Research Stimulus Fund

Final Report

'GreenGrass – developing grass for sustainable renewable energy generation and value-added products'

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Please tick below the appropriate area on the research continuum where you feel this project fits

BASIC/FUNDMENTAL ⟶ APPLIED/PRE COMMERCIAL

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Key words: *(max 4)*
Grassland biomass, anaerobic digestion, biogas, green biorefinery

1. Rationale for Undertaking the Research

Fossil fuels account for 94 % of the energy usage in Ireland. In 2010, the Irish government set targets of 40, 12 and 10 % renewable energy share in gross energy production for electrical (RES-E), thermal (RES-H) and transport energy (RES-T) in Ireland by 2020, respectively. The need to develop alternatives to non-renewable fossil-based resources has stimulated an interest in the use of plant biomass to provide renewable energy, chemicals and materials. Crops grown specifically for renewable energy production and other novel uses offer opportunities for sustainable agricultural systems. Where this involves marginal land or grassland use, new economic potential can be realised.

Methane-rich biogas can be produced from a wide range of feedstocks (e.g. organic fraction of municipal waste, animal manure and slurry, agricultural crops, etc.) through anaerobic digestion (AD), and can be used as a replacement for fossil fuels in both heat and power generation and as a vehicle fuel. The production of biogas in central Europe is closely linked to the agricultural sector and farm based AD plants are widespread. Most plants operate on manure based substrates, with a range of dedicated energy-rich crops including maize, cereals, sugar beet and grass. In Germany for example, maize silage is the dominant feedstock for on-farm AD.

Grassland is a dominant biomass resource in Ireland accounting for approximately 92 % of the agricultural land area. Not only is grass plentiful, but some of the highest grass yields (up to 20 tonnes dry matter ha^{-1} $annum^{-1}$) in Europe are also observed. In addition, grass often represents the cheapest biomass feedstock to produce and farmers have existing machinery and expertise for growing, harvesting and storing grass and grass silage. However, limited information is available on the potential of grassland biomass as a feedstock for anaerobic digestion. Thus, the objectives of this project were to investigate:

1. The potential of different grass species for use as a biomass feedstock.
2. The potential of these species to provide fibre for industrial applications (i.e. Green Biorefinery process).
3. The optimisation of anaerobic digestion technology for grass silage feedstocks.

2. Research Approach

- A range of common grass species (i.e. perennial ryegrass, Italian ryegrass, Timothy, Cocksfoot and Tall fescue) and red clover were grown under contrasting management conditions and assessed for their potential as a biomass feedstock for anaerobic digestion and green biorefining.
- The methane production potential of these herbages and the impact of grassland management practices and ensiling were determined in small-scale (160 ml), high-throughput batch digestion tests.
- A fibre-rich press-cake fraction was isolated from a range of silages and three potential applications were identified and investigated: ruminant feedstuff, biomass fuel for combustion and a fibre-reinforcement for clay and cementitious materials.

- The biomethane potential (BMP) of grass silage was investigated in a variety of BMP assay methodologies with a focus on understanding variables and improving the accuracy of the test.
- Grass silage was digested in a bespoke design two step wet continuously stirred tank reactor (CSTR) at a scale of 300 L for a period of ca. 12 months. The organic loading rate was increased and the hydraulic retention time decreased to assess optimal operation.
- An innovative reactor configuration was investigated which involved leaching the grass silage in leach beds to produce a leachate rich in soluble chemical oxygen demand (COD). The leachate was fed to an upflow anaerobic sludge bed reactor (UASB) where the COD was converted to methane. The liquor from the UASB was further re-circulated over the leach beds. This system was termed a Sequencing fed Leach Bed Reactor system coupled to an Upflow Anaerobic Sludge Bed (SLBR-UASB). The system operated at increasing loading rates for ca. 12 months.
- Mathematical modelling using ADM1 (developed by the IWA task group for mathematical modelling of anaerobic digestion processes) was used to assess the impact of a significant number of operational variables on the stability of the processes.
- Hydrolytic pre-treatment processes for grass and grass silage feedstocks were compared and optimized to maximise biogas yield and solids destruction.

3. Research Achievements

- The specific CH_4 yield of a feedstock will be determined by its chemical composition and more specifically it's content of digestible energy. The most important factor influencing the chemical composition of a specific herbage is its growth stage at harvest. Herbage specific CH_4 yield is positively correlated with increasing herbage dry matter digestibility and negatively correlated with increasing neutral detergent fibre concentration.
- Only small differences in relevant quality traits (e.g. dry matter digestibility) and specific CH_4 yield are observed between common temperate grassland species when they are harvested at the same phonological growth stage.
- Agronomic traits that have resulted in perennial ryegrass becoming the dominant grass species for ruminant production, including high digestibility when harvested at the appropriate growth stage, high yield in response to N fertiliser application and ease of preservation as silage due to a relatively high water soluble carbohydrate content, are also important for biogas production.
- A fibre-rich press-cake fraction can be isolated with great efficiency across a range of harvest dates and from contrasting grass species. Grassland management factors impact on the composition of the herbage presented for fractionation and this subsequently influences the composition of the separated press-cake fraction.
- The low energy and protein content of the press-cake fraction, especially at later harvest dates, will limit its use in ruminant diets.

- The substantial reduction in the concentration of compounds such as ash, N, Cl and K during fractionation improved the suitability of the press-cake fraction for combustion compared with the parent material.
- The fibre-rich press-cake fraction is capable of supporting tensile stresses of the order of magnitude experienced in laboratory-scale tests on clay and cementitious materials subject to significant shrinkage under restrained conditions.
- BMP methods were optimised, enabling high accuracy and low error between replicate tests. Accuracy was sufficient to enable discrimination between different methods of pretreatment.
- Digestion of grass silage in a CSTR was initially problematic due to the tendency of the grass silage to float on top of the liquor surface within the first digester. This was overcome by modification of the mixing system. The mixing system needed to break the surface and operate alternatively clockwise and anti-clockwise. The retention time of the system could be modified through varying rates of recirculation of the digestate back to the feed system. This proved to be an excellent method of distributing volatile fatty acids (VFAs) between the two digester tanks.
- The CSTR system yielded 451 L CH_4/kg volatile solids (VS) at an organic loading rate of 2 kg VS/m^3/d and a retention time of 50 days. This is equivalent to 90% destruction of volatile solids and is close to the maximum value achieved in the BMP assay.
- The system was modelled using the ADM1 model which could not correctly simulate total VFA and pH in the digester system. Lactic acid is a significant element of grass silage (73% of total acids) which is not included in the ADM1 model. Thus ADM1 was modified through assessment of lactic acid; the results allowed close fit to experimental data. The simulation suggested that inhibition of acetogenesis initiated failure, leading to accumulation of lactic acid, reduction of acetic acid (substrate for aceticlastic methanogens), a drop in pH, less methane production, less destruction of solids, increased dry solids content and eventually failure of the mechanical agitator.
- The SLBR-UASB achieved 350 L CH_4/kg volatile solids (equivalent to 70% destruction of volatiles) at a retention time of 30 days.
- The SLBR-UASB system produced less methane then the CSTR system (350 L CH_4/kg VS versus 451 L CH_4/kg VS) but it had a number of advantages, namely:
    - The retention time was 40% less (30 days versus 50 in the CSTR).
    - The methane content of the biogas was 71% as opposed to 52% in the CSTR.
    - The solids content of the digestate was 10.2% versus 5.6% in the CSTR
- Long term operation of the above digesters for the mono-digestion of grass requires the addition of trace elements. It is recommended to research optimal co-digestion rates of grass silage with slurry and/or to investigate trace elements required for successful long term operation.

  Pretreatment methods tested enhanced grass hydrolysis and increased gas production by up to 30% at a short (21 day) hydraulic retention time. This has beneficial implications for future reactor design.

  The use of elevated temperature (55°C) for the most beneficial hydrolytic pre-treatments will result in increased plant cost. Under the current Feed-in-Tariff support for biogas to electricity the payback to farmers of the increased investment is poor.

- Work in this project provided a basis of costing grass silage as a feedstock for biogas production. The intensive 2-cut system which utilised silage effluent to supplement silage feedstock yield, and returned digestate to the land so as to reduce inorganic fertiliser costs, had the lowest grass silage production cost. Directing the silage effluent stream to the digester (€4/t decrease in feedstock cost) and employing the digestate as a biofertiliser (€3/t decrease in feedstock cost) had a significant impact on feedstock cost.
- Work in this project has shown that there is a current average annual grassland resource of *ca.* 1.7 million t DM available in excess of livestock requirements. Furthermore, changes to current grassland management and production practices have the potential to significantly increase this resource to *ca.* 13.2 million t DM/a (or 12.2 million t DM/a following implementation of 'Food Harvest 2020'). In these instances alternative applications such as anaerobic digestion and green biorefining would not have to compete with traditional agricultural production systems, but could provide a potential alternative enterprise and income to farmers. The available grassland biomass resource in Ireland can make a significant contribution to the 2020 renewable energy targets.

4. Impact of the Research

  - The EC, Proposal for a DIRECTIVE OF THE EUROPEAN PARLIMENT Brussels 2012 (In:http://ec.europa.eu/clima/policies/transport/fuel/docs/com_2012_595_en.pdf) suggests that the share of biofuels from cereal and other starch rich crops, sugar and oil crops be limited to consumption in 2011 (ca. 5%). It further recommends that biofuels from lignocellulosic substrates shall be considered at 2 times their energy content. In essence no new facilities producing first generation liquid biofuels (such as sugar beet ethanol and rape seed biodiesel) may be constructed in order to satisfy renewable energy targets. Biomethane produced from grass shall be assessed at twice its energy content for the purpose of meeting the 2020 target of 10% renewable energy in transport (RES-T).
- Maize has proven to be the dominant feedstock in Germany. Implementation of the above proposal will not lead to construction of many (any?) more Maize digesters. Coupled with this, the better yields of grass in northern climates will likely lead to grass being the dominant biomass feedstock for future crop digesters.
- This project has provided a substantial amount of new information on the production and conservation of grassland biomass for biogas production and on the design and operation of AD technology for grass silage feedstocks.
- This information has been made widely available to industry in Ireland through national conference presentations, open-days and the project website and has been widely disseminated within academia via peer-review journal publications (n = 30 peer review journal publications and n = 2 book chapters) and national and international conference presentations (n = 30).
- Teagasc, University College Cork and Queens University Belfast have established an excellent working link and have collaborated in further successful funding calls on the potential grassland biomass to provide renewable energy and materials.

5. Exploitation of the Research

Outline the outcomes of the research that have commercial or economic importance and provide details of Intellectual Property / licences / patents generated. Details of outputs adopted by industry should also be provided

Outcomes from this project have not yet been adopted by industry because market conditions in Ireland are not currently sufficiently attractive for commercially viable biorefining or biogas production using grass as a biomass source. It is anticipated that adoption will occur if market conditions become sufficiently attractive. To this end, there is now a repository of knowledge and expertise developed during this project that will be available to industry when required. The existence of this information has been communicated to a range of interested industry individuals and groups, and they have acknowledged its considerable relevance.

6. Summary of Research Outputs

(a) Intellectual Property applications/licences/patents
None

(b) Innovations adopted by industry
There have not yet been innovations from this project adopted by industry because market conditions in Ireland are not currently sufficiently attractive for commercially viable biorefining or biogas production using grass as a biomass source. It is anticipated that adoption will occur if market conditions become sufficiently attractive.

(c) Number of companies in receipt of information
Presentations of the outcomes of this DAFM-funded research programme have been made at a number of industry events, so it is being guestimated that at least 50 companies are in receipt of the relevant information (or now know where to go to receive detailed communication of the information. In addition, it is not known how many other companies have accessed project outcome information on the website http://www.greengrassproject.ie/.

(d) Outcomes with economic potential
It is not possible to currently provide a number here because market conditions in Ireland are not sufficiently attractive for commercially viable biorefining or biogas production using grass as a biomass source. It should be possible to make this estimate once market conditions become sufficiently attractive.

(e) Outcomes with national/ policy/social/environmental potential

1. Elaine Groom (QUB) was invited in January 2010 to sit on the DETI (Dept. of Enterprise Trade and Investment) "Renewable Heat Oversight Committee" which is responsible for policy development in this area. Grass had previously been completely ignored as a potential energy source by consultants appointed to DETI. Now figures (quantities of grass/silage available in N. Ireland; likely biogas production etc.) coming out of the GreenGrass project have been fed into DETI quantification studies of renewable energy and renewable heat. The information from GreenGrass has more than doubled the forecast energy potential from biogas in the region and this is influencing policy change and support for farm-scale AD.
2. Bord Gais Eireann released a report on the future of Renewable Gas with the support of Dr. Jerry Murphy, University College Cork. The input to the report was influenced by the GreenGrass Project.
3. Dr. Jerry Murphy contributed to and was interviewed by the Oireachtais Committee preparing the Seventh report of the Joint Committee on Climate Change and Energy Security entitled 'Report on Biogas Energy in Ireland'
4. Dr. Elaine Groom (January 2011) was appointed by Minister Gildernew (Minister for Agriculture and Rural Development, Northern Ireland) as an external stakeholder advisor to the Renewable Energy Policy Division of Department of Agriculture and Rural Development. A report written as a result of this project provides a way forward for DARD's Renewable Energy Action Plan. This was submitted to Minister O'Neill (current Minister for Agriculture and Rural Development, Northern Ireland) in December 2012 and will shortly be published by DARD, along with a departmental response.
5. Dr Jerry Murphy is an editor on the recent book:
    - Wellinger, A., Murphy, J., Baxter, D. (2013). The Biogas Handbook: Science, Production and Applications. Woodhead Publishing Series in Energy Number 52 and the International Energy Agency (IEA). Input to the report was informed by knowledge gleaned during the Green Grass project.
6. Dr Jerry Murphy is lead author on the International Energy Agency (IEA) Brochure "Biogas from crop digestion" Available from: http://www.iea-biogas.net/. Input to the report was informed by knowledge gleaned during the Green Grass project.
7. Dr. Jerry Murphy was invited and travelled to ISPRA (Italy) to the EU Joint Research Centre (JRC) Energy Institute (EI) to advise on the sustainability criteria in the Renewable Energy Directive (REN) for biogas, solid biomass and biofuels (November 2011).

(f) Peer-reviewed publications, International Journal/Book chapters.

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published by Woodhead Publishing, Cambridge, U.K. <http://www.woodheadpublishing.com/en/book.aspx?bookID=2616>

(g) Scientific abstracts or articles including those presented at conferences

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(h) National Report

1.

2.

(i) Popular non-scientific publications

1. Groom, E. and Orozco, A. (2012) Optimising Biogas Yield. AWE International. <http://www.aweimagazine.com/article.php?article_id=709>

2. Grass set to be the root of green energy (2010) Interview with Padraig O'Kiely (by Eithne Shortall), Sunday Times, 21 November 2010, page 5.
3. Scientists hope to use grass on farms for energy (2011) Interview with Padraig O'Kiely, Irish Times 28 February 2011.
4. McEniry, J, King, C. and O'Kiely, P. (2011) The Grass is Greener – alternative applications for Irish grass. T-Research, 6 (2), Summer 2011, pp. 26-27
5. Jerry D Murphy: "Let's get wise to biogas" Irish Independent, Renewables Farming, September 2011.
6. Clare O Sullivan; "Grass key to gas demand, shows UCC Report, Irish Examiner, 13 August 2010
7. Annon; "Alternative Energy Report is heartening" Editorial Irish Examiner, 13 August 2010
8. Paul Melia; "Gas from Grass could supply up to 300,000 homes" Irish Independent, 13 August 2010
9. Paul Melia; "Abattoir waste has helped fuel city's public transport for years" Irish Independent, 13 August 2010
10. Barry Roche; "Silage may hold key to heating homes" Irish Times, 13 August 2010.
11. Barry Moran; "That's Grass! Green Energy Experts say waste can power Ireland" The Irish Sun, 13 August 20
12. Annon; "Energy: We can turn gas into grass" Irish Daily Mirror, 13 August 2010
13. Annon; "Making gas from waste" Irish Daily Star, 13 August 2010
14. Annon; "The natural alternative" Irish Daily Mail, 13 August 2010
15. Ray Ryan; "Anaerobic digestion systems could generate energy, boost incomes" Irish Examiner, 12 August 2010.
16. Majella O Sullivan; "Tapping grass potential," Irish Independent Farming Supplement, Tuesday April 20, 2010.
17. "Prof's grass plan makes the cut," Evening Echo, Thursday April 15, 2010.
18. Dan Buckley; "Green, green grass of home could be key to renewable energy," Examiner, Thursday April 15, 2010.
19. "Conference on grass resource," Irish Independent, Thursday April 15, 2010.
20. Dick Ahlstrom; "Organic Waste key source of viable fuel alternatives," Global Energy: A Special Report; The Irish times May 22, 2009.
21. Dick Ahlstrom; "Research could lead to Cork City Buses running on eco fuels," Global Energy: A Special Report; The Irish times May 22, 2009.
22. Alan Healy; "A gas idea and it could only cost €10 million," Evening Echo, 17 April, 2008.
23. Jennifer Hough; "The grass is greener; could the power be right at our feet?," Irish Examiner, September 22, 2008.
24. Jennifer Hough; "Energy Future in algae and grass," Irish Examiner, September 22, 2008.
25. Claire O' Sullivan; "UCC is looking at grass to create biogas," Irish Examiner, June 14, 2008
26. John Reynolds; "Minister calls for increase in biofuel production," Business, Sunday Independent, June 1 2008.
27. Laurie O'Flynn; "Grass next in Line of oil runs out," Farming, Irish Examiner, 13 March 2008

28. Maria Rolston; "Why the grass under our feet could hold the key to a greener Ireland," Evening Echo, 30 January, 2008

(j) Workshops/seminars/ open days at which results were presented (excluding those in (g))

1. McEniry, J. (2009) GreenGrass – Developing grass for sustainable renewable energy generation and value-added products. Project overview – conference presentation. International Energy Agency Task 42 Green Biorefineries, Dublin meeting, 25 March 2009.
2. McEniry, J., Murphy, J, Groom, E and O'Kiely, P. (2010) GreenGrass – Developing grass for sustainable renewable energy generation and value-added products. Project poster overview. Sustainable Energy Association of Ireland/Teagasc Anaerobic Digestion Conference, 20 October 2010, Tullamore, Co. Offaly.
3. McEniry, J., Murphy, J, Groom, E and O'Kiely, P. (2011) GreenGrass – Developing grass for sustainable renewable energy generation and value-added products. Project poster overview. AD Europe – The future of anaerobic digestion in Europe, 24-25 February 2011, Dublin Ireland.
4. Groom, E. and Orozco A. (2011) Opportunities for AD of Energy Crops. Cré Workshop on Anaerobic Digestion, Lough Neagh Discovery Centre, March 2011.
5. O'Kiely, P. (2011) Overview of the GreenGrass project. Teagasc Oak Park Crops and Energy Open Day, Oak Park, Co. Carlow, Thursday 23 May 2011.
6. O'Kiely, P., McEniry, J., King, C. and Lenehan, J.J. (2011) Biogas research in Teagasc Grange. International Energy Agency Task 37 Energy from Biogas, Cork meeting, 15 September 2011.
7. Thamsiriroj, T. and Murphy, J. (2011) Biogas research in the Environmental Research Institute, UCC. International Energy Agency Task 37 Energy from Biogas, Cork meeting, 15 September 2011.

7. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (months)	Average time contribution per permanent staff member
Teagasc	1	12	12 months
University College Cork	1	11.5	11.5 months
Total	**2**	**23.5**	**23.5 months**

8. Researchers Funded by RSF

Type of Researcher	Number	Total Time contribution (months)	Average time
Post Doctorates	4	59	14.75 months
Contract Researchers	1	48	48 months
PhD postgraduates	2	91	45.5 months
Masters postgraduates	0	0	0
Temporary researcher	0	0	0
Other		0	0
Total	**7**	**198**	**108.25 months**

9. Postgraduate Research

Total Number of PhD theses: 2

1. Abdul-Sattar Nizami (2011) GreenGrass: Developing grass for sustainable gaseous biofuel. Department of Civil and Environmental Engineering, University College of Cork.

2. Colman King (2012) The ensilage of grass as a biomass feedstock and the subsequent utilisation of the fibrous fraction as a bio-based material. School of Civil, Structural and Environmental Engineering, University College Dublin.

Total Number of Masters theses: 0

10. Project Expenditure

Total expenditure of the project: € 1,169,936.71

Total Award by RSF € 1,181,437.05

Other sources of funding (specify) € 0
1.
2.

Breakdown of Total Expenditure

Category	Teagasc	University College Cork	Queens University Belfast	Total
Contract staff	220,355.11	0	0	220,355.11
Temporary staff	0	0	0	0.00
Post doctorates	0	29,869.61	187,177.42	217,047.03
Post graduates	82,250.00	81,898.30	0	164,148.30
Consumables	121,350.00	20,540.99	36,572.42	178,463.41
Travel and subsistence	26,629.56	9,455.78	15,449.95	51,535.29
Sub total	450,584.67	141,764.68	239,199.79	831,549.14
Durable equipment	18,337.31	73,554.60	6,363.15	98,255.06
Other	3,045.37	0		3,045.37
Overheads	132,801.55	42,529.39	61,756.19	237,087.14
Total	604,768.90	257,848.67	307,319.13	1,169,936.71

11. Future Strategies

- Teagasc and University College Cork have contributed to a successful application for a recent 'E.U. FP7 People [ATBEST - Advanced Technologies for Biogas Efficiency Sustainability and Transport]' funding call coordinated by the Questor Centre. This has completed contract negotiations and will start on July 1st 2013
- Teagasc, University College Cork and Agri-Food Research Finland (MTT Finland) have started (2012) on a collaborative project entitled 'Biogas from grass'. Teagasc have provided funding for two Ph.D. students. This is a direct follow-on to this project (RSF 07 557).
- Teagasc have committed to the development of a farm-scale anaerobic digester in Teagasc Grange for further research and demonstration purposes.

12. Industry Collaboration

Summarise details of industry collaboration in the research project.

Erneside Engineering, Lissarda, County Cork
Bord Gais
Ecoventii and Ecobeets
AgriAD