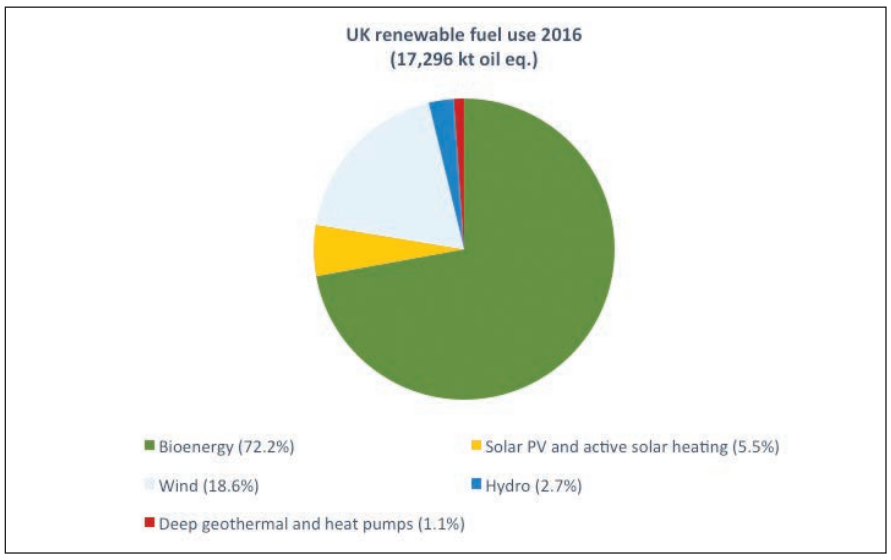
Miscanthus:
The Seeds to Grow a Sustainable, Low-Carbon Economy

Jon Paul McCalmont, jpm8@aber.ac.uk

Renewable energy now represents 24.6% of total electricity generation in the UK (DUKES 2017) with the UK exceeding its third interim Renewable Energy Directive (RED) target for percentage of total energy generation from renewables (8.9% in 2016 compared to the target of 7.5%). Bioenergy makes up by far the largest proportion of that renewable fuel use with around a quarter of this provided by plant biomass with the majority of this imported from North America, Canada and Europe in the form of wood pellets.

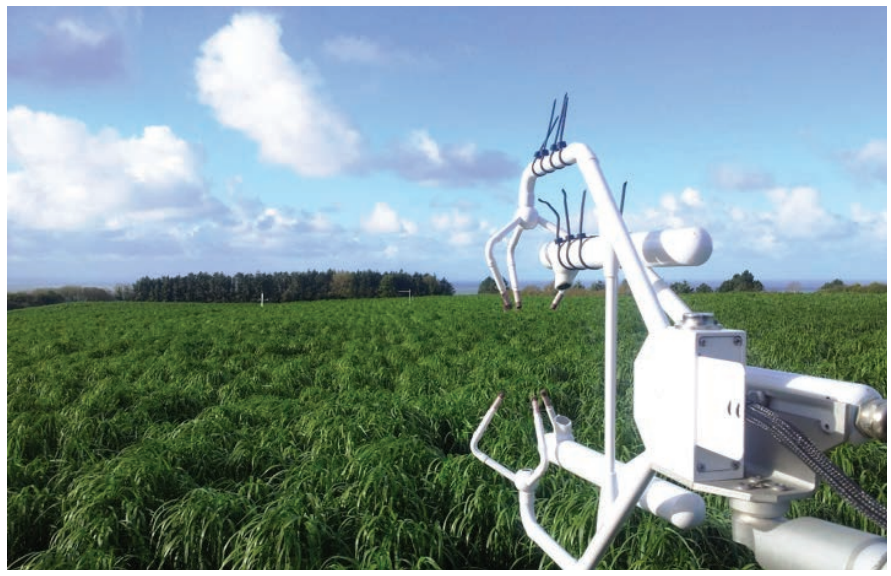


Total UK renewable energy use in 2016. (DUKES 2017)

In 2015 the UK imported a total of 6.52 Mt of wood pellets for electricity generation, primarily at Drax power in North Yorkshire which provides up to 10% of total electricity for the UK (4 GW). There are, however, new power stations coming on stream which burn domestically produced cereal straws, as a side product from grain production. Two of them, Brigg and Snetterton, in the East of England, produce around >80 MW between them and consume around 500,000 tonnes of straw per year. As a proportion of a total straw production at around 8.4 Mt/yr this is a significant amount and competing users of these straw products are beginning to feel the impacts in rising prices.

One solution to this increasing demand for biomass is domestic production of perennial crops, particularly where these can be grown on economically marginal areas of agricultural land, circumventing the well-rehearsed food vs fuel debate. The government was well aware of the potential role sustainable energy crop production could play in the domestic energy mix and even wrote targets into their UK biomass strategy in 2012 which suggested 350 kha of second generation, low input, perennial energy crops could be produced without any conflict with food production. Perhaps the most promising crop fitting these criteria, certainly the most commercially viable, is the giant Asian Elephant grass *Miscanthus*. This perennial energy grass, similar in appearance to bamboo, shows prodigious growth on little or no fertiliser and no herbicide or pesticide sprays beyond some weed control in its early years as it establishes (McCalmont et al. 2015). Once mature it can be cropped year after year from a single planting. Remarkably efficient end of season senescence and nutrient re-cycling to below ground modified root systems called rhizomes mean that nutrients are conserved within the system. The dried canes are harvested in late winter/early spring, clearing the ground for the new growth which grows rapidly from new shoots off the rhizomes. The commercial standard *Miscanthus* crop, *Miscanthus* x giganteus (Mxg), is a naturally occurring, sterile clone which can only be propagated by digging up and splitting these below ground rhizomes and replanting them into new plantations.

With a long history of grass breeding, IBERS at Aberystwyth University recognised early on that if *Miscanthus* was ever going to be scaled up into commercially relevant production levels then



Environmental monitoring of a commercial scale Miscanthus x giganteus plantation at IBERS in Aberystwyth, Wales (photo: Jon McCalmont).

Biomass harvesting in Aberystwyth, following over-winter ripening of the Miscanthus canes (photo: Jon McCalmont)

this clonal propagation, which can only be scaled by about 20:1, would need to be seriously improved upon. The approach taken was a bold one, the goal was to produce seed-based inter-species hybrids from fertile parents found across their native range in Asia. Starting in 2006, a team led by Professor John Clifton-Brown, with colleagues from JKI in Germany and partners in China, Japan, South Korea and Taiwan, began a series of plant collecting missions across Asia and assembled one of the world's largest ex-situ *Miscanthus* germplasm collections. With specialised quarantine facilities and procedures in the UK, this collection effort has been fully licensed by DEFRA in partnership with host countries. These collections have been made with

Planting of new seed-based hybrids as seedlings under bio-degradable mulch film, novel germplasm and novel agronomy, the way forward to satisfying market demand for sustainable biomass crops (photos courtesy of Terravesta).

partners in each country, respecting the guidelines of the 1993 ratified Convention on Biological Diversity (CBD) which recognises national sovereignty over genetic resources and thereby governs access to non-indigenous germplasm. The later Nagoya Protocol, 2010, maps out the fair and equitable use of genetic resources internationally. The *Miscanthus* collections by IBERS team have been an early example of applying these principles, and have informed CBD policy makers. The collections form the basis for the ongoing *Miscanthus* breeding program, with seed production of unique parental crosses beginning at the field scale with partners CERES in the USA (http://www.miscanthusbreeding.org/). From 2011, a £6.4 million collaboration project (GIANT-LINK) between IBERS, BBSRC, DEFRA and private partners (CERES, Blankney Estates, E.ON, NFU and Terravesta) pushed the breeding programme on rapidly (Clifton-Brown et al. 2017). The aim was to produce high yielding seed-based hybrids with desirable traits for end-users to be planted as young seedlings rather than clonal rhizomes. Seed production from parental crossing blocks increases the multiplication rate dramatically, 1 ha of rhizome 'mother plantation' can only produce perhaps 20 to 30ha of new crop, for the new seed based hybrids this is more like 2000:1. It is only with this level of multiplication that a truly significant contribution to the demand for plant biomass can be made with these highly sustainable biomass crops.

Eight genotypes from the Aberystwyth/Julius Kuhne Institute (Braunschweig, Germany) *Miscanthus* breeding program were selected for the OPTIMISC project alongside seed based population varieties bred by the Dutch *Miscanthus* breeding programme at Wageningen and the standard genotypes Mxg and M. x sinensis Goliath. These fifteen genotypes were tested in the UK, Germany, The Netherlands, Russia, Ukraine, Turkey and China in a comprehensive genetics x environment stress test to quantify yield potential across a wide range of climates. In addition to these science scale plot trials, large-scale farm demonstration plots of several hectares in three countries were used to develop the agronomy, harvesting systems and conversion technologies. Yield ranking was used to produce a recommendation list (Lewandowski et al. 2016) for novel *Miscanthus* hybrids in specific climatic zones while the larger scale trials in the project produced important insights into financial and greenhouse costs of production, harvesting, and transportation (Hastings et al. 2017).

Without translation into commercial agriculture this hard won knowledge is destined to remain in the annals of the scientific literature, so it was with good fortune that, in 2013, IBERS began their close collaboration with Terravesta, the UK *Miscanthus* supply chain specialists (http://www.terravesta.com). Together they began the MUST (*Miscanthus* Upscaling Technology) project to learn how to produce and plant hybrid seed at commercially relevant scales for three promising hybrids produced during the GIANT LINK project. The common theme running through all these projects is the marginality of the target lands that are considered for *Miscanthus* production. Beyond energy production, these second-generation, low input crops may play a useful role in rural development, soil carbon and biodiversity improvements and even phyto-remediation or stabilisation of contaminated soils. In a smaller, side project, MISCOMAR (http://www.miscomar.eu/), IBERS and Terravesta are working with colleagues in Poland and Germany to understand the performance of some of the GIANT/MUST novel hybrids under extremely marginal conditions. For the UK and Germany these conditions cover heavy, waterlogged, nutrient depleted soils, but for Poland the target is heavy metal contamination. Led by Dr Marta Pogrzeba at the Institute for Ecology of Industrial Areas, the MISCOMAR team are investigating whether *Miscanthus* may be a promising alternative to producing food crops on around 1 million ha of Polish arable land that are suspected to be contaminated with heavy metals. Early results from the testing of four novel hybrids and the commercial standard, M x giganteus have shown a range of tolerance and metal uptake with clear yield differences between genotypes. Biomass from this material is further tested for performance in anaerobic digestion with the aim of modelling economic and environmental benefits to the rural economy.

Inspired by the MISCOMAR project, this production of useful biomass produced on contaminated and marginal land has now been taken up in a much larger Europe wide project, led by the University of Hohenheim in Germany. The GRACE-BBI project (https://bbi-europe.eu/projects/grace) has just been awarded €15 million over the next five years to investigate the yield potentials of a range of seed-based *Miscanthus* hybrids from both IBERS and Wageningen University in side by side trials across multiple sites in six countries. All sites proposed for the biomass production are considered economically or agriculturally marginal for one reason or another; running from straightforward climatic challenges such as flood or drought to significant soil contamination, from aviation fuel at airport sites and lead deposition from local industry to organic pollution from long term sewage disposal. Each country has industrial partners who will be finding novel ways to utilise the resulting biomass and these end uses are not restricted to energy production. One of the primary aims of the project is to develop higher value products through the development of bio-refining feedstocks. Environmentally sustainable bio-plastics, fibre boards, packaging and even building materials are all target uses for the *Miscanthus* biomass.

There is little doubt that commercial, and policy, interest is growing rapidly for second generation, low input, low impact, biomass crops. Market demand is already beginning to outstrip supply, both in the UK and Europe, and it would seem that the biomass industry is poised to expand rapidly in the burgeoning bio-economy. But this expansion will be heavily dependent on prosaic agricultural concerns: land availability, producer confidence and the capacity to supply and establish enough planting material. Through MUST, MISCOMAR and GRACE-BBI, IBERS and Terravesta are at the heart of answering some of these challenges.

Some of the leading members of the Miscanthus breeding and commercialisation team at the GIANT-LINK finale in Lincolnshire, June 2016. Representatives from IBERS, Aberdeen University, Terravesta, CERES and the JKI Institute joined farmers and policy makers to report on the great progress made in Miscanthus breeding over the lifetime of the project. The leader of the Miscanthus breeding programme, Professor John Clifton-Brown, can be seen on the far right.

For the full round-up of our *Miscanthus* breeding story, please see the following short film available on YouTube -- (https://www.youtube.com/watch?v=sOPxw2OwlWg&t=125s)

References

Clifton-Brown J., Hastings A., Mos M., et al. (2017). Progress in upscaling Miscanthus biomass production for the European bio-economy with seed-based hybrids. GCB-Bioenergy 9, pp.6-17. doi:10.1111/gcbb.12357

DUKES (2017). Digest of UK Energy Statistics: Chapter 6 Renewable Sources of Energy. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/633782/Chapter_6.pdf

Hastings A., Mos M., Yesufu J., et al. (2017). Economic and Environmental Assessment of Seed and Rhizome Propagated Miscanthus in the UK. Frontiers in Plant Science. doi:10.3389/fpls.2017.01058

Lewandowski I., Clifton-Brown J., Trindade L., et al. (2016). Progress on Optimizing Miscanthus Biomass Production for the European Bioeconomy: Results of the FP7 Project OPTIMISC. Frontiers in Plant Science 18(7). doi: 10.3389/fpls.2016.01620

McCalmont J.P., Hastings A., McNamara N.P., Richter G., Robson P., Donnison I.S., Clifton-Brown J., (2015) Environmental Costs and Benefits of Growing Miscanthus for bioenergy in the UK. GCB-Bioenergy 9(3). doi: 10.1111/gcbb.12294