# UPSCALING UK SRC WILLOW PLANTING AND HARVESTING CAPACITY:
# NET ZERO WILLOW (RIC-293-1)

## Final Report – Redacted Version

**Prepared for:** BEIS Biomass Feedstocks Innovation Competition

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# 1. INTRODUCTION

Rickerby Estates Ltd trading as Willow Energy (WE) was awarded funding by the Biomass Feedstocks Innovation Competition to investigate the feasibility of developing innovations to upgrade three key aspects of the Short Rotation Coppice (SRC) willow biomass supply chain and make them fit for purpose in the UK climate and working conditions and provide marginal gains in efficiency, yield potential, cost savings, revenue increase and life cycle carbon reduction.

The project which has been renamed “Net Zero Willow” (NZW) is a partnership between WE, Systems Hydraulics Ltd (SHL), GC Engineering (GCE) and Crops for Energy Ltd (C4E).

# 2. CURRENT SITUATION

The first part of the feasibility study involved an assessment of current state of play in SRC willow multiplication, planting and harvesting. C4E produced three questionnaires as a means of collecting the relevant information on current machinery and methodologies. In total these questionnaires had 136 detailed questions. This proved to be a very useful exercise and required the team to think about the industry and its limitations in a structured way.

The information was collated in detailed internal report of the current situation. A summary of the findings is provided in the sub-sections below.

## *2.1 SRC willow multiplication*

At present most willow planting material is produced and processed by hand. This is labour intensive, time consuming, expensive and wasteful.

- It is the most significant cost of establishing SRC and needs to be reduced if the planting area is to expand.
- The current multiplication rate for plantations is quite low. A 1-ha field can produce enough material for 28-35 ha of new planting.
- In the current situation, each 3m stem harvested will produce a 2m rod and the top 1m of growth will be discarded.

## *2.2 SRC planting methodology and machinery*

Mechanised SRC willow planting is a challenging undertaking. Most aspiring growers seek to plant SRC on marginal land that is unsuitable for arable crops. As a result, contractors are frequently working in sub-optimum conditions that include wet and weedy sites with heavy clay or flinty soils, and small, sloping and irregular shaped fields. Most planting machinery has been designed and tested in Sweden and Denmark. It is therefore not ideally suited to the UK situation.

The ideal planting time for SRC willow is mid-March. This is when the soil is moist and warming up and weed seeds have not germinated but usually most soils are simply too wet at this time to accommodate machinery trafficking. As a result, the majority of mechanised planting takes place between April to July.

Current willow planting machines are very mechanical and rely on operatives to feed a chute with willow rods. Problems include:

- Chutes become blocked or clogged on muddy, wet soils.
- Mechanical parts wear at different rates and require running repairs.
- The need of up to six planting operatives working in cold, inclement weather conditions. During an 8-hour day they get tired and distracted.

These problems lead to expensive contracting costs and inaccuracies and gaps in the plantation. Typical establishment rates are as follows:

- 85% - well prepared, weed free sites with low incidence of herbivores.
- 60-80% - wet and muddy conditions.
- 30-60% - poorly prepared sites with high weed competition and herbivores

Assuming, the current work rate and maintenance time, the maximum area that each machine could plant in one planting season is 150-200 ha.

### *2.3 SRC harvesting methodology and machinery*

Harvesting should ideally take place when the SRC willow crop is dormant and all the leaves have fallen between late October-March. In the UK it is rare for SRC to be harvested at the optimum time due to wet soils.

Current large-scale SRC willow harvesting is carried out using modified self-propelled forage harvesters that were designed to chop grass and maize. Usually the harvester discharges chip 'side on' into a trailer unit that is being pulled along by a tractor. This is then transported to freight trucks or storage facilities. A minimum of two tractors and trailers are required if the harvester is to work continuously.

This system works well in optimal weather conditions when the land is dry or very hard with winter frost. However, in wetter conditions there are several issues:

- The fields can quickly become rutted and soil compaction can occur
- The tractor and trailer can also become stuck in the mud
- Ruts in the field mean that the height of the cutting blades needs to be set higher meaning that potential biomass remains unharvested.
- Certain sections of plantations grow better than others due to edge effects or lack of competition in poorly established crops. This necessitates the use of hydraulically driven headers that are more flexible and powerful but they are also heavier and require more diesel to run.

The result of all this is expensive contracting costs, unsatisfactory soil management and the production of poor-quality fuel due to leaf contamination.

The potential area of SRC that can be harvested is significantly hampered by poor weather conditions. In years with inclement autumn and spring seasons a harvester may harvest 250-300 ha. By contrast in years where the weather is favourable the area harvested per harvester may increase to 500-750 ha.

The three innovations outlined below will significantly increase the efficiency of the SRC willow supply chain and facilitate rapid scaling up of UK planting potential to 5,000-10,000 ha a year. They will extend the working season and provide marginal and sometimes substantial gains in productivity, yield potential, cost savings, revenue increase and life cycle carbon emissions reduction.

## 3. INNOVATION 1 AND 2 WILLOW-BOT

The innovations for multiplying and planting SRC willow are collectively termed the Willow-Bot. This comprises an All-Terrain Robotic Base Vehicle (ATRBV), a robotic guided vehicle on hydraulically driven rubber tracks complete with two separate attachments, the Rod Harvester Attachment (RHA) and the Rod Planting Attachment (RPA).

### *3.1 Rod Harvester Attachment (RHA)*

The RHA is designed to be attached to the ATRBV. The operating task is to autonomously harvest willow rods from standing 1-year old willow multiplication beds.

### *3.2 Rod Planting Attachment (RPA)*

The operating task of the RPA attachment is to autonomously plant willow rods in the ground according to best practice planting protocols. The aim is to achieve accuracy similar to that attained by manual planting.

### *3.3 Scalability of the Willow Bot*

The technology used in the Willow-Bot is designed to be scalable. Rod harvesting and planting are seasonable tasks and take place at different times of the year. It makes economic sense to produce different attachments mounted on the base robot which can be swapped depending on the season.

We are considering the development of additional attachments for other production tasks; for example, weed monitoring and precision fertilising.

### *3.4 Contribution to increasing sustainable biomass supply*

The flexibility of the Willow-Bot system would make it possible to have small willow multiplication beds dotted all over the country allowing willow cuttings to be produced quickly and affordably and closer to growers and markets. The RPA could be delivered to a site on a pallet truck or car trailer. Once a multiplication site has been harvested it could then be simply and efficiently dispatched to the next site. The willow cutting bales it produces would be designed to be stacked on a standard size pallet and stored in a local cold store, ready for planting later on in the season.

Due to the size and light weight, the machine can operate in wet conditions so the cuttings can be picked at the optimal time of year when the willow bed is in full dormancy, usually January-February. Through the proposed innovation we believe the following improvements are achievable:

- Labour required to produce willow cuttings reduced by up to 90%
- The machine will be able to work much longer hours than a manual work force without breaks. The work rate may be increased by at least 200%
- Increase the potential output of a multiplication bed by up to 33% as more parts of each harvested stem will meet the minimum standards.
- Increase the quality of cutting material to exact specifications leading to fewer blockages in planting machinery and less down time for repairs.
- Reduced cost of producing cutting material by up to 15%.
- Lower plant material costs will increase returns for growers.

The advantages of the RPA are:

- It will have fewer exposed moving and wearing parts and will avoid losses in production due to breakdowns and cost in replacing parts regularly.
- It will work longer hours without breaks enabling the area planted per hour and per day to increase significantly - perhaps as much as a 300% increase. The contract planting price will be reduced by up to 15%
- More consistent establishment will reduce the number of gaps between plants leading to more efficient harvesting with less wear and tear on the machine. This will reduce harvesting costs by 15%.
- A current planter can require 3-5 people to operate. By contrast, with this innovation 1 person could run 2-3 automated planters at the same time
- Lower establishment and harvesting costs coupled with improved establishment rates will increase yields and returns for growers.

### *3.5 Wider environmental benefits*

These innovations will see some substantial environmental benefits such as:

- Reduction in material waste used in packing and distribution by 50% as there will be less requirement for bespoke crates to be created and therefore a reduction in materials such as wooden batons, nails, plastic film, elastic bands etc. This will reduce the carbon footprint of production.
- The production of standard weight bales of cuttings will increase the bulk density of planting material by 15% which will take up less space and reduce cold storage and transport costs and life cycle GHG emissions.
- More efficient multiplication plantations and higher establishment rates and yields will increase land resource efficiency and lead to greater biomass production from a smaller planted area.
- The proposed system will be light weight and easy to transport keeping transportation costs and emissions to a minimum
- The RPA won't require a large tractor thereby reducing fuel use and a further reduction in lifecycle GHG emissions. This will also mean that there is less soil damage and allow planting on wetter land earlier.

# 4. INNOVATION 3: HARVESTER AND BUNKER

The proposed harvester innovation is a tracked system with an integrated storage bunker.

One of the major advantages of this proposal is that the system is capable of harvesting and collecting the willow as one complete unit and once the trailer is full, the whole assembly can be driven to the edge of the field and unloaded directly into an articulated trailer.

## *4.1 Contribution to increasing sustainable biomass supply*

By being on tracks and having its own chip bunker, the proposed harvester will be able to work in all but the very worst conditions. This will allow SRC crops to be harvested at the optimum time of year and mean that crops are kept in the correct 3-year harvesting cycle. The harvesting window could be increased by up to 5 months per year and enable the harvesting of an extra 400-600 ha per year per harvester.

Through this proposed innovation and less down time with breakdowns we envisage the following improvements are achievable:

- Higher work rate
    - Dry conditions 10% increase
    - Average conditions 25% increase.
    - Wet conditions 75% increase
- Reduced labour by up to 50%
- Reduced maintenance due to not having to maintain as many machines The harvester will end up being heavier but will have a lighter footprint because of the track system fitted. The increased surface area of the tracks on the harvester will allow it to run on top of the ground rather the rutting into to ground
- Reduced contracting cost to grower
    - It will reduce unnecessary time wasted when machines get stuck.
    - Savings will come from not needing at many tractors and trailers.

## *4.2 Wider environmental benefits*

This innovation will see some substantial environmental benefits such as:

- The harvesting process will cause minimal damage to the soil in the way of soil compaction and rutting
- The harvester will produce the same amount of noise but as there are fewer tractors and trailer operating then there will less machinery so an overall reduction in noise
- The overall fuel consumption of the harvesting operation will be reduced because there are fewer tractors and trailers required so less fuel will be consumed.

## 5. SUMMARY OF THE GAINS FROM THE THREE INNOVATIONS

In order to investigate the potential gains compared to the current situation, C4E produced a questionnaire of 42 questions covering economic improvements, yield benefits, life cycle analysis and greenhouse gas savings, potential roll out in the UK and export potential. The questionnaire was completed by WE. A summary of the findings is provided in the sub-sections below.

### *5.1 Grower income and savings in production costs*

Based on the marginal gains from planting accuracy and harvesting we envisage yields increasing by 10.8 green tonnes per ha per harvest. This will significantly increase grower income from sales or if they are using SRC as self-supply woodfuel. Furthermore, the savings in plant material costs and contracting costs will further reduce production costs and increase revenue potential.

### *5.2 Land resource efficiency*

At present the average yield per ha of willow per harvester is 55 tonnes. An increase of 10.8 tonnes per ha would mean that more yield would be produced from a lower amount of land. For instance, based on current yields an area of 200,000 ha would yield 11 million green tonnes of SRC chip. To produce the same amount of fuel based on the higher yields that could be achieved, would require 167,173 has. This equates to a saving of nearly 33,000 ha of land. This area is not insignificant equating to more than the current total area of soft fruit and orchards and just slightly less than the area of root crops, brassicas and fodder beet for stock feeding in England[1].

### *5.3 Headline environmental benefits*

A partial life cycle assessment was performed comparing the current willow cultivation process with future practices using the upscaling innovations (NZW model). From the estimated innovations gains included in this study (see Appendix 5) the impacts for all the environmental categories assessed have been reduced by 10% or more. These include:

- Climate change (greenhouse gas emissions CO2 eq.) reduced by 11%
- Human toxicity-non cancer environmental indicator decreased significantly by 80% due to tracks being used on the willow harvester instead of tyres. This means that there will be zero tyre abrasion emissions to soil
- A reduction of impacts in the region of 20% are observed for marine eutrophication and land use, which are strongly linked to a reduction in waste stems during the production phase and increased yield respectively.

Transport emissions were not considered in the above LCA analysis. However, these are likely to be extensive. The NZW scenario will significantly reduce

[1] Farming Statistics – Land Use, Livestock Populations and Agricultural workforce at 1 June 2020 – England (DEFRA) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/928397/structure-landuse-june20-eng-22oct20.pdf

transport emissions because of the increase in bulk density of cutting material (fewer journeys), lower weight machinery, fewer machines being used to harvest the crop and higher work rate.

A second simpler GHG analysis using the Solid and Gaseous Biomass Carbon Calculator 2.0 was performed to investigate this. In this analysis we compared the higher yields from the NZW scenario along with a 25% reduction in diesel use in establishment and harvesting. This reduced the heat carbon intensity from 5.04 gCO2/MJ to 3.98 gCO2/MJ – a saving of 21%.

# 6. PHASE 2 PROJECT PLAN

## *6.1 Timelines for deliverables, including key milestones*

Redacted – commercially sensitive information

## *6.2 Project management, including project delivery team*

Redacted – commercially sensitive information

## *6.3 Risks and risk management*

An extensive assessment of the risks associated with Phase 2 of the project is has been produced. 20 risks have been identified.

## *6.4 Quality assurance, Project controls and governance*

Individual WP leaders will produce a Task plan to be agreed by the PMs and participating team members. Each WP will be reviewed weekly by the Task leader / PM to keep abreast of:

- Deliverables
- Any risk issues threatening the delivery of the project
- Allocated time
- Changes in work programme
- Redeployment of team members etc.

The project team intends to implement the practices of PRINCE2 (Projects In Controlled Environments) within the delivery of this project. By following the correct PRINCE2 process a governance model is created, which serves as a function of the team structure and ensures visibility and speed in decision-making for the project team.

The governance model will be based on the following;

- Be pragmatic and efficient
- Provide standardisation in the key elements of the governance, while allowing team leaders to have flexibility to meet specific needs
- Provide a weekly drumbeat and a project team meeting with agility to solve issues

- A steering committee led by the PM will be formed. This committee will be actively involved throughout the project to make project critical decisions, provide strategic direction and guarantee alignment with the business case.

The engineering workshops for each of the engineering partners will have dedicated floor space and designated caged areas to safely store all procured items for the project duration.

Personnel involved in this activity have proven suitable transferable skills highlighted for the efficient handling of all procured materials within this project.

The whole project team will meet online every month to monitor progress. Minutes will be taken and any sticking points highlighted and activities set in motion to address these. An iterative approach that involves interim review/analysis will enable flexibility based on feedback from the monitoring process.

## *6.5 Reporting plans*

The project will communicate and report according to the following schedule:

- Monthly core project team meetings – last Friday of each month
- Monthly meetings with BEIS MO and PM
- Internal reports to present the work done at the completion of each WP
- Quarterly reports – 4 per year providing updates (Q1-11) covering
    - Progress against the delivery plan and milestones, upcoming work over the next quarter
    - Financial information (including budget spend and budget forecast)
    - Updated risk register (including where risk ratings have changed, or new risks/issue have emerged)
    - Any key lessons learnt during delivery
    - Progress against relevant programme KPIs
- 2 x Annual reports collating information from quarterly reports (Q4 & 8)
- Attend all stage gate reviews, held every six months after project commencement to assess the project's deliverables, progress, costs, risks, and spend against the project plan.
- Facilitate annual site visits with the MO and BEIS representatives.
- Participate in BEIS Phase 2 dissemination events.
- Draft report (Q11) and Final report (Q12)

### *6.6 Commercialisation plan*

The UK Government is considering a large expansion in the area of PECs to meet net zero commitments: 7,440 ha by 2025, 21,275 ha by 2030 and 26,350 ha by 2035[2]. For the purposes of this report, we will assume a long-term sustainable annual production capacity for SRC of 10,000 ha per year. Achieving

[2] Net Zero Strategy: Build Back Greener, HM Government, October 2021

this will require significant areas of land for multiplication beds (Each 1 ha bed producing 50 ha of planting material per year) and tens of machines to produce material, plant and harvest the biomass.

The potential UK market for SRC willow (700,000 ha) is a mere fraction of the potential global market. In May 2021 the International Energy Agency published a report suggesting that to meet net zero emissions by 2050 the global land area for bioenergy crops would need to rise to 130 million ha[3].

As a result there is a large market and our innovations could be at the forefront of meeting this demand.

### 6.7 How Phase 1 informed our commercialisation plan

Redacted – commercially sensitive information

### 6.8 Phase 2 Commercialisation strategy

Redacted – commercially sensitive information

### 6.9 Knowledge gained during Phase 2

Prior to commercialisation we anticipate needing to test the innovations extensively We propose that for harvesting jobs, that both the innovation and our existing harvester could be used. This would enable:

- Thorough testing of the harvester on a wide range of crops
- Backup if the harvester fails
- Independent evaluation by growers – they can see the innovation work compared to the existing machine and fill out an evaluation form. We will analyse these responses providing a third layer of independent evaluation on top of any Lot 2 scrutiny and our own independent expert evaluator.
- A detailed logbook of harvesting successes and issues encountered and how the design was adapted to deal with these. This will provide a detailed record for potential investors and any requirements for due diligence.
- Holding demonstration days in more locations than just centralised Lot 2 hub sites – this would build grower confidence in the crop and the kit needed to harvest it and allow more opportunities to court investors
- WE to continue doing our day job whilst developing the new machinery.

### 6.10 Promotion

In addition to the testing events above we also intend to liaise with the Lot 2 winner and provide up to 16 demonstrations at centralised sites.

Based on the in-depth analysis of markets and country specific policy we will contact companies of interest and seek online B2B interactions.

[3] Net Zero by 2050 A Roadmap for the Global Energy Sector, IEA, May 2021

### *6.11 Post phase 2 Financial growth plan*

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### *6.12 Dependencies*

We envisage the following dependencies:

- Logical dependencies - We won't begin construction until we have received the necessary kit and we won't be able to order until we have contract sign off.
- Resource dependencies - The RPA and RHA require similar resources and completion of one will be dependent on the completion of the other.
- External dependencies - There may be delays from the suppliers.

We will build in contingency plans so that progress is enabled.

## 7. CONCLUSIONS

The NZW feasibility study produced designs and specifications for machinery involved in the three main parts of the SRC cultivation pathway. These innovations should lead to marginal or significant gains being achieved in terms of efficiency, productivity, lower weight machines reducing environmental impact, reduced waste, yield potential, cost savings, revenue increase for grower and contractors, and life cycle GHG reductions.

In Phase 2 of the competition the intention is to assemble prototypes, test and refine these leading to definitive working models that are ready for commercial manufacture. If the assembled machines can achieve the anticipated improvements then they will help revolutionise the scale up of the SRC willow biomass feedstock industry, not only in the UK but worldwide.