AD Ingenuity LLP
The Gornall-Mulliner Partnership

Deal Farm AD Plant

Planning Appeal ref no APP/L2630/W/23/3324060

Proof Of Evidence - Dr. L.K. Gornall

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Plans and Calculations which form part of Appendix 3 have been submitted as separate PDFs. So too have Appendices 7 (Enforcement Notice), 8 (Appellant Response to LPA's questions), and 9 (Pentair Budget Quotation).

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Introduction

1. AD Ingenuity LLP was originally instructed by South Norfolk District Council ('the Council') to to review a planning application 2022/1108 ('the 2022 Application') and also a planning permission granted in 2015 ('the 2015 Permission').

2. AD Ingenuity LLP provided some draft comments to South Norfolk District Council on the 2022 Application and the 2023 Application in order to support their statement of case for the the Appellant's appeal against an Enforcement Notice and also against the refusal of planning permission for the 2022 Application.

3. The Appellant has now withdrawn its appeal into the Enforcement Notice and has accepted that the 2015 Permission cannot be implemented as relied upon.

4. As such, this proof of evidence is now limited to issues regarding the 2022 Application.

5. In particular, I have been asked to provide evidence which addresses the following issues:

    a. The capacity of the AD equipment which has been applied for;

    b. What the implications would be if the AD plant were designed for the throughput proposed by the Applicant, both in terms of its design and its efficiency;

    c. Whether the application includes all of the equipment necessary to facilitate the AD process;

    d. Whether the figures provided in the Appellant's application documents as to the amounts of liquid and solid digestate likely to be correct and the potential implications of this; and

    e. If the permission were granted, whether the Appellant is correct as to the levels of energy which would be generated by the proposal.

The Author of this Proof of Evidence and declaration

13. I am Dr. Lesle Keith Gornall, D.Phil, BSc(Hons) C.Biol. FRSB. I am a founder-partner of AD Ingenuity LLP.

14. I am a UK Pioneer of Anaerobic Digestion (full-time since 1978). Over four decades I have developed an expertise as an Anaerobic Digester, composting and Wastewater Treatment Process designer. I have in-depth experience including laboratory and bench experimentation, pilot plant and full-scale plant design (up to city scale), building, commissioning operating and optimizing typically one to three Anaerobic Digester plants per year.

15. My qualifications are a B.Sc. degree (1st Class Hons.); Dissertation on the uptake by grasses of Nitrogen from digestates. D.Phil. in Environmental Science; Thesis 'Interaction between Anaerobic and Aerobic processing of Farm Effluent.'

16. I designed the first full scale integrated farm digester and organic composting system in Northern Ireland in 1984-5. It won the UK Pollution Abatement Technology Award from the Royal Society of Arts, the CBI and DOE jointly with Farm Gas and the Monks of Bethlehem Abbey. I subsequently built two successful businesses making peat substitutes and organic golf course amendments from digestate and went on to design and/or commission some of the iconic UK biogas plants including The Cory AD Plant adjacent to a retail park in Western-Super-Mare, The odourless WWTW at Ford Airfield serving Littlehampton and Bognor Regis (200,000 PE), The B9 Energy AD Plant in Dungannon design for funding and commissioning support, Goddard's Green Sludge Treatment Centre for Southern Water, The AC Shropshire digester 3.2Mwe, winner of the 2013 Bioprocessor of the year award from the IChemE, Westcott Park 3.2MWe food waste AD plant and many others.

17. Other Qualifications and Awards:

- 2016: Anaerobic Digestion and Bioresources Association (ADBA) award 'AD Hero of the year'
- 2013: IChemE Bio-processor of the Year award for a two-phase food waste and pig slurry digester that I designed and commissioned.
- 2005: The UK Engineering Contractor of the year award - presented in the House of Commons Committee room 10 for my work with wastewater treatment at BP described as 'Best Practice' by D'Appolonia, Environmental Consultants to the World Bank.
- Member of / advisor to the Anaerobic Digestion and Bioresources Association (ADBA, the trade body for the AD industry in the UK) health and safety committee

18. Other Skills and Awards:

- Awarded 3 Patents relating to AD, odour control and composting.
- Expert Witness to 17 Planning Appeals, adjudications, and arbitrations, including:

- 2022 -2023 Expert witness instructed by DACB in the Derby (Severn Trent) UK biogas plant dispute adjudication. Adjudicators found in favour of DACB's client.

- 2022 Expert Witness in a planning appeal instructed by the residents living around the Queens Charlton proposed AD Plant who objected to the plant being built. The appeal was dropped after initial documents were exchanged.

- 2021 Expert Witness instructed by AJ Bowler Regarding a rapid adjudication in a dispute involving a large UK biogas plant for SUEZ. Ref. below:

https://ajbowlerconsult.com/2023/01/15/ajbc-awarded-2-6-mil-gbp-in-uk-adjudication-on-behalf-of-its-client/

- 2019 Baranault Road AD planning appeal. Instructed by the residents living close to an AD plant that had been built with 5,426m^3 of Primary + 5,426m^3 secondary digester plus a gas domed Storage tank/secondary digester of 4,239 m^3.

- 2018 BSG Civil Engineering. Instructed by the engineering company solicitors because of the EPC Wrap company [WIS] going into administration. Very large agricultural digester in Scotland, Technical Opinion provided. Matter settled between the parties.

- 2017 Crouchland AD Plant West Sussex, planning appeal, instructed by solicitors for the Parish Council reporting under CPR part 35. 10-day inquiry. Parish Council position accepted by the Planning Inspector. Crouchland facility instructed to be removed as it did not have planning permission.

19. In 2008 I became Technical Director of the AD and sustainable energy team in RPS one of the UK's Premier Planning Consultancies. In this role I worked with GIS and spatial development departments to support digester developers who needed certainty in these key parameters to secure funding:

    - A legal interest in the land,
    - planning permission,
    - a source of feedstock,
    - grid connection,
    - a land bank for digestate,
    - a process design and
    - a Permit to Operate from the EA.

20. In 2008 at RPS I created and led the team that wrote and delivered the UK wide WRAP training course for AD operators and developers. This was the highly successful biogas training program that created a body of several hundred skilled developers and operators that enabled the growth of the AD Industry in the UK.

21. I was also Process Consultant for PM PROjEN and technical lead for the Bioenergy Team for almost a decade until 2019 creating a team of experts who were able to work up my process designs into full scale AD plants that could be delivered. We were awarded several prizes for our AD design projects including some of the sites previously mentioned. This also provided me with the time required to provide expert witness opinions on cases in Toronto, and Crouchland while optimizing biogas plants that were functioning below design expectations such as Corbiere's Gas to Grid in Norfolk. This plant operated at 40% capacity when we took on the job and now produces 120% of its design capacity.

22. In December 2020, after the Covid Lockdown, I formed AD Ingenuity LLP with Russell Mulliner, who had recently sold to his employees Marches Biogas, the most successful AD manufacturing company in the UK. Our CVs are in the appendix.

23. The evidence which I have prepared and provide for this appeal reference APP/L2630/W/23/3324060 (in this proof of evidence) is true and has been prepared and is given in accordance with the guidance of my professional institution, the EWI and I confirm that the opinions expressed are my true and professional opinions.

Dr. Les Gornall

16/01/2024

Structure of this proof

24. The remainder of this proof of evidence is structured as follows:

    a. I set out the basics of anaerobic digestion;

    b. I comment upon the information provided by the Appellant during the application and appeal process;

    c. I set out a summary of my own calculations which have been necessary to understand the likely outputs of the anaerobic digestion proposal;

    d. I address each of the questions asked of me;

    e. I set out my summary and conclusions.

Anaerobic Digestion The Basics

25. At appendix 1 of this proof of evidence I have set out a simple guide to the process of anaerobic digestion including some microbiology. It is important that the terminology used in this proof of evidence is understood and the diagram below, Fig.1 will assist the reader. This is a general instruction model to illustrate the principles and nomenclature the basic anaerobic (*without air*) digestion process in which a typical mixture of grass silage, powdered or finely chopped straw and manure combining to (say) 40% dry matter blended digester feed is processed to biogas and digestate. The liquid digestate output from the digester is separated into a damp 'cake' (typically referred to as solid digestate) and separated liquid digestate. These are organic fertilisers and are ultimately land spread, the solids with a muck spreader, the liquids with irrigation or advanced slurry spreaders driven by tractors.

26. There are two types of digester, dry and wet. The dry digesters sometimes called anaerobic composters, operate by continuously turning the waste at 20-35% dry matter. Wet digesters are larger and operate with liquid contents of below 12.5% dry matter. However to maximise yields and prevent foaming, the ideal dry matter content of the 'soup' in the digester is below 9.5%. The proposed plant at Deal Farm is a wet digester with both wet and dry feed systems listed being the pre – tank and dry feeders.

27. The input feedstock, being such a high dry matter is stackable and is prepared for digestion by blending it with water to form a stirrable 'soup' that is fed to the digester. The amount of water required will depend upon the amount of dry matter in the type of feedstock. For example, a feedstock such as straw is made up of c85% dry matter, good maize silage is c40% dry matter

whereas a feedstock such as pig manure is made up of c25% dry matter and therefore using straw as a feedstock will require significantly more water addition than manure[1]. Note that water may also be added through the addition of re-circulated liquid separated digestate. However, not all water can be added through this means because there is a limit to how much digestate can be recycled. Recycling digestate increases the salinity of the digester contents which inhibits the working bacteria and reduces methane yield. In the absense of detailed data being made available from the Appellant's mass balance for the plant, in our calculations we have used as much recirculated separated digestate as we think possible without inhibiting the microbiology.

28. The remainder of the water required to make 'soup' from the dry feedstock is made up of rainwater, ground water and mains water. I make no distinction as to the sources for fresh water in the calculations for water use.

29. The added process water may be augmented with recycled separated digestate liquid – this is omitted from the the following diagram for clarity. Reycled separated liquid digestate is diverted from the output of the plant back to the inlet. However the added volume of process water passes through the system and out to the storage lagoon carryiing with it the soluble salts rich in plant nutrients for use as grass and arable land liquid fertiliser. The cake is spread on the land using a muck spreader as a compost-like soil conditioner and fertiliser most suitable for root crops. The actual blending point between liquids and solids can vary between an external blending tank (pre-tank), within the mixer-feeder mechanism or water can be added directly to the digester tank.

[1] See calculation ADI504-203-G for the Feedstock dry matter design assumptions

30. The fate of one tonne (1000kg) of 40% dry matter silage is broadly as follows in Fig. 1:

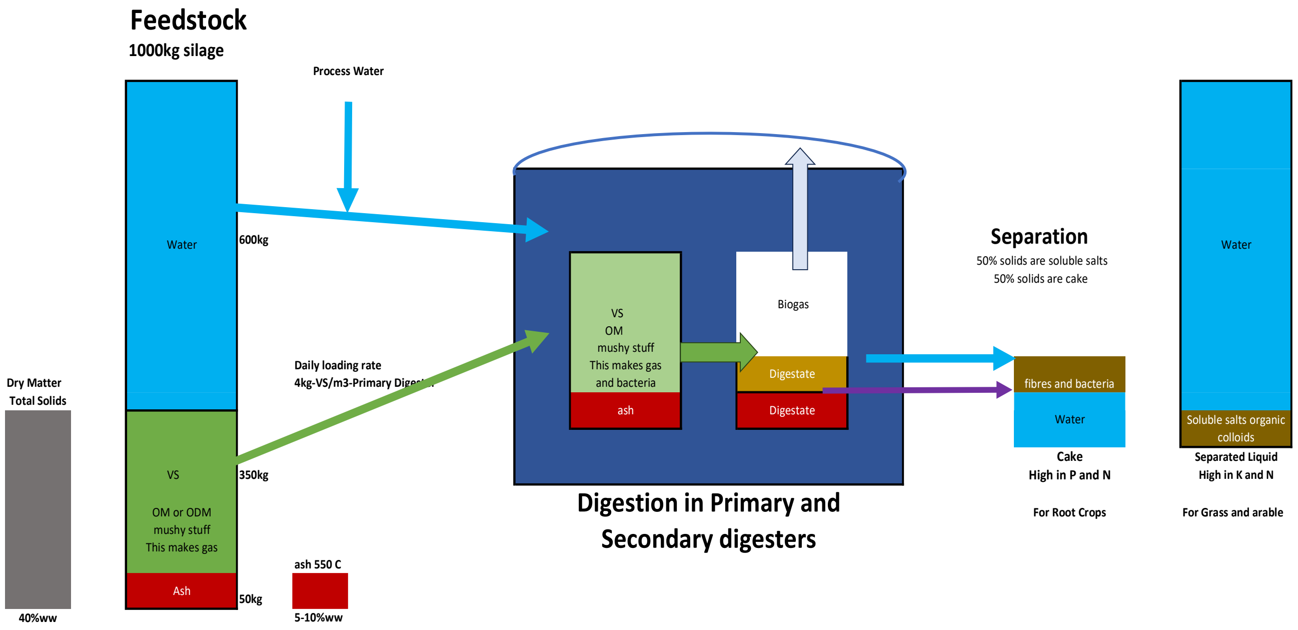

Figure 1 The basics of Anaerobic Digestion

31. The key elements of a typical digester with a feedstock of (say) 1000kg containing 400kg dry matter perhaps a silage or straw based manure:

   a. A feedstock blend is prepared from farm wastes, crop residues and energy crops, typically maize and ryegrass silage together with water and re-circulated digestate. In this simplified version for illustration, a dry silage is fed with the option of adding process water to the digester feed to dilute it and enable efficient stirring and to provide some free water for the bacteria to use in their motabolism. .

   b. The illustration above shows 400kg out of every 1000kg (1 metric tonne) of this silage feedstock is dry matter , i.e. the silage feedstock has a 40% dry matter content.

   c. 50kg of this dry matter is ash when burned in an ashing oven. The ash comprising inert minerals, clay, salts.

   d. The dry matter component of interest to gas production is the volatile solids, VS. This is found by subtracting the ash from the total dry matter. VS is sometimes referred to as loss on ignition at 550°C from the laboratory experiment used to measure it and in other documents 'Organic Dry Matter' or ODM. Thus 400kg of dry matter less 50kg of ash = 350kg of VS. It is the organic matter in the feedstock that is available be eaten by the bacteria in the digester. The biogas is made from the VS.

e. The bacteria in the digester are anaerobic meaning they thrive without air and they respire methane and carbon dioxide in roughly similar proportions which is captured in the gas dome of the digester as biogas. A fraction over half the biogas is a fuel, methane, which is the same 'natural gas' as piped through the UK gas grid, and a fraction less than half of the biogas is carbon dioxide.

f. Some of the energy from the VS is used for bacterial reproduction and biomass is created in the process that converts VS to biogas.

g. The mixture of digested feedstock and new bacteria plus some of the feedstock that has not yet been digested is called digestate.

h. The digester bacteria are a more or less constant population fed daily at an 'Organic Loading Rate'. For conservative design this is about 4 kg-VS/m^3 of digester volume. Most modern digesters are operated efficiently at 6 kg-VS/m^3 of digester.

i. After 15 to 20 days in the digester, the one tonne of feedstock has lost say 300kg of the VS as biogas leaving approximately 50gk of undigested organic matter including resistant woody materials. Mineral salts are dissolved in the liquid digestate. The total dry matter of the whole digestate is typically 7-10% dry matter comprising fibre and bacteria organic matter up to 50kg plus up to 50kg soluble salts dissolved in the water in this example.

j. It is a characteristic of a completely mixed digester tank that some of the digestate removed from the tank today will have been put into the tank yesterday. For instance if a 100 cubic meter tank was fed 10 tonnes a day, and 10 tonnes is removed from the tank today, about 1/10 of the material that is removed today would have been fed yesterday and therefore 1 tonne of the feedstock would only have been digesting for one day. This is known as 'short circuiting' and is a consequence of good stirring. A secondary digester is added to provide further processing time for the feedstock that is discharged. In most digesters about 10-15% of the total biogas comes from the secondary digester operated in series with the primary digester.

k. The digestate separator compresses the digestate through a 0.5mm screen at perhaps a hundred bar pressure to produce a fibrous stackable cake that is typically ≥28% dry matter and 72% water, say 50kg of mainly undigested organic fibre in about 179kg of wet cake.

l. The separated liquid contains most of the dissolved salts. This will be about 511kg of digestate from the original feedstock plus any process water used for dilution.

m. A mass balance for the plant can be estimated as follows:

Input 1000kg Feedstock + process water =	Outputs	Biogas	300kg
		Cake	179kg
		Sep Liquid	511kg + process water
		Total	**1000kg + process water**

32. The process water is the fluid required to make the dry haystack-like feedstock into a pumpable soup of about 16% dry matter for feeding the digester and enabling the digester contents to be stirred. As can be seen in the above figures, the amount of separated liquid, or liquid digestate, will depend to a certain extent on the amount of process water including recirculated digestate liquid added at the beginning in order to create the ‘soup’. This thin digestate is strained through a screw press and the organic fibre cake compressed to perhaps 100 Bar to squeeze out the water thus separating the thin soup into a small amount of dry cake at 28%-40% dry matter and a large amount of saline liquor.

33. These principles are expanded further to the specific 2022 design proposed below.

Planning Background Provided by Birketts

34. The planning application which is currently under consideration is situated on land which forms part of Deal Farm, Kenninghall Road, Bressingham, Norfolk, IP22 2HG. The ‘Design and Access/Planning Statement Deal Farm’ which accompanies the application describes the farming operation as follows:

a. The Oaks (on Kenninghall Road: 350m from the AD site) – comprising a farmhouse (Farmer’s residence) large chicken unit, beef-cattle unit, grain stores, straw stores and various farm buildings;

b. Deal Farm (on Kenninghall Road, adjacent to the AD site) – comprising a large pig fattening unit, producing liquid and solid pig manures and used bedding; straw storage; maize/wholecrop field clamps; muck pads & heaps; and beet pads;

c. 335 hectares of arable land (owned by the Farm) – details submitted along with the application; [using the latest set of field maps provided by the Appellant and listing and summing the areas I get a slightly different land area, 357.96 ha [appendix 6]

d. 101 hectares of arable land (3rd party land – farmed and cropped);

e. Straw Contracting (harvesting, baling and onward sale).

35. Deal Farm and The Oaks operate as a single agricultural holding. The Oaks is the main farm site and Deal Farm is an additional site. They are both working agricultural farms comprising of arable land and livestock. Both sites are situated on Kenninghall Road, 0.5 miles apart. They are south west of Common Road and 2 miles north of Bressingham village in Diss, South Norfolk.

36. There have been seven planning applications in relation to an anaerobic digestion plant at Deal Farm since 2013. The first two planning applications were situated near The Oaks, with the remaining applications relating to Deal Farm. The applications have related to a various feedstock inputs to the proposed plant. Six of the planning permissions with clear input figures we have identified and illustrated in fig.2 below.

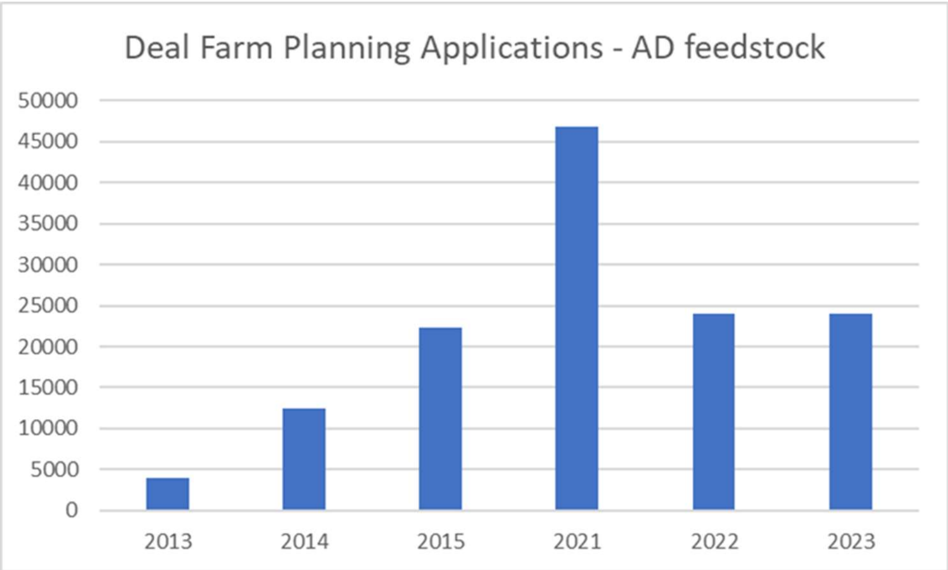

Figure 2 The feedstock input (tonnes per year) for each planning permission application

The 2022 Application

37. Prior to the submission of a planning application in 2022 (which I come on to address below) the Appellant submitted a planning application in 2021 ('the 2021 Application'.) This was the largest increase in the series of feedstock input statements and is related to the purchase of the site by Storenrgy. The input in the 2021 application increased to 46,750 Tonnes per year with a note on natural variation possibly enabling the maximum feedstock to be increased by a further 20% reflecting the impact of weather on crop yields and therefore necessitating a design capable of handling 56,100 Tonnes per annum of feedstock (being 46,750 TPA x 1.20).

4.2 It is estimated that the plant will process the following feedstock - 'waste' and 'non-waste' – annually, although it is important to note that inherent flexibility (+/- 20%) is required as such reflects variations in availability, and the impact of weather on crop yields:

<u>Non-Waste (56%)</u>

Maize Silage	5,000 tonnes
Wholecrop Cereals	8,250 tonnes
Grass Silage	8,250 tonnes
Straw	3,000 tonnes
Top Bales (Straw)	1,750 tonnes
NON-WASTE TOTAL:	26,250 TONNES

<u>Farm Waste (44%) – estimates based on local availability</u>

Chicken Manure	500 tonnes
Pig manure	6,000 tonnes
Cattle Manure	5,500 tonnes
Duck Manure	8,500 tonnes
WASTE TOTAL:	20,500 TONNES
GROSS TOTAL	**46,750 TONNES**

Figure 3 Paragraph 4.2 2021 D&A/Planning Statement for 46,750TPA Feedstock (CD6.20)

38. The Deal Farm digester purchase was noted on the Storenrgy web site. A copy of the website page advertising the acquisition is in the appendix 5 below. In this website Storenrgy Claim the designed output of the biogas plant is 5 million m^3 biomethane per year (570 m^3 -Biomethane/hr) the equivalent of 1,112 m^3-Biogas/ hr.

39. In 2021 this planning application was withdrawn.

40. I have not been asked to address this application in detail in the body of my report. However, it is relevant to the extent that as far as I can ascertain the 2022 application is the same as in the 2021 Application but with three amendments:

i. the feedstock table is halved

ii. one of the lagoons is removed in the later planning application,

iii. one of the access roads proposed is no longer required.

41. An enforcement notice ref. 2021/8158 was served. It is noteworthy that this document contains a useful listing of the build status of each piece of equipment listed in both the 2021 and 2022 application. The enforcement notice also required the removal of a generator, diesel tank and rechargeable battery. These were photographed on the site and I note they were labelled Aggreko which is a company I have used in the past. Aggreko hires portable generators and pumps for building sites and to replace generator equipment that has failed in service. I do not think this equipment was ever meant to be permanent but is probably installed temporarily to power the fans that maintain the integrity of the inflated gas holders. Typically if these are deflated they are subject to damage and a few hours of deflation may invalidate the warantee on these expensive covers, thus justifying the high cost of hiring a large battery and battery-charging generator. The generator would also be used for local lighting, charging of power tools and similar uses during construction. The rest of the equipment in the enforcement notice appears to me to reflect the equipment listed in the 2022 planning application that was refused and is the basis of this appeal. The full enforcement notice is attached in appendix 7 with the listed equipment on page 17 of that document.

42. The key request in 2022 is that that site equipment will be unchanged from the 2021 design (with the three caveats above) but that the appellant proposes to manage it to have a lower throughput.

43. The planning application which forms the subject of this appeal was submitted (2022/1108) to the District Council on 9 June 2022 for the construction of an Anaerobic Digestion facility (part retrospective), comprising: one digester tank and one secondary digester/digestate storage tank, silage clamps, liquid and dry feed system; digestate separation, handling and pasteurization, biogas upgrading and mains gas-grid connection; carbon capture, CHP, agricultural building; office buildings, weighbridge, two covered digestate storage lagoons, and associated plant, vehicular accesses, roads and landscaping (including earth bunds). This is proposed to be situated at Deal Farm.

44. This application seeks to reduce the feedstock level from the 2021 application level to a nominal 23,950 tonnes +/- 20%, reduce the number of digestate lagoons from three to two and removed the proposal of site access via Kenninghall Road (in comparison with the 2021 Application). Much of the development would remain the same as that which sought consent under the 2021

Application, which means that much of the equipment now applied for has the capacity to take significantly more feedstock than is now proposed by the Appellant (I address this further below). The Appellant proposes to secure the limited throughput by the use of conditions as opposed to the physical capacity of the plant. I understand that the application seeks to limit the throughput as a mechanism to reduce the number of vehicles movements. I am not a planning expert nor a transport expert and the practical enforcability of this will have to be addressed by other witnesses for the Council.

45. The 2022/1108 application was refused planning permission in late 2022 and an appeal was lodged in June this year. There will be a two-week inquiry to determine the appeal in February 2024.

46. Some of the plant has already been constructed by the Appellant (and is the subject of the Enforcement Notice). As viewed on Google Earth, the road view from Google Maps, and as listed in the table attached to the enforcement notice 2021/8158, the constructed equipment is:

    a. A landscaped, below ground level concrete bund

    b. Weighbridge

    c. Three silage clamps 70 m long, one 23.5m wide, one 34m wide, one 45m wide.

    d. A manure store

    e. Preliminary Pit

    f. Two digester feeding units

    g. Feeding tank – Separator (partially Complete)

    h. Hygenisation (Pasteurisation) units

    i. A primary digester of 35.6m diameter with an 8m wall height provides a top working level of approximately 7.5m yielding a working volume of 7,200m^3.

    j. One secondary digester and digestate store of 35.6m diameter with an 8m wall height and a top working level of approximately 7.5m provides a working secondary digester volume of 7,200m^3.

i. The digesters as built appear to be of a typically conventional flat aspect design with roof mounted double membrane biogas holders, the outer of which is permanently inflated with the use of air fans.

ii. The tanks have been insulated and clad and the mixing systems installed.

iii. Lightning conductors (they look like tall lamposts and are clearly visible in the images)

47. The additional equipment required to build the plant out as a waste processing digester <u>for which only concrete foundations or bases have as yet been constructed</u> is listed on the Enforcement Notice.

a. Oxygen Generator

b. Separator

c. CHP

d. Biogas Boiler

e. Flare (Waste Gas Burner)

f. Biogas to Biomethane Upgrader (Gas To Grid)

g. Grid Entry Unit (GEU)

h. Biomethane Compressor

i. Remote Operable Valve

j. Low Voltage Electrical Distribution Board

k. Pressure Reduction Skid

l. Substation (Monitors High Voltage to Low Voltage transformer)

m. Transformer

n. Propane tanks

o. Pump Set -Containerised with electrical panels

p. Biogas Treatment Container

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48. In addition, there is provision on the plans for a building to house a Carbon Dioxide liquifaction plant and storage of liquid CO_2 but no works have begun for this. Also no works have begun for the pipeline that connects the GEU to the high pressure mains. The CO_2 plant is noted on the plot plan of the site in the enforcement notice.

49. The biogas holders over the secondary and primary digester have been offered as a tent like structures supported by a central column. It is not know whether or not this design is a single or double membrane option. Normally ammonia control is achieved on slurry storage tanks using a single 'tent' membrane cover and pressurised double membrane domes are used for biogas covers using the air trapped between the inflated dome and the inner membrane as the biogas pressurisation system.

Information provided by the Appellant

50. In order to assess the feasibility and the design of an anaerobic digestion plant the applicant and/or their technology provider would normally provide a process description, a list of equipment, and process calculations including a mass balance.

51. This mass balance detail is important in order to understand the energy generation of the proposed development and also the amount of digestate (liquid and solid) that can be expected from the proposal. I understand that this has implications for the traffic generation of the proposal.

52. Despite the Thoni (digester manufacturer) Mass Balance being cited in descriptions of the outputs for the plant, the Appellant has not thus far provided a full process description/mass balance of their proposal. Moreover, the information which has been provided has often been inconsistent.

53. Requests were made to provide the cited Thoni Mass Balance for the plant on :

- 29 November 2023;
- 12 December 2023;
- 22 December 2023;
- 2 January 2024;
- 3 January 2024.

54. None of these requests have been answered despite the Thoni Mass Balance being quoted as the source of other data supplied as I shall demonstrate below.

55. Not being able to have sight of the manufacturer's mass balance to verify proposed digestate production and energy benefits is simply a waste of time and effort that makes it difficult for the Appeal experts to find common ground. As a result I have had to rely on the AD Ingenuity LLP design models to predict the outputs from the feedstock table. These have their source in several decades of practical application of the biotechnology and verification in field conditions. I will come to these models below and discuss the outcomes but first it is important to understand some of the ambiguities and missing information in the data provided by the Appellant.

56. In order to understand the processes which are to be involved I have had particular regard to the following information provided by the appellant during the application and as part of its appeal:

   a. The plans of the proposed development; CD 1.1-CD 1.18 inclusive

   b. The design, access & planning statement (9 June 2022); CD 1.38

   c. The transport statement (9 June 2022);CD 1.32

   d. The transport statement addendum (27 October 2022); CD 2.7

   e. The quod planning benefit and need analysis submitted with the appeal (26 June 2023); CD 5.11

   f. The royal haskoning transport statement submitted with the appeal (26 June 2023).

   g. As part of my review of the appeal documents I sought further information from the appellants through Birketts solicitors. This request was by email dated 29 November 2023 and is attached in Appendix 8 below.

   h. Royal Haskoning Transport Planning Skeleton Proof and Appendices Royal HaskoningDHV 20 December 2023 CD 5.15

   i. Planning, Design and Access Statement 2021/2036 9 September 2021 CD 6.6

57. The key document for calculating the performance of the equipment is the feedstock table that is in section 4.2 of the 2022 Design and Access Statement CD 1.38

Design & Access/Planning Statement: AD Plant, Deal Farm, Kenninghall

Non-Waste (56%)

Maize Silage	3,500 tonnes
Grass Silage	5,000 tonnes
Straw	6,450 tonnes
NON-WASTE TOTAL:	14,950 TONNES

Farm Waste (44%) – estimates based on local availability

Chicken Manure	500 tonnes
Pig manure	5,500 tonnes
Cattle/Duck Manure	3,000 tonnes
WASTE TOTAL:	9,000 TONNES
GROSS TOTAL	**23,950 TONNES**

Figure 4 2022 Feedstock Table

58. The Appellant responded to the Council's request for further information of 29 November 2023 by email on 14 December 2023 (this is found in Appendix 1 to CD5.5). I draw upon some of the information provided as part of my evidence below. At this stage I would note that in relation to the mass balance the Appellant's response states 'The technology provider is presently reviewing the mass balance model and a further revision will be provided in due course'. The response to the query regarding digestate re-circulation states 'Please refer to the mass balance model issued by the project technology provide Thoni which identified the substrate recirculation including the level of detail request'. However, no process calculation or mass balance was provided. Despite requests for this information being made on numerous occasions.

59. As set out above, on 20 December 2023 the Appellant's highways consultant provided the County Council with a document which is entitiled 'Transport Skeleton Proof' (CD5.15) which opens by stating that the operational data which underpins the transport position for the proposed AD plant has been revisited. This letter and its appendicies contain relevant additional information in relation to the process for the AD facility. In particular, Appendix D gives figures for 'Process Additives and Materials Exported'. These include the amounts of CO_2, Propane, solid digesate and liquid digestate.

60. Overall, there is a frustrating lack of information and internal inconsistencies in the information which has been provided by the Appellant in the 2022 planning application, in the answers to my request for information (Appendix 8 below) and the technical appendices (CD 5.15) recently presented for the Appeal and unhelpfully presented on the last Friday before Christmas.

Amount of feedstock

61. The excerpt below is from the 2022 D&AS (CD 1.38)

> 4.2 It is estimated that the plant will process the following feedstock - 'waste' and 'non-waste' – annually, although it is important to note that inherent flexibility (+/- 20%) is required as such reflects variations in availability, and the impact of weather on crop yields:

Figure 5 Section 4.2 of the 2022 D&AS (CD 1.38) Re. 20% variability in feedstock

62. There is ambiguity in section 4.2 of the 2022 D&AS statement (figs. 4 and 5). Does the +/- 20% refer to the individual line items or the whole declared feedstock mass for the year? The Thoni Mass Balance may clear up this issue if I have sight of it. The transport and benefits calculations are reliant on this understanding because if the variation, up and down, is allowed on line items the output of the system will be relatively even around the nominal total figure for annual feedstock mass given, but if the % means the % of the total, then the feedstock transport and the benefits would have to be calculated as 20% above the 23,950 TPA = 28,740TPA.

The processing of straw

63. The appellant's proposed feedstock includes 6,450 tonnes of straw. Straw is very dry. While maize and beets have a dry matter of about a third of weighbridge mass, straw has a dry matter content > ¾ of the weighbridge mass. However there is a problem with digesting straw.

64. Straw is not a digester feedstock until it has been prepared for digestion. Chopping to 25mm length, grinding, bricketting or mulching in caustic soda are the conventional methods of processing straw into a digester feedstock and this preparation can take a lot of energy and land area to achieve consistently good results at large scale.

65. In my review of the 2022 application plant I noted that there was no indication as to how the straw was to be processed into a feedstock. Therefore, as part of a request for further information (on 29th November 2023) the Council asked 'Please can you confirm how the straw

to enter the AD facility will be stored, processed and where' (line 8 of APPENDIX 8 BELOW). The response provided by the Appellant on 14 December 2023 states:

'Straw will be stored in the feedstock storage clamps.

Straw will enter the anaerobic digestion process through one of two 90m^3 feeding hoppers. As part of the input feedstock, straw will then be conditioned for digestion through a Linder Limiator (sic) chopper pump to improve the digestion qualities of the material.' (See Appendix 8). I believe this is straw processing equipment manufactured by Lindner in Austria to crush the straw and blend it with water or liquid separated digestate to produce a normal liquid feed for the digester.

66. This is a substantial machine, about 6 meters high with a large amount of supporting equipment. It remains the case that the Appellant has not provided information as to (a) where the straw processing works will be sited, (b) how the operation will be conducted or (c) the energy which the chopping process will take. One Lindner model is powered by a 90kW crusher motor plus a set of 'auger wall' motors and conveyors. Processing 17.67 tonnes a day of straw is a big manufacturing effort. The energy requirement for preparation of straw into a digester feedstock would further reduce the overall plant net benefit summarised in Table 1 of this report. On the basis of an engineer's estimate, based on 50 kW of absorbed power at 5 tonnes per hour, I evaluate the parasitic load for straw processing alone at approximately 180kWh per day.

Digestate production

67. All the stated feedstock materials have a low moisture content. Overall the average dry matter content of the feedstock is 44.2% dry matter which could be stacked like a haystack. This is also very fibrous material and once inside the digester will be difficult to stir. In conventional wet digesters in order to make the digester contents stirrable the digester contents need to be diluted to about 16% dry matter and fed either as a liquid slurry to the digester or diluted inside the digester with added water. This will degrade to biogas and a digestate of <9% dry matter required to achieve a reliable non-foaming, non crust forming digestion.

68. The water added to the digester to achieve an efficient digestion is added to the digestate volume and mass that has to be spread and stored in lagoons.

69. The application states that the lagoons must be able to store 9 months worth of liquid digestate.

> 4.6 The release of the Reduction and Prevention of Agricultural Diffuse Pollution (England) Regulations 2018 - also known as the "Farmers Rules for Water" (and more specifically the enforcement of these Regulations from March 2022), has extended the period over which liquid digestate must be stored from 5 months to 9 months of the year. The addition of the proposed lagoon storage will enable the site to meet these statutory obligations. There will be no direct, additional impacts in relation to vehicle movements to/from the AD plant as a result of the proposed storage lagoon as all materials will be pumped to and from the storage.

Figure 6 2022 D&AS CD 1.38 section 4.6 - Re. 9 months storage requirement for liquid manures

70. I note that the appellant has given inconsistent accounts as to the relationship between digestate spreading and vehicle movements. This is a matter for the transport evidence. However, I am concerned with the inconsistent figures given for the production of liquid and solid digestate.

71. The Transport Statement dated June 2022 prepared by plandescil (CD 1.32) states on page 10 that 'the total digestate from the plant is expected to be 23,950 tonnes which is expected to be split 50:50 between solid and liquid fraction'

72. The Transport Statement by Royal Haskoning (dated 7 June 2023) (CD 5.9 and 5.10) submitted with the appeal states that the proposal would result in the production of 10,339 tonnes of solid digestate per annum and 10,309 tonnes of liquid digestate per annum (page 14 and also table 3.5 on p18).

73. However, most recently, in the appendices that accompanied the Royal Haskoning DVH Transport Planning skeleton Proof dated 20th December 2023, (CD 5.15) is the following statement of Materials exported:

Process Additives and Materials Exported (New Movements Highlighted)

	T	Payload (t)	Two Way Trips	
CO2	3285	20	329	Payload data from Biocarbonics, and CO2 t from Storengy
Propane	170	10	34	Propane requirements from Storengy, small tanker size confirmed by Storengy
Solid digestate	20075	12	4015	t digestate from Thoni mass balance. Spread using muck spreaders per existing farming operations on RG Aves landholdings.
Liquid digestate	14235	0	0	t digestate from Thoni mass balance. All can be umbilical fed to RG Aves landholdings - see WRM data.

Figure 7 Materials Exported from Appendix D Royal Haskoning DVH 20th Dec. 2023 (CD 5.15)

74. Fig. 7 From appendix D citing the Thoni mass balance (which has not been provided, despite multiple requests), indicates that 20,075 Tonnes of solid digestate (separated Cake) and 14,235 T of Liquid digestates are generated from the AD Plant and require export. These figures are very different from those which have previously been provided by the Appellant. They are also impossible to achieve on a wet digester as I shall demonstrate later.

75. As is clear from the above, the Appellant has given three different sets of figures for the solid and liquid digestate which the proposal will produce. Below, I set out my process calculations and directly address a question asked of me as to whether the Appellant has correctly identified the level of digestate which its facility is likely to produce.

76. In short, I conclude that none of the Appellant's sets of figures highlighted in yellow can be correct and I address this further below.

CO_2 production

77. As with the figures for digestate production, the Appellant has provided inconsistent figures for the amount of propane required for the facility to operate and the CO_2 which the proposal will capture for sale, offsetting vehicle carbon production.

78. With regards to CO_2 production, at p14 the Transport Statement dated 7 June 2023 (CD 5.9) states that 4,835 tonnes per annum would be produced. Whereas, the Appellant's latest information in appendix D to the Transport Skeleton Proof (CD 5.15) states that 3,285 tonnes of CO_2 would be produced.

79. Calculation ADI504-215-G estimates the 3,889.4 tonnes of CO_2 per year will be produced from the stated feedstock. The basis of this calculation is explained in the mass balance calculation in Appendix 3.

Propane Use

80. With regards to propane use, at p14 of the Transport Statement dated 7 June 2023 (CD 5.9). It is stated that the proposal will require 572 tonnes per annum of propane. Whereas, the Appellant's latest information in appendix D to the Transport Skeleton Proof states that 170 tonnes of propane would be required. I consider that this is an over-estimate and my mass balance calculation considers that 89.35 tonnes per year would be required.

81. Propane is required when injecting the biomethane into the gas grid to ensure that the burning quality of the injected methane gas exactly matches a standard for the gas in the pipeline to ensure that the flame height of all pilot lights in consumer equipment is maintained at a constant level. The characteristic that determines flame quality is related to the Calorific Value and density of the gas and named after its inventor the 'Wobbe Number'.

82. Using AD ADI504-215-G the Biogas and Methane Production is estimated as follows:

    a. Biogas production = 568.9 m^3 / hour
    b. Methane = 291.42 m^3/hr (51.2% methane in biogas transferred to grid upgrader)
    c. Propane Dose Rate = 0.0689 litres/m^3-CH_4 (I have used the propane dose rate from a digester I monitor every day which will use the same 'Wobbe index' number to calculate the propane application rate (it is on the same gas network in Norfolk))
    d. Propane Dose = 291.42 m^3/hr x 0.0689 litres-Propane/m^3-CH_4 x 8,760 hours per year
    e. Total Propane =175,928 litres per year
    f. 1Kg Propane = 1.969 Litres and therefore the total mass of propane is 89.35 tonnes per year.

83. The Appellant's Propane consumption estimate is twice as large as the projected propane consumption from the stated feedstock table and that is assuming scenario D applies in ADI-504-209-G, the Energy and Heating calculations. Scenario D is one of the four scenarios for how the plant is projected to operate.

84. Note that in this calculation Scenario D assumes all the parasitic loads required by the digester boiler, CHP unit and electric panels are provided by external grid connections and imported to the site. If the internal gas and electrical energy was provided by the digester biogas / CHP unit, then the surplus methane requiring propanation would reduce from 291.4 m^3/hour to between 92.8 to 178.4 m^3/hour with a proportional reduction in propane consumption.

Summary of information provided by the Appellant

85. Overall, whilst the Appellant has provided some information through its application documents, appeal documents and responses to requests for information from the Council, at the time of writing this proof, a full process calculation has not been provided (despite being requested on a number of occasions as listed previously). Some limited information has been provided but the figures are often inconsistent. As such, in order to understand the likely energy generation and digestate production of the proposed facility it has been necessary for me to undertake my own calculations. These are best estimates on the information I have at the present and on the basis of my own experience as to the operation of AD facilities. In the event that the Appellant provides updated or new information I reserve the right to re-visit my calculations accordingly.

AD Ingenuity Calculations

86. The ADI Calculations and the assumptions behind them are set out in detail in Appendix 3. I have taken data from the Appellant's documents beginning with the feedstock table (Fig.4 above) and used a conventional wet digester process model that has been tested over some decades.

87. The lack of a mass balance from the Appellant or detailed information as to how the plant will run has meant that it has been necessary for ADI to make assumptions which are based upon our experience of operating wet digesters.

88. One assumption relates to the addition of water and the amount of re-circulated digestate. The raw feedstock is very dry. This will have to be blended with water and as much digestate as we can envisage without compromising the digester bacteria functions due to salinity that increases with each recirculation of the digestate. There has to be a fresh water feed in these digesters. The feed will enter the digester at a total solids % consistent with making a pumpable soup that is pumped into the digester for processing. From experience fibrous fluids can gell in pipes when flow is stationary and block the system. Therfore, we chose a feed of 16% dry matter. Pipe diameter choice may widen this slightly but we have a lot of

experience with straw and manure digesters in the USA and 16% would be a recommendation for any designer wishing to make a reliable plant.

89. We have also had to make some assumptions/calculations regarding the parasitic load of the equipment used as part of the facility. As is explained in Appendix 3, the Appellant has provided some information as to the heating requirements of the digesters and the pasturisers. However, it is considered this is not reliable. Full justification for AD Ingenuity's calculations is set out in appendix 3.

90. Ultimately, the mass balance is a mathematical certainty in a series of calculations that follow using the assumptions detailed in Appendix 3. As already stated, in the absence of detailed process information from the Appellant some of the assumptions have been based upon experience. In the event that the Appellant provides updated/new information then I reserve the right to re-visit these calculations, if required, to take account of that new information.

91. I address the detail of my calculations relating to digestate and also the benefits of the plant in my response to the questions asked of me below. I do not repeat them here.

92. I now turn to the specific questions which have been asked of me.

The capacity of the AD equipment which has been applied for;

93. The capacity of the equipment that has been applied for is at least 2x larger than required for the feedstock table in the application.

94. Moreover, the Gas Upgrading Plant (Appendix 9 – Pentair Quotation attached) and associated equipment is sized at 1,680Nm^3/h approximately 3x the size required to treat the full 568.9m3/hr of biogas from the given 2022 feestock table.

95. According to the website of Storengy recorded on 06/01/2024 (see appendix 5 below) 'the proposed Anaerobic Digestion plant is projected to produce over 5 Million m^3 of biomethane per year'. This is over 570 m^3-Biomethane/hr equivalent to a digester biogas production of 1,157 Nm^3-Biogas/hr including an allowance of 4% for gas slip in the equipment and precisely 2x the size of the plant applied for.

96. Based on the feedstock in fig. 4 above, the planning permission sought would produce by my calculations only 569 m^3-Biogas / hr. This implies the planning permission sought will be for a plant operating at approximately half its digester capacity and one third of the gas upgrading plant capacity.

97. This conclusion is supported by the fact of the 2021 application which was withdrawn. This included the same plant but was for double the throughput.

What the implications would be if the AD plant were designed for the throughput proposed by the Applicant, both in terms of its design and its efficiency?

98. The short answer to this question is that if the AD digesters were designed for the throughput proposed by the Applicant they would be half the size they are now in volume. I have sought to illustrate one way of achieving this in ADI 504-011-0 and ADI 504-012-0 (Appendix 3).

99. Smaller digesters would be more efficient. This is because the retention time in the digester would halve and that would reduce the digester heating load, probably by a third and similarly for the electrical stirring load. Both the smaller digester and the digester that has been built would be able to provide a stable biological fermentation. However, the larger unit as built would be underloaded by modern standards by a factor of about 2x. In relation to other digesters the larger unit would have a longer retention time which results in a disappointingly low overall output and higher energy costs per tonne of feedstock. The digestate would essentially be lingering in the digester absorbing heat and stirring energy for longer than the correctly sized unit while not producing significant biogas. The economy of the smaller plant would be much improved given lower capital costs for essentially the same biogas production. I consider that there is no good reason to build the plant at more than twice the capacity required.

Does the AD facility include all the equipment necessary to function?

100. My review of the application has revealed two pieces of equipment which appear to be missing. The first relates to the control of odour from the pasteurisation process. The second relates to the processing of straw.

101. Pasteurisation is governed by strict rules and monitoring by the local Animal and Plant Health Agency (APHA). The rules were set by the EU and adopted by the UK and require digestates to pass though a 12mm screen to limit maximum particle size and be heated as an isolated batch for one hour at 70°C

102. Hydrogen sulphide is a toxic and malodorous gas generated by sulphate reducing bacteria, usually known as SRBs. These grow very slowly but tend to thrive in biogas plants that are underloaded and that have long retention times. The hydrogen sulphide is soluble in water

(typically 7,500 mg/l in cold water and close to 1mg/l when heated). The process of heating the digestate will expel dissolved H_2S into the headspace of the pasteuriser. The odour theshold for H_2S (the minimum concentration that can be detected by humans is about 6 parts per Billion ($6x10^{-9}$) making this a priority chemical for odour control. When the batch pasteuriser is filled, the expelled air with its load of H_2S needs to be controlled in an odour control unit.

103. In its request for further information from the Appellant on 29 November 2023 the Council asked how odour from the pasturisation process is intended to be controlled and what equipment will be used. The Appellant responded with:

'The proposal to utilise the second digester as a digestate store prior to pasteurisation will reduce residual biogas and therefore reduce odour potential.

Swan neck valves on each of the pasteurisation tanks shall be connected to feed either a carbon filter or acid scrubber filter for the treatment of displaced air within the pasteurisers. The specification of this equipment is to be confirmed.'

104. I consider that the comment: 'the proposal to utilise the second digester as a digestate store prior to pasteurisation will reduce residual biogas and therefore reduce odour potential' is not in my opinion correct. I agree with the residual biogas being reduced, this is what secondary digestion is all about, but the primary digester is underloaded and already has a long retention time and the H_2S is very likely to increase greatly due to the time given to allow the SRBs to increase in biomass. Doubling the temperature of the digestate in the pasteuriser will cause the H_2S solubilty to halve and this will expel H_2S from the liquid phase to the head space air in the pasteuriser. This is where most of the odour will come from during pasteurisation.

105. It is suggested in the response to the LPA's questions that swan neck valves on each of the pasteurisation tanks will be connected either to a carbon filter or an acid scrubber filter with the specification as yet unconfirmed. The equipment is not yet specified and I consider that it will take up considerable space that is not on the plot plans. It may take a combination of wet scrubbing plus a biological filter and the size of this equipment is significant.

106. This application proposes that significant amount of its energy generation will come from straw. I have explained above that straw cannot be loaded into an AD facility without first being processed. Nowhere do the plans show any equipment for this processing to occur or where it is to occur. The Appellant has stated that it is proposed that the straw would be chopped

through a 'Linder Limiator' chopper pump. As stated above, this I believe is a misspelling and the equipment is made by Lindner in Austria. It is a large piece of equipment 6 meters high and I would note that it does not appear to be shown on the approved plans.

Are the figures of liquid and solid digestate likely to be correct?

107. The short answer to this question is no.

108. As demonstrated above there has been no consistency in the Appellant's documents regarding the amount of liquid and solid digestates produced in this plant. The mass balance from Thoni the designer of the plant has been cited but this has not been released. Where information has been provided it has been incomplete and unreliable. In the absense of the often reported Thoni mass balance, the only data set that I can trust here is the ADI standard model that has been tested and tried on wet digestion plants.

109. Appendix 3 sets out an explanation of the ADI standard model (ADI504-215-G) and explains how the amount of liquid and solid digestate has been calculated. ADI504-215-G concludes that the proposal will output 32,896 tonnes of digestate and that 20,360 tonnes of this will be separated liquid digestate and 12,536 tonnes will be solid/cake digestate.

110. The table below summarises the various statements made by the Appellant and my own conclusions. Table proves the proposed cake is liquid, and Table B is my expected surplus:

source		Tonnes per annum			
		Total digester output	Sep Liquid	Sep Cake	Comment
Jun-22	Page 10 Transport Statement	23,950	11,975	11,975	That is the same as the input - no lost mass to gas production?
07/06/2023	Royal Haskoning	20,678	10,339	10,339	If the lower digester output is due to gas production then 3272 Tonnes of gas is only 311 m3/hr of biogas?
20/12/2023	Royal Haskoning Transport skeleton Proof	34,310	14,235	*20,075*	94 T/day digestate
04/01/2024	ADI504-208-G Table A from given feed table	32,537	12,536	*20,001*	Cake is 17.55% Dry matter (slop) to match separated cake mass given by Royal Haskoning 20/12/2023 See Full Mass Balance in ADI504-214
04/01/2024	ADI504-208-G Table B from given feed table	32,896	20,360	12,536	Conventional wet digester performance - See Full Mass Balance in ADI504-215

Figure 8 Listing of Appellant's separated cake and liquid for export and ADI prediction Table B

111. It can be seen from the above (Fig.7) that the most recent claim of the Appellant is that the total digstate output of the plant would be 34,310 tonnes. This is broadly aligned with the 32,896 tonnes which is estimated in ADI504-206-G, table A

112. However, there is a significant difference between the Appellant and myself as to the fraction of solid and liquid digstate. The figures are broadly the reverse of the other.

113. In short, it is impossible for a well mixed 9-12.5% dm digestate in an anaerobic digester to produce more solid digestate than liquid. 208-G Table A proves the proposed cake is a liquid. Table B is our expected surplus after some digestate has been recycled.

114. I attempt to demonstrate this in the following simplified way. Assume 100 tonnes of digestate leaving the digester and entering the screw press separator. For ease of mathematics assume here that the whole digestate in the digester tank is 10% dry matter. 100 tonnes of this material will contain typically 5 tonnes of fibre that has not been turned to biogas and 5 tonnes of soluble salts (actually the fertiliser Nitrogen salts, Sodium and Potassium Chloride salts etc.)

i. The 100 tonnes of whole digestate comprises 90 tonnes of water, 5 T Fibre 5 T salt.

ii. When separated all the fibre is in the cake = 5 T but also the cake dry matter is about ¼ of the cake so the cake consists of 5T of fibre and 15 T water = 20 T cake

iii. The separated liquid contains 90-15 T of water = 75 T of water plus 5 T salt = 80 T

iv. The ratio of cake to separated liquid is 1 T cake to every 4 T separated liquid.

v. It is impossible to find a liquid fed digester with more separated cake than separated liquid. This is explored in the Appendix 3 where the figures provided by the Appellant for the mass of separated cake (being greater than the liquid mass) is obtained by increasing in the model the liquid content in the cake. The cake it is found is not cake but a 17.5% dry matter liquid and therefore cannot be made by a screw press.

115. A small adjustment is required in the above model as some of the salt will be in the 15 T of water in the cake but within the limits of this simplified example this does not alter the big picture which is in practical systems, based on a pumped-liquid fed digester that converts half the solids into biogas, the separated cake is going to be about 20% of the Separated Liquid, mass a ratio of 1 : 4 cake to liquid.

116. Even if half the separated liquid is recycled that still leaves a balance between the two products of digestion as a ratio of 1 T cake to 2 T of separated liquid for storage and distribution.

117. In order to test the Appellant's latest figures, I have conducted an additional calculation in order to understand what the dry matter content of the Appellant's solid digestate would be to make 20,075 T per annum

118. I have done this by back calculating the solid digestate dry matter to broadly match the latest Royal Haskoning figure for solids mass whilst maintaining the mass balance from the same feedstock table. This was done by trial and error changing the cake dry matter in the model until the mass of it matched the target figure and it transpires that the cake dry matter is 17.55% which is actually a liquid.

119. The detailed calculations for this are in the Appendix 3 of this document with the document numbers as follows:

a. Calculation ADI 504-208 is the key calculation predicting the amount of cake/solid and separated liquid digestate from the given feedstock after digestion. This contains the side by side comparison of the consequences of changing fom 17.55% to 28% dry matter in the cake and illustrates the symmetry of the numbers that leads one to consider if the Appellant has inadvertantly mixed up the figures for its liquid and solid digestate.

b. ADI 504-208-G is based on a comprehensive analysis of the initial Feedstock ADI 504-203-G, and then traces the fate of the feedstock through the process of preparing the raw feedstock into a digester feedstock, extracting the biogas and separating the digestate. The following prior calculations apply: Feedstock Delivery and Preparation ADI 504-205-G, Anaerobic Digestion feed substrates ADI 504-206-G, and the Anaerobic Digestion process ADI 504-207-G.

c. In more graphical form, the Full Mass balance for the 17.55% separation phase is shown in ADI504-214-G and the Full Mass Balance for the 28% separation phase is shown in ADI504-215-G.

120. The result of my calculation demonstrates that the Appellant's asserted solid digestate will in fact be only 17.55% dry matter which is a pumpable liquid and would need to be stored as such. In other words, the digestate which the Appellant desribes as solid would not be solid.

121. Given the fact that (a) we do not have the designer's mass balance for reference, and it is impossible for a wet digester to produce more solid digestate than liquid, (b) the overall level of surplus digestate (liquid and solid) arrived at by myself and in the Appellant's latest calculations are similar and (c) it is the proportion of liquid vs solid digestate where we disagree and the figures almost mirror one another I wonder whether the Appellant has erroneously transposed the digestate figures on the designer's mass balance, citing the solid as liquid and vice versa.

122. The amount of digestate produced and its distribution is important because it is relevant to potential transport movements and also the level of lagoon storage required.

123. The proposed installation includes two 5,000m^3 lagoons that will provide a total of 10,000 m^3 of storage and the 'secondary digester and digestate store' has the capacity of 7,200 m^3. The amount of secondary digester capacity that can be used for long term variable storage volume is not stated. Some of the volume of the tank will be used to buffer the separation system, typically at least 4 days retention time. In addition an emergency contingency will normally be held free for icy conditions or power failures. That could be one week to ten days. What is stated is that the secondary digester is required to operate as a secondary digester but the retention time is not stated. The type of stirring system and the stirring system minimum depth is also not stated. It is shown as a slow moving Thoni paddle type on one drawing and nowhere is the minimum operating depth mentioned. The amount of secondary digester retention required for processing is an open question. Therefore the amount of variable volume in the secondary digester that is available for long periods of time (months) is also an open question. As the operating philosophy is not declared it is impossible to know how the variable volume in the secondary digester is to be used and whether or not this can be included in the required digestate storage. I note however that all the references to the 9 month storage have been related to the building of lagoons and I am therefore minded to assume that long term storage of liquid digestate is only to be considered as lagoon volume.

124. The amount of storage volume for our best estimate in ADI504-215-G is defined by a surplus of 55.78 tonnes per day surplus separated liquid after 110 m^3 – separated liquid digestate per day is recirculated. 10,000 m^3 storage will hold 179.3 days of surplus separated liquid. This is 5.98 months storage not the 9 months required.

125. Whilst reserving the right to revisit these figures if the Thoni Mass Balance is eventually presented with statisfactory explanations for the previously reported estimates, I can say that at the time of writing, the Appellant has not provided correct figures as to the amounts of liquid and solid digestate generated, rather the Appellant has provided a set of internally inconsitent

and contradictory figures as I have explained. Further, it would appear that the Appellant's proposal has too little storage for its liquid digestate.

126. I would add that adequate storage of digestate is an important part of an Anaerobic Digestion facility. This is because the spreading of digestate (and other manures) is highly controlled according not only to the time of year when spreading is allowed but also the nature of the land. The Appellant's farm is within a Nitrate Vulnerable Zone and therefore the guidance for 'Using nitrogen fertilisers in nitrate vulnerable zones' (DEFRA and the Environment Agency) applies. There are different application rates for grass land and arable land and to this end I have made a listing of grassland and arable land areas for spreading from the Royal Haskoning Appendix (CD 5.I5) and note that the Appellant has made varying statements about where it will ultimately spread the digestate. However, at present I have not seen any assessment of whether this is practically achievable. In previous years this farm would have been spreading mainly manure and solids and the window for doing this is much wider than for liquid digestates.

Is the Appellant correct as to the levels of energy which would be generated?

127. Fig. 8 below sets out the benefits stated in (CD1.38) by the Appellant in 2022 in two sections the first is for the digester and the second is for the carbon dioxide recovery unit. There is no change in the calculated outputs in the most recent documents provided by the Appellant in 2023. I will examine each section in turn beginning with the Energy generated.

4.11 Within this context, the application proposals are for a 4MW biomass fueled renewable energy facility. The plant will produce up to 35-39,000MWh of renewable energy (biomethane) from local biomass, sufficient energy (based on an average household consumption of 12 MWh/annum) to serve around 3,250 homes. Total CO_2 emissions saved (based upon a CO^2 output from burning gas of 0.185 kg/kWh) would be 7,215,000 kg/CO_2 per annum.

4.12 The proposed CO^2 recovery plant (not part of the 2015 scheme) would also produce over 5,000 tonnes of CO^2 in liquid form; as a by-product of the anaerobic digestion process, carbon dioxide will now be captured, processed (liquified) and distributed to manufacturing industry (food, drink, cement, etc.). In recent times, production of certain food, drink and other products was compromised due to national carbon dioxide shortages. The plant will help alleviate some of the UK's supply issues for a gas that is critical in so many industries. This process displaces the use of fossil fuels with sustainably-produced green gas, reducing the net flow of CO2 (there are no atmospheric emissions from this part of the process) to the atmosphere and capturing all the by-product of the process. This is the equivalent of removing:

- 1,150 cars each year from UK roads; or
- 13,800,000 road car miles per year.

Figure 9 2022 D&AS Benefits Statements (CD 1.38)

128. 4.11 in the 2022 D&AS (CD 1.38) suggests the digester has a 4MWthermal output. If operated continuously, i.e. for 8,760 hours per year that would have an output of 35,040MWh per year which is at the low end of the estimate given in fig. 9 above of 35,000 to 39,000 MWh/year. The lower figures is equal to the energy consumption of 3,250 homes at 12 MWh/year per home.

129. However, the plant was purchased by Storenrgy and the energy production of the system according to Storenrgy, the new purchaser of the plant (see web site page in the appendix below) will be 5 million m^3 biomethane per year (570 m^3 -Biomethane/hr) the equivalent of 1,112 m^3-Biogas/hr. Since 1m^3 of biomethane contains 10kWh of energy, the claimed output on the web site is 50,000,000kWh which is a declared intent of producing 50,000MWh/year, considerably more than 35-39,000 MHh/year in the D&AS.

130. I have also considered the Planning Benefits and Need Analysis document which has been produced by Quod and was submitted in support of the appeal. In the document it states

131. “4.7 The Appeal Scheme would make an important contribution to the UK’s energy needs, helping to diversify. The Appeal Scheme would provide the following benefits:

132. 4.7.1 Biogas: Anaerobic digester facility would produce up to 39,000MWh of renewable energy (biomethane), which is enough energy to serve approximately 3,250 homes” I have been asked to check whether this is a correct statement of the energy output of the 2022 Application.

My assessment of the benefits

133. For reference the energy in one m^3 of refined biomethane contains 10kWh of energy at normal temperature and pressure, that is to say before it is compressed into the gas pipeline. Biogas varies in composition but approximately half the volume is methane and half carbon dioxide. Typically one m^3 of biogas contains 5 to 6kWh of energy depending on the methane content. For instance a cubic meter of 54% methane biogas contain close to 5.4kWh of thermal energy.

134. Biogas production is calculated using the information in the feedstock table in figure 4 and the AD Ingenuity digester calculations model.

135. AD Ingenuity calculates a biogas production rate from the digesters of 568.9m^3-Biogas/hr from the Appellant’s proposed feedstock.

136. There are a number of ways of operating the plant which would impact upon the amount of energy generation. I consider that there are four main ways of operating the plant and I have evaluated each these. These are identified with notes in ADI504-209-G using the 2022 Design and Access statement only. The four scenarios for which an energy balance is provided are these:

a. 800kWe CHP unit operated full time, boiler on standby not used, surplus electricity is exported. Heat from the CHP is used in the process, excess heat is lost to atmosphere

b. The same CHP engine is operated at the maximum turn-down for the engine, a half load, 400kWe producing 429kWth of hot water for process use. The boiler is used for peaks, no heat is lost to atmosphere.

c. The CHP unit is used at 500kWe and 537kWth to eliminate the boiler use

d. All heat and electrical use by the plant is supplied by importing from the gas and electricity grids. 100% of the biogas produced is sent to the upgrader and all the biomethane is exported to grid. This produces the best overall output but from this figure the grid consumption has to be subtracted. The digester heating load is calculated for each month providing the process heat requirement of 3,906.76MWh/yr. This to be subtracted from the heat in the biogas as would the electrical grid consumption.

137. As is demonstrated in the table below, the various operating strategies result in differing levels of benefit.

b. **Table 1 Operational Strategies when producing 568.9m3 Biogas/hr from the feedstock fig.3**

Operation Strategy	**Boiler Consumption m^3-Biogas /hr**	**CHP Consumption *m^3-Biogas /hr***	**Biogas *Export* m^3-Biogas /hr *input to Gas To Grid Upgrader***	**Benefit Biomethane m^3/hr**	**Exported Electricity kWe**	**Exported CO_2 at density of 1.6kg/m^3**
Biogas to CHP at full output 800kWe 'Scenario A'	*0*	*387.8*	*181.1*	*89.1*	*506.7*	*136 kg/hr*
CHP at minimum 400kWe boiler providing additional heat 'Scenario B'	*26.8 For heat peaks*	*193.9 Excluding loss in engine efficiency*	*348.2*	*171.2*	*106.7*	*261 kg/hr*
CHP 500kWe to eliminate boiler use 'Scenario C'	*0 (back up and service standby)*	*242.4*	*326.6*	*160.6*	*206.7*	*245 kg/hr*
Electricity 293.3 kWe imported from grid, 53.1 m3/hr natural gas imported from gas grid 'Scenario D'	*0 (back up and service standby)*	*0 (Back up and service standby)*	*568.9*	***279.8* m^3/hr**	*0*	*426 kg/hr* ***3733.9 tonnes CO_2 per year***

138. The most likely strategy is the last strategy, 'Scenario D', importing all the internal requirements for heat and power from the domestic grids to maximise the GGSS returns and CO_2 collection.

139. Under Scenario D the digester would produce 291.4m3/hr of biomethane. This becomes 279.8m^3/hr of biomethane for sale after processing losses in the upgrader equipment of 4%.

140. The carbon capture equipment would capture 3733.9 tonnes CO_2 per year.

141. To be clear, these are the gross benefit figures and they do not take account of the parasitic load, i.e. the energy which the plant would consume.

142. The AD Ingenuity model calculates the surplus methane as 279.8m^3/hr giving an annual production of Biomethane as 279.8 x 8,760 hours = 2,450,748 m^3-Biomethane/year from the above feedstock table of 23,950 tonnes of raw feedstock per year.

143. **The heat value of this Biomethane** is given by 2,451,048 m^3-Biomethane/year X 10 kWh/m^3 = 24,510,480 kWh/year = 24, 510 MWh/year THERMAL ENERGY. The average house uses 12 MWh/year (1.33kW/h continuous heat). Therefore, the number of house equivalents is a benefit of 24, 510 MWh/year/ 12 = **2,042 house equivalents gross.**

144. Therefore, the Appellants estimate of 3,250homes has overstated its biomethane benefit, even without taking into account the parasitic load to run the digester.

145. **Turning to carbon capture.** The AD Ingenuity model calculates this to be 3733.9 tonnes CO_2 per year for sale. This is materially less than the c5,000 tonnes cited in the Appellant's Design and Access Statement. Again, this is without taking into account the parasitic load.

After parasitic loads are considered to define the Net Benefit

146. Taking into account the estimated parasitic loads of the AD facility as calculated in appendix 3, provides further reduction. Attributing the gas purchased off the grid to the biomethane **reduces the output by 19% to 1,654 houses NET Benefit.**

147. Attributing the electricity purchased from the grid to the CO_2 at the rate of 0.185kg/kWh I consider that the benefits would be reduced by 293kWh/hr x 0.185kg -CO2 = minus 54kg per hour of CO_2 **a 13% reduction from 3733.9 tonnes CO_2 per year to a net figure of 3,260 Tonnes per year**

148. For the avoindance of doubt, these figures do not take into account any increase in traffic movements.

Summary and conclusion

149. I was instructed by South Norfolk Council to review the applications made by the Appellant in 2015 and 2022 for Anaerobic Digesters at Deal Farm. Now that the Appellant has withdrawn its appeal against the enforcement notice and has accepted that the 2015 permission cannot be built out my evidence has focussed upon the 2022 application.

150. The Appellant has provided inconsistent information with regards to aspects of its proposal. This has been notable in relation to the amount of digestate which it would produce, the CO_2 which it would produce and the propane which it would require.

151. Despite requests, the Appellant has not provided process calculations or a mass balance for its facility. Such a mass balance is necessary to understand the operation of an AD facility. In particular, it is necessary to understand the amount of digestate which a facility will produce and its benefits (energy and carbon capture).

152. Therefore, it has been necessary for ADI Ingenuity to produce a mass balance. This is set out in detailed calculations in appendix 3. I have explained the assumptions made which relate to water use/digestate re-circulation and parasitic loads.

153. I have then gone on to answer a number of questions asked of me. In summary, I reach the following conclusions.

154. First, the plant applied for has a capacity greatly in excess of the proposed througput. If the digesters were designed to have a capacity which matched the througput then these would be half the volume. Using equipment which is matched to the feedstock proposal would increase the efficiency of the process. I can see no reason to construct a digester which is twice as large as the proposed feedstock.

155. Second, I conclude that the proposed plans appear to be missing two items of equipment which are necessary for the functioning of the AD facility. The first of these relates to addressing odour from the pasturisation process. The second relates to the need to process straw.

156. Third, I conclude that none of the various digestate figures produced by the Appellant are correct. In short summary the Appellant has overestimated the solid digestate and underestimated the liquid digestate in the most recent figures it has provided. This leads me to

question whether the Appellant has inadvertantly mixed up these figures. The consequence of this is that the lagoons applied for by the appellant are not sufficiently large to accommodate 9 months of digestate storage.

157. Fourth, I conclude that the Appellant has significantly overstated the benefits of its proposal.

Statement of truth

I believe that the facts stated in this proof of evidence are true. I understand that proceedings for contempt of court may be brought against anyone who makes, or causes to be made, a false statement in a document verified by a statement of truth without an honest belief in its truth.

APPENDICES

APPENDIX 1 ANAEROBIC DIGESTION FOR THE NON-TECHNICAL READER

a. Anaerobic [without air] digestion [decomposition] or AD is a natural biological process that breaks down organic matter into its mineral components = controlled rotting. It takes place most efficiently in a large tank and requires a controlled temperature, a selection of suitable bacteria, food for the bacteria to eat, normally provided as a soup, and most importantly the process is done without air. It is a biological process that uses many of the bacteria found in cattle digestive systems to degrade organic food into biogas, indeed we often start commercial anaerobic digesters with a mixture of cattle slurry and cattle food (grass silage) as cattle slurry contains the correct bacteria for the industrial digestion process and grass silage is a suitable food for the bacteria.

b. An anaerobic digester is therefore a living organism, typically a 4,000 cubic meter tank of living bacteria in water that is constantly stirred and fed hourly with organic matter. The bacteria in the tank eat the organic matter, multiply, and respire Methane and Carbon Dioxide, (Biogas) in a continuous process. The Methane the bacteria breathe out is a fuel, the same gas that comes in a pipeline from the North Sea, Russia, or Kuwait to most homes in the UK.

c. Each day, approximately 5% of the contents of the digester is pumped out to provide space for the fresh daily feed which is also fed on a very regular and consistent basis. Once the digester has been seeded with suitable bacteria (filled during the commissioning phase,) the bacterial population grows continuously on the organic feedstock and while some bacteria are washed out each day in the largely de-gassed, digestate, the growth rate of bacteria receiving a constant supply of food more than compensates for the loss of bacteria in the digester effluent. Thus, unless something happens to damage the growth rate of the bacteria in a digester, the digester should not normally require seeding again with bacteria.

d. The digester is fed every day and approximately the same amount of digestate is removed from the digester every day as the dry feedstock plus the dilution water 'soup' that is added. 60 tonnes of dry feed plus 60 tonnes of water to make soup = 120 tonnes of digestate to be removed less a few tonnes for the biogas produced. The digestate can be separated to provide small daily loads of separated digested cake.

e. Natural gas in the gas grid contains close to 100% methane, essentially the same gas chemically as the methane produced from an anaerobic digester. The carbon dioxide fraction of the biogas can be stripped from the biogas using membranes to create pipeline quality methane with >95% methane and this is then known as Biomethane which points to its origin and specifically denotes a non-fossil fuel origin. This can be compressed to pipeline pressures, typically 7-30 Bar and injected into the grid. At these pressures gas travels down the pipeline at almost the speed of sound and so gas injected in Scotland can be used in London in an hour or two. The largest electric motor in the system is usually the final gas compressor, typically a 50 to 100kW motor. The compressor it drives is important for the local people. Low speed oil-field claw compressors are notoriously noisy at distances measured in miles. High speed screw compressors are much easier on the neighbourhood if the compressor is provided with noise attenuation equipment that also allows cooling of the equipment in the summer heat without leaving the doors open. Technical choices here are important.

f. The digester vessel is stirred to both prevent crusts (of 'floaters') and settlement (of 'sinkers') and to ensure the fresh feedstock that is fed into the digester is evenly distributed throughout the vessel. The bacteria are temperature sensitive so are kept at a constant process temperature by either recirculating hot water through internal coils within the digester or recirculating the digester contents through an external heat exchanger which is also heated by hot water. For most digesters a few degrees around 40˚C is found to be optimal for the digester bacteria although there are some biogas plants operating with a different set of bacteria that operate at 56˚C. The medium temperature bacteria are called mesophilic and the high temperature types are thermophilic. The electricity used for stirring and pumping and the biogas used to heat the digester are known as 'parasitic' loads, energy that cannot be sold as it is used to maintain the biogas plant in good condition for the bacteria. In assessing the benefit of a plant, we normally look at the electrical and thermal potential outputs and subtract the parasitic loads.

g. Proteins and Urine in the digester feedstock contain nitrogen and break down into energy and high concentrations of ammonium (NH_4) dissolved in water. Where there is ammon**ium** (NH_4) present it is perceived by humans as malodorous but with a low toxicity. A small fraction of the NH_4 sheds a hydrogen atom and becomes ammon**ia** (NH_3) which is toxic and kills bacteria and is a general nuisance, malodourous as well as a health hazard. Both these forms are often referred to as 'Ammonia' or 'Ammonia Nitrogen.' Ammonia-N is applied to crops each year by spreading pellets of artificial fertilizer as it is the main driver of leaf growth in crops. The nitrogen in the feedstock is preserved by the anaerobic digestion process because it does not evaporate to atmosphere during the process because the atmosphere is excluded in an Anaerobic [without air] process. The only Nitrogen losses are during spreading and this is minimised with very efficient trickle bars or soil injection. Most farms with digesters no longer need to use artificial fertilisers.

h. Adding water to break down organic molecules is called Hydrolysis and is the first step of decomposition in the digester tank (and usually the most difficult step) in a chain of chemical reactions that break down solid feedstock into water-soluble biodegradable materials that can be absorbed through the skins of very small bacteria that decompose the organic matter.

i. If Hydrolysis is the start of the biological decomposition of the digester feedstock, the end point is mainly acetate that in water becomes dilute acetic acid (vinegar). Try making wine, cider, beer, yoghurt and sour-dough bread starter and you will soon discover how easily organic matter turns to vinegar. Vinegar is acidic and is the most well-known of the series of related chemicals known as the Volatile Fatty Acids or VFA.

j. Vinegar (acetic acid) is a vital molecule for digesters. It comprises two carbon atoms linked together. When this link is broken (by bacteria), methane and carbon dioxide is the result, hence biogas. More than ¾ of all biogas is formed in this way. The remaining mechanisms for biogas production are fascinating but for another time. The big biogas picture chemically is this simple step performed by 'acetate cutting' '*Acetoclastic Methanogenic'* bacteria where one hydrogen atom is moved to form biogas from acetate:

Acetate [CH_3 COOH] --> Biogas [$CH_4 + CO_2$]

k. The process of anaerobic digestion may therefore be summarised as:

- Prepare organic matter by filtering out the stones, soil, plastic, metal, and other contaminants from the feedstock
- Make good soup by blending dryish materials with process water, rainwater, silage effluent, pig slurry etc. Process any straw or lumpy material before adding the water.
- Feed good soup to hydrolysing bacteria in an 'hydrolysis tank' or directly into a primary digester
- Make good acetate – with the right bacteria this just happens
- Feed good acetate to the *Acetoclastic* bacteria in the primary digester – if all the bacteria are in the same tank this just means stir the contents of the tank and maintain stirring.
- Make biogas from the acetate using a large population of *Acetoclastic methanogenic* bacteria – these are sensitive bacteria and need looking after, hence steady temperatures, steady feeding, control of ammonia and hydrogen sulphide etc.

l. The final stage is to do something with the de-gassed digested liquid stream discharged from the digester 'the digestate.' Digestate is a useful organic fertiliser for horticulture and agriculture and can rebuild the right type of organic matter into soils depleted by intensive agriculture. It must be stored during the 'closed period,' when spreading slurry on land is banned. Storage is provided in either lined earth bunded lagoons or in large agricultural storage tanks. If these have lids, then the lid can be a gas store as well as preventing ammonia evaporation. In general biogas storage is most efficient in dome-shaped double membranes. A simple roof with a central pillar has been used in the past with a single membrane (not recommended because bad odours seep through the single membrane into the atmosphere) or a double membrane that collapses to a tent shape when not filled with biogas.

m. Each raw feedstock contains a different amount of available carbon, the building block of the CH_4, methane molecules. Sugars (chemicals with names ending in 'ose' such as sucrose, fructose, glucose, lactose etc.) and fats, contain a lot of readily available carbon that can be converted into biogas. Straw, wood, and cardboard also contain carbon, but it is presented in the form of lignin bonded to cellulose and other tough organic molecules that can be very resistant to breaking down in a few days passage through the digester at 40˚C. These recalcitrant materials usually end up as either screened – out trash or fibres in digestate cake for land spreading. If straw is a feedstock this would normally be ground to a fine powder before adding to the soup, or it could be chemically pre-treated with caustic soda or even pre-processed with steam. Long straw packed into a digester simply makes a rotating haystack inside the tank.

n. In our analysis of feedstock, we concentrate on the fraction of the feedstock that is biogas producing, not the water, not the soil or ash, it is the mushy stuff in the soup that makes biogas. This has several names, OM for organic matter, ODM for organic dry matter, VS for volatile Solids. So, what are these? A key efficiency indicator to watch in such a process is the biomethane produced per tonnes of organic matter (volatile solids). To assess how much volatile solid there is in a sample of feedstock, the sample is dried at 110˚C to produce a pellet of dry cake = Total Solids, TS, or dry matter, DM. Then the dry pellet is ashed in an oven at 'dull red heat,' 550˚C. The Lost (mass) On Ignition (LOI) is the VS = an analogy of the organic matter in the feedstock. There are potential errors in this estimate but it is quick and widely used. In common parlance with laboratory and full-scale digesters we measure 'how much biogas is made from the mushy stuff' from a particular feedstock, Poultry Manure, sugar beet, straw etc. and use these measurements to predict the performance of digesters. This is the basis of the modelling in this report.

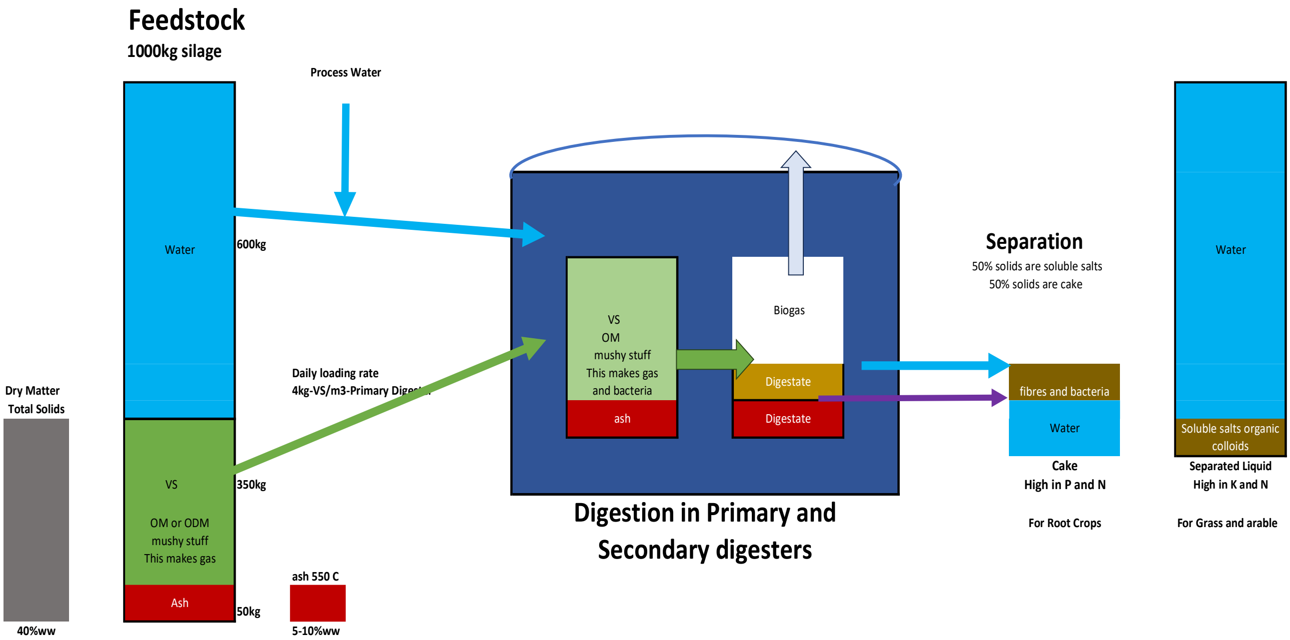

Figure A1The way feedstock components are broken down in the digester

o. Effective biogas production using anaerobic digestion is a biological fermentation that relies on maintaining a steady feed to a fixed, large population of bacteria. Operationally then, we consider an anaerobic digester to be more like feeding a cow than driving a tractor. Feeding must be steady and the feedstock consistent, with changes made very slowly to protect the biology from indigestion.

p. The daily organic loading rate (OLR) is an important control parameter and will be fixed by the nature of the feedstock and especially the management strategy for the site. You can run a digester very hard, i.e., with a high daily organic loading rate at 5-8kg-VS/m^3 of primary digester, but it is like driving a Ferrari at speed through a country lane with limited visibility and its risky because if the stirring system fails the digester may fill the biogas lines with foam in a short time. In a commercial environment, a daily feed rate of about 3kg-5kg of Volatile Solids per cubic metre of primary digester can be managed comfortably with little process instability if the changes to the loading rate are done over several days. The operator feeds the digester as if it was a young cow to prevent ‘indigestion.’ Changes to feed rate are slow to avoid other undesirable consequences such as ‘slugs’ of undigested food sitting in the digester, floating layers appearing, and worst of all, foaming in which the rate of foam production exceeds the rate of foam reduction by the stirring system.

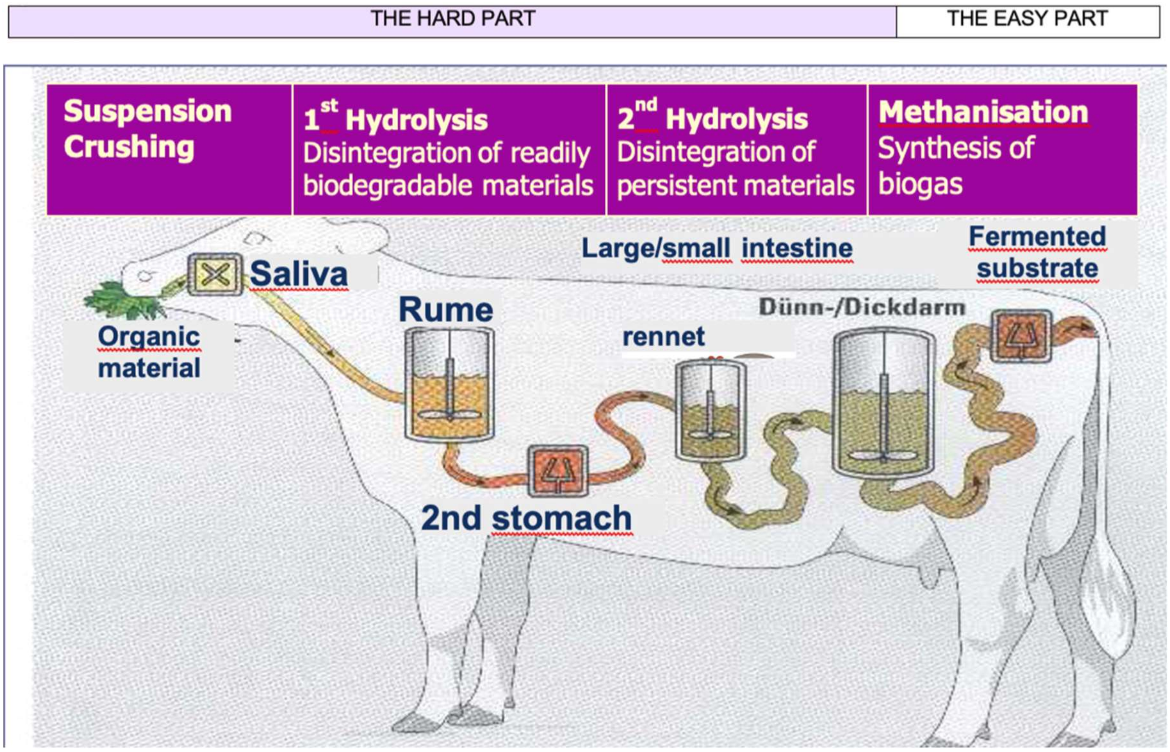

Figure A2 The anaerobic digestion process

q. Typically it takes 2 to 3 hydraulic retention times (HRT) of the digester to stabilise the process biologically, the HRT is the average time the feedstock dwells in the digester. Hydraulic Retention Time is simply calculated as the Operational Volume of the Digester / Daily Volume of Feed. So a 4,000 m^3 digester fed 100 cubic meters per

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day would have an HRT of 4,000/100 = 40 days. Two to three retention times is in this case is 80-120 days and if the digester feed composition is is changed quickly relative to these time scales foaming can occur inside the digester. A primary digester will operate well at 20 days retention if there is a backup secondary digester that can catch and release the biogas from the 1/20th of each daily feed that passes through the digester each day undigested, a process known as short circuiting, this being a consequence of the continuous mixing in the tank. This secondary digester will be responsible for generating about 10%-15% of the total biogas from the plant because it increases the contact time between the bacteria and the feedstock.

r. In summary, anaerobic digestion (AD) is a bacterial decompostion using a series of varied species of bacteria in the anaerobic digester that may be classified into their functional groups: hydrolysis, acid forming, acetate forming and methane forming bacteria. Each group of bacteria has a role and a set of particular needs. The process is therefore highly controlled.

s. The operational picture is :

- Make good soup,
- Make acetate (vinegar) from the soup,
- Break acetate to make biogas
- Make changes slowly,
- It’s a cow not a tractor.

t. I have provided a wider glossary of terms at the head of this document to assist in reading the technical documents and analyses that follow.

APPENDIX 2 AD INGENUITY LLP INTRODUCTION AND CVS

AD Ingenuity LLP,

AD Ingenuity LLP brings the anaerobic digestion knowledge and experience of Dr Leslie Gornall and Russell Mulliner together in a partnership with a joint mission to establish and maintain the further development, improvement and advancement of anaerobic digestion and associated processes. The LLP has Associate Partners.

The Business

The objectives and aspirations of AD Ingenuity LLP include:

The research, design and development of monitoring, processes, and equipment to improve the environmental footprint, operation, and efficiency of:

- Anaerobic Digestion
- Organic Matter Hydrolysis
- Organic Matter Nutrient Recovery
- Aerobic Processes,
- Activated Sludge Processing,
- Composting of Organic Wastes and Digestates
- Soil Amendments

Support for the academic research of the above anaerobic and aerobic processes

Providing marketing support, lecturers, seminars, and social activities relating to the dissemination of information and knowledge.

Providing expert services to companies wishing to optimise anaerobic digesters and related processes.

Providing expert support services to governing bodies, insurance companies, solicitors of law on matters in which the expert is qualified to opine.

Dr. Les Gornall – ADI Founder - Partner

D.Phil, BSc (Hons) C.Biol. FRSB

UK Pioneer (full-time since 1978) of Anaerobic Digestion and has developed in over four decades a skill as a successful Anaerobic Digester, composting and Wastewater Treatment Process designer, with in-depth experience including laboratory and bench experimentation, pilot plant and full-scale plant design (up to city scale) building, commissioning operating and optimizing typically one to three plants per year.
B.Sc. degree (1st Class Hons.) Dissertation on the uptake of Nitrogen from digestates. D.Phil. in Environmental Science. Thesis 'Interaction between Anaerobic and Aerobic processing of Farm Effluent' - designed the first full scale farm digester and organic composting system in Northern Ireland. It won the UK Pollution Abatement Technology Award from the Royal Society of Arts and pioneered some of the first nutrient fractionations from a full-scale biogas plant with data for N, P and K from separated digested farm wastes. Built two successful businesses making peat substitutes and organic golf course amendments from digestate.

OTHER QUALIFICATIONS AND AWARDS:

- 2016 Anaerobic Digestion and Bioresources Association (ADBA) award 'AD Hero of the year'
- 2013 IChemE Bio-processor of the Year award for a two-phase food waste and pig slurry digester that I designed and commissioned.
- 2005 The UK Engineering Contractor of the year award - presented in the House of Commons Committee room 10 for my work with wastewater treatment at BP described as 'Best Practice' by D'Appolonia, Environmental Consultants to the World Bank.
- Member of / advisor to the ADBA health and safety committee

OTHER SKILLS AND AWARDS

Carbon zero Award. Awarded £10k from ERDF for designing and building 'Solar House' the first ZERO-CO_2 house and office in N. Ireland in 1995. This was 6 years before the first 'official' UK PassivHaus in Camden.
Awarded 3 Patents relating to AD, odour control and composting.
Expert Witness to many Planning Appeals, adjudications, and arbitrations,
Technical Director of the AD and sustainable energy team in RPS one of the UK's Premier Planning Consultancies. Working with GIS and spatial development departments to support digester developers who needed certainty in these key parameters to secure funding:

- A legal interest in the land,
- planning permission,
- a source of feedstock,
- grid connection, and
- a land bank for digestate.
- a process design and
- a Permit to Operate from the EA.

In RPS I created and led the team that wrote and delivered the UK wide WRAP training course for AD operators and developers. This was the highly successful biogas training program that created a body of several hundred skilled developers and operators that enabled the growth of the AD Industry in the UK.
Process Consultant for PM PROjEN and technical lead for the Bioenergy Team until 2019 – full details in LinkedIn.com

Russell Mulliner – ADI Founder - Partner

A multidisciplined engineer with 25 years' experience in the Anaerobic Digestion industry with an extensive mechanical and process engineering background and a unique flair for process enhancement and improvisation.

Built and developed Marches Biogas one of the most successful biogas equipment manufacturers in the UK. Built from a single-man company to a leading UK anaerobic technology provider, consulting, and support business. Employed more than 100 full time staff. Developed the strategy which led to the ownership of Marches Biogas being transferred in 2020 to a new management team and members of staff who also have a share of the business.

ANAEROBIC DIGESTION EXPERIENCE AND ACHIEVEMENTS

As the Operations Director of Greenfinch set out to research and develop the design of digesters for the recycling of food waste, whilst at the same time working in other anaerobic digester market sectors, particularly the water industry.

Carried out three consecutive R&D projects into the anaerobic digestion of source-segregated food waste. One of the projects was in partnership with the University of Southampton which investigated the eradication of pathogens in conjunction with mesophilic anaerobic digestion, thermophilic anaerobic digestion, and batch pasteurisation.

Received 'Shell Innovation Award' for the 'AgriDigestore' a novel slurry-only anaerobic digestion system.

Coordinated, planned, and ensured the successful delivery of more than 40 anaerobic digestion plants.

Developed a proven track record of understanding all the processes involved within all sectors of the anaerobic digestion industry

Since 2001 Russell has given more than 50 public presentations, particularly about the anaerobic digestion of food waste and energy crops.

Successfully carried out due diligence on behalf of clients that have required an independent assessment for projects which are being delivered by other technology providers.

Expert Engineer on several investigations into part or complete process plant investigations.

Extensive experience of Wastewater Anaerobic Digestion, including process design, commissioning and pre and post digestion processes of conventional and advanced system (Cambi, TPH, Acid Hydrolysis, nutrient recovery).

APPENDIX 3 (ADI DRAWINGS AND PROCESS CALCULATIONS AS ATTACHMENTS)

Appendix	3.1	ADI504-011-0	Digester Size / Capacity Drawing
Appendix	3.2	ADI504-012-0	Digester Size / Capacity Overlaid Drawing
Appendix	3.3	ADI504-203-G	Feedstocks Process Calculations
Appendix	3.4	ADI504-205-G	Feedstock Delivery and Preparation Calculations
Appendix	3.5	ADI504-206-G	Anaerobic Digestion Feed Substrates Calculations
Appendix	3.6	ADI504-207-G	Anaerobic Digestion Process Calculations
Appendix	3.7	ADI504-208-G	Separation and Digestate Processing Calculations
Appendix	3.8	ADI504-209-G	Energy and Heating Calculations
Appendix	3.9	ADI504-212-G	Mass Balance Calculations
Appendix	3.1	ADI504-214-G	Deal Farm Daily Mass Balance Calculations (17.5% Separation)
Appendix	3.11	ADI504-215-G	Deal Farm Daily Mass Balance Calculations (28.0% Separation)
Appendix	3.12	ADI504-216-G	Simplified Process Heat Requirement Calculations
Appendix	3.13	ADI504-217-G	Estimated Parasitic Electrical Loads

APPENDIX 3 ADI MASS BALANCE CALCULATIONS, A NARRATIVE SUMMARY

Introduction

158. As explained in the main proof of evidence, I have provided a mass balance in order to understand the likely outputs of the Anaerobic Digester proposal at Deal Farm (the benefits in terms of energy production and the amount of digestate). This has been necessary given the inconsistent and incomplete information provided by the Appellant.

159. Before going on to provide a summary of my calculations it is necessary for me to address a couple of matters. First, the benefits from an AD proposal accrue from creation of renewable energy and the reduction of carbon dioxide in the earth's atmosphere. The former is measured in kilowatt hours, kWh, the latter in kg of CO_2

saved or to make this more readable these units are frequently expressed in terms of social equivalent units, the energy expressed in terms of homes and the Carbon Dioxide in terms of number of cars equivalents. This has been done in the Appellant's documents and I have done the same in my proof.

160. Second, with regards to digestate, as set out in my proof of evidence, at least three descriptions of the masses of digestate have been offered by the Appellant and they are all different although apparently being sourced from the same feedstock table and with the same digestion process. The unreliability of the numbers presented is further confused by reference to the Thoni mass balance for the plant that is presumably one document but this has not been offered for examination and therefore I have created in Appendix 3 a set of transparent calculations that use a standard wet digester model to predict the mass of digestate. A guide to these calculations is set out below.

161. Broadly, in order to understand the outputs of a digester it is necessary to understand: (a) the inputs, this includes the amount and distribution of feedstock as well as the addition of process water and recycled digestate as explained in my main proof of evidence as well as (b) the parasitic load of the AD equipment. In simple terms the parasitic load is the amount of energy which it takes to run the equipment.

162. The Appellant has, in response to questions from the Council provided some discrete information relevant to the asserted heating requirements and therefore parasitic load of some of the equipment used. However, I consider that key figures provided are incorrrect. In the section below, before going on to explain my calculations I set out why this is and why my calculations are different.

Parasitic Loads provided by the Appellant

163. The information provided by the Appellant on 14 December 2023 included an appendix which is entitled 'Digester Heating Calculations'. It states:

Digester Heating Calculations.

The following digester heat balance was calculated by the technology provider for an annual input of 58,150 tonnes per annum.

The reduced input of 23,950 tonnes per annum will require around half of the energy load at 1,315 GWh/a.

This heating load will be met by a 500kW gas boiler which provides sufficient capacity for the calculated peak loading.

7.2 ASSUMED PARASITIC THERMAL HEAT CONSUMPTION

The net heat requirement from the Biogas Boiler is: **1.600 MWh/a** *

The calculated total parasitic Thermal Heat Consumption of the Fermenters is: 2.630 MWh/a
These values are based on the following calculation:

Average Temperature per month:

January	February	March	April	May	June	July	August	September	October	November	December
4,4	4,6	6,3	8,8	12,1	15	17,3	17	14,8	11,6	7,6	5,1

Input stated in 2.1 digester temperature 42 °C 8,760 h/ a heating

Average temperature of the input substrate per month:

January	February	March	April	May	June	July	August	September	October	November	December
10	10	10	15	20	25	28	28	24	15	10	10

Peak heat consumption: 402 kW (in Jan.)

* Due to the heat recovery from the recirculated material and use of the CHP engine off-heat to preheat the incoming water, the net heat to be produced by the Bigas Boiler can be reduced to the value addressed above.

Figure 10 Heat calculation supplied by Appellant

164. 1,315 MWh/a. is an average continuous process heating requirement of 150kWth which indeed could be provided by the 500kWth biogas boiler as described above in figure 8. The boiler would consume approx 35m3/hr of biogas directly from the digester to provide digester heat or approx 17m3/hr of imported Natural Gas depending on the operational mode.

AD Ingenuity's Digester Heat Requirement Calculation

165. On a daily basis, AD Ingenuity provides a technical auditing service to optimise production on a biogas to biomethane to grid anaerobic digestion facility comprising six 6,000m3 primary digesters fed pre-processed straw with a small amount of cattle manure. In this case my calculations, estimates and assumptions are largely based on this practical knowledge of straw digestion with animal manures.

166. ADI has used the following inputs to calculate the internal site (parasitic) heating loads on the plant:

a. To heat the feedstock in the Appellants feedstock table (65.6 tonnes/day) to 42°C digester temperature from 15°C ambient would require approximately 85.9kWth.

b. The heat loss from the digester is an engineers estimate of 30kWth resulting in a total of 115.9 kWth for feedstock heating and maintaining digester temperature. However this is only part of the heating requirement.

167. As explained previously the feedstocks listed in figure 5 above when combined have a very high dry matter content of 44.2% DM . The digester has to be stirred to produce and release the biogas and also to enable a heat exchange in the digester. From our experience in straw / manure digesters this digester would be fed with a combined liquid feed of 16%-DM by adding water and recirculated separated digestate. This will result in an internal digestate with 9.5% DM, a thin porridge-like consistency required for stirring, heating, and to allow biogas bubbles to escape without causing foaming.

168. Some of the liquid required for feedstock dilution can be recycled digestate (sometimes called process water), it is important to understand how much digestate is recycled because recycled digestate is not exported and spread on land. Whereas other water or liquid slurries added for the purpose of making the digester contents stirrable are added to the feedstock mass and are spread to land as liquid digestate. The recycled digestate required to reduce the viscosity of the digester contents is thus an offset against added water that would then have be spread to land in the spring/summer and stored in the NVZ closed winter season.

169. There is a limit to how much digestate can be recycled. Recycling digestate increases the salinity of the digester contents which inhibits the working bacteria. In the absense of detailed data being made available from the Appellant's mass balance for

the plant, in our calculations we have used as much recirculated separated digestate as we think possible without inhibiting the microbiology.

170. The remainder of the water required to make ‘soup’ from the dry feedstock is made up of rainwater, ground water and mains water. We make no distinction as to the sources in our calculations for water use.

171. Pig slurry contains a lot of water and is frequently used to dilute dry feedstock but liquid pig slurry is absent in these estimates as pig wastes are described in figure 6 as pig manures in the Appellant’s data, presumably with dry straw bedding.

172. To obtain the dry matter target within the digester we estimate 110 tonnes of recycled separated digestate, and 39.8 tonnes of water is required per day on top of the 65.6 tonnes of feedstock. The total feedstock mass with liquids/fluids is 215.4 tonnes per day[2].

173. The separated liquid digestate is warm and this plus the cold water for feedstock dilution will likely retain some of its heat so we have assumed a combined liquid feed temperature of 25°C . The heat requirement for the feed liquids is 123.5kWth in addition to heating the feedstock in the table figure 6.

174. The total digester heat requirement for the primary digester we calculate is therefore 239.4kWth continuous or 2,097MWh/a. When the heat for pasteurisation at 70°C is added to the heat required for digestion the total heat requirement of the system related to feedstock and digestate is 447.32kWthermal amounting to 3,906.76 MWh/yr (forgive the decimal places but this enables a quick location on the spreadsheets). Please note that no allowance has been made for heating propane to evaporate it in the Gas Entry Unit (GEU)

175. This could be provided by the 500kWth biogas boiler consuming 58m^3/hr of raw biogas or approx 29m^3/hr of imported Natural Gas depending on the operational mode.. The ADI parasitic heat calculation is 3 times more than the 1,315 MWh/a estimated by the Appellant (although written as GWh/a by the Appellant), the difference being attributed to the amount of process water and liquids used in the plant and the lack of

[2] **ADI504-209-F (2022 Application Only) line122**

process calculations for the pasteurisation system including any heat recovery from that system.

176. I now turn to the Appellant's pasturisation heat requirement calculation. This was also provided by the Appellant in its additional information in December 2023. It states:

Pasteuriser Heating Calculation

The following pasteuriser heat balance was calculated by the technology provider, identifying a peak loading of 750kW.

This heating load will be met by and Edina genset with thermal output of 862kW, providing sufficient capacity for the calculated peak loading.

Pasteurisation Unit

Pasteurisation is required to prevent of the distribution of pathogens that might have survived the digestion process. The unit is set up as a batch system holding the substrate at a temperature level of min. 70°C for one hour of time.

Nominal capacity: **10 m³/h**

- ✓ Loading pump speed controlled (Wangen KL65 S.114)
- ✓ Vogelsang RotaCut maszeration unit
- ✓ Mazerator unit to keep particle size to acceptable dimensions
- ✓ 6 Pasteurisation tanks (10 m³ each)
- ✓ Discharge pump
- ✓ Process valves, instrumentation
- ✓ All process piping (including heat supply lines from the CHP to the unit)
- ✓ Control system to the unit

Product side:	AISI 316L stainless steel
Service side:	AISI 304 stainless steel
Support structure:	Galvanised steel

Thermal energy consumption nominal:	Hot water 90-92°C; app. 500 kW
Thermal peak consumption at start up:	Hot water 90-92°C app. 750 kW
Electrical power consumption:	app. 40 kW

Figure 11 Appellants pasteurisation heating statement

177. The pasteurisation technology provider has identified a peak load of 750kWth in figure 11 above provided by the heat output from an Edina CHP Unit that has a thermal

output of 862kWth. This calculation does not state whether this pasteurisation heat load is attributed to the 58150 TPA or the 23,950 TPA feed.

AD Ingenuity's Pasteurisation Energy Calculation

178. After the biogas and water vapour is subtracted, 200.1 tonnes per day whole digestate at 9.6% dry matter is discharged from the digester as a liquid at 42°C. The pasteurisation process requires the digestate to be held for one hour at 70°C. Pasteurisation will require a heat input average of 271.7 kWth. The provision of 6 pasteurisation vessels will smooth the heat demand and therefore the Appellant's stated 750kWth peak likely refers to the full capacity of the digester. Heat recovery from the pasteurisation is technically possible but the heat exchangers are subject to fouling due to crystalisation of struvite, a concrete-hard scale in the heat exchangers so we assume that it is not fitted in these calculations.

179. If the technology provider is running the Edina CHP to provide the heat for the pasteurisation system and it has a thermal output of 862kWth as stated, it is likely that an 800kWe CHP unit has been selected. This can be run at 50% output i.e. 400 KWe / 429kWth and would provide both the heat for pasteurisation and electricity to supply the electrical requirement of the plant and all the ancillary equipment. The CHP at this output of 50% of its rated capacity would consume approx. 193.9m^3/hr of biogas depending on its stated electrical efficiency.

ADI's Calculations

180. Having addressed the preliminary issues above, I now go on to explain the documents which contain ADI's calculations.

181. The first document in the appendix 3 is the Listing of the appendices. These use the AD Ingenuity document numbering system, ADI504 is the Deal Farm project number. The appendices numbered 011 and 012 are drawings of the plant as built and indicating the size of the plant if it was built to suit the limited feedstock table in the 2022 Planning Application. Each of the remaining calculation sheets has a specific function that provides solutions that feed to the next sheet in the series as described below. The letter is the version number used internally for checking. Publication level here is version G.

Calculations for ADI 504-

203-G – Feedtocks Process Calculations

182. The feedstock table in this calculation is the table provided in para. 4.2 in the 9th June 2022 Design and access/planning Statement – Cornerstone Planning Ltd. The exact composition of each of the feedstocks, Cattle and duck manure, Poultry manure, Grass silage, Pig manure, Maize and Straw are all listed and the % Dry matter content is estimated from tables and personal experience. There is a note against each feedstock on the quality issues. The highlights are that duck manure is a rarely seen manure and a nominal value is placed on the dry matter and organic dry matter content for this without reference to any known sites. The poultry manure is high in nitrogen and this will form ammonia in the digester and ammonia is toxic and needs to be diluted to below 2,800mg/l to prevent methane inhibition. The cutting of grass silage for the digester is assumed to be once per year but if high speed bio-cut harvesting machinery is available the gas yield could be improved by employing multiple cuts per year, a process that eliminates much of the indigestible lignin in the grass. The single cut, worst case is used here. Maize harvesting is assumed single cut, late season for maximum yield per hectare. Straw is the hardest to prepare for digestion but it has the potentially the highest energy density due to its high dry matter content. The characterisation of each individual feedstock %DM and Organic Dry Matter = VS chosen on this sheet is reflected in the next calculation ADI 504-205-G.

205-G – Feedstock Delivery and Preparation Calculations

183. The Appellant has provided annual feedstock masses in the feedstock table. In this calculation these are summed to provide the total 23,950 tonnes per year and then broken down to a daily loading rate at the same rate each day of the year. The overall %dry matter is estimated at 44.21% highlighted in grey. This is on average drier than the best dry Maize silage and would form a stackable solid with a vertical dry wall if evenly blended. This would exclude bacteria in the same way that a silage clamp excludes bacteria. It will not digest until water is added and the mixture continuously stirred. This is where the Thoni mass balance would have been helpful as the blending ratios are a choice and depend on the fibre length of the straw and other digester parameters. The ADI model assumes that the digester contents, the digestate that is inside the tank and being stirred and heated has contact with the heating system and moves freely and that puts a top limit of 12.5% dry matter on digestate. This is

measured after most of the gas has been removed and therefore the choice of feed mixture of dry feedstock and process water will depend on the efficiency of the digestion process and having an intial feed of between 16% dry matter and 20% dry matter using water and separated liquid digestate to blend. The latter must meet salinity and ammonia limits to prevent inhibition of the bacteria. The water component can be rainwater. Highlights of this sheet are: 65.62 tonnes of digester feedstock is blended with 39.79 tonnes of water and 110 tonnes of recirculated separated liquid digestate each day. In the absense of salinity measurements this high level of recycled digestate is from experience as much as I consider can be used without compromising the bacteria. The potential biogas production from this blend is estimated from the 25.86 tonnes of organic dry matter (VS) fed per day, a little over a tonne per hour multiplied by the typical Biochemical Methane Potential and provides a good estimate of 568.92 m^3 methane per hour.

206-G – Anaerobic Digestion Feed Substrates Calculations

184. This is a quality control check on the previous numbers enabling a comparison between a known plant operated on straw and water addition. The mass of non-waste and waste feedstocks is calculated and the recirculated separated digestate and water addition summed with the feedstock to a total of 215.40 tonnes of feed including 110 tonnes of recycled digestate giving a 16.02% dry matter feed at 72.70% organic fraction. We know from experience this is a stable digestion.

207-G Anaerobic Digestion Process Calculations

185. The AD Process is modelled and the gas mass leaving the digestate is calculated leaving a 9.61% dry matter digestate to be passed on to the separators for separation into cake and separated liquid. The importance of straw and grass in the production of methane is indicated as the total gas production of the two feedstocks represents 70% of the total methane production from the plant. Straw makes 51.11% of the methane production. If anything inhibits these two feedstocks it will severely impact the overall gas production from the plant.

208 -G Separation and Digestate Processing Calculations

186. Separating the cake and liquid from the whole digestate depends on the dry matter in the cake and the dry matter in the digestate. If there is poor gas production more

solids will be left in the digestate for separation. The gas production in the ADI model assumes a very efficient digestion but the mass balance model from Thoni would be required to make this an accurate estimate. Given that the diference between the June 22 Transport Statement, 11,975 T cake, the June 23 Royal Haskoning statement 10,339 T cake and the latest table from Royal Haskoning in their Appendix D that indicates 20,075 T per annum of cake, from the same feedstock model, there are two models presented in this calculation. Model A is assumes that the cake is 17.55% dry matter from trial and error matching to obtain 20,000 T per annum of cake from a fixed amount of digestate. I explain this further in my proof. In short, it demonstrates that the amount of solid digestate which the Appellant states will be generated is impossible. The Model B is the normal model used with an achievable 28% dry matter cake. It is interesting to compare the output masses for solids and liquids after the separator as the numbers are a close reflection of each other and might suggest that the figures in the Appellant's table have been inadvertantly switched. The total digestate figures for the two models are a close match. The separated liquid from the normal model would leave only 6 months storage in the lagoons. The appellants model results in precisely 9 months storage for the separated liquid.

209 -G Energy and Heating Calculations

187. Calculation 209 was required because there is no operating philosophy stated for the listing of equipment for the proposed site. This is important because the way the equipment is operated dramatically impacts the net benefits from the plant. The difference between the worst case benefits and best case benefits is a range of 92m^3/hr of methane benefit to 291.4m^3/hr of methane benefit from the same feedstock. This stems from two issues: The first is how the CHP is operated when the electrical demand is not matched by a heat demand on a one to one basis. That is to say if the electricity is needed but there is no need for heat from the engine the excess heat is wasted to atmosphere. The second is that value put on carbon sent to the atmosphere due to the supply of mains electricity and mains gas for digester heating is likely an underestimate. These four ways of operating the plant are evaluated for net benefits, and the surplus methane produced net of parasitic loads are calculated. The greatest benefit is found when all the electricity required to operate the plant is purchased from the mains and similarly all the heat for the digesters and processes is purchased from the gas mains. That scenario yields a net benefit of 291.4m^3/hr of methane for export.

212-G Mass Balance Calculations

188. The Royal Haskoning 17.5% dm cake and ADI 28% dm cake models are compared again but this time with the goal of estimating the Overall Outputs for the Benefits including Methane production, CO_2 capture, Separated Fibre and Separated Liquid. Highlighted in grey, these numbers make an interesting comparison being mirror images of each other.

214-G Deal Farm Daily Mass Balance Calculations at 17.5% separation.

189. In graphical form the 17.5% dry matter and 28% dry matter models are compared in calculations 214 and 215 and provide daily and annual mass movements through the process. The models compare the outputs to the lagoon capacity and find that that lagoon capacity produced by the 17.5%dm model is 283 days or just over 9 months. However, as set out in my proof this is not possible. A 17.5% dry matter mix would not be solid.

215-G Deal Farm Daily Mass Balance Calculations at 28% separation

190. In graphical form the 17.5% dry matter and 28% dry matter models are compared in calculations 214 and 215 and provide daily and annual mass movements through the process. The models compare the outputs to the lagoon capacity and find that that lagoon capacity of the 28%dm model is 179.3 days or just under 6 months as more water is squeezed out of the dry cake than the wet cake and this extra water has to be stored as separated liquid .

216-G Simplified Process Heat Requirement Calculations

191. The process heat requirement is built up for the various heat loads, the solids loaded into the solids feeder, the digester, the recirculated digestate, and digester heat losses to the environment plus pasteurisation. The total heat requirement is found and compared to the Heat requirement statement and there is a 37% difference that is attributable to heating the separated liquid recycled to ensure the digestion is stirred and the microbiology produces an efficient gas conversion.

217-G Estimated Parasitic Electrical Loads

Using the same operating strategies for the equipment as as before in 209 above, the electrical parasitic loads are calculated. Again this would not have been necessary if the Thoni mass balance had been provided. This still leaves the potential benefits, less the parasitic loads, i.e. the Net Benefits with some uncertainty. Above, I have explained why the heat requirement figures which have been provided by the Appellant are not accepted.

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APPENDIX 4 USEFUL ABBREVIATIONS

Abbreviation	Meaning
ACPH	Air Changes Per Hour
AD	Anaerobic Digestion (Biological decomposition of organic matter to methane and carbon dioxide in the absence of air)
ADBA	Anaerobic Digestion and Bioresources Association
ADQP	Anaerobic Digestion Quality Protocol
AMINE	A chemical formed by modifying ammonia (NH_3)
APHA	Animal and Plant Health Agency
AT	Acceptance Test
ATEX	Atmosphere Explosif (European Legislation designed to prevent explosions and fires)
BAT	Best Available Techniques (EU Commission documents)
BEIS	Department for Business, Energy and Industrial Strategy
BMP	Biochemical Methane Potential (m^3-methane /kg-VS)
BOD	Biological Oxygen Demand (a 5-day long test normally)
BREF	Best (Available Technique) Reference (EU Document)
BSI	British Standards Institution
BTEX	A group of chemicals [Benzene, Toluene, Ethylbenzene and Xylene] - in burned organic matter
C&I	Commercial and Industrial
CDM	Construction (Design and Management) Regulations
CFD	Computational Fluid Dynamics
CH_4	Methane
CHP	Combined Heat and Power
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand (a one-hour test)
COMAH	Control of Major Accident Hazards
COSHH	Control of Substances Hazardous to Health
CoTC	Certificate of Technical Competence
CPD	Continual (or Continuing) Professional Development
CSTR	Continuously stirred tank reactor
CV	Calorific Value
DAF	Dissolved Air Floatation
Defra	Department for the Environment, Food and Rural Affairs
DfT	Department for Transport
DM	Dry Matter
DMDS	A malodourous chemical dimethyl disulphide
DNO	Distribution Network Operator
DNR	Defect Notification Report (DN = Defect Notification)
DS	Dry Solids
DSEAR	Dangerous Substances and Explosive Atmospheres (UK legislation that is stricter than ATEX)
EA	Environment Agency
EGHE	Exhaust gas heat exchanger
EIA	Environmental Impact Assessment
ELDs	Engineering Line Diagrams
EPC	Engineering, Procurement and Construction
EPD	Explosion Protection Document
EPR	Environmental Permitting Regulations

FIT	Feed-In Tariff
F/M Ratio	Food to Biomass Ratio
FOG	Fats, oils, and greases
FWAD	Food Waste Anaerobic Digestion
FYM	Farm Yard Manure
GCV	Gross Calorific Value
GGSS	Green Gas Support Scheme
GIS	Geographic Information System
GPS	Global Positioning System
H&S	Health and Safety
H_2S	Hydrogen Sulphide (malodourous and toxic gas responsible for many industrial fatalities)
Ha	Hectares
HAZOP	Hazard and Operability
HGV	Heavy Goods Vehicle
HSE	Health and Safety Executive
HS&E	Health, Safety, and the Environment
HV	High Voltage
IChemE	Institution of Chemical Engineers
IOSH	Institute of Occupational Safety and Health
IPPC	Integrated Pollution Prevention and Control
IRR	Internal rate of return
ISO	International Organisation for Standardisation
KPI	Key Performance Indicator
kT	Thousand Metric Tonnes (1 metric tonnes is 1000kg) +-
kW	Kilowatt
kWh	Kilowatt Hour (suffix e for electrical, th for thermal)
%LEL	Inflammable gas concentration as % of the Lower Explosion Limit concentration
LLC	Limited Liability Company
LLP	Limited Liability Partnership
LNG	Liquefied Natural Gas
LV	Low Voltage
MBT	Mechanical Biological Treatment
MEL	Maximum exposure limit
Mg	Magnesium
MJ	Mega Joules
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids (the organic fraction of MLSS)
MW	Megawatts
MWh	Megawatt hour
NEC	New Engineering Contract
NH_3	Ammonia (toxic gas)
NH_4^+	Ammonium
NIEA	Northern Ireland Environment Agency
NOx	Nitrogen Oxides
NO_2^-	Nitrite (product of *Nitrosomonas*)
NO_3	Nitrate (product of *Nitrobacter)*
NPK	Nitrogen, Phosphorous, Potassium
NVZ	Nitrogen (or Nitrate) Vulnerable Zone
OAS	Odour Abatement System
O&M	Operation and Maintenance
ODM	Organic Dry Matter (=VS or volatile solids = loss of mass on ignition at approximately 550°C)
OEL	Occupational exposure limit
OLR	Organic Loading Rate
OMP	Odour Management Plan

P&IDs	Piping & Instrumentation Diagrams
PAS	Publicly Available Specification (Issued by the British Standards Institute BSI)
PAS110	2014 - Specification for Digestate
PC	Progressive Cavity (if a pump)
PD	Positive Displacement (if a pump) or Primary Digester
pH	Logarithmic acidity scale = −log10 c, where c is the hydrogen ion concentration in moles per litre, 7 is neutral.
PPE	Personal Protective Equipment
PUWER	Provision and Use of Work Equipment Regulations
RAS	Recycled Activated Sludge
RAMS	Risk Assessment Method Statement
RHI	Renewable Heat Incentive
ROC	Renewables Obligation Certificate
ROS	Renewables Obligation (Scotland)
RPM	Revolutions per minute
RT	Retention Time (in days, tank volume m^3/ daily feed volume m^3)
S	Sulphur
SS	Suspended Solids
SAS	Surplus Activated Sludge
SCADA	Supervisory Control and Data Acquisition
SEPA	Scottish Environment Protection Agency
SLD	Single Line Diagram
SOP	Standard Operating Procedures
SORP	Sustainable Organics Resources Partnership
SPV	Special Purpose Vehicle (e.g., a limited company to build an AD Plant)
SSAFO	Silage, Slurry and Agricultural Fuel Oil (Environmental Regulations)
STEL	Short term exposure limit
THP	Thermal Hydrolysis Process
TPA or tpa	Tonnes per annum
TPD	Tonnes per day
TS	Total Solids (Dry matter at 105°C)
TSS	Total Suspended Solids
TWA	Time weighted average
UKAS	United Kingdom [Laboratory] Accreditation Service
VCD	Volume Control Damper (airflow rate control device for the air)
VFA	Volatile Fatty Acid (Acetate = Vinegar is the most common one)
VOC	Volatile Organic Compound. Complex set of organic chemicals, by-products of microbial and plant life.
VS	Volatile Solids (loss on ignition at 550 °C)
WRAP	Waste and Resources Action Programme

Common Terms

Common Term	Description
Activated Sludge	Sludge particles produced in raw or settled wastewater by the growth of organisms in aeration tanks in the presence of dissolved oxygen
Aerobic	With air. In microbiology there are three types of living organisms, air-breathing (aerobic), those that do not require air to survive (anaerobic) and those that can switch from being anaerobic to aerobic or vice-versa. The latter are known as 'facultative' organisms.
Anaerobic	Without Air. Applied to bacterial descriptions normally. For example; methane-producing bacteria that split acetate molecules into methane and carbon dioxide are strict anaerobes. Exposure to air kills them.
Anaerobic Digestion	Wastewater solids and water are placed into a large tank where bacteria decompose the solids in the absence of dissolved oxygen
Biomass	The quantity or weigh of all organisms within the treatment process
Biosolids	Thickened and dewatered sludge obtained from a digester
Biosurfactant	A compound released by an organism that reduces the surface tension of wastewater or sludge and permits the production of foam
Centrate	The liquid and its content that are discharged from a centrifuge
Centrifuge	A mechanical device that uses centrifugal or rotational forces to separate solids from liquids
Colloid	Suspended solid with a large surface area that cannot be removed by sedimentation alone
Contraries	Non-putrescible materials in feedstock such as soil, cardboard, eggshell, bone, metals, plastics, and glass. Some of these if from an organic source may be turned into 'soup' with 'pressure cooking.'
Crust	Permanently rafting light material on the surface of the digester or aeration vessel. It is effectively feedstock out of the influence of the bacteria in a digester and when blended into the process fluid by application of extra stirring energy forms a shock load of food to the microbial biomass in addition to the normal feed rate. This can cause foaming.
Delta T	In heat exchangers and some biological processes, efficiency or heat added is calculated from the change in the temperature 'T' experienced by the cool input fluid as it passes through (say) the heat exchanger and emerges hotter at the output. If the input temperature is 10˚C and the output temperature is 15˚C, then the Delta T is +5˚C.
Dry Matter (DM)	What remains after all the water/moisture is removed
Fermentation	A mode of energy-yielding metabolism that involves a sequence of oxidation-reduction reactions to degrade organic substrates
Filtrate	The liquid and its content that pass through a belt press
Floaters	Materials that float in water. See above. Normally includes plastics and fibrous materials especially if they have gas bubbles attached to them.
Generation Time	The time required for the cell population or biomass to double
Grit	Undefined term that means different things to different people. The Soil Survey Field Handbook uses only percentage of clay, sand and silt for soil classification yet mud, clay and stones on potato peelings and similar wastes may be regarded as 'grit' in a waste treatment facility if so defined by the contract. Under stoniness classifications the Soil Survey Field Handbook states, soils containing 'very small stones' strictly 2-6mm are 'gritty', and with 'small stones' strictly 6mm-2 cm are 'gravelly. Fragments of bone, egg shells and cherry pips could be classified as 'grit' in waste streams along with broken glass, pottery, soil on potato peel etc. ABPR regulations require screening of solids in organic matter to 12mm and non-putrescible solids passing a 12 mm screen has in some contracts been defined as grit. Grit must be defined by the contract to avoid confusion in technical discussion.

	There are organic grits like bone and eggshell and inorganic grits such as glass, soil particles, sand, and silt from potato peels etc.
Hydraulic Retention Time (HRT)	The time that a given volume of sludge remains in the digester
Hydrolysis	The biochemical process of decomposition involving the splitting of a chemical bond and the addition of water
JRP	JRP provide a range of Volumetric, Weighbridge and on-board vehicle mounted solutions with custom software packages to provide monitoring, visualisation, and complete control of the road tankering operation.
Mercaptans	Chemicals that are extremely malodourous – varieties of which are used to put the odour in domestic pipeline gas. Mercaptan smells can come from leaks in biogas upgrading and grid -entry equipment or may be formed naturally in anaerobic decomposition processes.
Organic	Compound containing carbon and hydrogen
Organic Dry Matter (ODM)	The proportion of the organic constituents of a substance, after complete removal of water and all mineral constituents.
Organic Loading Rate (OLR)	
Oxidation	The biological or chemical addition of oxygen to a compound or the removal of electrons from a compound
PAS 110	Publicly Available Specification for whole digestate, separated liquor and separated fibre derived from the anaerobic digestion of source-segregated biodegradable materials.
Proteinaceous	Containing proteins
Reduction	The biological or chemical removal of oxygen from a compound or the addition of electrons to a compound
Scumberg	A 'scumberg' is the site definition of sludge solids equivalent of an Iceberg but floating in the digester. They can weigh as much as one or two articulated trucks; small ones tend to grow to larger ones by fibre accumulation. Most of the Scumberg is out of sight under the waterline. Moving at 0.2 meters per second a large (60 tonnes) Scumberg can destroy a lot of equipment including heating elements, stirring systems and sensors.
Sinkers	Materials that sink in water. Most biological processes in waste treatment use aerated water or gassing water (even recycled biogas stirred digestates) and this has a lower density than water and therefore it is not just materials with a specific gravity >1 that may sink. Some lighter materials may also sink in non-buoyant water. The time it takes to sink generally follows Stokes Law and involves particle size, density and critically the viscosity of the fluid. High viscosity fluids hold more sinkers for longer than low viscosity fluids.
Slugs	A dense lump of compressed feedstock that sinks immediately it enters the process vessel.
Solubilization	To place particulate or colloidal materials in solution
Soup	A blend of organic matter and liquids the enables a continuously stirred anaerobic digester to be fed reliably to a plan using simple pumps. The liquid can be water, waste beer, whey permeate, or other material that does not inhibit bacterial growth in the digester. Overflow from swimming pools with bacteria – killing chlorine for instance, would not be acceptable. The aim of the designer is to make each tonne of soup contain as much soluble organic matter while retaining a moderate viscosity so that it can be pumped. Critically, when the digester feed pump stops, the soup should not 'gel' or solidify in the pipe and water content is critical because of this. Ideally soup is screened to remove contamination and held in a tank to allow for some fine sand to settle out.
Substrate	Compounds that are used by bacteria to obtain carbon and energy

Supernatant	The liquid above settled solids
Surfactant	Soap or detergent; a compound that alters the surface tension of wastewater or sludge
Thermal Hydrolysis Process (THP)	Thermal hydrolysis exposes sewage sludge or other types of wet organic waste to high temperature and pressure
Volatile	Changing readily to vapor
WwTW	Wastewater Treatment Works

APPENDIX 5 – STORENGY WEB SITE – DEAL FARM ACQUISITION

Claiming 5 million m^3 biomethane per year (570 m^3 -Biomethane//hr) the equivalent of 1,112 m^3-Biogas/ hr.

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Deal Farm acquisition to put Storengy on the UK Biogas map

News 12 April 2021

Deal Farm acquisition to put Storengy on the UK Biogas map

We're thrilled to reveal the acquisition of Deal Farm Biogas Ltd.

In line with our strategic business goals and growth in the green gas sector, we're thrilled to reveal the acquisition of Deal Farm Biogas Ltd, a unique development opportunity which will enable us to construct and operate our first 'biogas to grid' facility in the UK.

With a connection to the local gas network, the asset is projected to produce 55 GWh/year equivalent to over 5 million cubic metres of biomethane, with guaranteed revenue in RHI.

Biogas in the UK is a well-established sector, with over 500 AD Plants, 75% of which are agricultural. BEIS aims to treble the amount of biomethane in the grid between 2018 and 2030, on the road to the UKs Net Zero target in 2050.

This Agricultural Anaerobic Digestion (AD) Plant will provide us with a unique opportunity for production and commercialisation of biogas derived from a traditional farming feedstock mix of livestock manure, straw and grass.

Construction of the Agricultural AD began in, April 2021, managed by experienced developer BioWatt. We expect completion in early 2022.

Michael Gibson, Managing Director at Storengy UK, said:

"Our acquisition of Deal Farm signals our entry into the UK biomethane market. Biomethane is an important part of the energy transition and I am very excited to be putting our strategic objectives in motion. This diversification of our business builds on our group strengths and supports our vision to be a leading sustainable energy storage and solutions provider".

If you are interested in discussing a biogas project, please contact our Business Development team.

Site works are progressing at pace at our new build Biogas Facility at Deal Farm in Norfolk. This Timelapse photography illustrates the current phase of the Project, which includes establishment of the process compound and the construction of the Biogas Digester Tanks. The tanks measure an impressive 7,200m^3, that's the same size as three Olympic sized swimming pools!

APPENDIX 6 – LAND CROPPING HISTORY 2022

Land Bank Deal Farm	area	2022 crop
	Ha	Grass
Hoskins yard	0.85	Grass
5 acre S	2.22	Grass
Seaman's Field	5.71	Grass
Clayhall	15.35	Grass
Algar House	3.16	Grass
Topsoil Heap	1.2	Grass
Piggery	15.76	Grass
Newstead	10.89	Grass
Rosary	0.52	Grass
grass	0.8	Grass
House	1.2	Grass
Montys 8	3.31	Grass
uncropped	0.33	Grass
west Hall 26	11.1	Grass
west Hall 18	7.26	Grass
	79.66	Grass total
Glebe 23 acre	9.03	arable crops
L Shape 15	5.79	arable crops
TH Bungalow	1.54	arable crops
Lodge S	15.41	arable crops
Sugar Beet	4.86	arable crops
School	22.24	arable crops
High Point	23.73	arable crops
Acorn Lodg	10.27	arable crops
Lodge N	18.51	arable crops
Oaks	50	arable crops
Behind Jeffs	38.99	arable crops
winter wheat	9.29	arable crops
ad left	2.61	arable crops
shelfnger road 18	7.38	arable crops
common road	9.43	arable crops
ted mercers	1.33	arable crops
billy kerries	2.01	arable crops
benny gaze CR small	2.09	arable crops
Benny Gaze common road large	17.22	arable crops
dove farm	0.3	arable crops
Benny Gaze house field	2.04	arable crops
west hall 55	23.46	arable crops
game cover	0.77	arable crops
	278.3	crop total
Total	**357.96**	Ha

The simple sums of grassland area and arable crops areas from the supplied Appendices are totalled above. There is no indication here of what legal interest in the land is held by the Appellant.