• SEFARI (Scottish Environment, Food and Agriculture Research Institutes) is a collective of six Research Institutes, each with global reach, expertise and reputation

• SEFARI along with Higher Education and other institutional partners delivers the Scottish Government funded Strategic Research Portfolio (the Portfolio) 2016-2021 on environment, food, agriculture, land and communities.

• Delivering new knowledge and innovation to the agricultural sector is amongst the key priorities for SEFARI.

• There is absolute recognition that innovation resides not just with technologies but in practice change and developing and supporting best practice on farm.

• SEFARI Gateway, the Knowledge Exchange (KE) and Impact Centre for SEFARI, works across SEFARI and the Portfolio to support and enhance the flow of research, expertise and knowledge to and from SEFARI and the Portfolio.

• Close liaison, engagement and partnership across sector-representative bodies, KE networks and direct with farmers and land managers is critical to ensure timely delivery and uptake of innovation and identification of knowledge gaps and emerging and future needs.

• Primary production is set within a cross-cutting drive for innovation across the economy, underpins a food supply chain through to consumer and is inextricably and critically intertwined with food and drink industry, environmental, climate change, land use and reform, societal health-wellbeing and resilience agendas.

• A strategic research approach with core multi- and inter-disciplinarity is critical to address such multiple needs and thereby support the long term resilience of the agriculture sector.

• Examples of agriculture research delivering innovation, technology and new practice are provided for: crop and grassland production and disease control; livestock production, health, welfare and disease control; agricultural systems and land management; climate, environmental and biodiversity resilience; improved food and drink production; healthier diets; the role of agriculture within the rural industries.

• UK Agri-Tech Centre participation and interaction is described.

• Extensive SEFARI core facilities, collections and data sets underpin delivery of agricultural technology and innovations and provide important resources for engagement and partnership with the sector and collaborators out-with SEFARI.

• SEFARI agricultural research benefits from extensive national and international collaboration.
Agriculture Technology and Innovation

1.0. Introduction

1.1 SEFARI (Scottish Environment, Food and Agriculture Research Institutes) is a collective of six Research Institutes, each with global reach, expertise and reputation:
- Biomathematics and Statistics Scotland;
- The James Hutton Institute;
- Moredun Research Institute;
- The Rowett Institute;
- Royal Botanic Garden Edinburgh;
- Scotland’s Rural College

1.2 SEFARI along with Higher Education and other institutional partners delivers the Scottish Government funded Strategic Research Portfolio 2016-2021 (the Portfolio) on environment, food, agriculture, land and communities. The Portfolio encompasses the Strategic Research Programme (SRP), innovation projects, policy-facing Centres of Expertise (for climate change, water, animal disease outbreaks, plant health) and underpinning capacity funding for national capabilities.

1.3. Branded in 2017 but the realisation of a sustained history of collaboration through Scottish Government funding and shared complementary objectives, SEFARI delivers its research under a concept of “Leading Ideas for Better Lives”, emphasising that research must be translated to and informed by those who need it. To capture the range of research delivered from the Portfolio and from research-funding leveraged or underpinned by it (industry and academic funding leveraged from the SRP being £13.3 and £16.5 Million respectively for 2017-18), a series of leading ideas categories are used to group areas of research output, benefits and impacts: Land and Communities; Climate and the Environment; Agriculture; Plant and Animal Health; Food and Drink Innovation; Healthier Foods; Rural Economy; Science Education.

1.4. SEFARI Gateway, the Knowledge Exchange (KE) and Impact Centre for SEFARI, works across SEFARI and the wider Portfolio to enhance and support the flow of research, expertise and knowledge to and from policy, sector representatives and public audiences within environment, agriculture, food, land-use and rural communities. Gateway deploys a series of funded programmes (SEFARI-stakeholder Fellowships; Think Tanks and Responsive [mode] Opportunity funding) to forge partnerships and projects between researchers and stakeholders. These programmes are closely and iteratively designed with the stakeholder to deliver to a priority need.

2.0. Strategic Research and the knowledge exchange environment

2.1 Delivering new technology and innovation to the agricultural sector is amongst the key priorities for SEFARI. There is absolute recognition that innovation resides not just with technology but also in practice change and developing and supporting best practice on farm: for which close liaison, engagement and partnership across sector representative bodies and direct with farmers and land managers is critical.

2.2. SEFARI agriculture research, as exemplified in the SRP, also recognises that primary production is set within a cross-cutting drive for innovation across the economy, underpins a food supply chain through to consumer and is inextricably and critically intertwined with food and drink industry, environmental, climate change, land use and reform, societal health- wellbeing and wider public good agendas.
2.3. This multiple need is reflected by the future strategy for Scottish agriculture: final report (2018)\textsuperscript{12} which noted the need to assist the Scottish agricultural industry through a period of major transformational change, helping to improve the productive efficiency of Scottish agriculture, enhancing Scotland's Natural Capital and with improved integration of the whole supply chain for the benefit of all.

2.4. A strategic research approach with core multi- and inter-disciplinarity is critical to address such multiple needs and thereby support the long term resilience of the agriculture sector.

2.5. The economic impact assessment\textsuperscript{13} for the SRP 2011-16, assessing GVA for 2016, estimated £35.9 million genetic livestock and crop improvement benefits, £16.6 million from plant health research, and new crop varieties research (potato, soft fruits, brassicas) worth £12.9 million per year and emphasised that benefits and impacts of strategic research and innovations accrue over time.

2.6. There is, therefore, a constant requirement for knowledge-sharing, linking of networks and building of partnerships with agriculture to ensure timely delivery and uptake of innovation and identification emerging, future needs and knowledge gaps.

2.7. Engagements are undertaken directly by SEFARI investigators (see 3.0.), by SEFARI Institutional KE and consultancies and via Gateway’s provision of project funding to Portfolio investigators and its creation of partnerships with the sector. Gateway is one of the bridging sector organisations (sector representative bodies, levy bodes, Agencies, Innovation Centres, enterprise bodies, regional economic development initiatives such as City Deals for which SEFARI institutions are engaged [Tay Cities Deal, Aberdeen City Region Deal]) and that sit between research and agriculture (farms) and wider sectors and enterprises that influence and are influenced by that research (e.g. food and drink business, environment, tourism-recreation). SEFARI Gateway sees the networks that each ‘bridging sector’ organisation has access to as an opportunity for partnership and to connect networks and thereby accelerate access to Portfolio expertise and innovation across the sector.

3.0. Examples of agriculture technology and innovation within the context of strategic research

3.1. SEFARI is the main research provider for the SRP, which forms a major component of agricultural research funding within the UK. While SEFARI agricultural technology and innovation includes a range of funding streams, the SRP is an appropriate focus with which to illustrate agricultural innovation, technology and its benefits. Examples presented here include both direct technology and innovation, approaches to deliver improved and best practice and also to provide understanding for the economic, environmental and societal context in which technology and innovations may be applied.

3.2. The SRP is comprised of three themes: Natural Assets, Productive and Sustainable Land Management and Rural Economies; and Food, Health and Wellbeing. These themes have strong interdependencies.

3.3. Collectively SRP agriculture research aims to strengthen the performance and sustainability of agricultural systems in Scotland. As part of that, the research seeks to understand how land can be managed for greater societal benefit and explore how rural industries, including agriculture, can best adapt to key future challenges. This is linked to SRP work on how performance of the food and drink sector may be enhanced with new agricultural produce improvements, assesses the role of short food supply networks and also examines the role of food in public health and social equalities as part of the broader challenge of ensuring food security in Scotland. SRP work on Scotland’s land-based natural assets of soil, fresh water and biodiversity, and the ecosystem services (e.g. cultural services
such as recreation, amenity and wellbeing) which they support are also key effectors that influence the agriculture sector.

### 3.4. Crop and grassland production and disease control:
SRP crop and grassland research seeks the provision of crop cultivars and varieties with improved quality, yield and resource efficiency traits, which are resilient to key biotic and abiotic stresses. The research focuses on barley, potato and soft fruits. Integrated Pest Management (IPM) systems are being developed to translate an interdisciplinary understanding of plant-pest interactions, host resistance, epidemiology and new disease threats, supported by the use of monitoring, modelling and diagnostic technologies to improve on-farm crop performance. Outputs from these contribute to more efficient production systems, healthier soils and more sustainable crop rotations. The SRP also conducts work on opportunities for novel and minor crops that could underpin the circular or bio-conomy by developing approaches to support their integration into existing rotations, practices, processes and food supply chains.

- **Developing improved crops**: New crop genomic technologies for sustainable production of barley, potato and soft fruit are being deployed. Examples include commercial breeding programmes aimed to reduce the devastating impact of raspberry root rot in Scotland and to improve the quality of winter barley to satisfy the un-met demand of the distilling industry.
- **Uptake of Integrated Pest Management**: An online IPM planning tool developed in the SRP is now a requirement of the Scottish Quality Crops farm assurance scheme which assures >90% of Scottish combinable crops. The Hutton criteria, is also a new disease risk tool which transforms the performance of potato late blight alert systems and an on-line planning tool to implement the UK IPM National Action Plan and the Sustainable Use Directive.
- **New discovery of Ramularia collo-cygni secondary metabolites**: Ramularia Leaf spot causes yield losses in barley by producing toxins which damage the leaves. Recent research is assisting in the design of new anti-fungal agents for its control.
- **Increasing protein production and utilisation in Scotland’s economy**: Research has demonstrated that novel home-grown protein crops (e.g. pea, fava bean, lupins, quinoa) and intercropping methods improve nitrogen use efficiency and are less environmentally damaging. These crops are practical and profitable at the farm gate and downstream through the development of new products.

### 3.5 Livestock production, health, welfare and disease control:
SRP livestock research focuses on:

- **application of genetics and genomics to increase productivity in the beef and sheep sectors**;
- **exploration of endemic livestock diseases**;
- **design and development of new diagnostic disease/health tests which are specific, sensitive, affordable and speedy**;
- **design and development of new vaccines which are safe, effective, practical and affordable**;
- **improving measurements of disease and health status**;
- **methods for disease control within and between farms**;
- **methods of assessing animal welfare**, and improvement of practical, on-farm methods of livestock husbandry;
- **exploring the relationships between diet, grazing, genetics and greenhouse gas emissions**, to meet requirements for sustainable livestock production.

- **Genomics, genetics and improved breeding strategies in livestock**: Genomic selection is having a huge impact on the efficiency of livestock industries by insemination of cattle with semen from sires with desired production traits. Computed tomography (CT) has been developed to determine estimated breeding values (EBVs). These EBVs have been used in breeding programmes to accelerate genetic improvements in meat quality.
- **A novel test to diagnose sheep scab**: Sheep scab is currently controlled by chemicals that can leave residues in the environment and to which the scab mite is becoming resistant. The new test diagnoses mite infestation before clinical signs appear, allowing better targeted use
of the chemicals thus reducing their negative impacts. The test has been trialled successfully and represents a major step-change in disease management.

- **A novel vaccine for the prevention of a parasite infection in sheep:** Research has led to the development of a vaccine to control an intestinal parasitic infection. This is the first vaccine of its kind in any species. The vaccine has been successfully deployed and leads the way in innovation for controlling an economically-devastating disease in farmed sheep.

- **Green House Gas (GHG) mitigation:** GHG emissions remain a major challenge for Scotland’s (and the global) ruminant industry and ensures a research focus on mitigation options across SEFARI members. Work is using state-of-the-art respiration chambers and feeding facilities, as well as cutting-edge techniques to understand the microbial processes and organisms involved. Other studies are developing markers for breeding programmes to reduce emissions intensity (GHG per unit milk or meat produced) both by reducing emissions and improving technical efficiency factors such as feed conversion efficiency.

- **Pig supply chain interest in 3D camera technology to predict tail biting:** SRP research led to two successful Innovate UK grants. Early results from the first of these (3D Tails), showed that machine vision algorithms could detect low tail posture from overhead 3D camera images, which is an early warning sign of a tail biting outbreak. The continuation of this research is to develop a farm-ready prototype (TailTech project).

3.6. **Agricultural systems and land management:** SRP cross cutting livestock and crop research seeks to enable and enhance sustainable agricultural land use across Scotland.

- **Uptake of Precision Agricultural Technologies (PATs) in the Arable Sector:** PATs provide a potential route to meet the sustainable intensification of arable farming. SEFARI assessed the likelihood of uptake of 7 potential PATs with 244 Scottish farmers. Observance of institutional and trust barriers towards the technologies led to recommendation for the use of demonstration farming in support of PATs. Further external funding was secured (NERC SARIC) to co-create solutions with farmers and to understand the limits to uptake.

- **Perception of best practice in animal welfare:** The definition of ‘best’ practice is not constant across stakeholder groups, due to differing objectives and priorities. This lack of agreement leads to inconsistent messages and promotors of better practices can overlook key barriers to adoption. As a result confusions arise and trust may be lost with practitioners, detrimentally affecting the uptake of better practices. SRP research has engaged separate communities along the supply chain on the concept of ‘positive animal welfare’. Work has been conducted with farmers through the development of an app and website to assess cow welfare management, collect data and provide assessment of current welfare states. Progress towards uncovering different societal understanding of best practice in animal welfare is developing from interviews with farmers, consumers and retailers.

- **International partnerships on nitrogen in agriculture.** As an example of the benefit of SRP underpinning for global partnerships to support innovation; SEFARI researchers contribute to ‘Legumes Translated’, a Horizon 2020 Thematic Network supporting innovation in grain legume-supported cropping systems and value-chains by linking sources and users of quality-assured knowledge. SEFARI researchers are also part of the UKRI Global Challenges Research Funds’s new ‘South Asian Nitrogen Hub’. This ambitious new Hub brings together partners from the UK and South Asia; in collective of 32 research organisations. The Hub seeks to improve nitrogen management in agriculture, saving money on fertilizers and making better use of manure, urine and natural nitrogen fixation processes.

3.7. **Rural industries:** SRP research must also place agriculture in the wider context of the rural economy. It seeks to develop a range of indicators which can be used to assess resilience at the farm
and rural industry level, improving the efficiency of production and consumption via increased circulatory within the Scottish economy. This thereby provides an important insight into the environment in which agriculture business technology and practice will be applied.

- **New databases**: New databases have been generated to provide insights into the agricultural and wider rural business. The 2018 Farmers Intention Survey was co-designed with Scottish Government analysts and policy to provide information that can support post-Brexit policy development and the 2018/19 Rural Business Survey was co-designed with Scottish Government officials and Scottish Enterprise to help improve policy knowledge on issues such as: business performance and outlook; employment and family labour; Brexit; export and imports activity; links to the land-based sector, business constraints and training/advice needs.

- **Modelling trade scenarios impacts on Scottish agriculture**: The ScotFarm model has been adapted to assess the impacts of change (e.g. to support policy, input or output prices, or environmental factors) on Scottish farms. The model was used to predict the impacts on business performance and management decisions that may arise from post Brexit policy decisions.

- **Modelling and mapping spring barley yields in Scotland**: Spring barley yield maps for Scotland for the period (1995-2015) have been completed. The map is generated for unique combinations of climate and soils across all areas in which spring barley has been grown historically and for adjacent areas to assess the potential for new areas to be exploited under climate change. The main use of the barley yield mapping is with the Scotch Whisky Research Institute to look at the potential to increase supply of barley within Scotland and the risks to supply from climate change.

3.8. **Improved food and drink production**: research on food and drink production links directly with agricultural innovation. Food and drink research includes the identification of the nutritious and health beneficial components in major, underused or emerging seasonal Scottish produce; the characterisation and development of strategies for improving the nutritive value and health benefits of processed foods; the development of technologies and strategies for the detection and prevention of food related toxins; the development of tools, techniques and best practice to reduce or create value from otherwise waste or under used produce from the food chain.

- **SEFARI discovery that physical reformulation of ruminant diets for larger particle size reduced the incidence of subacute ruminal acidosis (SARA), a condition where prolonged periods of low pH in the rumen lead to inflammation and even necrosis, led to feed reformulation being adopted by a Scottish manufacturer, opening up markets in 20 different countries.**

- **Wild, heritage and F1 crop varieties are being assessed for nutritional composition and resilience traits, and may retain higher levels of non-nutrient components with health benefits than commercial crops. These varieties offer potential opportunities for future agriculture use and food product reformulation.**

- **SEFARI scientists have adopted an integrated approach to waste along the agri-food supply chain, exploring the views of farmers, the causes of waste, mitigation strategies, barriers to adoption, and supporting campaigns for waste reduction and/or opportunities to farmers and others along the food-supply chain for creating added value.**

- **SEFARI scientists have isolated high value chemicals from crop ‘waste’ – in this case, potato haulms, which are normally ploughed back in. Economically relevant quantities of a compound which is used in beauty products have been isolated and collaboration with a drug discovery services company initiated. Such innovations create new market opportunities for farms and for post-farm gate industry.**
3.9. Healthy diets and dietary choice: The linkages between diet, behaviour, lifestyle, and the social and cultural environment in order to improve health, while a longer term influencer, are part of a nutritionally sensitive approach to agriculture that aims to enhance primary production

- Expertise in gut microbiology has seen SEFARI scientists at the forefront of developments linking dietary fibre health benefits to human gut bacteria. Opportunities have been identified for food reformulation that exploits this relationship, for example, by revalorisation of fibre in current food waste.

3.10. Natural Assets: SRP natural assets research offers a range of innovations, technologies and practice change to improve climate and economic resilience while mitigating environmental impacts within the sector. The research includes indicators and measures for soil nutrient cycling and testing their performance in grassland and crop systems; tools to measure and manage soil structure (to help combat compaction/erosion); improved understanding of the impacts of management practices and changes in management (such as long-term agricultural intensification) on soil carbon sequestration; soil mapping (e.g. for soil erosion) in Scotland. Ultimately the research seeks to deliver towards natural assets management to achieve sustainable land use and contribute to sustainable growth of the Scottish economy and health and wellbeing.

- Crop system biodiversity: research is looking in detail at the mechanisms underlying crop mixtures, including crop species and cultivar mixtures to understand when and how enhancing crop system biodiversity increases productivity and resilience, and how this information can then feed into the development of more sustainable crop production systems.
- Rare plants may be helped by crops: A study investigating the interactions between a rare vascular plant - *Valerianella rimosa* - (broad fruited corn salad) and a barley crop has shown that the conditions found within the crop might help promote the establishment of the rare plant at the start of the growing season. When combined with the negative impact of the crop on common weeds, these findings indicate that crops may play a role in the conservation of some rare plants by creating space in the farmland weed community.
- Potential for crop improvement in marginal soils: New research has shown that extant barley landraces selected over many generations on marginal soils have adapted to tolerate soils with limited Manganese (Mn) availability. By contrast, modern elite varieties on similar soils fail to complete their lifecycle, due to their poor Mn efficiency. Landraces derived from regions with reduced soil fertility constitute a valuable resource of adaptive genetic variation and provide opportunity to identify key traits to underpin crop improvement in marginal soils.
- Soils Risk Maps: A series of risk maps for much of the cultivated land in Scotland have been developed to help farmers identify areas vulnerable to erosion, compaction, leaching and runoff.

4.0. SEFARI Resources underpinning capacity and capability for innovation and technology

4.1. Extensive SEFARI core facilities, collections and data sets underpin SRP and wider Portfolio delivery of agricultural technology and innovations and provide important resources for partnership with collaborators out-with SEFARI.

4.2. Core facilities include research farms, field-trial plots, extensive glass house facilities; GHG emission-livestock measurement (Greencow) facility; human nutrition research facility.

4.3. SEFARI scientists are collaborating with agri-tech business to develop arguably the world’s most technically advanced indoor farm. A vertical farming demonstration building brings potential for new
crops and new opportunities for rural and urban communities, quality beyond that achievable through conventional agriculture, and seedling generation to support traditional farming.

4.4. Collections include: National Seed Store, National Soils Archive, Insectaries, Germplasm, Pathogen & Bacterial Culture collections, Animal Genomes.

4.5. Livestock resources include the world’s longest-running dairy cattle selection experiment on the Langhill Estate; selection lines of hill sheep (data, genotypes, samples); specific pathogen free livestock.

4.6. Crop resources include: mapping collection of ear types in winter wheat; long term evaluation of diversity in cereals (especially barley); 200+ collection of barley landraces; collection of 240 wild barleys; Commonwealth Potato Collection.

4.7. Data and maps include: soil data and mapping, land capability data and maps; bioinformatics tools; extensive data on livestock production, food intake, health, reproduction & estimated methane emissions; access to national dairy, beef, sheep data (with consent) via EGENES; crop health data bases; extensive production & environmental data on farming systems; pathogen proteomic and genomic databases; human gut bacteria collection.

4.8. SEFARI partners have differing partnerships or levels of interaction with the UK Agri-Tech Centres, in part reflecting the focus of the individual institutions. SRUC were founding partners for the Agri-Tech Centres and have board representation on Agrimetrics, AGRI-Epi and CIEL. There has been significant capital investment leveraged from these relationships. James Hutton Institute are involved with Agrimetrics, CHAP, AGRI-Epi. BioSS are a member of CIEL. Moredun Institute has been involved with Agri-Epi and would welcome further interaction, seeing considerable opportunity in collaboration on smart farming.

4.9. SEFARI agricultural research also benefits from an international network of collaboration. Across its full range of research, the SEFARI collective has over 1100 individual collaborations, involving 750 separate organisations and institutions in over 60 countries. This provides access to global expertise across environment, agriculture, food, human-health, land and communities; delivers a flow of expertise and ideas to and from Scotland, enhancing SEFARI research capability; promotes the reputation for Scotland’s publically funded-translational research; provides opportunities to support agri-food export markets and new products grown or produced in Scotland; provides knowledge for tackling biodiversity and climate challenges; enhances preparedness against pest and diseases in a changing climate; and enhances understanding of rural economy and communities.

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