be utilised). The time and expertise to make good comparisons between the various *in vitro* models and *in vivo* settings is lacking. There also needs to be good communication between industry and academia as to what equipment and reagents can be made available to them to produce these models.	

Delegate	What do you see (from your perspective, company interests or academic field) as the problems or needs in achieving the prevention of biofilm formation? What are the problems with current approaches?	In your view what priority activities and actions could and should be carried out to address these needs/ problems either in industry, academia or jointly?	What do you think it would take in terms of cost, time and effort to close these gap(s)? For example, time, expertise, capabilities, effort (£, FTE)?	Do you have any other thoughts, contacts, opportunities, ideas or proposals relating to Biofilm formation prevention?
11	The chilled food industry relies on rigorous hygiene measures to prevent biofilm formation - this consists of regular cleaning and sanitization plus additional less frequent "deep cleans" which may also be instigated when a non-compliant hygiene test is recorded. This approach works well but the additional cleaning required in difficult to access areas (e.g. within a conveyor roller) is cumbersome and costly to carry out.	Anti-microbial surfaces have been discussed for many years, but have yet to make any impact in food processing equipment. The industry is open to new technology, but needs to be convinced that it is effective and cost-effective. Are there any standardised methods for evaluating anti-microbial surfaces?		What we want to prevent is: • A biofilm harbouring pathogens or one which harbours levels of bacteria high enough that lead to release of free living organisms which could contaminate equipment or product. • Biofilms that are visible to the human and eye but also fragments of a biofilm which if not removed or inactivated would grow into a visible biofilm.
12	From the academic aspect, the mechanisms involved in the development and dispersion of biofilm haven't been fully elucidated. Cannot think some problems related to current approaches.	Meetings, seminars or workshop.	Cost, time, and efforts.	By interrupting the signalling pathway of the biofilm formation such as the inhibiting the concentration of second messengers.
13	From my perspective and research approach I would say we need to better understand bacterial behaviour and their relation to the surface (mostly organic surfaces are a big unknown). If we know how and when this initial step happens, we can use this knowledge to apply biofilm prevention methods more successful.	From my previous perspective it would be the research tasks to gather further knowledge, but this can be achieved best in collaboration with industry.	This would be a combination of basic research and applied projects with the industry. Which would take years and might be more an ongoing project depending on the latest research outcomes.	I think question 3 is very difficult to answer, as research will always continue to improve and gather new knowledge. Therefore, I think it is not possible to set a timeline and especially cost range for such a challenging approach to prevent biofilm formation in food industry.
14	Bacteria and biofilms are highly heterogenous and we often miss this by using the average. Looking at the single cell level at biofilm formation/prevention may yield a differential view.	More single cell and sub-population research.	Could be basic research into mechanisms of formation. This could take 5-10 years and much funding, but breakthroughs could occur much faster! Again, I think heterogeneity is key. Interdisciplinary approaches could also be key here, more funding for interdisciplinary research?	
15	Biofilm models that are representative of the specific disease/condition/environment in which they occur, rather than a 'one size fits all' approach. Current approaches ask too much of simple models, and it's important to understand and report the limitations of each. Reproducibility of biofilm models *in vitro*, specifically for industry claims - how do we ensure that the biofilms we are reporting in product marketing material are actually biofilms, and not just planktonic models tailored to give favourable results?	Standardised models that are shown to be reproducible (reproducibility data shown as supplementary). Minimum CFU specified for different types of model with different organisms that have been proven to be growing as a biofilm.	Academia: stricter rules on publishing models - what evidence do you have that your biofilm model is actually a biofilm model? Supplementary data to prove this should be published alongside results. Industry: standard models used for product claims to reduce bias.	
16	Tolerant microbes, recurrent contamination.	Discover and test new environment-friendly antimicrobials.	10 years, several million £.	ESCMID Biofilms Group, several academic collaborators across UK/Europe.
17	Our company interest is in a new technology for biofilm prevention and removal, using a process which uses only water and electricity to create a powerful disinfection fluid (dissolved ozone). The potential is to remove traditional bought-in bulk chemicals for biofilm control, which reduces carbon footprint, improves safety, and lowers environmental impact. Our issue as a SME is to cover demonstration projects sector by sector, as the application potential is huge. For example, proving the application in the dairy sector does not mean that the poultry sector will adopt it just like that - they need proof in their application.	There should be pull from the market on this subject as everyone wants to move away from chlorine disinfection (e.g. it has been banned in the Irish dairy industry), and other aggressive disinfectants. Can we get more industrial partners on board? Are those companies looking hard enough for solutions, or do we (NBIC) need to tell them? If we can increase the number of demonstration sites in key markets e.g. agritech, by establishing partner projects with key players/ end-users, which generate the data to support no-chemical solutions, then "blue barrel" chemicals may start to disappear. Speed to market is critical. End user participation in data generation from demonstrations is also critical. The timing has never been better with global emphasis on the Environment and achieving Net Zero.	Getting representative end-users on board is the key. Demonstrations don't have to be expensive, and don't have to be risky for end user production lines if they are planned carefully. Cost may be approximately £50k per trial in selected agritech markets e.g. vertical farming. 3-6 month projects with 1 FTE involved.	Preventing biofilms using careful interim doses of low mammalian (and high microbial) toxicity biocides like dissolved ozone could remove the need for expensive and environmentally malign chemical or heat treatment control measures e.g. for Legionella control in buildings where heat treatment is the go-to remedial measure - heating water is expensive.

Delegate	What do you see (from your perspective, company interests or academic field) as the problems or needs in achieving the prevention of biofilm formation? What are the problems with current approaches?	In your view what priority activities and actions could and should be carried out to address these needs/ problems either in industry, academia or jointly?	What do you think it would take in terms of cost, time and effort to close these gap(s)? For example, time, expertise, capabilities, effort (£, FTE)?	Do you have any other thoughts, contacts, opportunities, ideas or proposals relating to Biofilm formation prevention?
18	Biofilm initiation depends on the interaction between species such as competition for space and resources as well as mutual inhibition. The challenge is to integrate all relevant information to develop an informative and predictive model .	In academia, we can look at the spatial-temporal dynamics of bacterial strains with different growth and motility signatures, and identify how cell-cell interactions, such as toxin production, affect space- filling properties. In this project we focus attention on the very early stages of bio film formation where cell behaviour and motility can profoundly impact what happens in the later stages.	Academic staff, PhD and postdocs to come together to identify the correct model for the early stages of biofilm formation. Ideally, we would also carry out experiments to be able to test the accuracy of our model. These would all require funding time and effort from all parties involved.	
19	While not all bacterial species are motile, several are, and motility plays a significant role in how bacteria approach surfaces. The shapes of bacteria, their swimming velocities and the fluid shears they experience affect how they approach surfaces, and therefore, the likelihood of biofilm formation. Motility is of specific interest in healthcare technologies, because motility plays a significant role in bacterial infection due to both biofilm formation and upstream swimming. From a mathematical perspective, modelling plays a key role in understanding the motility effects. There are two types of numerical models that are used: individual-based models and continuum models. The former are highly expensive and, therefore, the latter is used preferentially. However, we have identified that current continuum models do not take into account the complexity, and non-uniqueness of boundary conditions, and can lead to highly unphysical results in a boundary layer. This results in a lack of useful dynamical information near boundaries for understanding biofilm formation. We believe that existing models need to be refined, and improved, to obtain useful and relevant information about wall interactions, and therefore the early stages of biofilm formation.	From a modelling perspective, further experimental data regarding the swimming approach of various species of microswimmers (bacteria, algae, etc.) would be highly beneficial. Currently, our numerical models are compared to other numerical models, and analytical expectations of how swimmers in a channel approach surface. Close up experiments (for swimmers of various shape ratios) with information regarding angles of incidence, angles at which swimmers might depart from surfaces (as all wall interactions don't necessarily lead to surface binding), and the rates at which cells adhere to surfaces as opposed to swimming away, would allow for the formulation of more accurate and representative models.	In order to cross these gaps, we firstly need experimental partners with the funding and set-up which could capture these near-wall dynamics. A general problem with measuring these types of data, is that three-dimensional trajectories are difficult to image, and it can be difficult to ascertain whether or not swimmers have only come close to surfaces or actually interacted with them. This will likely require the development of new rigs, which may require industry support. Furthermore, connecting with industrial partners involved in healthcare technology testing would be highly beneficial, as an improved understanding of what metrics are used in testing can allow us to advise further development accordingly, as well as information on the flow rates expected when their technologies are in use.	I'm not sure whether this is something that is already being looked into, but as there is a world-wide push against plastic straws this leaves the option of using paper straws or reusable straws. While the former can be used for the general populace, it is still highly wasteful as much will be incinerated or end up in landfills due to poor recycling habits. It is also not practical to use paper straws for people with special needs. The only truly sustainable option, instead, are reusable straws. However, these are prone to biofilm formation. I wonder if there is any experimental work being done academically or in industry, to make reusable straws safer.
20	Biofilms and Listeria are one of the biggest problems facing the Food Industry at present. Their identification and removal are both difficult, with biofilms sometimes surviving cleaning and disinfection, protected by dead cell layers and can continue to grow. Also Viable But Non-Culturable (VBNC) Biofilms can exist and are then undetected by swabbing post cleaning and disinfection. We need to be able to see them and detect them in order to eliminate them and prevent them forming	There needs to be work carried out on biofilms to look into levels of maturity and thickness of the film and the effects of cleaning and sanitising to assess the effect of protective layers of dead cells on viability. Research also needs to done to look at VBNC populations in Biofilms which can be undetectable.	Very hard to say on costs. University research projects may be one way forward. Industry and Academia partnerships could set up working groups on biofilm detection and prevention in the Food Industry and set up a biofilm bank, maybe with Chilled Food Association involvement	
21	Lack of good understanding of what promotes biofilm formation and the lack of connection with the role biofilms play in human diseases or secondary infections. The lack of good representative biofilm models and quantitative, high-throughput assays. AMR.	Topic-specific meetings between industry and academia are most useful. Collaborative research with industry.	Funding of both basic and applied research is essential. More funding for collaborative research with industry and healthcare.	Meetings such as these are extremely useful.

Appendix 2: Syndicate Outputs

Contents

(note: am – morning session/pm – afternoon session; groups have different team composition)

Group 1 am

Problems/needs

- Lack of association between bacteria and biofilms: Undergraduate level needs work. Clinicians and other professionals.
- Language in marketing.
- Awareness of biocidal regulations in academia/industry.
- Appropriate standards.
- Links with Antimicrobial resistance (AMR)/ language around AMR.
- Sceptical training as part of outreach.
- Science journalism.
- Healthcare staff education and policy makers.
- Take over Whitehall.
- Royal academy groups.
- Standardised reproducible model: Trying to get around regulatory guidelines. Education on biofilms; each better/different.
- Understanding at basic level. Knowing they're a problem but not really understand why.
- Combatting of the rise of AMR.
- Targeted methods: Not all behave in the same ways with the same treatments.
- Representative models: Changes in elements / surface composition.
- Funding for biofilms all equally split between areas. Regulatory – healthcare.

Solutions

- Better biofilm communications.
- Funding to internally network within institutions.
- Grass roots/general public education alongside industry/university level.
- Increase awareness.
- Better regulations.

What would it take?

- Public health to push awareness.
- Achieving specific targeted therapies.
- Lobbying funding bodies for specific biofilms research: Reference parts of economy specific for biofilms.
- Coherent multi-centre action plans: Industry research, publicly centralised sectors.

Group 2 am

Problems/needs

- Awareness is an unmet need at general level (clinicians etc).
- Regulatory issues: too difficult to transition from standard process to SMART technologies. Education needed in standards but also in general behaviours.
- Standards and lobbying required on both sides.
- Scientific modelling needed for processes and interfaces to enhance research efficacy: enamel vs glass for dental microscopy.
- Often university research labs have better techniques and tools for things in industry manufacturing: Difference between translations, skills and analytical care between the two.
- Standards to national testing centres.
- Model specific knowledge is limited. Many pathogens are secondary infections physically bonding on more innocuous organisms which adhere better to surfaces.
- More multi-species modelling in biofilms needed. Even lab conditions, multi-species biofilms never reach a mature stage before one subsumes another.

Solutions

- Lobbying needed from IKCs/industry/academia.
- Best practice guides from industry: messaging is key and a wider societal issue that takes in several other fields.
- Interdisciplinary nature of the field requires wider networking and understanding.
- How can academic institutions become more flexible in pollinating these research areas between institutions?
- Funding longevity across institutions.
- Standardisation to mitigate variables in practice across fields: Addressed in reporting and journal articles/giving more information on techniques and practice.
- Methods and practice standardised across reporting.
- Resources for experimental research: Do companies need more bespoke matching?
- How do we bridge *in vitro* to *in vivo?* Often most consistent technique taken over by the bigger picture.
- EPS stage of biofilm prevention.

Group 4 am

Problems/needs

- Marine: move away from biocides. Heavy metals are still predominantly used as there are no alternatives. Antimicrobial coating drives resistance.
- Devices and antibiofilm coatings: Lack of interdisciplinarity in developing solutions of antimicrobial coatings end up ineffective in contact with physiological fluids (conditioning biofilm).
- Need for adequate tools to assess/measure prevention: microscopy, imaging, detection of single cell, /non disruptive.
- Lack of dialogue between academia and between sectors e.g., NHS. What the needs are and what the solutions can offer.
- Lack of standards to make claims against.

Solutions

- Include biofilms into the curriculum.
- Educating NHS.
- Understanding of what prevention means for different sectors/industries.
- Learning from nature/mimicking.
- Selective prevention of pathogenic species.
- Databases of biofilm data.
- Data sharing.
- Data integration.
- Biobank.
- Created by community and publicly available.
- Toolkit document/minimum information guidelines and better communication of the existence of guidelines.
- Standards to align with.
- More sector focused workshops/networks to create dialogue and ideas forming/understanding needs in an interdisciplinary setting.

What would it take?

- Make industry pay to enable research: databases/ repositories. Contamination workshops.
- NBIC to help with facilitating/ guiding on more focused/ sectoral workshops and networks.

Group 7 am

- Academic motivations: Keep regulations in mind, follow through and contextualise in funding applications (e.g., with biocides).
- Speak to industry – they know the rules!
- ISO standards: Not many covering biofilms and the ones that do, don't get used.
- Fund predictive biofilm assays and models, need academic-industry method development.
- Need to translate from *in vitro* to *in vivo.*
- Develop the use of modelling as an exploratory tool; collaborate with other disciplines.
- Need to bridge clinical-research to industry gaps.
- Tackling the 'hard' industries not just where regulations are potentially easier to meet.
- Longer testing times: surfaces of medical devices in the body are being coated – how does this effect their preventative ability?
- How can we streamline tech transfer from academia to industry?
- Joint/bone models needed.
- Fail fast, fail hard.
- Funding for predictive assays.
- £20k projects: constrained, outcome pilot data to take forward.

Group 8 am

Problems/needs

- Better techniques/methods to define the biofilms in early stages to prevent.
- Mathematical models improved (numerical) to capture surface interactions (continuum modelling).
- More gentle methods to identify/investigate 'weak' early-stage biofilms (oral care).
- Develop more accurate *in vivo* representation of biofilm model in healthcare.
- *Listeria* biofilms are the biggest problem in food safety. They survive cleaning/disinfection.
- What surface treatments prevent adhesion? (Post electrical, pulsed fields).
- Intervention to detect surface adhesion.

Solutions

- Better methods: Translation from academia to industry (publication to real life).
- Better experimental data to inform mathematical model development (simulations in channels, catheters, water transport systems).
- Develop a platform to investigate a method (full disclosure) and disseminate this knowledge.
- Identify similarities and shared aspects of problems to realistically target these in industry/*in vivo*/ in nature.
- We don't know it's there.

What would it take?

- Need for basic research to prioritise methods (years).
- Need new experimental collaborations. New setups needed. Direct industry involvement (parameters, flow rates input).
- Platform development needs IT expertise – work with scientists for input (1 year develop to launch, continual development).
- NBIC to encourage and bring together a project. Industry/clinical expertise, academic to field sharing.
- NBIC event taps into collaboration (networking groups) and sharing cross industry. Developed matric of what we know and gaps. Still fragmented. Lack of food manufacturers. Get act together. A need for more biofilm biomarkers.
- Use Chilled Food Association.

Other thoughts?

- Useful workshop today.
- Small grants helpful.
- Metal straws research.
- Foster early-stage research interaction (academia SME).

Group 9 am

Problems/needs

- Lack of standardisation and benchmarks.
- Lack of consistency and transparency.
- Quantification.
- Lack of models.
- Lack of basic understanding of microbial adaption to different surfaces.
- Managing expectations between industry and academia e.g., timeframes and communication.
- Regulations: Poor fit of anti-biofilm agents to typical biocide regulation.
- Difference between prevent colonisation e.g., wounds and prevent conditioning e.g., marine.
- Prevention as maintaining microbiome.
- Maintaining performance.
- Gap *in vitro* vs *in vivo* (conditioning). Models lack information from usual environment.
- How do you know if you have a biofilm i.e., prevention worked.
- Health: bio compostable surfaces.
- Responsive surfaces to biofilm formation: way to interrupt biofilm build up.
- Coatings that do not get released into the environment.
- Need more knowledge on fundamental biology: Singe cell analysis in different environments and sectors.
- Address heterogeneity (strains/ media).
- Develop physical interventions to prevent biofilms: Environment dependent.
- Consider cost and timing.
- Funding: demonstrate economic benefits of prevention as main focus is on treatment.

Funding

- Increase UKRI allocation to NBIC to translational research: bigger and longer projects.
- Partner with charities for funding.
- Health economics: Commercialisation, justification – prevention.

Solutions

- Minimum standards/criteria: discussion with publishers.
- Increased communication between industry and academia.
- More public and dedicated engagement.
- Increase engagement with industry regarding awareness of biofilms.
- Bringing both industry and academia together to work towards the same goal.
- Minimum requirements for repository on biofilms.

What would it take?

- Networking event with all stakeholders: regulatory board, academia and industry for creation of minimum information.
- Setting up platform: short term and low cost.
- Long term finalisation: long term and high cost.
- Time frame will adapt to challenge.

Other thoughts?

- Bacterial phage technology.
- Awareness campaigns for both industry and public.

Group 11 am

Problems/needs

- Limited models for soft materials/organic matter: Food safety, *listeria.*
- Prevent lung function decline in cystic fibrosis patients: host pathogen interactions.
- Translation from *in vitro* model to *in vivo* models.
- Having a reproducible model system.
- Understanding molecular mechanisms behind biofilm formation: Targets can be designed.

Solutions

- A model system that works: throughput. Across all industries. Reproducible. Standardised.
- Devices which interact with soft organic material.
- Packaging use in food microbiology: Preservation methods that are beneficial to the consumer. Use of natural products.

What would it take?

- Models will always keep evolving. Long term goal to provide a standardised model system.
- Certification of biofilm models which can be used in industry.
- The model organisms used e.g., PA01: variations. Application to *in vivo.*
- Industries could have internal model systems in place: Share ideas/ concepts used across industries – openness within disciplines.

Group 2 pm

Problems/needs

- Adoption of biofilm expertise by the food industry e.g., why are bacteria not seen as distinct from biofilms?
- Models: Variability in physiochemical traits of organise surfaces like food.
- Food industries will adopt new technology, but they must be aware of it, and it must be ready to be implemented – more standards required.
- The limitations of models are often beyond the scope of any one PhD or Postdoc: Biofilm multispecies. Biofilm age. Scale of model. Physical forces (industrial grade flow rates).

Solutions

- Industry and academia need more cohesion to be aware of the research available to them: A database? Wiki? A heatmap?
- Industry to get involved with more fundamental, blue-sky research.
- Rethink industrial collaborations: longer partnerships. Multidisciplinary. Mutual understanding between needs of individual scientists (progression) and company goals.

What would it take?

- Multi-industry grants supported by several sectors (£££, years). De-specialised funding calls for the aim of preventing biofilms.
- Changing minds of industry (from competition to collaboration) could take less time if done through industry engagement (boards above the company level).
- Awareness days by organisations e.g., *listeria*, biofilms to stimulate projects (£, months).

Group 4 pm

Problems/needs

- Why current approaches don't work: Toxic nature of current anti-biofilm actives/ technologies (biopolymers, naturals, phage).
- Industry awareness of biofilm prevention is low.
- Definition of success? (90% killed/ statistically significant).
- Translation *in vitro* to *in vivo* (best versus most reproducible).
- Translation academia to industry (frequency of equipment maintenance). Academics have better equipment – difficult to reproduce the results in industry.
- Standardisation: Define success and how big the difference applies to real life. Consensus.
- Public engagement: AMR! Not all bacteria are bad.
- Regulations: they use of probiotics difficult to get regulatory approval.
- Public engagement: Unify terminology of biofilm/ microbiome. Buzzwords. Public knowledge.
- Relevant testing.
- City of microbes: Good/ bad bacteria. Buzzwords.
- Public understanding the real message beyond antimicrobial claims versus biofilms.

Solutions

- Characterise natural anti-biofilm compounds.
- Invite industry to events. Understand the problems they don't realise they have.
- Approval by NBIC: Standard stamp for biofilm removal. Speaking consumer language.
- Anti-biofilm claims: testing not done currently.
- We need to develop models for all 'problems' then consistency/ they differ.
- Review regulations in probiotics: not to stop product development (10 years is too long).
- Lobbying groups for biofilms (US and Europe).
- Unify and promote biofilm standardisation: Really specific about methods (enforced by journals).
- Good and bad bacteria around us: message for public engagement.

What would it take?

- Naturals: 5-10 years. £1M. Collaboration with industry.
- Models/ standards have to come from academia. PhD: Some time talking to regulators. 5-10 years.
- Building models: 4 years. 1 PhD. £80-100k.
- Educate regulators (months – years). Some attend conferences.
- Collaborate academia – industry to help this.
- NBIC to get people together for consensus: Propose initial terms and models – discussion. E.g., Persistent concerns statement (nature).
- Regulations: 5-10 years. NBIC fresh awareness campaign. Involve the government.
- NBIC to spearhead regulations as single university may not follow (more power).
- A PhD sponsored to create "NBIC standard". Published and peer reviewed (they don't know which model to use).

Other thoughts?

- Showcasing technology.
- Phage for prevent and manage biofilms.
- Follow-on funding from substantial pot.
- Very happy.

Group 6 pm

Problems/needs

- Targeted prevention e.g., targeting particular organisms: Communicating this to general public; not all bacteria are bad all of the time.
- Prevention is established behaviour in dentistry: Can we learn from this sector?
- Lack of regulatory framework means there's no motivation to develop better solutions: Resources needed. Resources need to reach the regulators.
- Prevention isn't exciting: People don't want to pay for a problem that doesn't exist yet. Collaborate with behavioural scientists. Dentists do this!

Solutions

- Educating medics at an undergrad about biofilms e.g., spending more money on equipment now could prevent infections later – influencing those spending this money.
- More collaboration with NHS.
- Co-develop research: user groups.
- Raising public awareness around AMR.
- Demonstrate economic benefit of non-drug preventative/ interventions. Get drug companies interested.
- Biofilm database: Shared resources.
- Promoting collaborative problem solving, avoiding duplication of efforts.
- The basic research is there; it's translation that's the issue: more funding for this.

What would it take?

- National research programme for antimicrobials "Ministry of antimicrobials": Not controlled/ run by companies.
- A biofilm Greta. PR.

Group 7 pm

Problems/needs

- Move away from bulk chemicals (e.g., farming industry) in disinfection (chlorides): Improving carbon footprints. Sustainability. Environment contamination.
- Communication/understanding of a problem and its implications to get funding and develop solutions. End user.
- Biofilm education.
- Build infrastructure preventing biofilms e.g., taps, washing machines.
- Understanding when and where prevention is needed (to what extent we can co-exist with biofilm – where is the balance).
- Define problems on specific manifestations of biofilms: If we know the specific problem a biofilm causes, we can devise a specific solution.

Solutions

- Engineering early-stage biofilms to address/prevent/target specific problems.
- Development of physical and chemical approaches to prevention.
- Updating/upgrading/developing standards to be anti-biofilm not only antimicrobial.
- Standards for substrates.
- Measurement standards: Is seeing believing?
- Biofilm compendium/data: Machine learning – biofilm properties influenced by different factors.

Group 8 pm

Problems/needs

- Looking at what problems are and defining how to 'prevent'.
- Prevent definitions differ between industry and academia: Killing or dispersing. (More clarity around this needed).
- Clash between disciplines and models: Education needed around differing science for academics, industry and clinicians.
- Single or multi-species.
- Translating findings from papers into the real world.

Solutions

- Placements in industry to address unmet needs and work experience placement to define 'what is the goal?'.
- Database of methodologies needed: biofilm community to get involved as a collective to do this.
- Different sectors coming together to determine the standards and research incentivising.
- More experimental data needed: Hard to run, need to talk to engineers.
- Have to be interdisciplinary (within industry) to see results and address challenges.
- No one wants to talk about biofilms after covid (fed up). Investment goes into this.

- More information needed from academics on specialisms: Searchable. So, more content on lab research. Keyword optimisation.
- Biofilm festival: Science exhibition.
- Influencing standards: How do you influence the government? Committees. Should come from people in industry. Regional S&R needed: variety of regulators. Tools required to do this.
- Industry conferences: Book talks for S&R at these.
- More webinars.
- Use of anti-biofilm term needed (can be applied to algae and bacteria).

Group 9 pm

Problems/needs

- Lack of education: Sector. General public – what are biofilms?
- Obtaining the evidence to make a commercial case for prevention technologies: cost/benefit.
- The gap between industry standards versus academic standards.
- Biofouling antimicrobial materials that subsequently allow biofilm formation.
- Appropriate models for prevention of infection/colonisation.
- Prevention of re-formation.

Solutions

- NBIC facilitating partner market / end-user research: Current practice e.g., NHS, water treatment, agriculture. Need driven research within requirements e.g., cost effective. Market analysis.
- Cross talk: academics, industry, clinicians, regulators.
- Regulatory pathways to make anti-biofilm claims.

Group 11 pm

Problems/needs

- Stopping bacteria being able to form a biofilm in the first place e.g., in implants, prevent ingress in the wound.

Solutions

- Simpler models (that reflect real life).
- Looking at realistic bacterial loads (often we look at too many Colony-forming unit (CFU)'s).
- Looking at real samples e.g., debridement.
- Moving away from our 'safe' model strains.
- Benchmarking / assays / reproducibility.
- Multi-centre validation of assays.

What would it take?

- Need funders to fund more high-risk activities to look at track record not preliminary data: Allows investigators to use different organisms / real world samples instead of models which are 'safe'.
- Need input from stakeholders e.g., clinical staff, regulators (FDA etc.)

Appendix 3: Companies and Organisations Registered for the Workshop

Bactiview Ltd
Brunel University London
Chilled Food Association
ConvaTec
Fixed Phage Limited
Fourth State Medicine
Lancaster University
Liverpool John Moores University
Liverpool School of Tropical Medicine
National Biofilms Innovation Centre (NBIC)
Nottingham Trent University
Oxi-Tech Solutions
Perfectus Biomed
Swansea University
The University of Manchester
University College London (UCL)
University of Birmingham
University of Edinburgh
University of Essex
University of Glasgow
University of Hull
University of Liverpool
University of Nottingham
University of Oxford
University of Southampton
University of Surrey
University of West England (UWE) Bristol

Thank you

For further information please contact nbic@biofilms.ac.uk