BEIS Biomass Feedstock Innovation Programme

Phase 1 – Final Report- Redacted

SOILLESS CULTIVATION FOR RAPID BIOMASS PRODUCTIONS

CES- 303-1- A
University of Surrey
Centre for Environment and Sustainability

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EXECUTIVE SUMMARY

This report summarises the Phase 1 BEIS Feedstock Innovation Programme project entitled ‘Soilless Cultivation for Rapid Biomass Production’ led by the University of Surrey.

The innovation planned under Phase 1 is looking at soilless cultivation of short rotation crop (SRC) willow with further application to other crops. Soilless cultivation is a well-established, proven technology to grow crops faster and independent of location, however, its use for larger crops remains a marginal practice. Preliminary trials under Dr Zoe Harris have successfully demonstrated the propagation of SRC willow in a basic soil-free system. Additional benefits, such as faster growth and preferential biomass allocation were observed, setting the premise of further testing of soilless cultivation of SRC willow. Phase 1 planning and detailed discussions with design, engineering and controlled environment agriculture expertise have cemented the technical feasibility and delivery of optimised systems for large crops.

Preliminary trials data processing as well as stakeholder interactions during Phase 1 have established that SRC willow in a soilless system has the potential to fill in an inevitable bottleneck in the upscaling of perennial biomass production. With the faster growth cycle, estimated at 30 weeks in our system, and the higher planting density than conventionally grown willow (100,000 trees/hectare compared to 40,000 in multiplication beds), one hectare of soil-free grown willow can supply 30% of the annual required planting material to achieve the Committee on Climate Change[1] recommendations of increasing perennials by 2050, to meet net zero targets.

An important finding of Phase 1 has been the interest in and the potential of the innovation to be applied for additional biomass gains such as rapid genotype development and development of forestry planting material.

Phase 2 will focus on establishing the feasibility of growing willow to desired specifications in a soil-free environment, the viability of cuttings in the field as well as optimising production. Trials are planned in a variety of environments for growth: glasshouse, controlled environment room, polytunnel and outdoors, while the viability of cuttings will be tested in a variety of sites across the UK. Additional focus, supported by expert collaboration established in Phase 1, will be given to other crops and applications in Phase 2.

Environmental risks and benefits have been assessed during Phase 1, based on preliminary trials findings and un-optimised systems. A scoping life cycle assessment has established that, with further refinement, the innovation has the potential for similar or superior environmental profile when compared to conventionally grown willow. The greenhouse gas profile has identified energy as a hotspot, with potential for optimisation in the type of energy used (renewable vs conventional) as well as

increased energy efficiencies in the operation of the systems. Significant land use benefits have been identified for an operationally optimised system.

The Phase 2 project plan has been developed to ensure system optimisation is addressed and viability of cuttings is demonstrated under a comprehensive environmental, social and economic profile of the innovation. Phase 1 team will continue work during Phase 2 with additional expert input in controlled environment agriculture, additional crops and applications and business development.

From a commercialisation point of view, the immediate application of the innovation will be in the production and sales of SRC willow planting material from a small-scale operation. A financial analysis of the operation has proven this venture profitable in the short term and in the long term, assuming expansion to a larger area of one hectare. However, we see the innovation acting as a platform technology, developed with willow multiplication in mind and applicable to other crops. As such, franchising opportunities, the commercialisation of the system and the application to research and development of other crops is considered in the commercialisation of the application beyond Phase 2.

1. OVERVIEW OF THE INNOVATION

1.1 Technical description

Our innovation is a modular, closed-loop system for rapid multiplication of high-yielding biomass feedstocks.

Soilless cultivation has the roots of plants supplied with a mix of water and nutrients. Our modular system is made up of a number of growing containers connected through a central irrigation line to a single reservoir. The total current footprint of our system is 5m^2. This give us a planting density of 100,000 cuttings per ha, which is significantly higher than traditional multiplication beds of 40,000 cuttings per ha, or field grown crops of 15,000 cuttings per ha. Our innovation requires an electricity supply (mains or PV+batteries) to power a pump which delivers water and nutrients to the cultivation containers. The crops are on an irrigation schedule where roots are fed at intervals throughout the day, again this will be optimised in Phase 2. Passive drainage returns any unused water/nutrients to the reservoir. An automatic doser ensures the pH is kept at the right level and the optimal nutrient mix is in the system.

We consider this technology to be at TRL5, whereby successful growth of SRC willow has already been proven, however work is required to optimise the design and operating parameters. By the end of Phase 2 we expect our innovation to be at TRL8.

1.1.1 Soilless cultivation merits

Soilless cultivation is a well-established technology which has historically been applied to crops such as lettuce, or tomatoes which are grown indoors in glasshouses or in Controlled Environment Agriculture (CEA). A number of significant benefits of this technology have been realised and documented in the scientific literature, and underpin the success of a number of commercial operations:

- Faster growth and higher yields compared to field grown, with one study showing a range of between 19%-65% increase in yield for fruit and vegetable crops[2].
- Speed of cultivation allowing farmers to produce multiple crops per year due to reduced harvesting cycle (e.g. Lettuce takes 20 days to reach harvestable size in CEA versus 80 days in the field).
- Reduced water and nutrient consumption - at least 70% less water than field-based agriculture (majority of estimates being >90% less) [3]. The closed-loop system recirculating water and nutrients completely contains any potential environmental pollutants and increases efficiency.
- Land use efficiencies resulting from the tighter grouping of plants to ensure optimum water/ nutrient delivery, resulting in higher yields in smaller land

footprint. For smaller crops, additional land use efficiencies are realised by vertically stacking crops[4]. However, at this stage of the innovation and considering crop size, land use efficiency will be more modest for willow than for smaller crops.

1.1.2 Applications to Willow

Preliminary trials have demonstrated that the use of soilless cultivation can be applied to willow. In 2019, we conducted pilot studies to develop a system to grow SRC willow. This system operated in a glasshouse without supplementary lighting. It was low cost, it allowed testing of a variety of SRC willow cultivars and operated at a planting density of 100,000 cuttings per ha. Preliminary findings showed that the resulting willow grew 25% faster than willow cultivated in soil. Total biomass allocation was changed to favour aboveground biomass with over double the amount of biomass in our system, and three times fewer roots. This preferential allocation into aboveground biomass is promising for feedstock production.

During Phase 1, using preliminary trials data, we estimate that it will take approximately 30 weeks to get to harvestable size (specification required for contract planters). This estimation does not account for potential application of supplementary lighting or any system optimisation. The 30-week harvest cycle allows for an average of 1.7 crops per year. Within Phase 2 we will run a number of trials and fully quantify the inputs and outputs of our system.

Phase 1 saw detailed discussions with an engineering, design and manufacturing sub-contractor that has confirmed the technical feasibility of multiple systems for Phase 2 trials and supported preliminary refinement of the systems for the same phase. Alongside this discussion, we have developed a partnership with a leading UK CEA technical expert who will use their expertise to further refine the system during Phase 2.

Note, our proposal is to grow willow for multiplication of cuttings which will be subsequently planted out into the field. The proposition is not to grow willow for bioenergy which is directly combusted for energy generation. A phase of soilless cultivation followed up by land-based production is still likely to significantly reduce pressure on water resources and land, which will be quantified in Phase 2.

1.1.3 Remaining Technical Uncertainties

Despite impressive growth of SRC willow in the preliminary trials, the innovation has the potential to see further improvements in cultivation speed and yield through optimisation to the system design, the cultivation processes (fertiliser amount, fertiliser composition, irrigation scheduling etc.) and the cultivation environment. The primary aim of Phase 2 is to develop our innovation for optimal performance with high operating efficiency and minimal environmental impacts and financial costs.

Technical scalability also remains an uncertainty at this point and will be investigated in Phase 2. Examples of questions to be answered include (1) how many growing containers can operate within one system to maintain yields and reduce costs? (2) how tightly spaced can we have the systems to maximise usage of our footprint whilst not impacting plant growth or comfort and safety of staff?

Resolving these uncertainties in Phase 2 will lead to optimised system design for commercialisation, but none of the questions pose challenge to the overall technical viability of the innovation.

1.2 Biomass supply benefits

During Phase1, the team has identified and quantified the supply challenges and the benefits of the innovation for biomass supply. It has also assessed potential integrations, identified gaps to be addressed and refined in Phase 2 and has assessed the role of the innovation and its potential within the supply chain.

Overall, our innovation can contribute to sustainable biomass supply in a number of ways, which will evolve over time throughout Phase 2 and beyond: (i)The primary focus of the innovation is to demonstrate and optimise the innovation for SRC willow for the purpose of rapid multiplication for deployment into the field. (ii) During Phase 2 we will begin research into other crops of interest with select partners. (iii) Beyond Phase 2 we will look to de-risk and optimise production for a wider suite of biomass/forestry crops in line with government priorities for sustainable biomass supply and afforestation. (iv)There is also a potentially game-changing application of this technology for further research and development of crop breeding through the rapid expression of genotypes, and multiplication within nurseries which will be explored with partners in Phase 2.

1.2.1 Supply Challenges

The UK is facing a significant biomass supply challenge, and this has been acknowledged by BEIS as part of the rationale for funding the Biomass Feedstock Innovation Programme. We foresee three significant challenges for the UK:

Firstly, there is the challenge of ramping up feedstock production. The CCC's 6th Carbon Budget[1] recommends that in order to reach our climate targets, the UK must plant 700,000 ha of perennial bioenergy crops by 2050, a 70-fold increase from the current 10,000 ha [5]. Assuming time for identification of suitable land and significant shifts in policy and bioenergy markets, a realistic starting date for planting is 2026, which translates to planting 30,000 ha per year, up to 2050. The allocated area for the first year of planting represents a 300% increase from the current planting area (Appendix I, Table 1, Figure 1). Estimates from our Phase 1 market feedback indicate that 20%-25% of the area could be allocated to SRC willow crops. On this assumption, the UK will require 6,000 hectares per year

(2026 start), which translates to roughly 90 million cuttings per year (Appendix I, Table 1).

Second is the challenge with current UK-based feedstock cutting supply. Based on the projected demand described above and following our stakeholder engagement as part of Phase 1, it is clear that the current UK planting stock is not sufficient to meet this growing demand. We were unable to discern exactly how much land is currently dedicated to SRC willow multiplication, but we estimate this is less than 10 ha (Appendix I, Table 2), insufficient for meeting the demand at pace without significant reliance on imports. Furthermore, the UK feedstock shortage is not isolated to SRC willow, with forestry species also seeing supply challenges in their sectors. We have learnt from Phase 1 that there is an increasing demand on nurseries who do not have the supply nor the means to multiply their planting stock fast enough. As a result of increased demand and insufficient supply, the price of saplings has almost doubled. There is a clear need for a technology which can rapidly multiply these species, further evidenced by a number of recent funding schemes [6], [7], [8], [9]. The UK cannot currently supply sufficient planting material for their afforestation and woodland creation aims and requires solutions for dedicated biomass crops in order to reach climate goals.

Finally, there are the challenges of importing cuttings. Since the UK's exit from the EU, the import of cuttings into the UK has been met with numerous challenges, including increased taxes, shipping fees and regulations. A number of contactors we spoke to in Phase 1 are expressing concerns about securing sufficient supply from the EU for the upcoming planting season. Relying on imported biomass presents a significant risk for UK companies who need security of supply.

Our Phase 1 market discovery journey and stakeholder engagement have confirmed that the shortage of high-quality UK cuttings represents a significant and undervalued gap in the supply chain which will present a substantial bottleneck in the secure supply of bioenergy feedstocks. Failure to meet demand for bioenergy puts the UK at significant risk of failing to meet our climate targets and continuing to accelerate us towards dangerous climate change.

1.2.2 Solving the supply challenge with our innovation

Given the significant supply challenges outlined above, here we detail how our innovation will help address these.

Our willow preliminary trials have demonstrated a series of advantages when compared to field grown crops:

- 25% faster growth, independent of seasonality
- Twice the above ground biomass and three times less root biomass
- Over 150% higher planting density: 100,000 trees per ha compared to 40,000 trees per ha for multiplication beds

- Results independent of soil quality
- Reduced and contained use of environmental contaminants (e.g., fertilisers, herbicides, pesticides).

Based on our planting density, and increased growth rate, our conservative estimates indicate that we can produce over 25 million cuttings for 1 ha of land, approximately four times higher than traditionally multiplied willow (6 million cuttings per ha). Operating on just 1 ha of land would allow us access to 30% of the market share for the projected willow quantities the UK will require for meeting 700,000 ha by 2050

Throughout Phase 2 we will be using several Key Performance Indicators (KPIs) for our technology. These KPIs have also been carefully chosen to feed into our Commercialisation Plan, as we engage with potential customers and seek to attract investment.

a) Cuttings produced. Our main KPI will be the number of cuttings produced per unit area of land per unit time relative to traditionally field multiplied willow.
b) Field establishment. Our hypothesis is that our soil-free multiplied willow will outperform traditionally multiplied willow due to the optimal conditions of initial rearing. We will measure crop establishment in field trials relative to traditionally field multiplied willow. To be measured as % cuttings which develop into viable trees.
c) Field yield. As above, we will undertake field trials to assess if we have inferred fitness benefits from our innovative multiplication method, relative to traditionally field multiplied willow. To be measured as tonnes biomass per ha.
d) Cost of cuttings. To be commercially relevant we need to ensure we can provide cuttings for a competitive price. In Phase 2 we will quantify production costs and subsequently costs per cutting.

These KPIs are working on our primary focus, which is willow multiplication, and do not consider the additional advantages our system can bring for premium feedstocks or high value bioproducts. These applications will be considered in Phase 2.

1.2.3 Future potential of breeding

Preliminary trials demonstrated specific genotypic responses to soilless cultivation, i.e. that some genotypes respond to soil-free cultivation more favourably than others. An extensive review undertaken in Phase 1 demonstrated the vast potential for this technology to assist with crop breeding and the development of desirable traits for both biomass for bioenergy and other high value bioproducts. Following the EU exit, applying advanced genetic techniques such as gene editing for crop development is now permissible, opening significant avenues for our innovation[10]. Work is already being undertaken in other crops to optimise for indoor cultivation, e.g. CRISPR/Cas9 has been used to produce dwarf tomatoes which produce fruit in more concentrated inflorescences[11]. Our innovation, in combination with advanced genetic techniques, may allow for:

A) Faster expression of phenotypes – owing to the increased speed of cultivation, as opposed to multiple years using traditional methods. This includes enhancing expression of pest resistance, rust resistance and expression for high value bioproducts.

B) Better biofuel crops – reducing the lignin content is important for increasing bioethanol yields as current sugar extraction methods are prohibitively expensive/intensive to make second-generation biofuels viable. However, reducing lignin compromises the physical stability of the crop in the field. Reduction of lignin within our systems, where environmental stresses such as wind are limited would allow us a significant advantage to cultivate second-generation crops for bioethanol production.

C) Optimisation of crops for controlled environments – this includes accelerating growth, reducing plant height and increasing stem thickness to allow for easier cultivation within controlled environments. Where the end product may be high value bioproducts (e.g. the anti-cancer miyabeacin compound found in willow) it is important that there is long-term feasibility of cultivation in controlled environments through optimisation of space and resources.

1.2.4 Integration with other innovations

Phase 1 has allowed us to explore potential integrations with other innovations. Here we detail two potential integrations: supporting breeding and crop development; and automation of harvesting and processing of cuttings.

The main area to which we see this technology being applied is the multiplication of feedstocks and linked to this is the nursery stage of crop propagation. That is, our innovation will produce cuttings, or immature plants to be planted out into the field. However, we also see a key application here in advancing plant breeding. Given the speed of advances in the technological capabilities to genetically modify plants and precisely select traits, there remains a bottleneck in how quickly one can assess if a breeding cross has been successful and the desired trait expressed. Our system is able to rapidly express phenotypes and could accelerate the types of breeding programmes proposed within the BFIP and beyond. Phase 1 has established partnerships with two leading research institutions to assess how our innovation can support their advanced breeding programmes, opening up the potential for a distinctive R&D arm to the venture.

There is also a role for the integration of higher levels of automation within the wider bioenergy and agricultural systems. At the moment we have a fairly basic system which is reliant on significant labour inputs, however efficiency is expected to be dramatically improved through automation of processes. We have had conversations with one other Phase 1 project about how their innovations (autonomous willow rod processing machine, autonomous SRC willow planting machine and purpose-built tracked willow harvester) can be adapted and applied to automate and optimise our operations. Additional innovations, monitoring crop health, crop growth rate etc., could be integrated with our technology to significantly reduce repetitive labour efforts. The role of automation will be explored within Phase 2 as part of socioeconomics analysis and commercialisation.

1.2.5 Interactions with Supply Chain

One of the key advantages of our technology is the ability to have an agile response to market demand and thus reduce supply chain burdens and uncertainties such as a shortage of supply. We are able to plant willow independent of environmental conditions and time of year; we are not restricted by field conditions (which can prevent access), the need to prepare land (till, treat with herbicides) or reliance on contract planters (to economically and efficiently plant large areas). Our systems can cater for an unprecedented surge in demand and can do so with shorter notice than traditionally multiplied willow, given the c. 30 weeks to harvestable size and the higher planting density. This allows us to respond flexibly to demand and shocks in the supply chain.

If our innovation could be realised for supporting the development of higher quality feedstocks (such as those with better combustion properties, higher calorific value, etc.) or for the production of liquid biofuels, we would anticipate positive knock-on effects in the supply chain. This would allow simpler biomass processing and biorefinery operations leading to reduced energy and resource consumption and a more competitive price for bioenergy produced. How our innovation can support these premium feedstocks will be assessed in Phase 2 with collaborators from other research institutes.

1.2.6 Knowledge Gaps to be closed (in Phase 2)

In Phase 2, we will be able to confirm the yields that are possible in the various environments. We will be able to establish the time reduction to harvestable size for cuttings. We will be able to quantify and optimise the delivery of water and nutrients, as well as optimising the relative environments for cost reductions and to minimise environmental impacts. We will be able to quantify, with experimental data, the environmental life cycle impacts of the system as well as quantify the socio-economic impacts of the innovation.

Gaining an understanding of all these aspects will provide the necessary clarity as to the commercial opportunities and benefits to be derived from our technology.

1.3 Wider environmental benefits and trade-offs

During Phase 1 we have mapped the environmental risks and benefits using a whole life-cycle thinking perspective, a scoping life cycle assessment (LCA) on soilless willow (SLW) cultivation vs 'conventional' willow cultivation (CWC) for biomass and cuttings, and reviewed the wider relevant sustainability frameworks (and opportunities) such Environmental Land Management Schemes (ELMS), the UN-SDGs, and the 25 Year Environment Plan (25yEP).

Overall Phase 1 findings**:** preliminary, scoping LCA work and wider review to date indicate that the SLW innovation has potential to achieve parity or better vs CWC regarding environment impacts. Ongoing LCA and other 'sustainability' information should form an important component of decision-making in the SLW innovation development programme.

1.3.1 Greenhouse Gas (GHG) balances

The preliminary LCA has shown that SLW requires further optimisation to bring its GHG profile to be equivalent to that of CWC. These finding, detailed below, are unsurprising at this stage, given its early development and clear opportunities for such optimisation, supported by life-cycle thinking and LCA.

CWC is straightforward and well established in UK and many parts of Europe and Scandinavia. The majority of studies note CWC willow biomass, typically in an SRC system as a low-carbon fuel for heat and power against several fossil fuel alternatives [12]. SLW is an intensive high-productivity approach to cultivation that relies on energy and material inputs to achieve acceleration over 'conventional' field growth of plants, and the present innovation is at an early stage of development. We therefore conducted a 'prospective', scoping LCA to explore possible GHG and other environmental impacts between these two approaches for the production of willow cuttings. We chose our 'middle impact' scenario which involves cultivation in a greenhouse with supplemental lighting during the winter months. Initial results centred on a Functional Unit of 1000 willow cuttings per annum (10-year production system) indicate that SLW using UK average grid power (for fertigated water circulation and lighting) accounts for over 90% of the Functional Unit's GHG impact.

The GHG impact for SLW in the assessed set-up is considerably higher than that for CWC. Whilst this is an unfavourable comparison for the SLW innovation (based on uncertain data and no 'optimisation') a clear opportunity exists to move to low-carbon power for the SLW system and this was modelled using a UK offshore wind scenario. This brings a substantial reduction in the SLW GHG and a much more evenly balanced set of drivers for this GHG profile across the SLW system. Mitigation for this higher GHG usage could using a renewables energy supplier and/or local onsite renewable generation.

This suggest that further development of the SLW system holds a broad set of optimisation opportunities for further GHG reduction, both in the operation of the systems, to reduce power usage whilst maintaining yield, and the cultivation environment. It should also be noted that in this low-power system SLW exhibits only about 30% of the land use required for CWC.

[*NOTE: these initial findings need ongoing verification with further Life Cycle Inventory data that will become available during Phase 2*]

1.3.2 Other environmental impacts

Several other environmental impacts have been noted in the scoping LCA (e.g. stratospheric ozone depletion, ecotoxicity, acidification, particulates). In narrative terms, the ability to establish SLW on non-agricultural land is a clear benefit. The ability to establish SLW using existing system components is a benefit as much of the 'platform' for this innovation is available to optimisation of configurations, costs, sourcing and whole life cycle management. Based on preliminary work in Phase 1 we expect the SLW systems (and for other crops) will provide evidence relevant to 22 of the 66 indicators in DEFRAs 25yEP framework[13], 6 of the 11 'Planetary Boundaries'[14] and 11 of the 17 UN-SDGs[15]. All to be further refined and specifically quantified during Phase 2.

1.3.3 Biodiversity impacts

The assessment of the contribution of SLW and other crop systems is predicated on reaching an overall environmental profile that is comparable or better than CWC (on a Functional Unit basis), and, given that this is achieved, we then must understand how the land that is 'spared' due to SLW implementation is re-purposed - this could be greatly to the benefit of biodiversity, but this is dependent upon that land use. This aspect is premature at present but will be amenable to robust scenario analysis in Phase 2.

2. Phase 2 Plan

The timeline of Phase 2 is based on demonstrating the viability of soilless grown willow and the growing cycle in both soil-free environment and in the field. The critical pathway is represented in Figure 1.

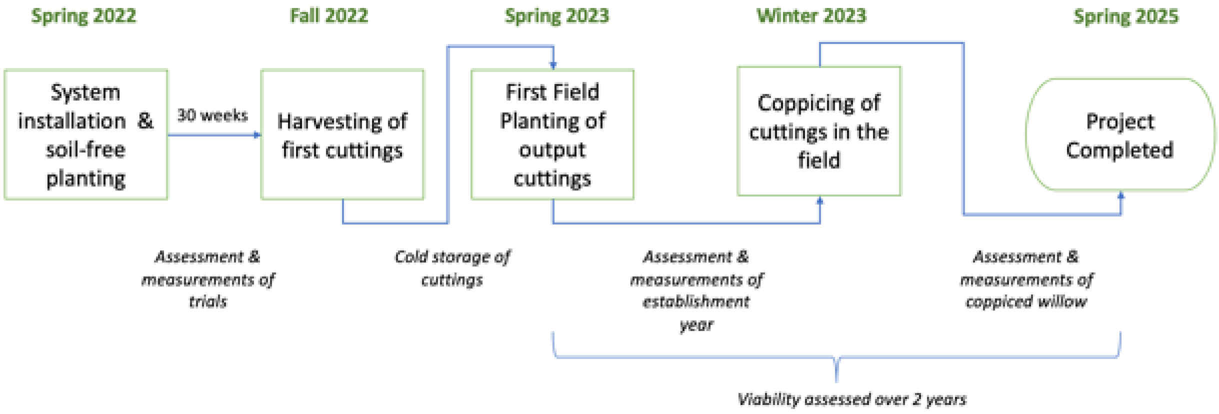

Figure 1: Simplified representation of activities in the critical path that ensure viability of soil-free grown willow is demonstrated. Note: this representation does not take into account the multiple experiments during the project.

The overall project is led by Dr Zoe M Harris with support from a dedicated project manager (Simona Stangaciu) and the Steering Committee. ZH and SS have led and managed Phase 1, ensuring continuity with the project content and familiarity with the project team. ZMH is responsible for project delivery and interacting with BEIS.

Phase 2 is a direct continuation of Phase 1, with added focus on other crops and has seven workpagackes:

1. Technology and Site management
2. Research and Development Trials
3. Opportunities for breeding and other crops
4. Environmental Benefits and Trade-offs
5. Socio-economic performance evaluation
6. Commercialisation and Communications
7. Project Management

All risks related to the successful delivery of the Phase 2 project and demonstration of the innovation have been thoroughly reviewed and presented in a risk register made available to BEIS.

To aid with governance, we have identified the need for a steering committee for Phase 2 of the project. The steering committee will bring together a diverse range of people with expertise in relevant areas. They will utilise this expertise and experience to guide the project, to provide advice and critical feedback. The committee has been designed to broadly match the areas of work within the project and includes expertise in: willow growing, plant science and controlled environment agriculture, bioenergy, finance, governance, business development.

3. COMMERCIALISATION POTENTIAL

Our vision for the innovation is to meaningfully contribute to bioenergy feedstock production while accounting for wider sustainability parameters, such as social and environmental impacts and maintaining commercial viability. The soilless innovation acts as a platform technology, developed with willow multiplication in mind and applicable to other crops.

3.1 Phase 1 Insights

During Phase 1, we carried out extensive stakeholder engagement to produce a comprehensive stakeholder map and identify where our innovation would have the greatest impact in the supply chain. We engaged with over 30 stakeholders from across the supply chain and, given the diverse application of our innovation, did not limit ourselves to those associated with SRC willow (Appendix I, Figure 2).

Stakeholders' interactions generated qualitative understanding of the identified markets. This engagement uncovered challenges for current growers, and potential future users of our technology, and a high level of interest in our innovation. We learnt that: i) demand on nurseries is increasing and many cannot keep up, ii) importing biomass (cuttings, saplings etc.) has become incredibly challenging post EU-exit, iii) contract planters and end-users are interested in our innovation if it can supply the same or superior quality feedstocks at competitive prices.

One of most significant outcomes from Phase 1 is a clear interest in this technology's application to other crops, thus enabling access to a suite of other market opportunities.

3.2 Scale of the Markets

As the main focus of our commercial operations immediately after Phase 2 is willow multiplication, our market research focused here.

The current market for willow cuttings is hard to quantify, and is small, with only c.4 main suppliers of planting stock for SRC willow for bioenergy and a number of smaller operations (selling bioenergy and basket weaving cuttings). Contractors buy a mixture of UK feedstocks as well as importing varieties from the EU (predominantly Sweden). With current multiplication capacity, we estimate the supply of UK cuttings is around 6 million cuttings per hectare per year, and that there is likely not more than 10 ha of total land currently dedicated to multiplication. Our innovation has the potential to disrupt the market by supplying much higher quantities of biomass feedstocks, in less time over a significantly smaller land footprint with potentially high performance in the field.

The potential market size, on the other hand, looks promising and is defined by the amount of land assigned to SRC willow and the rapid transition to feedstock for bioenergy in line with recommendations from the Committee on Climate Change (CCC) for the UK to reach Net Zero [1]. Briefly, using the CCC's recommendation of needing 700,000 ha of land for dedicated biomass feedstocks by 2050 [1], we have estimated 25% of this will be SRC willow (based on market research). With 6000 hectares per year dedicated to SRC willow, roughly 90 million cuttings/year will be required, creating a total UK market size for SRC willow cuttings of £30 – £35 million/year.

Our innovation has the potential to dominate this supply by producing an average of 25 million cuttings per year, occupying 30% of the annual market share with just 1 ha of land and could meet the full demand for the UK on just 3.6 ha of land. As a comparison, in a business-as-usual scenario, this would require 15 ha of land solely dedicated to the production of willow cuttings. (See Appendix I, Tables 1).

During Phase 1 we have identified a series of potential commercial applications of the innovation, from direct sales of willow cuttings, franchising of the willow multiplication systems, R& D for other crops, to the system commercialised as a standalone product.

Partnerships established during Phase 1with CEA specialists, willow research institutes and experts in other crops will support the refinement and commercialisation of the innovation while a dedicated commercialisation team will work on promoting and distributing the innovation and further work will be undertaken to quantify the potential of revenue streams, as well as gaining further clarity on the IP landscape.

3.3 Dependencies

The commercialisation plan depends upon:

- An increasing demand for SRC willow for bioenergy driving the demand for multiplication;
- Technology acceptance of the innovation by consumers;
- BEIS/DEFRA policy supporting farmers in a transition to growing bioenergy crops;
- A regulatory environment that enables the biomass feedstock sector to grow;
- Availability of appropriate land to plant out feedstock.

APPENDICES

Appendix I – Tables and Figures

Table 1: Assumed willow cutting requirements based on CCC recommendations and stakeholder insights.

Land Requirements - Future				**Basis of Assumptions**
Total perennials area required by 2050		700,000	ha	Based on CCC projections[1]
Planting Material - Future				
Year planting start assumption	Year 2022 Planting (28 years) '2022 start'	Year 2026 Planting (24 years) '2026 start'		Potential planting starting years. 2022 – immediate start. 2026 – post Phase 2 and more realistic to allow policy and markets to catch up
Annual land requirements (ha) per year	25,000	29,167	ha per year	Total land area required divided by number of years to achieve target
SRC Willow 20% of total perennials (ha/ year)	5000	5833	ha per year	20% estimate based on stakeholder engagement. Assume lower update of SRC willow due to 3-year return period vs 1 year return on *Miscanthus*.
Annual cutting requirements; willow @ 15,000trees / ha	75,000,000	87,500,000	Cuttings per year	Area required x planting density for bioenergy of 15,000 trees/ hectare
Annual multiplication area to achieve the above (high density) (ha)	13	15	ha of multiplication	= annual cuttings requirements divided by the number of cuttings produced by 1 hectare of multiplication (e.g. 75 million/ 6 million). This is on the assumption that the whole multiplication bed will be harvested, and all stems will be at harvestable size the following year which is not current commercial practice. This number is likely underestimated

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[1] Committee on Climate Change - The Sixth Carbon Budget- The UK's path to Net Zero, pp. 170, (2020)

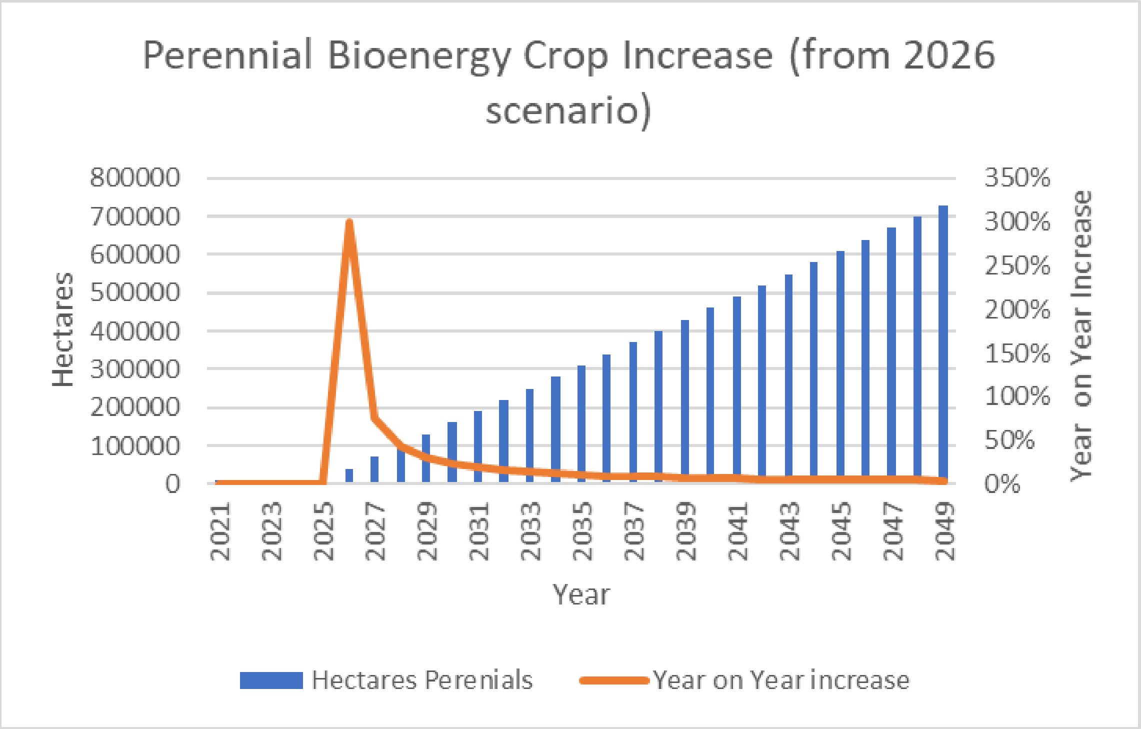

Figure 1: Comparative Perennial Bioenergy Crop Increase and Year on Year Increase under 2026 planting start. Figure 1 shows comparative scenarios based on CCC perennial crop recommended area for 2050. Starting planting from 2026 requires a 300% increase in the first year. This sudden increase provides scope for immediate disruptive innovations that can speed up deployment of planting material. The year-on-year increase remains over 20% during the first five years of the shift, and between 10%- 20% in the following five years.

Table 2: Size of multiplication beds from engaged stakeholders. Stakeholders have not been named to maintain anonymity

Stakeholder	Total multiplication area (m^2)	Planting density (plants per ha)
Stakeholder 1	200	c. 38,000
Stakeholder 2	400-500	c. 40,000

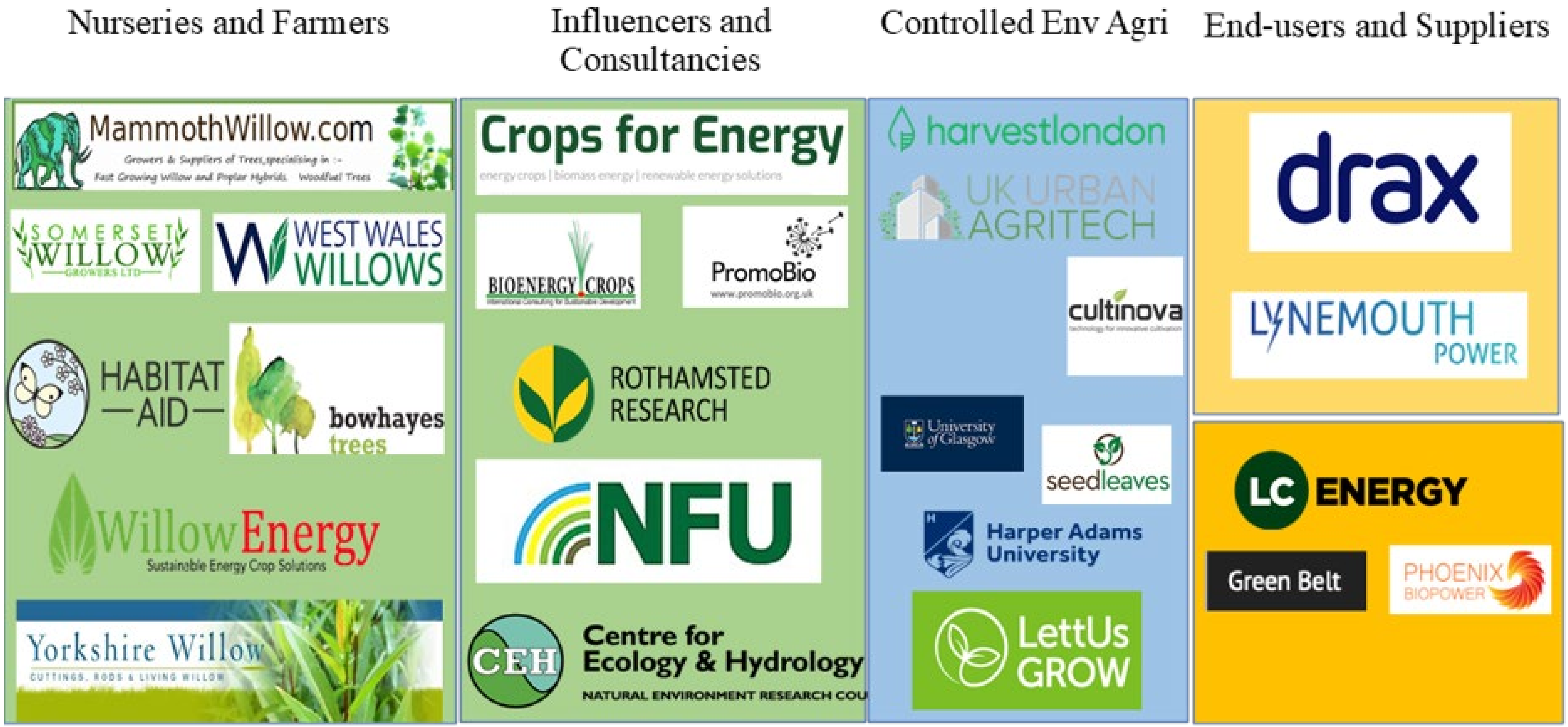

Figure 2: Examples of stakeholders engaged in Phase 1 (December, 2021)

Appendix II- References

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