25th March 2015

Dr Andrew N. Rollinson,
Blushful Earth,
Castleford,
West Yorkshire.

Mr Shlomo Dowen,
UKWIN

<u>Re: EPR/RP3132ND/A001</u>

Dear Mr Dowen

I am a Doctor of Energy Engineering and I specialise in reactor design, process engineering, and gasification of biomass/waste direct to engine systems. I have worked on such projects at Universities in the UK, Australia and Qatar, and I have experience of gasification to engine systems from India, North America and Europe. I am qualified by BSc (Hons), MSc, and PhD, in addition to being a Member of the Royal Society of Chemistry.

This report contains my independent scientific and engineering appraisal of the Washwood Heath Environment Agency permit application (EPR/RP3132ND/A001). It has been completed using all documents from a dossier sent to me from The Environment Agency in January to March 2015. The report is split into sections, preceded by a general summary. I have evidenced my assessment by reference to written information, diagrams, and tables provided within the application dossier, and these are cited within the text in parentheses using document and/or file names along with a page/Figure or Table caption number. I have also used peer reviewed scientific literature to frequently support the evidence that I submit, and these are cited numerically within the text. The Reference list at the end of this report contains all independent citations.

1. Summary

The dates on the permit application documents are spread over a number of years, and there is high prevalence of contradiction between the information they contain. The proposal is weakly resolved on all scales, and it has a generally high amount of disorder to it. Even within the same document, and occasionally across succeeding paragraphs, there are contradictions and discrepancies relating to process design and operational expectations. Auditing to elucidate definitive details of the proposal at both a general and unit/material specific level is difficult, and far greater clarity should be expected as standard. Much of the support information is unsubstantiated description and many of the process units are "black boxes" which have either general terminology or a title with no common meaning. Where assertions are made about plant operation or design, they too frequently refute established scientific fact, and sometimes proven physical laws. There is also an overall lack of definition, and weak adherence to engineering methodology, with essential process design components such as energy and material balances not provided to a basic level. All this undermines confidence about safe and stable plant operation. My professional opinion is that overly challenging measures above and beyond what the permit dossier suggests will be needed to obviate environmental impact.

2. Summary of System Choice

2.1. There is a footnote on page 93 of Application Support Document_30/10/14 that states "Gasification typically produces a much lower quality (in terms of CV and cleanliness) syngas than pyrolysis". This footnote is **<u>incorrect and consequently misleading</u>**. Pyrolysis is just a stage in the gasification process, which on its own produces poorer quality gas in comparison to a gasifier. Gasifiers incorporate

optimised features such as reduction zones, to increase the purity (therefore calorific value and lower tar content) of producer gas, and the gas is therefore better and cleaner for gas engine use.

2.1.1. The footnote is also wrong and very misleading when it states adds that "Gasification requires much more complex and gas cleaning *[sic]* technologies to achieve a gas quality suited for gas engines". A gasifier will actually require **much "less" complex gas cleaning technologies than a pyrolysis retort**, as gas purification stages are incorporated in its design. By its nature it is designed with heightened complexity.

2.2. This design is un-proven. To send gas from a MSW pyrolysis retort direct to an engine is very rare, and where it has been attempted recently it was a failure, e.g. Seamer Carr , North Yorkshire. In this example, construction was completed in late December 2008 (1), never got past its commissioning phase, and ceased operating in 2009 (2), with only 584 tonnes of waste processed and a description given that the plant "has suffered continual commissioning problems and did not produce a continuous and extended fully operational period to design specification" (1).

3. Energy and Thermodynamics (General)

The permit application is very weak with respect to its process energy production and use. There are many quantitative omissions, and among those provided there are contradictions and/or an absence of proof. This, along with major qualitative discrepancies points to an overall energy imbalance and indicates a design which is thermodynamically flawed. Even though this is an experimental system, greater planning at the design stage should have been done to prove that the mass and energy flows balance. This impacts not just on investment, but on labour and materials efficiency, safety, and environmental impact. My reasons for these conclusions are as follows:

The Sankey Diagram

The Sankey diagram is a stand-alone document (Celan power.pdf – Simplified Sankey and Mass Flow Diagram) but it was also used as **the source of data** from which the Carbon Impact Assessment Scenario were created (SLR Consulting, Carbon Impact Assessment utilising WRATE, October 2014_ Appendix 6, section 4.3). This diagram is described as a "simplified mass flow diagram", but there is no other more "detailed/complete" version. It is not of an acceptable level of quality or detail:

3.1. The mass flows between the segments don't balance.

3.2. The energy flows between the segments don't balance.

3.3. The values for energy are significantly different from those provided elsewhere: in Section 6.2 of Application Support Document_30/10/14 and in response to Question 11 of Formal Response to Schedule 5_5thNov14.

3.4. The water treatment plant, the autoclave, the heat recovery thermal oxidiser, the APC unit, exhaust gas abatement units, syngas cleaning units, are all missing from the diagram.

3.4.1. Consequently, because these units are missing, there are no flows and quantifications of the heat and mass transfer between these and other units, e.g. the exhaust from this APC unit "discharges directly into the pyrolysis char combustion plant" (page 32, Formal Response to Schedule 5_5thNov14), and "All recovered packaging and solid fraction of the Anaerobic Digestate material will be reprocessed through the autoclave units" (page 25 of Application Support Document_30/10/14).

3.5. It is not made clear how the process stages have been split, e.g. which are contained in which segment. The segments have no titles attached to them.

3.6. It has not been explained where the values originate. For example, the input energy of the first box (359,808 MWh) is not supported and its origin explained, nor is it mentioned in any other document.

3.7. There is only one single efficiency loss provided on the whole diagram, and this being unspecified as just "conversion losses 12%" from what would appear to be a segment related to the pyrolyser feedstock.

3.8. There is a parasitic electricity input but only an "exported electricity" output from the engines.

3.9. There is a single water mass input but no output flows.

3.10. None of the gaseous mass flows are present.

3.11. The quantity of char stated (18,000 tonnes) appears to have been miscalculated and overestimated (no details are given about how these values were arrived at in the Sankey diagram). This is important for the proposal is to use this char to provide most of the process heat. The actual quantities of char available can be calculated from the given char content of the pyrolysed fibre (Fibre data in Appendix 7 and Table 2 of Formal Response to Schedule 5_5thNov14). Multiplying the values for fixed carbon in the fibre on a dry basis (9.1% to 15.4%) by the annual amount of fibre processed in the pyrolysers according to the Sankey diagram 104,576 x 0.8 (mass input of fibre minus 20% moisture) reveals that the actual quantities of char will be within the range **7,613 ≤ tonnes ≤ 12,883**. It indicates that **there will be only ca. 40% to 70% of the energy available** compared to that which the application proposes.[*] This is a significant mistake because the application has designated the energy produced by exothermic char combustion to a number of unit processes in addition to heating the pyrolysis retorts.

<u>The Energy and Mass Balance (Appendix 6)</u>

The "energy and mass balance" provided as Appendix 6 to Formal Response to Schedule 5_5thNov14 is not of an acceptable level of quality or detail. It is not a full and proper energy balance, it contradicts other documents, it introduces new units, and omits major ones.

3.12. The flow diagram component of "energy and mass balance" (in Appendix 6) is not only incomplete, but it differs in many ways from the plant design described elsewhere:

3.12.1. It shows units not previously described and/or with unusual titles e.g. "APPU Advanced Pure Pyrolysis Unit", "BSCU", "SISEI vessel".

3.12.2. The AD tanks have no output flows

3.12.3. "Oil" is shown coming from the pyrolyser and going to something called "NOVOGAS™ and oil polishing".

3.12.4. A line of "VOCs" transfers into something called an "NGC Capture system and AHUs"

3.12.5. Units central to the permit application are absent, e.g. the Autoclave unit is omitted (**probably the biggest energy consumer in the design**), and there is no Heat Recovery Steam Generator.

3.12.6. There are no quantified mass flows at all on the diagram, and as the associated table, is also incomplete and unclear, it is impossible to examine the process.

3.12.7. Less than half of the process flow arrows have no qualitative marker attached to them.

3.12.8. Between unit 2 and unit 4 there is a two way arrow with no title attached to it. What is this two-way flow and what is the quantified value of separated unit flows?

3.12.9. There is one line of "heat" going to the "Biomass Fuel Recovery and Drying System" that originates at the engines. But, there is no arrow for process heat coming from the steam generation lines (indeed there is no HRSG unit on the diagram!) which contradicts the assertion on page 7 of Formal Responses to Schedule 5_5thNov14) about where the energy comes from to dry the biomass: "All of the heat provided to the compaction screw conveyor is provided from the pyrolyser HRSG".

3.12.10. Unit 18 is titled "Parasitic thermal load" and has one input and two output lines. What is this unit?

3.12.11. There is an un-named box supplying something and accepting something to and from unit 17. Boiler Feed Tank, supplying the Water Treatment Plant, and accepting something from the Exhaust Steam Condensing System. This unnamed unit is not listed in Table 1.1.

3.12.12. Unit 9, the Cyclonic Combustion Furnace (thermal oxidiser) is shown to accept "oil" and "gas" from the pyrolysis retorts in addition to char.

3.12.12.1. What is this oil and what is its quantity?

3.12.12.2. This is the first mention of producer gas/syngas being supplied to the thermal oxidiser. This contradicts all other statements about the use of the syngas. Quantification is needed and elaboration on this.

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[*] Elsewhere the application claims a different (unsupported) value of char: 16,575 tonnes (page 100, Application Support Document_30/10/14), but this still significantly overestimates the actual quantities.

3.12.13. The undefined Unit 22, "NCG Capture and AHU's" is shown to supply "VOC's" to the Cyclonic Combustion Furnace, yet no quantity is given and there are no mass units listed for it in Table 1.1.

3.12.14. What is unit 10 "NOVOGAS™ and oil polishing"? This accepts oil and gas from the pyrolysis retorts.

    3.12.14.1. According to Table 1.1, associated with it is the consumption of 10kg of **something** per hour.

    3.12.14.2. What is its modus operandi, wastes and emissions?

    3.12.14.3. If this is a gas and tar clean up unit, then why is it separate from unit 16 Water Treatment Plant"?

    3.12.14.4. The Application Support Document_30/10/14 mentions NOVOGAS (page 41), but this is contradictory as it states that NOVOGAS is a "pyrolysis system" with a trade name of 'NOVOGAS' to pyrolyse the biomass fibre produced by the autoclave process."

    3.12.14.5. Table 1.2 states that its temperature is 950°C. How is this unit heated and maintained?

3.13. Regarding the Table components of "energy and mass balance" (in Appendix 6):

3.13.1. Half of Table 1.1 is unpopulated, and it is not clear whether the values given relate to in or out flows, products, consumptions, gains or losses.

3.13.2. There is no standardisation/baseline to the units in Table 1.1 (e.g. per tonne, per batch, per mol) such that it cannot be assessed whether anything balances.

3.13.3. Many of the process units are bunched together and/or have no values attributed.

3.13.4. Table 1.1, row 11, column 3 refers to unit process numbers 12 and 13. Instead of values, this cell has the text "Heat recovered from 8 & 9". However, on the accompanying diagram there are no heat arrows connecting units 12 and 13 with units 8 and 9.

3.13.5. There are two footnotes below Table 1.1 under the heading "start Up Requirements". These relate to "sodium bicarb" and have titles of "FG Cleanup" and "FG residue". No explanation is made about what these describe,why they are not part of the main table, and why the values differ from the 1200 tonnes per annum of sodium bicarbonate in Table 4.1 of Formal Response to Schedule 5_5thNov14.

3.13.6. There are non-standard undefined acronyms used, e.g. "FM", "NFM", "REC", "FG".

3.13.7. Table 1.2 assigns units 7,8, and 9 with a value of "1200 c" [Assuming this should be 1200 °C].

    3.13.7.1. Unit 8 is the "APPU Advanced Pure Pyrolysis Unit". If this is the same as the pyrolysis retorts described in other documents, its temperature is 350°C too high.

    3.13.7.2. What the BSCU is (unit 7) has not been described, but an explanation is needed about how it can attain and maintain temperatures of 1200°C.

    3.13.7.3. According to manufacturer documentation, Unit 9 (the "Cyclonic Combustion Furnace") cannot reach temperatures of 1200°C (cf. 7.4.1).

3.14. By its design, this process will necessitate a number of heated lines (e.g. the "VOC" transfer to the "NGC Capture system and AHUs", steam lines, the syngas cleaning lines). No description or values are attributes to this in Table 1.2.

4. Pyrolysis (System Practical Aspects)

Pyrolysis is the unoxygenated heating of a carbon-based feedstock and a method for producing gaseous, liquid and solid products that have chemical functionality and calorific value. The pyrolyser therefore thermally treats the waste after it has left the Autoclave, and the gaseous component is termed Producer Gas, although the name Synthesis Gas (Syngas) is frequently used due to similarities in chemical composition. Historically, wood is pyrolysed to make bio-oil or "tar" (the liquid component), while gasifiers optimise gas yield and purity. With this proposal, because mixed waste material rather than just wood is to be pyrolysed, there is potential for much higher concentrations of impurities and variations in operating temperature.

<u>Process Operation</u>

4.1. The brief statement in response to Question 35 of Formal Response to Schedule 5_5thNov14 that "The temperature of the pyrolyser casing and retorts are all continuously monitored and controlled" requires further explanation. Monitoring is conventional, but control is not, due to the endothermic demands and the varying reaction kinetics of the feedstocks. This is the major challenge of gasification and pyrolysis, accentuated by this proposal using a mixed waste with potentially wider variations in heterogeneity. Gas quality and outputs of tar all are dependent on maintaining internal reactor temperature. Even with a homogeneous material like coal, temperature is still the major challenge. Sometimes, it can be assisted by the engine, but this proposal has complex interconnected and disparate units, so that the engine is greatly detached (by the gasometer) from gas flow control. This aspect is very important.

4.2. It is described on page 50 of Application Support Document_30/10/14) that "The pyrolyser retorts have been specifically designed to have a short length to ensure that the gas dwell time within the retort is minimised. The minimisation of gas dwell time reduces the formation of hydrogen in the pyrolysis gas. This design also prevents the potential of heat deformation." This assertion is concerning:

4.2.1. It is not explained why "dwell time should reduce the formation of hydrogen" or indeed why reduction of hydrogen should be sought. **Increased** hydrogen content is a desirable outcome for producer gas as it is a combustible product which increases the gas calorific value, and its presence indicates that less tar can have formed.

4.2.2. An explanation is needed regarding what exactly might deform under "heat".

Design for Material Input

I have concerns about the adequacy of design with respect to pyrolysis retort fuel feeding. How exactly the feedstock is fed into the pyrolysis retort is not explained and this has major implications for the temperature of the reaction vessel (then consequent product concentrations and emissions) and fugitive emissions pre-processing, along with satisfactory design due to energy and mass balances.

4.3. The diagram provided (Figure 4, page 30 of Formal Response to Schedule 5_5thNov14) does not show a feedstock entry point. **No alternative diagram is provided, and no text description is given to explain the method of feedstock entry.** This seems incompatible with a continuous feeding system.

4.4. The table on page 43 of Application Support Document_30/10/14 states that for Zone Z3-1, "Conveyer systems fitted with enclosed extraction to thermal oxidiser plant". What exactly is "enclosed extraction"? Extraction of gases, or solids, or liquids, and what composition of extractate is expected? As this "conveyer system" must be subjected to a temperature gradient as it feeds the retort, volatile emissions can ensue. The fate of these compounds in relation to the whole plant has not been provided.

4.5. The odour management plan (SOL0213CPP01_OMP_Nov/14, page 19) gives a different option: "All autoclaved fibre material is stored in sealed bulk hoppers prior the introduction to the pyrolyser feed conveyor thermal recovery."

4.6. In response to Question 43 of Formal Response to Schedule 5_5thNov14, it is introduced that the biofibe/biofibre, as it is being fed into the pyrolyser, is first compacted into a large log and then "…pushed through into another screw mechanism that breaks the log down into a less compact structure to allow for complete pyrolysis." This is very odd practice indeed and highly inefficient. No rationale is given for this unnecessary process inefficiency of shaping the fibre from small to large and back to small again.

Design for Material Output

4.7. How the char is removed from the pyrolyser retorts is not properly explained and the design proposed appears intrinsically flawed.

4.7.1. Figure 4 (page 30 of Formal Response to Schedule 5_5thNov14) shows "char exit auger from pyrolyser". This is in the rotational centre of the retort, and therefore its potential to extract

char seems impossible. If this operates as a batch process, the char will settle at the stationary outer radius, and so the auger will only be able to extract at most, half the contents of the retort. If this operates as a continuous reactor, then during rotation, the char will, by centrifugal forces, also move to the outer radius of the reactor, and there will be much less than 50% of the contents accessible for extraction. No description of the char extraction is provided.

4.7.2. Is the syngas exit point the same as the char exit point? It appears to be from Figure 4 (page 30 of Formal Response to Schedule 5_5thNov14). With such a design, entrainment of fine char particles in the gas stream is certain to occur thus imposing higher demands on the syngas cleaning system than already suggested.

4.8. In response to Question 1 (Formal Response to Schedule 5_5thNov14), it is stated that "The charcoal combustion thermal oxidiser exhausts will always operate at the same rate irrespective of the throughput through the pyrolysers". This statement is incorrect, as the amount and quality of char available for combustion is an independent variable - a function of the feedstock. Notwithstanding that there are gross omissions in information about the process throughputs and feeding rates which dictates char quantity, the two analytical reports provided (by Alfred Knight and titled "fibre data"/part of Appendix 7) show wide variations in the fixed carbon content (essentially the combustible components of the char). The two values given show a high standard deviation, with (on a dry basis), concentrations of 9.1% and 15.4%. This is classic heterogeneity of a mixed waste feedstock. This is too high a difference to be confident that the pyrolyser heat input can be stable.

5. Pyrolsyer Feedstock: "BioFibe/Biofibre".

Pyrolysers and gasifiers are at present not generic waste conversion systems. They are rigid, feedstock specific technology and incomplete conversion products <u>always</u> ensue (3, 4, 5). Variations in feedstock composition will affect the satisfactory operation of the whole plant and the quality of gas produced.

5.1. On page 6 of SOL1211VT01 End of waste submission, the BioFibe log shown is described as "prior to pyrolysation (note that this material has been subject to significant testing and proven to contain very low levels of inorganic material or contaminants)."

5.1.1. **This statement is incorrect**, for the inorganic mineral content is relatively high in both the samples analysed by Alfred Knight. These value reported for the ash are between **ten and twenty times higher than woody biomass**. This is in the range expected for municipal solid waste (4).

5.2. In Table 1C of SOL1211VT01 End of waste submission, it is stated that the "The pyrolysis plant will be operated using clean (non hazardous) BioFibe…which will be free of glass contaminants".

5.2.1. **This statement is incorrect.** The ash reported by Alfred Knight (in document "fibre data"/Appendix 7), is predominantly SiO_2, with concentration values of 42% to 45%.

5.3. It is repeatedly stated that the low tar production occurs as a consequence of the Autoclave process: "Naturally very low levels of tar due to the removal of plastics and lignin due to *[sic]* autoclaving process" (Table 6.76, Application Support Document_30/10/14). It has not been explained how the autoclave process can reduce lignin content but leave it as predominantly cellulose/hemicellulosic: "The autoclave fibre is almost devoid of lignin and is predominantly cellulose materials" (page 35 of Formal Response to Schedule 5_5thNov14). There has been an enormous amount of research on biomass pyrolysis, and **cellulose and hemicellulose decompose more easily, and always at lower temperatures, than lignin**. Lignin is more robust and only begins to break down **AFTER** cellulose. What the application proposes is therefore that the autoclave breaks down lignin, but leaves cellulose. **This assertion is discordant with scientific studies completed over that last half century, and no explanation has been offered to account for this.** For an accessible scientific discussion of these compositional aspects of biomass pyrolysis see (6).

5.4. The application (in response to Question 42 of Formal Response to Schedule 5_5thNov14) lists four at least (including "etc") testing laboratories to support the statement that "third party analysis has been

undertaken on innumerable samples [of biofibre]". This information is crucial for a satisfactory assessment to the material.

5.4.1. Only one of these (Alfred Knight) is included with the permit dossier.

    5.4.1.1. Half of the Alfred Knight analytical report document (titled "fibre data"/part of Appendix 7) is missing. Only pages 7 to 12 are provided, and the samples are named as No 3 and No 4, thus suggesting that should also be results for samples No 1 and 2.

    5.4.1.2. The fibre analyses shown in Table 2 and Table 3, page 6 of Formal Response to Schedule 5_5thNov14 [tables repeated also page 44 of Application Support Document_30/10/14], is not supported by any analytical report. It is described as "a typical fibre analysis". Most of the values are the arithmetical mean from the two Alfred Knight analyses. Whether this has been done is not explained.

    5.4.1.3. Page 10 of Application Support Document_30/10/14 refers to a number of technical appendices, one of which has the title "Annex B9 – char and fibre data". Despite it saying that "All technical appendices associated with the Installation are included within SOL0514CPP01 - Volume 2". There are no appendices included, and Annex B9 is not provided.

5.4.2. The provenance of the samples still remains undisclosed for all reports on fibre composition within the permit application dossier. Needed for authenticity are:

    5.4.2.1. The detailed composition of the feedstock that created the biofibe/biofibre from which the syngas was derived in the analysis.

    5.4.2.2. Full details of the biofibe pyrolysis tests for these analyses (temperature, residence time, pressure, duration, number of repeat sets, process diagram of all components).

    5.4.2.3. It is pertinent to know what stage of the process at which the samples were extracted since it has now been stated that post-autoclave the fibre is subjected to heightened pressure and temperature such that it loses a further 20% to 30% of its mass (cf. Sections 7.7 - 7.8).

6. Pyrolysis (Tar)

Tar production is the major cause of gasifier to engine system failures, and within the permit application this issue has not been adequately addressed. Despite the application making the unequivocal statement that "there are no tars or oils produced by the pyrolysis of biofibre" then later "has been slightly taken out of context and should not be literally translated" (page 35 of Formal Response to Schedule 5_5thNov14), claims about tar formation are still contrary to scientific fact and years of extensive research. Gasification and pyrolysis of biomass tar formation is not only a function of biomass composition, temperature, and residence time but also heating rate.

Biomass Composition

6.1. Even if all lignin could be removed from the feedstock (see Section 5.3), **this will not obviate quantities of tar higher than the applicants suggest.** There has been extensive work in this field for at least the last thirty years (see refs 6, 7, 8, 9, 10), and it is proven that bio-oil/tar does not form from lignin alone. Biomass composition is of much lesser importance than temperature, and moisture content, indeed **"The composition of the dry fuel has little effect on the tar amount and composition"** (8).

6.2. Additionally, lignin only constitutes a small percentage of biomass. 60% to 80 % (dry basis) of biomass is cellulose and hemicellulose (6). Since "Lignin produces [only] slightly more tar than cellulose" (8, and references therein), the Biofibre feedstock will have high propensity for tar production.

6.3. Experts in this topic are ECN, and they describe how "Lignin produces [only] slightly more tar than cellulose, but the tar dewpoints are the same" (8), thus meaning that regardless of the component, the **difficulty in removing the tar remains the same**, and hence removing lignin (even if it were possible- cf. Section 5.3) from the feedstock **will be insignificant in regard to syngas cleaning strategies** in this permit application. Best available technologies for abating tar have not been incorporated.

6.4. The following response to Question 46 of Response to Schedule 5_5thNov14 is **misleading**: "During pyrolysis the primary tar fraction from cellulose is ready *[sic]* converted to CO, CO_2, CH_4, and H_2, resulting in very low levels of tar".[†]

6.4.1. One way of categorising tar is to name the first low temperature group of long-chain hydrocarbons that evolve from biomass pyrolysis as "primary tar". This "primary tar" does begin to thermally convert at ca. 500°C, **but it does not simply convert to the molecules named by the application,** and consequently it will not, as the application suggests "result in very low levels of tar components". As temperatures increase from 500°C secondary tars begin to form from the primary tar decomposition products, which reach a peak at around 700°C (7, 11). It is not therefore a simple matter of increasing temperature and cracking the tars. New tars form as temperature increases and these new tars are longer chain, heavy, refractory molecules that are very difficult to remove from post-processing stages (see section 6.3).

6.5. The response to Question 46 (Response to Schedule 5_5thNov14) contains the statement that "cellulose based materials yield $1/5^{th}$ to $1/6^{th}$ of the tar formation of lignin based materials".

6.5.1. A citation for this assertion should be given. I have never encountered or read about this before.

6.5.2. The statement is in many ways irrelevant since it does not matter at what rate the lignin thermally converts in contrast to the cellulose for the purposes of process tar mitigation (as explained in 6.3 and 6.4 above), due to the secondary and tertiary tar formations that ensue and the overall tar dewpoint.

6.5.3. It is not clear at all, what the sentence means by "materials yield…of the tar formation". Does this infer a "yield $1/5^{th}$ to $1/6^{th}$" of the *quantities* of tar? If it is supposed to mean that tar will form in these fractions from the raw biomass, then it likely confused with the actual cellulose:lignin composition of biomass which is in circa the same ratio of 5:1 (6). Using this however to justify low tar production from a low lignin feedstock is illogical as even if the lignin could be removed, then there will still be five times higher concentration of tar forming material from which the tar is derived.

Temperature

6.6. The permit application does not adequately respect the significance of reactor temperature on tar production. The following extract is based on extensive tests with numerous pyrolysis and gasifier reactors over a 19 year period (8):

"The temperature has the most marked effect on tar amount and composition. A higher temperature promotes polymerisation, resulting in compounds with a larger number of rings. The total amount of tar decreases, but the concentrations of class 4 and 5 compounds increase. Because the heavier tar compounds have lower vapour pressures, the tar dew point rises with the gasifier operating temperature. Increasing the gas residence time in a hot zone has a similar effect too but smaller than increasing the temperature".

6.7. The permit application contains many discrepancies and design statements which give major cause for concern that temperature can be maintained along with aspects of the design which can combine to adversely affect reactor temperature (see Sections 7, 4.1, and 4.2).

Residence Time and Heating Rate.

6.8. The residence time in the pyrolyser and heating rate remains unclear and confused as a consequence. No definitive answer is available on whether the pyrolysis retorts operate as a batch, semi-batch, or continuous flow process. This is a gross omission which affects material flows in and out of the retort, along with all other connected process units, and emissions. What the application initially proposed was fast heating of biomass under pyrolysis conditions and

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[†] It is assumed that this means "readily" converted.

some of these statements remain:, e.g. "The pyrolyser retorts have been specifically designed to have a short length to ensure that the gas dwell time within the retort is minimised" (page 50 of Application Support Document_30/10/14).

6.8.1. Contrary to these statements, on page 36 of Formal Responses to Question 5 (answer to question 46), the applicant now states that "The retention time within the pyrolysis chamber will be in excess of 20 minutes, thus allowing for full conversion to take place".

6.8.2. Heating rate is absolutely crucial and is the key parameter that determines tar formation. To state that the residence time is twenty minutes is only meaningful if it is known whether the reactor is batch, semi-batch or continuous, and values are given for feeding rates along with temperature. This may be instantaneous input of a batch at 700°C, which will create rapid contact and then rapid cooling due to the endothermic nature of the reaction.

6.9. In Response to Schedule 5_5thNov14, page 36, the application states that "the phrase 'fast' heating of the feedstocks should not be confused with 'fast pyrolysis or flash pyrolysis'". This statement is somewhat irrelevant, for the terms are merely titular. Fast heating of biomass in unoxygenated conditions _is_ fast pyrolysis. There is no demarcation between temperature regions, rather a continuum along a thermal gradient such that at the shortest residence time and highest heating rates favour liquid products whereas the slowest heating and longest residence time favour gas yield. The science is proven and unequivocal: **tar will be produced in higher quantities when subject to shorter residence times.**

6.10. The statement "very little, if any, pyrolysis oils and tars are produced" in the pyrolysis retort (page 61 of Application Support Document_30/10/14) by just heating to ca. 700°C alone can be refuted. The following are extracts from relevant peer reviewed tar cracking research literature:

> "The rate of thermal cracking is such that high temperatures are required – in the order of **1200°C or higher** (also depending on the residence time at high temperature) – in order to break down enough tars so that the remaining fuel gas can be used problem-free in a downstream device such as a gas engine, gas turbine or catalytic synthesis processes" (12).

> "**Converting tar completely to gas requires greater than 1,100°C without catalyst** (13).

> "**Temperatures lower than 1,000°C - 1,100°C are inadequate for thermal tar cracking and elimination** (14).

7. Char Combustion Energy Audit

This section highlights the apparent energy imbalance that exists with the process design. I was mindful not to do the work of creating the application energy balance, but, I needed to collate the information on energy designations for waste heat and put together some connectivity and clarity.

I have used the term "char combustion" to define the plant heat generation units associated with the pyrolysis retorts for consistency. The application dossier however uses a number of other synonyms: "thermal oxiser", "cyclonic combustion furnace" and "vortex unit" along with occasionally "Pyrolyser HRSG".

Figure 1 shows the energy input from char combustion in red. The blue arrows represent the assigned energy demands and other inputs/outputs which impact on the energy budget. Marked on Figure 1 are section headings of this report, where each demand is discussed. Where data permitted, I have also attempted some quantification of the energy flows.
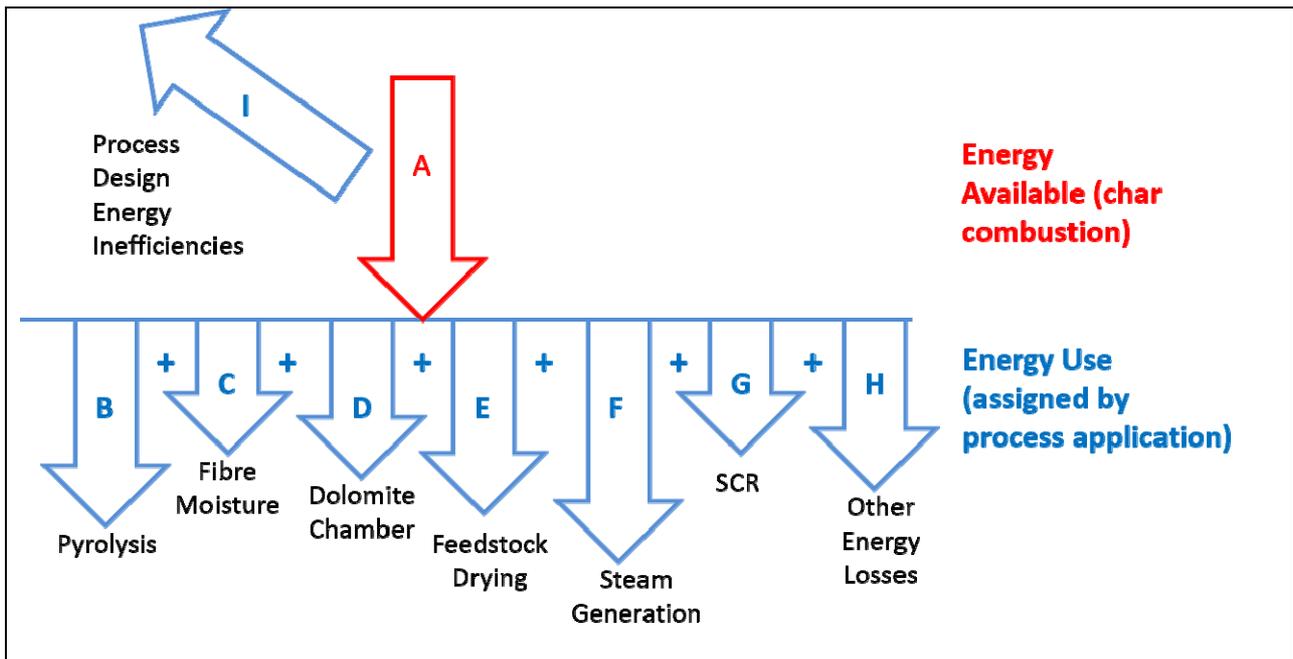
Figure 1. Energy allocation for plant from char combustion. See text for descriptions related to alphabetic annotations. Arrow size is estimated only due to insufficient data.

Heat Output from Char Combustion – (A)

7.1. The energy available from the char has been discussed in Section 3.11, and can be calculated at between **25,377 ≤ MWh ≤ 42,946** annually derived from fixed carbon content of biofibe/biofibre multiplied by the calorific value of 12 MJ/kg given on page 100 of Application Support Document_30/10/14). **The fixed carbon content of the biofibre is the most accurate way to determine char content of biomass**. These values are both much lower than those claimed elsewhere within the application, namely: 55,250 MWh (page 100 of Application Support Document_30/10/14), and 64,000 MWh (Celan power.pdf – Simplified Sankey and Mass Flow Diagram). There is no explanation within the application for why these values are used. This discrepancy is significant because the plant is designed to operate using this heat.

7.2. The method of heat transfer _to_ the pyrolysis retorts will have associated energy losses (radiative conductive and convective transfer). This will further reduce the amount of heat energy available for downstream use. These heat losses are not quantified or described, but also it is unclear how the heat is actually transferred. What descriptions that are given are inconsistent:

7.2.1. Page 58 of Application Support Document_30/10/14 states that "All combusted exhaust gases from each of the charcoal combustion units are routed around the external shell of the pyrolysis retort". This conflicts with the image of the pyrolysis retort depicted as Figure 3.11 of the same document which shows **no external shell** and also showing "hot air from char burners/thermal oxidisers" **passing some distance above the retort and disconnected from it.**

7.2.2. In Application Support Document_30/10/14, half of a diagram which should show the char combustion configuration (Figure 3.9. Zone 3 and 4, Pyrolysis and Generation) is missing, and there are inconsistencies between the accompanying (uncaptioned) table and the figure. The diagram is too poor a resolution to make out any of the detailed features; and items "Z3-1 (Combined Pyrolyser Feed System)", and "Z3-2 (Pyrolyser Plant)" are named in the table, but they are not shown on the schematic.

7.2.3. If heat exchangers (and working fluids) are used, the efficiency of these heat exchanger systems are not given.

7.2.4. If conduction is assigned to provide sufficient reaction heat from the small quantities of char, then radiative losses should be assigned.

<u>Heat Demand for Pyrolysis – (B)</u>

7.3. Heating the retorts to maintain pyrolysis of the biofibe/biofibre feedstock is the fundamental use for the exothermic heat of char combustion. No values have been suggested within the application, although these can be derived from reaction kinetic activation energies for the Refuse Derived Fuel (RDF). Energy use also depends on throughflow of material and temperature.

7.4. The quantity of heat transferrable to the pyrolysis retorts appears to have been significantly over-estimated: "The temperature of the flue gases will typically exceed 1200°C as they are passed over the retort, dropping to approximately 850°C upon exit" (page 59 of Application Support Document_30/10/14). Figure 3.10 of Application Support Document_30/10/14, shows that the combustion chamber will operate at "1200 ≤ °C ≤ 1250".

7.4.1. These assertions are actually refuted by the manufacturer's technical specification document (Charcoal Combust0.pdf) which gives internal temperatures of a maximum 1093°C, and shows an operating system readout with an internal temperature of 843°C.

7.4.2. Even if the char combustion chamber could achieve temperatures of 1200 ≤ °C ≤ 1250. It is unlikely that "The temperature of the flue gases will typically exceed 1200°C". The gases evolved from a dry combustion source will be at a <u>much lower temperature than the char</u>.

7.4.3. The temperature of combustion affects:
  7.4.3.1. The ultimate fate of metals which are contained in the char.
  7.4.3.2. Achieving the minimum 850°C for 2 seconds (IED requirement).
  7.4.3.3. Providing sufficient heat for downstream process stages which have been assigned to utilise energy from the pyrolysis stage (such as the syngas cleaning).

<u>Heat Demand for Moisture Content of Fibre/Biofibre – (C)</u>

7.5. It is highly energy intensive to raise the temperature of water/steam. Consequently feedstock moisture content imposes a parasitic energy demand. This can be calculated from known values of the sensible enthalpy of water and steam, and the latent heat of water vaporisation. Page 40 of Application Support Document_30/10/14, states that the moisture content will be below 10%. From this, a value of **5898 MWh** per year will be required (see Figure 2).

<u>Heat Demand for Dolomite Chamber – (D)</u>

What energy left after the heating of the pyrolysis retorts will be low grade heat. However, before assigned to steam generation, there are other units in line, the first of which is a Dolomite Chamber.

7.6. How the dolomite chamber can be heated to 850°C, and the question of how the temperature is maintained has not been adequately explained. The temperature of the external casing of the pyrolysis retort is 850°C (page 36 of Formal Response to Schedule 5_5thNov14) and, aside from whether this is achievable (cf. Section 7.4), the energy needed and the method of heat transfer is not given. It is described on page 53 of Application Support Document_30/10/14 that "The gas exits the pyrolyser at approximately 650°C and passed immediately into the dolomite chamber and raised to a temperature of 850 – 900°C". On page 62 of Application Support Document_30/10/14, it is stated that "The location of the reactor within the refractory casing means that the unit is heated automatically as a result of the combustion of the char within the thermal oxidiser units".

7.6.1. The unit is labelled as part of the pyrolyser (page 53, Figure 3.11, ibid). However, a contradiction occurs in the same document (page 62), and also repeated in Formal Response to Schedule 5_5thNov14 (twice on page 29) where it is stated that "The gas cleaning train will be supplied as independent self-contained, pre-assembled 'skid'. This would preclude it from being part of the pyrolysis retort and so will not be heated by conduction as suggested. Table 2A of SOL1211VT01 End of waste submission, also shows the dolomite chamber **external** to the pyrolysis retorts.

7.6.2. That the Dolomite Chamber is directly heated by char combustion exhaust gases is also contradicted by Figure 3.11 of Application Support Document_30/10/14 which shows "hot air from char burners/thermal oxidisers" **passing some distance away from the dolomite chamber and completely disconnected from it.**

7.6.3. In terms of heated "automatically", does this mean heated "passively" or by some adjustable control? It is not clear how the char combustor can heat the retorts to 700°C, and then at the same time also maintain the dolomite chamber at 850°C. How can the heat be satisfactorily distributed in this way?

Feedstock pre-heat/Compaction Auger Drying – (E)

7.7. The application states that the total moisture reduction is from 40% to 10% as the biofibe/biofibre is transferred to the pyrolyser with energy input for this coming from post-process stages. Some or all of it is assigned to come from char combustion, although there is no quantification of the extent of drying between conveyer and auger, and if this heat input comes from different sources, plus what contribution each input has (cf. energy and mass balances). These are not trivial amounts of water and quick calculations reveal minimum energy demands of **13,108 ≤ MWh ≤ 23,688** per year in Figure 2. **Thus this value of energy alone would require perhaps half of that available from char combustion (cf. Section 7.1).**

7.8. Page 7, of Formal Responses to Schedule 5_5thNov14 asserts that biomass drying is "heated from recovered heat from the HRSG and gas engines". In the very next paragraph this is contradicted by "All of the heat provided to the compaction screw conveyor is provided from the pyrolyser HRSG".

7.9. It is not stated whether this compaction auger is heated by direct contact with hot process gases, or by non-contact heat exchange. If direct contact, then no explanation is given about where the spent gases (which are likely to contain volatile metals, particulates, and soluble compounds) go.

Steam Generation for Autoclave – (F)

7.10. By this stage the heat of reaction from char combustion will have given up most if not all of its energy. However the application assigns it to the task of generating copious amounts of steam requiring tremendous energy of **27,456 MWh** per year. **This would demand more energy than would be available from char combustion if the feedstock had its lowest fixed carbon content (9.1%) (cf. Section 7.1).**

Selective Catalytic Reduction – (G)

7.11. Although no definitive answer has been given (Question 38 of Formal Response to Schedule 5_5thNov14), all indications are that this process stage is designated as requiring heat from char combustion. No values have been assigned to this and none can be calculated since no volumetric flow rates are known, and temperature differences are not available.

7.12. Response to Question 38 states that the energy to maintain this unit's operating temperature will be "provided through the use of a steam storage (accumulator) system, which required a continuous heat load *[sic]*".

7.12.1. What this unit is, how much energy demand the SCR system imposes (to prove that it can be met), and how the energy will be transferred and maintained have not been explained.

Process Designs which Reduce Char Combustion Energy Output Potential – (H)

Notwithstanding the above, there are a number of statements contained in the application dossier which relate to design choices that can have a detrimental effect on the satisfactory operation of the char combustion reactor. This is through diluting the oxygen content and/or through the input of colder gas streams.

7.13. The final odour management plan proposes that the exhaust gases from the autoclave go directly to the char combustion units (page 18, SOL0213CPP01_OMP_Nov/14): "All of the ducted autoclave extraction, as well as the ambient air within Zone 2 and 3 will be ducted through the charcoal combustion units." This low temperature (Autoclave operating temperature is 160°C – Table 8, Formal Response to Schedule 5_5thNov14), and probably substantial gas flow rate could basically put out the pyrolyser due to its temperature, high moisture content (likely) and probably also diluting effects of reducing the amount of oxygen for combustion.

7.14. "Relatively low levels of moisture" are stated, but there is no quantification of justification of this. On the contrary, according to page 39 of Application Support Document_30/10/14, there will be 75-80% of the 12,000 kg of steam per hour that enters the autoclave not recovered.

7.15. Hot "air" from the gas engines is proposed for drying the biofibe/biofibre pre-pyrolysis, and this "air" is subsequently sent to the charcoal combustion units for it to be "thermally oxidised" (page 40 of Application Support Document_30/10/14, and page 7 of Formal Responses to Schedule 5_5thNov14):

7.15.1. It is not explicit where this air originates. It is stated that it comes from "heat exchanger fitted to the gas engine hot water system" (page 7 of Formal Responses to Schedule 5_5thNov14). What exactly is the "engine hot water system" is unresolved. It cannot be the engine coolant, which is a closed loop system likely containing liquid glycol.

7.15.2. That this air comes from a "heat exchanger" also suggests a closed loop system, but this cannot be so since the ultimate fate of the "air" is terminal, into the char combustor.

7.15.3. No flow rates are given for this "drying air".

7.15.4. This drying air is said to reduce the moisture content of the biofibe/biofibre from "30-40% to below 10% rated at 15 tonnes of fibre per hour" (page 40 of Application Support Document_30/10/14). As previously mentioned (Section 7.7), the energy will be immense. Assuming values are on a mass basis, this equates to 3 to 4.5 tonnes of water per hour.

7.15.4.1. This moisture is likely to have contaminants which will be fed to the thermal oxidiser thus re-cycling these contaminants within the system.

7.15.4.2. This cold, moisture-laden air sent into the char combustor could rapidly cool it.

7.16. There is another combustion reactor introduced within the design – "APC Unit". Exhaust gas from this "discharges directly into the pyrolysis char combustion plant" (page 32, Formal Response to Schedule 5_5thNov14). This is an elementary process mistake which would have a major impact on the operation of the pyrolser char combustion units (which already appear to have a negative energy budget), which in turn will impact on the pyrolyser temperature leading to dirtier gas emissions. On page 1 it is stated that "The useful heat discharged by the APC unit will displace the equivalent heat input that would otherwise be provided through the combustion of charcoal within the thermal oxidiser." **This contravenes the second law of thermodynamics.** The exhaust gas from this unit, being primarily CO_2 and H_2O, will have an immediate and significant cooling effect on the char combustors, and the instant that it enters, the char combustion will likely be put out, and pyrolysis will stop. Flue gas is actually used in gasification plants to cool reactor chambers. Additionally, this exhaust is likely to contain gaseous and particulate pollutants which it will consequently transfer. So, it is erroneous to state that "The useful heat discharged by the APC unit will displace the equivalent heat input that would otherwise be provided through the combustion of charcoal within the thermal oxidiser" (Page 1, Formal Response to Schedule 5_5thNov14). This will be colder low grade heat (e.g. exhaust from a smaller char combustor) entering a higher temperature region (in-situ larger char combustion), and by the second law of thermodynamics it will create constant cooling of the char combustion, hence insufficient temperature and dirty gas emissions.

7.17. By the Odour Management Plan (page 10 of SOL0213CPP01_OMP_Nov/14), "All extracted air from the anaerobic digestion off gas extraction systems, tank vents and over pressure valves are extracted directly to the air intakes of the main thermal oxidiser units and thermally oxidised." This is another gas stream, at ambient temperature, that will impose a significant cooling effect on the combustion zone. The moisture levels (and other chemical components within the gas) are not disclosed, but these will impose parasitic energy demands too. H_2S concentrations are high in biogas and, along with HCl have potential to lead to adversely affect the pyrolysis system's structural integrity due to corrosion to process pipes, reactors and pumps, which can result in catastrophic failure.

7.18. A contradiction exists regarding "air drying". Page 11 of SOL1211VT01 End of waste submission proposes that "The fuel feed system is a key process to ensure the removal of oxygen/air in the input feedstock of the retort. The compaction of the feed stock by compression screw is key for the removal any intrinsic air, thus excluding oxygen." It is important to know whether this "air drying" is contact or

not contact. If it is contact then it involves adding air to the pyrolysis retort which will alter the reaction chemistry with a likelihood of internal combustion or even explosion. This is also crucial for gaseous emissions, for as stated "Excluding oxygen prevents combustion of the fuel and ensures that no dioxins can be formed" (page 11, SOL1211VT01 End of waste submission).

Un-defined Energy Losses – (I)

7.19. Figure 4 (page 30 of Formal Response to Schedule 5_5thNov14) describes how "Hot Air" exits the pyrolyser: "Hot air exit from pyrolysis casing/furnace at 850°C". This is very unusual terminology and the actual description needs elucidation.

7.19.1. How can "hot air exit" the pyrolyser?

7.19.1.1. The gas cannot be separated between syngas and "air".

7.19.1.2. Pyrolysis stoichiometry is by definition, oxygen limited, as described "...an oxygen free environment, where the thermal conversion of the fibre takes place" (page 5 of Application Support Document_30/10/14).

7.19.2. Clarification is needed on the flow rates of any carrier gas/diluent inputs to the pyrolysis retorts, e.g. nitrogen.

7.19.3. It is contradictory and apparently impossible for "hot air [to] exit from pyrolysis casing/furnace at 850°C", since, as stated in response to question 47 (page 36 of Formal Response to Schedule 5_5thNov14), "The temperatures within the pyrolysis units will be approximately 700°C". It disobeys the laws of thermodynamics to have a gas leave a central heat source at 700°C then acquire a further 150°C from the surroundings.

7.20. Efficiency losses must be included **for each of the process units described**. No quantification is given regarding the losses of energy but they are not trivial amounts, and they have particular relevance since waste heat is assigned for many other uses.

Summary

As described, there are examples that undermine the assertion that the plant will run on waste heat. It is of note that the highest energy demand (apart from perhaps maintaining the endothermic pyrolysis reactions) is right at the end of the energy transfer line, thus using low grade heat that has already been subject to numerous uses. Also of note is that this autoclave energy demand is likely greater than the amount of energy available from the char.

Some simple calculations highlight the significance of energy and mass balancing in relation to the size of the plant and values elsewhere assigned to energy and water use. Values should be compared with the energy available and energy demands assigned (see text and Figure 1).

Note that these are **minimum values** as they exclude the sensible enthalpy to heat water and steam. To include this, it would be necessary to know the temperature changes, which are not clearly provided by the permit application.

Water latent enthalpy of vaporisation = 2256 kJ/kg = 2,256,000 kJ per tonne.

a) Drying of Biomass from "30-40% to below 10% rated at 15 tonnes of fibre per hour" (cf. Section 7.15.4)

Energy to vaporise the stated values of water (3 to 4.5 tonnes per hour) would require: 6,768,000 ≤ kJ ≤ 10,152,000 per hour

This requires 1880 ≤ kWh ≤ 2820

Total energy for year = 15,792 ≤ MWh ≤ 23,688 (assuming 24 hours, for 350 days per year).

Mass of water = 72 ≤ tonnes ≤ 108 (per day).

  = 25,200 ≤ tonnes ≤ 37,800 (per year, assuming operation for 350 days).

b) Enthalpy demand of 20% moisture in the feedstock (based on RDF quantities given in Sankey diagram)

20% of 104,576 = 20,915 tonnes
Latent heat of vaporisation =(2,256,000)x(20,915) = 47,184,240,000 kJ = 13,108 MWh
c) Enthalpy demand on the pyrolysis retorts due to feedstock moisture based on 9% (See Section 7.15.4), and on the RDF quantities given in the Sankey diagram
9% of 104,576 = 9,411 tonnes of water per year
Latent heat of vaporisation =(2,256,000)x(9,411) = 21,231,216,000 kJ = 5898 MWh

Figure 2. Estimates of energy required to remove moisture from the biofibe/biofibre to the levels stated by the applicant in the pyrolyser feed system.

8. Mixing Biogas and Producer Gas

The proposal to mix gases from anaerobic digestion and pyrolysis then supply this mixture directly to an engine poses numerous inherent technological challenges and it has, to my knowledge, never before been attempted, even in bench or pilot scale research. The permit application does not adequately address these challenges.

Engines are set up to operate on a fuel with a limited range in composition. Within narrow limits, this set up relates to: The heating (calorific) value of the combined fuel and air mixture that enters the engine cylinders with each stroke, the amount of mixture that enters the engine cylinders with each stroke, the efficiency limits with which the engine can convert this mixture into output power, and the number of combustion strokes per unit time. Change the composition slightly and the engine will either not operate or it will lead to early onset of mechanical breakdown. Thus uniformity of gas mixture is required. This is due to the markedly different combustion rates of molecules such as H_2 and CO (Producer Gas) in comparison to CH_4 (AD Biogas), properties that create pre-ignition and backfiring, and engine "knock" (15).

Determination of Gas Compositions

8.1. The application response to question 24, of Formal Response to Schedule 5_5thNov14, that "the composition of the biogas and syngas are different but not radically so" is **incorrect**. This is used to support that "given the small variance between the methane content of biogas and syngas there will be no discernible difference in the engine performance" (response to point 24, in Formal Response to Schedule 5_5thNov14). But this is wrong because there is a large variance in gas compositions from these two processes. Composition of anaerobic digestion biogas is ca. 60% CH_4 rich, with H_2S, and negligible CO and H_2; while pyrolyser syngas is 20% H_2, 20% CO, 1-5% CO_2, 5% ≤ CH_4, balance N_2 (4, 16).

8.2. The suggestion that the methane content of the syngas "will be approx. 55% (ibid)" is not only unsubstantiated, but refuted by scientific proof, and also contradicted by other documents within the permit dossier.

8.2.1. Numerous experimental and theoretically modelled studies have shown that the composition of methane in pyrolysis producer gas from biomass and municipal solid waste is in the range of **0-5%.** This is from experimental results, but it has been shown to be **thermodynamically impossible to get higher concentrations of methane** due to equilibrium limitations which are based on intrinsic molecular properties and dictate which species are stable. This puts limits on the maximum that can theoretically be achieved even if there were infinite time available for the reaction to progress. This is explained in (4, 17, 18, 19, 20), and summarised as follows: "It is more or less the case that…the amounts of methane in the producer gas per kg of dry fuel are constant [values quoted at 2-3%]. Generally a good agreement with experimental results and theoretically calculated gas compositions is found" (16).

8.2.2. The document "SOL1211VT01 End of waste submission" gives the concentration of methane in the syngas at a variety of levels all of which are much lower than "55%": 10.1 – 21.51 % (Table

2CC), 19.3% (Annex A1, "sample 5"), along with 14.8 - 15.8% (Annex A1, sample "Autoclave biofuel").

8.3. The response to question 24, of Formal Response to Schedule 5_5thNov14 that "Hydrogen although present within the synthesis gas is a minor constituent" is also **incorrect.**

8.3.1. Pyrolysis and gasifier syngas is industrially defined by it having hydrogen as a major constituent along with CO (see 4, 16).

8.3.2. The response is also contradicted in document "SOL1211VT01 End of waste submission (Annex A1, sample "Autoclave biofuel")" where H_2 has the second highest concentration of all species (at 22%). Additionally, the first table in Annex D (SOL1211VT01 End of waste submission) shows H_2 concentration as 18%.

Gas Mixing Rates

There are major engineering challenges here that have not been addressed. There are also major discrepancies within the permit application about gas mixtures.

8.4. The fourth paragraph of the response to question 24 (Formal Response to Schedule 5_5thNov14) states that "The relative ratio of biogas to synthesis gas is approximately 5:1".

8.4.1. This contradicts with the next sentence which states that "the configuration of the engine will be biased towards the synthesis gas".

8.4.2. Since in the whole permit application dossier, there is no mass balance/gas flow quantification for either the pyrolysis retorts or the anaerobic digestion units, indeed for any of the gaseous stages in the process. There is no explanation for the applicant's being able to state that the ratio "is approximately 5:1".

8.4.3. This ratio quoted differs significantly from the ratios provided in the Sankey diagram (document titled "Celan power"). Since Sankey diagrams are sized according to quantified flow rates, a ratio of flows can be estimated by measurement. Alternatively, although this diagram is incomplete and excludes mass or moles, units are given here for MWh, which can be used to calculate syngas:biogas input ratios. Table 1 shows the discrepancies that pertain.

Table 1. Differing values within the permit application for ratios of gas volumes per unit time provided as entering the "gasometer".

Syngas (from pyrolysis)	Biogas (from AD)	Source
1	5	Formal Response to Schedule 5
8.2	1	From size of Sankey diagram segments
4.4	1	Calculated from MWh values in Sankey diagram segments

Calorific Values

8.5. The calorific value of natural gas is in the region of 36 MJ.m^3, whereas, the calorific value of producer/synthesis gas is ubiquitously ca. $5 \leq$ MJ.m^3 ≤ 10 (4, 15, 17).

8.6. The question of the syngas calorific value occurs in Question 22, of "Formal Response to Schedule 5_5thNov14". The response "assumes syngas GCV of 18-22 MJ.m^3" is anomalously high for producer gas (cf. Section 8.5).

8.7. The method (bomb calorimetry) used by the application to calculate calorific value **should not be used to estimate the energy produced by gas engine combustion as it includes the recovered heat of moisture within the fuel**. Calorific value (heating value) of any gas mixture depends upon the constituent molecules. To precisely calculate the energy from the fuel, lower (net) heating values should be used on an ash inclusive basis and with reference to the moisture content of the fuel (16).

Capacity and Volumetric Flows

8.8. The non-conventional term "gasometer" describes a non-standard design proposal. A description of exactly how it functions remains outstanding. The response to point 24, (in Formal Response to Schedule 5_5thNov14) that it is a holder to smooth out short-term variations in the production is inadequate, for there are great technological difficulties here in the mixing of these gases and the control of heterogeneity. Notwithstanding the differences in composition (cf. Sections 8.1 to 8.3), there are simultaneous inputs (from two sources each with their own flow rates and pressures) and output flow rates to be managed. The unit still therefore remains a 'black box' into which the blended gases are contained "prior to combustion".

8.9. The suggested size of the "gasometer" in comparison to the design volumetric flow rate of syngas gives cause for concern. It impacts upon how pressurised gas retention can be controlled, and how pressure build up will impact on upstream systems. Page 54 (of Application Support Document_30/10/14) describes this unit as a "compressed gas storage unit" as having an "operational capacity [which] will be maintained at 80% of the maximum capacity to ensure the availability of gas storage space in the event of an emergency shutdown of the plant." This statement is vague and does not address the issues of pressure and gas throughflow control to maintain steady state operation of the plant.

8.9.1. For syngas only, the unit must be designed for volume flow rates of "approximately **4000m³** of syngas per hour" (page 53 of Application Support Document_30/10/14). It must be bigger than this as the volume is obviously not yet including biogas from the anaerobic digesters. Compare this with the following stated sizes:

8.9.2. On page 17 (ibid), the volume is given as 6m (diameter) x 9m (height) = **254m³.**

8.9.3. In Formal Response to Schedule 5_5thNov14 (page 22, response to Question 23), the gasometer is said to hold approximately **600m³.**

8.9.4. Page 17 (of Application Support Document_30/10/14) describes this unit as a "**small gasometer**". No more elaboration is given.

8.10. Nitrogen is stated as being used as a diluent/carrier gas for the pyrolysis retorts at **50m³** per day (Table 3.4, page 27, Application Support Document_30/10/14). This will be needed to maintain process flow conditions.

8.10.1. The only value given on gaseous mass flows from the pyrolysers is that the gas cleaning system "has been designed to treat approximately 4000m³ of syngas per hour." This cannot be correct based on the quantity of nitrogen designated for use per day, the engines will not be able to "draw" the gas through from the pyrolyser because of the "gasometer". An explanation is needed here.

8.10.2. Although no throughputs have been provided, for the size of the retorts and plant, the concentrations of nitrogen in the syngas analysis report are also excessively low. Why the values of nitrogen in the analytical reports are only 1% (page 55 of Application Support Document_30/10/14) and 9% (Annex A1, of SOL1211VT01 End of waste submission) is unclear.

Engine Selection and Performance

8.11. It is not clear which engine the applicant's are proposing to use. There are three engine manufacturers mentioned and two technical data sheets provided. **All however quote specifications for natural gas (thus ca. 98% methane rich composition), and none of the technical specifications state that they are "capable of operating over a range of gas ratios"** – see Diesel and Gas Engines_2012_TCM92, and Annex B of SOL1211VT01 End of waste submission.

8.12. On page 15 (Table 2B) of SOL1211VT01 End of waste submission, it is stated that "Vaporo Tech have had written confirmation from a proposed engine supplier that the specific composition of the synthesis gas is suitable for use in Vaporo Tech's application." This written confirmation does not appear to have been disclosed.

8.13. Despite saying in the same Table that "Manufacturers letters of confirmation that these engines [GE Jenbacher, MWM Deutz, and Rolls Royce] can operate using this syngas are provided within the Annexes". They are not.

8.13.1. There is only one "letter of confirmation", that being from MWM. It is dated 2010, gives no description of the gas composition provided, and has caveats which relate to undisclosed documents: "Performance shall be in line with the datasheets previously supplied and subsequent correspondence".

8.13.2. A technical document is also provided for the MWM engine (Annex B of SOL1211VT01 End of waste submission) which states that the performance **data relates only to natural gas and "data for special gas and dual gas operation on request".**

8.13.3. In documents submitted after 2013, MWM does not feature as an engine of choice. The Rolls Royce engine is the only one mentioned in documents from 2014. No letter of confirmation is provided for this engine, and as stated above (8.11), its standard performance data is only for natural gas.

8.14. It is not in question that an engine can be set to operate on a unique gas composition (response to point 26 of Formal Response to Schedule 5_5thNov14). The issue is that the engines cannot operate with a **varying** gas mixture, and the proposal suggests that gases from two different production lines, incoming at varying compositions, rates and pressures will be mixed – a totally different concept.

8.15. It is important to know whether the engines will operate by fully gas spark ignition, or whether they will be dual fuel compression. This affects operational performance, gaseous and particulate emissions (see the variations in NOx from dual fuel engines in Diesel and Gas Engines_2012_TCM92, page 3). If they are to be dual fuel compression, then diesel will need to be included in the consumables budget, which it is not (see, Table 3.4 of Application Support Document_30/10/14, and Table 4.1 of Formal Response to Schedule 5_5thNov14).

8.16. In response to the question 25 answer (of Formal Response to Schedule 5_5thNov14): Engine modulation is a standard feature which can track and match external load fluctuations, and can also operate a servo to the air intake. This is conventionally **a narrow-limit feature which cannot make the engine operate for any extended period with markedly different and constantly varying gas compositions, and it cannot dictate in any way the nature of fuel which the engine draws in.**

8.17. The probable outcome to the whole plant operation due to the difficulties identified above is that the gas will constantly be flared rather than being used to generate renewable electricity. One statement exists to cover this eventuality: "At any time where the gas does not meet the specification stipulated by the engine manufacturers and described in the SynGas End of Waste documentations, the gas will be diverted from the engine and into the flare" (page 58 Application Support Document_30/10/14).

9. Flare

9.1. Question 27, Formal Response to Schedule 5_5thNov14 states that the flare must be used at "start up *and* during instances when gas production falls outside of the agreed EOW specification". It is used when the gas becomes too dirty for the engines to handles, which is when temperature drops. Pyrolysis is very sensitive to small temperature variations and engines are very sensitive to gas quality. A relatively small drop in temperature can result in a much dirtier gas and the outlet will need to be switched to the flare to preserve the engines and not to overload the syngas cleaning system.

9.1.1. For a proposal such as this, with numerous potential cooling gas streams sent to the pyrolyser combustion chamber and potentially wide variations in feedstock heterogeneity, the potential for use of the flare is exceedingly high.

9.1.2. Since this is a novel design also, there will need to be almost constant use of the flare during the testing stages.

9.1.3. The application states that "the flare will not be required to be operated during a controlled shutdown" (page 23, Formal Response to Schedule 5_5thNov14), **yet it must**. This is how gasifiers are operated in practice, for if the flare was not operated at shutdown, all the dirty gases would go to the filters and engine.

10. Syngas Cleaning System

Dolomite Chamber

10.1. The Application text is over-emphatic when describing dolomite as "a proven highly economic method of tar elimination" (page 28 of Formal Response to Schedule 5_5thNov14). Dolomite has inherent friability and is prone to rapid de-activation. As a secondary reactor for gas cleaning its efficacy has been shown only in trials much shorter than are proposed here, and only when fully calcined.

10.2. It is incorrect to state that a dolomite chamber "eliminates the need for collection and disposal of tars" (page 28 of Formal Response to Schedule 5_5thNov14). Mass just does not disappear. The dolomite will capture some of the tar, but then the tar and other particulates, along with gaseous emissions, will need to be removed and disposed of (usually along with the dolomite too). All packed bed dolomite sorbent systems soon become saturated and efficiency drops significantly. They can then either be regenerated or the whole packed bed of dolomite replaced. No description is given on extended period capture efficiency, or the frequency of regenerations/replacement of sorbent. No proof of system efficacy has therefore been given to support this, and no description has been given as to whether the plant will be shut down when this essential and frequent maintenance occurs.

10.3. Dolomite catalyst can be calcined to improve its efficiency, but the calcination process does not last long. It needs repeated re-calcination with carrier gases. The calcination process is indeed an established <u>research</u> technique. However, no details of the sorbent calcination process conditions are given. Obviously, for the sake of knowing how emissions are to be abated, clarity and specifics on this proposed unit are needed.

10.3.1. How frequently will the calcination process be applied for dolomite regeneration? This must necessitate the retorts being stopped and re-started.

10.3.2. What temperature is suggested for calcination, and how will this be controlled, considering the nature of external heat application to this unit in general operation.

10.3.3. Will the retorts have to be stopped to permit a change of temperature for calcination to the dolomite chamber?

10.3.4. What is the efficiency curve over time, how does this change post calcination, and at what level of efficiency is calcination applied?

10.3.5. How many repeat cycles of calcination is one batch of dolomite able to withstand?

10.3.6. The calcination of dolomite causes the dolomite to become friable and disintegrate.

10.4. Dolomite is essentially limestone. To therefore say (as on page 14 of SOL1211VT01 End of waste submission) that dolomite is "inexpensive and available", is misleading. The quarrying of limestone (e.g. Dolomite) is very environmentally damaging and the potential throughputs of material that the site proposes could be tremendous.

10.5. Notwithstanding these general aspects, **dolomite catalyst is not suitable for syngas/producer gas derived from municipal solid waste**. The applicants have not mentioned this in their cursory review of dolomite which just reports short term tests, all with gasification, and all with biomass (page 28 of Formal Response to Schedule 5_5thNov14). This is because MSW/RDF contains a relatively high content of chlorine. Small concentrations as low as 1% poison the dolomite. The chlorine results in halogenated compounds being formed, the deactivation of surface sites, and the entrainment of contaminants in the product gas. For a review and discussion of this see (7, 21). Consequently alternative catalysts are required. Note Table 2 of Formal Response to Schedule 5_5thNov14 shows chlorine content in the fibre as 1%, and see also Section 14.9).

10.6. On page 22 of (SOL1211VT01 End of waste submission) it is stated that "Any acid containing compounds are removed through the reaction within the dolomite chamber an *[sic]*". This is bad process design, for when acid gases come into contact with the alkaline dolomite, the dolomite will disintegrate. This also applies to sulphur (Annex D, of SOL1211VT01 End of waste submission), for which the dolomite absorbs readily resulting in disintegration and acid gas evolution (see again 7, 21).

10.7. The Dolomite chamber is described as the final repository for 19 metal species, such as arsenic, copper, chromium, zinc, etc (Annex D, of SOL1211VT01 End of waste submission). As these cannot be left to accumulate, and since they will not be removed by the calcination process this refutes the

assertion that the dolomite will be regenerative. No ultimate fate for the spent dolomite has been provided, and no volumes assigned. It is a major, undescribed, waste product, considering the design capacity of gas flow through the dry gas cleaning plant of "approximately 4000m^3 of syngas per hour" (page 53 of Application Support Document_30/10/14).

10.7.1. Since this unit is first in line, post pyrolyser, it is likely that the dolomite chamber will indeed be a repository for these metals rather than "retained in the liquors" (page 24 of Formal Response to Schedule 5_5thNov14).

10.8. What is the size of this dolomite chamber?

10.9. What is the lifetime of the dolomite and how frequent will there be full replacement?

10.10. What is the weighted hourly space velocity?

10.11. If regeneration, what gases will be used, and in what quantity? No gases are listed under consumables for the calcination process.

10.11.1. No quantified throughputs of dolomite are given.

10.11.2. Table 4.1 (Formal Response to Schedule 5_5thNov14) does not list dolomite as a raw material. This must be included as the dolomite will not regenerate indefinitely, and it is the repository for tar and metals.

10.12. By response to Question 33 (page 28 of Formal Response to Schedule 5_5thNov14), the dolomite chamber "will achieve efficiencies approaching 95%". Notwithstanding that this is a concept system only and so it can only be predicted what efficiencies "will" be achieved, the application has quoted the maximum value which is attributable to a newly calcined dolomite. In actual fact, the efficiencies for such a newly calcined dolomite are 77-95% (21), but these then begin to decrease as soon as the dolomite goes online.

What is included in the syngas cleaning system?

This is confused, with different documents describing different stages, and different arrangements of stages.

10.13. Page 22 of Formal Response to Schedule 5_5thNov14 states that "The syngas cleaning plant details are provided in Appendix 10". They are not. Appendix 10 contains: 1. a one page, very low resolution plan view of the site boundary and, 2. An undated document called "Volume 3 Non-technical summary" which does not relate to the syngas cleaning system".

10.14. In Formal Response to Schedule 5_5thNov14, page 28 – 29, the gas cleaning system is described as comprising **Five Stages**: Stage 1 (dolomite chamber), Stage 2 (water quench), stage 3 (packed tower scrubber), stage 4 (dryer), stage 5 (coalescent filter).

10.14.1. What the "coalescent filter" is, has not been described.

10.14.2. When describing the syngas cleaning line, page 29 of Formal Response to Schedule 5_5thNov14 states that "Stage 4: Syngas is passed through a dryer to remove any moisture". No energy input is given for this, and no description is given about what sort of dryer it is, or how it operates.

10.15. Application Support Document_30/10/14 describes a different system which varies dependent on which page of the document is perused:

10.15.1. Figure 3.9 (page 43) describes only **Three Stages**: single dolomite tower, ceramic filtration, and wet scrubbing". Note the inclusion of a ceramic filtration unit and the exclusion of dryer, coalescent filter or water quench.

10.15.2. Figure 3.10 (page 51) describes **Five Stages**: stage 1 ("Hot gas treatment –Dolomite 850°C"), stage 2 (Quench), stage 3 (Packed tower scrubber), stage 4 (Dry gas cooler), Stage 5 (Ceramic filter – COALESCENT), stage 6 (FMS).

10.15.2.1. What the unit described as "FMS" is, situated upstream of the "Syn Gas Storage" unit, is not explained. This process stage does not appear to be listed in any other document and therefore no assessment can be made of its possible emissions, consumables, process requirements, or site impacts.

10.15.2.2. No information is given about what type of gas is used for the drying stage, where it comes from and where does it goes.

10.16.   Table 2A of SOL1211VT_02 End of waste submission, describes a **Four Stage** syngas cleaning system that comprises stage 1 (Dolomite chamber), stage 2 (ceramic filtration), stage 3 (gas cooling/quench). Stage 4 is a unit described as "filter bag waste".

    10.16.1.1.   Thus, the wet scrubbing tower is missing.

    10.16.1.2.   Not shown on Table 2A, but described on page 14 is a "cooling plant…designed to cool the gas from around 350°C to 60°C. Any moisture in the gas will be condensed and removed". How this operates, and where this condensate goes is not described.

10.17.   The latest version of the odour management plan (SOL0213CPP01_OMP_Nov/14_Nov2014) gives contradictory statements:

    10.17.1.1.   (Table 3.4) describes only a **Three Stage** gas cleaning system, with no water quench, and no dryer: "Resultant syngas is fed directly to a three stage gas clean up system (gas scrubber, dolomite chamber, ceramic filter) and fired directly within a gas engine".

    10.17.1.2.   Page 32 describes **Two Stages**: "syngas produced by the pyrolysis unit will be pumped directly to the gasometer via a hot gas clean up systems *[sic]* and scrubber plant".

Wet Scrubbing

There are discrepancies about the material throughputs, operating conditions, and ultimate fate of waste water from a wet scrubbing system (if it is part of the design plan).

10.18.   The following are examples that infer there is to be no wet scrubbing:

10.18.1.   Wet scrubbing is excluded from Document SOL1211VT01 End of waste submission: in Table 2A on page 9, and Page 14 which describes how the "Dry Gas Cleaning Plant provides a number of advantages over water based scrubbing.

10.18.2.   On page 32 of Formal Response to Schedule 5_5thNov14, it is stated that "tars and oils from the syngas cleaning plant will not be present within the effluent of the water treatment plant".

10.19.   The following relate to a water-based scrubbing system:

10.19.1.   After passing through the dolomite tower stage, on page 29 of Formal Response to Schedule 5_5thNov14, the synthesis gas then enters "Stage 2" which is a "Water Quench" where "hydrocarbon compounds will reform in the quench and be removed through the water treatment process". What the "water quench" is, how it operates, what chemicals it uses, what its capture efficiency is, and where its spent solvent goes, is not adequately described in the permit dossier.

10.19.2.   Table 4.6 in Application Support Document_30/10/14 (and Table 4.2 in Formal Response to Schedule 5_5thNov14) state that "**50 Tonnes of Scrubber waste from a Gas Scrubber**" will be generated.

10.19.3.   Table 6.2 of Revised BAT Assessment_ SOL0514CPP01 shows a "water scrubber" which "removes water soluble syngas contaminants" the ultimate disposal of which is "processed through water treatment plant".

10.19.4.   In Appendix 6 (Formal Response to Schedule 5_5thNov14), the flow diagram titled "MHT AND PYROLYSIS FUEL MANUFACTURING AND ENERGY RECOVERY SYSTEM" has a unit described as ""NOVOGAS^TM and oil polishing" into which the output streams (both "gas" and "oil") from the pyrolyser go and which then lead into the "water treatment plant".

10.19.5.   A class of heavy metals such as mercury and selenium are said to "removed by the gas scrubbing processes and retained in the liquors" (Page 24 of Formal Response to Schedule 5_5thNov14). What exactly "in the liquors" means has not been described.

10.19.6.   Page 48 of Application Support Document_30/10/14, item Z3-11: "The gas treatment plant comprises...wet scrubbing".

10.19.7.   On page 50 of Application Support Document_30/10/14, it states that "Elemental chlorine and sulphur will be released during the pyrolysis process to form acidic compounds which are readily scrubbed into solution or neutralised in the gas treatment line".

10.19.8. Page 49 of Application Support Document_30/10/14: "Bromine (B), Chlorine (Cl), Fluorine (F), Nitrogen (N), Sulphur (S) are <u>water soluble and removed in the water treatment stages</u>...scrubbed in the syngas clean up stages".

10.19.9. On page 63 of Application Support Document_30/10/14 it is stated that "Any solid phase contaminants that form during the quenching process will subsequently be scrubbed from the gas flow by the reagent scrubber." Reagents are commonly used in scrubbers. Information is needed about these reagents, their quantities, and their fate.

10.19.10. On page 74 of Application Support Document_30/10/14, a "gas wash and second tower scrubber" are described.

10.19.11. There is a contradiction with the applicant's answer to Question 33 in Formal Response to Schedule 5_5thNov14. They state in Stage 3 "The cooled gas is then passed through a packed tower scrubber and treated for the presence of acid gases. However, on page 2 of Revised BAT Assessment_ SOL0514CPP01, they state that: "**there is no requirements** *[sic]* **for acid scrubbing plant**".

10.19.12. The Autoclave is said to have its own water scrubbing system (on Table 8, page 26, of Formal Response to Schedule 5_5thNov14). Is this the same as or different to the water treatment plant? This is described as capturing mercury, where mercury is "condensed into autoclave water treatment plant scrubbers". No water inputs or outputs are included for this unit, and no description of where the captured mercury will go. This question was asked in Formal Response to Schedule 5_5thNov14 (Question 29), but the reply is not as specified with a description of this "scrubbing liquor's" nature, its fate, and therefore the fate of all metals within it.

10.20. In Formal Response to Schedule 5_5thNov14 (page 32), it is stated that "All tars and oils, if not cracked by the dolomite chamber **will be separated and treated separately".** Elaboration is needed about what this means:

10.20.1. "separated" – Do the applicants propose to separate tars by some sort of fractional distillation? Nothing has been mentioned about this. It is wholly incorrect to maintain that "Gas contaminants in the pyrolysis gas……are easily removed through the conventional gas cleaning technologies" (Application Support Document_30/10/14, page 63). Tar is very difficult to clean at high efficiencies and it has been shown that with research over the last two decades that **"standard technology is insufficient for tar destruction or removal"** (17).

10.20.2. "and treated" – the application has not stated any other methods for treating tars. This affects ultimate fate and disposal of waste/process residues.

11. Char, Slag, and Syngas Analyses

11.1. The statement that "BioFibe pyrolysis char comprises carbon contents typically 66%wt with a very high carbon/hydrogen ratio" (page 13 of SOL1211VT01 End of waste submission) **is misleading**.

11.1.1. **The results of this analysis are on an ash-free basis.** The fibre samples have in fact a very high ash content, much higher than normal virgin biomass (see response in section 11.2), thus refuting that the char is "high purity" (page 5 of Application Support Document_30/10/14). It is the reason why the values contradict the proximate analysis results of the fibre (Appendix 7, and Table 2 of Formal Response to Schedule 5_5thNov14). **The Proximate analysis results are the correct ones to use for determination of biomass char quantity.** This is the standard methodology for determining fixed carbon (e.g. char) that remains after pyrolysis and it is this which has been provided by the analytical reports. The proximate analysis values reported are 9.1% to 15.4% dry basis. This is in the as expected range and corroborates the wealth of literature reports on pyrolysis char production/fixed carbon content (see 4, 22).

11.1.2. When stating that the carbon contents ranged from 11.8 % to 66 %, the authors have quoted the highest value only. On an ash-free basis, 11 % is a very low carbon content indeed.

11.2. Much emphasis is placed on the "biofibe/biofibre" being ultra pure and of a fixed consistency. However, with only five samples tested and a range of values from 11.8% to 66% this is definitely **NOT homogeneity** (page 102 of Application Support Document_30/10/14).

11.2.1. Low quality char will have detrimental impacts on emissions directly, but also indirectly as it will result in lower temperatures achievable within the pyrolyser (as this carbon content of the char dictates the energy output). This will in turn adversely affect the heat input to all other process stages designated as using this waste heat. This, and the overestimation of char produced is discussed in section 3.11.

11.3. The char has a very high ash content. Although no details are given regarding the provenance of the samples (in Appendix 7 of Formal Response to Schedule 5_5thNov14), the two given are consistent, with ash:fixed carbon ratios of ca. 2.3:1 - so over twice as much ash as fixed carbon. **This is a very poor ratio and definitely not what could be called "high purity char".**

11.4. The syngas samples reported in Annex A1 of SOL1211VT01 End of waste submission come from an independent analyst, however it is stated that "TES Bretby accepts no responsibility for the *collection* of any of the samples referred to in this report", and no explanation is given by the applicant regarding the sample provenance.

11.4.1. In the Annex A1 sample results, **13% of the total gas constituents are unaccounted for** (regarding sample 5). Since all the major species are assayed (CO, H_2, CO_2, N_2, O_2, CH_4 along with the anticipated lower homologous series hydrocarbons), it is difficult to offer suggestions about where this missing gas fraction has gone, and what it therefore is. Nitrogen is included, so this cannot be diluent. One option could be H_2O. An explanation is needed here. If these results are from a pyrolysis retort then they infer that it is one operating way outside of equilibrium, possibly very fast pyrolysis with high moisture (as initially affirmed and commented on with this table "pyrolysis gas produced by fast heating"). There should not be 25% CO_2 from a pyrolysis retort producer gas, and the relatively high concentrations of long-chain hydrocarbons suggest something is very wrong here. These concentrations suggest a high almost saturated moisture content, well in excess of 40 % (see for example 19)

11.4.2. The samples were analysed by TES Bretby in 2010. Residence time and heating rate will significantly affect the gaseous products and this submission has seemingly changed its approach from fast pyrolysis to a somewhat slower rate during the last year (see Section 4). Because of this, these analytical results appear unsuitable for this permit application in its present state.

11.4.3. Half of the char analysis document (Appendix 7) by Alfred Knight has not been provided. The first six pages are missing.

12. Water

There is an overall lack of connectivity or quantification on a general or specific level in regard to process water. There is no water mass balance. Consequently the fate of waste water along with the solute that it contains cannot be satisfactorily determined, and there are instances of potentially contaminated water transferral between unit processes. This is important because of the high volumes involved and the assertion that none of this will go to the sewer. Confusion is accentuated by the use of vague and undefined nouns to describe this spent water: "grey water", "wash down water", "permeate", "backwash water", "softened water", "rainwater harvesting" which seem to be sometimes used interchangeably.

Waste Water Fate

12.1. Upon closer examination of the permit application, it is difficult to feel supportive of the assertion that: "With the exception of domestic sewage from the offices and toilet facilities, there will be no releases to sewer arising from the Installation." (page 7 of Application Support Document_30/10/14), or that the **"4m^3 per hour "grey water [from the Waste Water Treatment Plant] will be used for wash down, floor cleaning, truck wash, etc"** (page 38 of Application Support Document_30/10/14) can go anywhere else but the sewer or groundwater.

12.2. Regarding the claim that: "Actual normal permeate will be 1m^3 per hour as a majority of the water is recovered from the process." (Formal Response to Schedule 5_5thNov14, page 10):

12.2.1. The noun "permeate" is unconventional terminology, and its origins, quantities, possible routes of contamination, and ultimate fate are unclear, e.g. Page 10 (Formal Response to Schedule

5_5thNov14) "the reverse osmosis plant permeate discharge will be routed to the rainwater harvesting tanks and grey water recycling system"; Page 11 (Formal Response to Schedule 5_5thNov14) "In summary the plant needs about 1m^3 per hour of mains water to replace rejected permeate." Clarification is needed on:

12.2.1.1. Whether this "permeate" is the same as or different to the "wash down water".

12.2.1.2. Where this "permeate" will ultimately go, and what is meant by "rejected permeate".

12.2.1.3. The chemical composition of this "permeate".

12.2.1.4. The statement that "Any permeate from the waste water process that cannot otherwise be reused by the process will be discharged to the AD tanks." (Page 32 of Formal Response to Schedule 5_5thNov14). For example, how much of this is expected to be re-routed, and the affect this will have with its potential for process contaminant re-introduction.

12.2.2. The application suggests that this "permeate" [1≤ m^3 ≤ 4 per hour] "will ultimately be lost to the environment as evaporation" (Page 10, Formal Response to Schedule 5_5thNov14). **This is impossible**. Even the lowest value, 1m^3 per hour of water, would not be likely to evaporate from the site on a hot, dry summer's day, irrespective of the rest of the year when atmospheric moisture levels are high, during episodes of rain, winter months, etc. Evaporation from urban areas is ca. 2-3 mm per day in summer, and negligible to zero in winter (23).

12.2.2.1. This assertion has not been accounted for in the Entran document Human Health (E1148 - Washwood Heath – HHRA_4/11/14) which gives modelled evapotranspiration rates.

12.3. Regarding Page 81 of the Application Support Document_30/10/14 which states that "All rainwater runoff arising from the plant will be harvested and utilised for steam generation and cleaning etc".

12.3.1. This natural precipitate input needs to be accounted for in a detailed water balance for the site.

12.3.2. Since post-process water is also used for "wash down", no practical discussion has been offered about how this can be separated from the natural precipitate when the "harvesting" occurs.

Process Water Volumetric Flows

Listed below are variations that exist in the application dossier in respect of total water use. All involve substantial amounts of water, and highlight my concerns regarding water use and its subsequent fate (along with solute).

12.4. Total volume of water used = **384 m^3.day^{-1}**. This value is obtained from Application Support Document_30/10/14 (page 38) and is based on the volumetric flow rates of water entering the water treatment plant: "16m^3/ph".

12.5. Total volume of input water will be **96 m^3.day^{-1}**. This determination is based on 25% of the values in Section 12.4, which as according to Table 1.1 (Appendix 6 "Energy and Mass Balance) represents a 1:3 ratio of input:recycled water.

12.6. Total volume of water used = **288 m^3.day^{-1}**. This derives from the 16m^3/hr sending 12m^3/hr for "clean process water storage". Although, what exactly the "clean process water storage" is used for is not described. One assumes that it will be the autoclaves, which leave still leaves 4m^3 to "grey water" use.

12.7. Not water used but "grey water" = **96 m^3.day^{-1}**. This is the 4m^3 remainder sent for "wash down".

12.8. Total volume of water used = **53 m^3.day^{-1}**. This value is obtained from the document "Revised BAT Assessment" (Section 6.2.2). It states that "The overall water use is approximately 100 litres per tonne of waste processed". With an annual throughput of "195,000 tonnes" (page 2 of Formal Response to Schedule 5_5thNov14, page 15 of Application Support Document_30/10/14, section 1.2.1 of Revised BAT Assessment), this gives a daily water use of 19,500,000 tonnes equating to **53 m^3.day^{-1}**. If operating for 365 days per year, as the plant is specified (page 72 of Application Support Document_30/10/14).

12.9. Total volume of water used = **35 m^3.day^{-1}**. This is added for completeness, and is a minimum value since it excludes the anaerobic digestion plant, and was solely attributed to the autoclave/pyrolyser process line. This is based on "128,000 tonnes" (page 5 of Formal Response to Schedule 5_5thNov14), giving a daily water use of 12,800,000 litres per annum if operating for 365 days per year.

12.10. Table 4.1 (Formal Response to Schedule 5_5thNov14) states that **24 m^3.day^{-1}** water is used "100% to process".

12.11. Table 4.1 (ibid) infers that **48 m^3.day^{-1}** water is used as "100% to process", for in column 2 the **24m^3.day^{-1}** supplements an additional **24m^3.day^{-1}**, e.g. "50% provided through grey water recycling".

12.11.1. This 50% fraction (cf. 12.11) of water use is contradicted by Table 1.1 (Appendix 6 "Energy and Mass Balance"), which states that water added to the water treatment plant is 25% mains supply and 75% recycled (e.g. per hour "1000 kg [mains], 3000 kg [recycled]").

12.11.2. Further to this, Table 4.1 (ibid) states that the fate of this **24m^3.day^{-1}** water is "100% to process". This is a clear imbalance, since if 50% (of water is not recycled) then it is a new input and yet no output is explained.

12.11.3. The footnote to Table 4.1 (ibid) states that 90,000 Litres of water is added "once per year". Is this in addition to the **24m^3.day^{-1}** or has it been included in the balance?

Additions to Water Volumetric Flows

12.12. Table 4.1 (Formal Response to Schedule 5_5thNov14) shows a number of materials which are liquid at room temperature or which will dissolve and add mass to liquid waste (sodium hydrochlorite, sulphuric acid, biocides and corrosion inhibitor, flocculants and coagulants). There is no ultimate fate given to these reagents, and the explanation "100% to process" is not an ultimate fate. The suggestion appears to be that these materials will constantly be recycling within the system.

12.13. When describing the syngas cleaning line, page 29 of Formal Response to Schedule 5_5thNov14 states that "Stage 4: Syngas is passed through a dryer to remove any moisture". No explanation is given about how much water is collected or where this water goes. It has the potential to be laden with pollutants since it is from the pyrolyser.

12.14. Moisture added to the system from the biomass feedstock does not appear to have been considered. In Figure 2, I have estimated the minimum values for this input and this results in **an additional 72 ≤ m^3.day^{-1} ≤ 108**. The fate of moisture "driven out" by this compaction auger is to be "subsequently collected and treated by the WWTP" (page 7, Formal Responses to Schedule 5_5thNov14). Since no quantification is given about the fraction removed by the compaction auger and that removed by the air drying, anything up to 3 to 4.5 tonnes of water per hour could be routed to the waste water treatment plant, which is not included in the water mass balance. This wastewater will likely have contaminants (solid and particulate), the extent of which are dependent on variations in temperatures and pressures.

Waste Water Treatment Plant – Operational Aspects

The functioning and efficiency (in addition to mass balances) for the Waste Water Treatment Plant (WWTP) is not adequately explained.

12.15. A list of possible components is given in section 3.3.3 (pp. 37-38 of Application Support Document_30/10/14) but it gives no detail. Page 38 (of the same document) refers to Application Support Document Vol 2 – Annex B4, but this is absent from the permit dossier. Therefore the proposal is lacking the following information about the water treatment systems listed, and so strong objection must be raised in respect of absence of information on:

12.15.1. Size

12.15.2. Operating temperatures

12.15.3. Volume throughputs

12.15.4. Efficiency

12.15.5. Materials (e.g. flocculants, pH buffers, etc)

12.15.6. Energy balances to all these.

12.16. Documents refer to water being diverted to the anaerobic digestion system: "Any water [of the 4m^3 per hour] that cannot be used (i.e. due to the grey water systems being full), will be discharged to the AD tanks" (Bullet point 1, page 11, Formal Response to Schedule 5_5thNov14), and "Any residual

waste water treatment plant permeate that cannot otherwise be used for wash water will be discharged into the anaerobic digestion plant tanks" (ibid).

12.16.1. This quantity and route of water is not shown on the Appendix 6 Energy and Mass balance. What this is saying however is that potentially contaminated water is continually looping within the system.

12.16.2. This is a first indication of the "grey water systems being full". This could lead to significant imbalance in the process water system, along with substantial quantities of waste water to sewer.

12.17. What is the volumetric capacity of the grey water systems?

12.18. What are the quantified flows in and out of these units?

12.19. In response to Question 13 of Formal Response to Schedule 5_5thNov14, regarding "Inputs (including the source) and outputs (including the fate) of the wastewater treatment plant", the application states that the the syngas cleaning plant is a closed loop system requiring approximately 250 L.day^{-1}.

12.19.1. This syngas cleaning plant cannot logically be a closed loop system, and at the same time still have a daily input? Where would the 250 L.day^{-1} of water go?

12.19.2. An explanation is needed about how the syngas cleaning plant can be a closed loop system and at the same time capture dissolved contaminants. Wet scrubbers, by their nature, dissolve polar hydrocarbons, and other pollutants, and create a dirty liquid waste. They cannot operate on a closed loop system for this reason. Constantly looping the water will just lead to saturation and then capture efficiency will rapidly fall to zero. Cleaning up scrubbing liquor is difficult and highly energetic. No explanation has been given about how this will be done.

12.19.3. If the waste water from the gas cleaning stage does not go to the waste water treatment plant (as elsewhere stated) then these process stages need completely re-visiting.

Backwash Water

The Environmental Procedure document, titled "CPP-E06 Autoclaving", describes a wastewater output called "backwash water" which is created following an autoclave process cycle and which is sent to the sewer: "backwash water containing magnesium and calcium salts are discharged to sewer".

12.20. This refutes that there will be no wastewater to sewer.

12.21. The quantities and composition of this wastewater has not been described.

Sludge Tank

A unit called a sludge tank is occasionally described: (page 31 and page 32, Formal Response to Schedule 5_5thNov14; and Page 38 of (Application Support Document_30/10/14). I have identified the following problems with this aspect of the application which would likely affect mass flows and the distribution of pollutants.

12.22. The fate of the sludge (and what becomes of its constituents) has not been described. There is some indication that is sent to the APC unit to be incinerated (page 46 and Table 3.7 of Application Support Document_30/10/14).

12.22.1. According to Annex 1b, the "APC unit" does not appear capable of accepting solid or liquid waste (see Section 13.1).

12.22.2. No waste from the "sludge tank" is given in the tables of Appendix 6 (energy and Mass Balance).

12.22.3. Page 38 of the same document contradicts that the APC unit accepts and incinerates sludge: the "APC unit....is purely for the treatment of the autoclave VOCs".

12.22.4. In Table 4.2 (Formal Response to Schedule 5_5thNov14), sludge waste is not included in this Waste Summary table, and no ultimate fate is given for any of the stated wastes as "incinerated".

12.22.5. By page 38 of Application Support Document_30/10/14, "solids are removed and pumped to the sludge tank for reintroduction to the autoclave." Yet, Appendix 6 (Energy and Mass Balance) only shows a process line going from the water treatment plant to the "Boiler feed tank".

12.23. There are contradictions regarding the location of this unit and what it accepts:

12.23.1. Page 31 of Formal Response to Schedule 5_5thNov14 describes this as the last stage "post sand and carbon filters".

12.23.2. Page 38 (Application Support Document_30/10/14) also describes a last stage in the water treatment as "Final liquor storage tank (post sand and carbon filters) for mixing with softened water prior to boiler feed)". Yet:

    12.23.2.1. The origin and quantity of the "softened water" is not described.

    12.23.2.2. The same page describes that "flocculated suspended solids are removed and pumped to the sludge tank" which appears to be a different unit to the one later described as "post sand and carbon filters".

12.24. Annex D of SOL1211VT01 End of waste submission, describes mercury as "settling as sludge at the bottom of an oils separation tank", but no description is given regarding what or where this "oils separation tank" is, or what happens to the oil (and mercury).

12.25. Page 31 of Formal Response to Schedule 5_5thNov14 states that the residue from flocculated solids are indeed extracted at stage 2 of the waste water treatment unit "All solids are separated within the tangential flow separator for separation of flocculated suspended solids". No more explanation is given about a "tangential separator", and where these solids then go is not described.

12.26. Due to the proposed high throughputs, information is required about:

12.26.1. How these filter media of the Water Treatment Plant be taken off-line for cleaning. Will the plant be shutdown totally during this time?

12.26.2. How frequently are the filters expected to be cleansed?

Flooding and Groundwater Contamination

The geographical location of the site appears to heighten the risk posed by water discharge and the dispersal of contaminants into watercourses and groundwater.

12.27. The site is adjacent to and surrounded on three sides by rivers.

12.28. The site drains to its eastern edge (section 4.6, Flood Risk Assessment Appendix 12_June2012), which is a location closest to the river Tame.

12.29. The site is entirely within zones 2 and 3 which have a "medium to high probability of flooding" (Flood Risk Assessment Appendix 12_June2012).

12.30. There are naturally occurring high groundwater levels at the site and as a consequence "The SFRA indicates the area could be very highly susceptible to groundwater flooding" (page 7, Flood Risk Assessment Appendix 12_June2012).

12.31. Table 3.1 (of Flood Risk Assessment Appendix 12_June2012), calculates the total volumetric flood storage loss of 240m^3. This calculation excludes the major buildings for pyrolyser, engine, waste processing and treatment. Consequently it is an underestimate. According to the site plan (Installation boundary showing release points, dated 14th October), the units used to calculate compensatory flood storage can be determined at less than half the footprint of the site, therefore the loss of flood storage capacity appears to be more nearer to an estimated 600 m^3.

12.32. Based on the buildings footprint (Installation boundary showing release points, dated 14th October), the area for potential surface evaporation is small.

12.33. The location of the site increases water contamination risk and consequent environmental impact being moderate to high significance with respect to surface water, and low to moderate sensitivity for groundwater - due to being situation on secondary aquifer (EAME Ltd Phase 1 Environmental Review, Annex D).

13. Combustion Chambers and Boilers (Other Aspects)

The "APC Plant"

This unit is given the function to incinerate "solids from the sludge tank" (Page 32, Formal Response to Schedule 5_5thNov14), and for "the disposal of WTP and Gas Cleaning Plant solid residues" (Page 24, Formal Response to Schedule 5_5thNov14).There are the following problems with the description of

this unit which impact on potential for successful operation of downstream processing and emissions abatement:

13.1. The unit (according to Annex 1b) appears to be capable of only capturing "gas phase contaminants" therefore not suitable for particulates.

13.2. The presence of this unit contradicts the footnote on page 10 of Application Support Document_30/10/14 which asserts that the only incineration occurring on site will be the thermal oxidiser.

13.3. The final odour management plan (page 9 of SOL0213CPP01_OMP_Nov/14) describes that extract gases from the Autoclave go "to a special purpose combustion unit which thermally oxidises these air streams." But:

13.3.1. It is not made clear whether this is a different unit to the APC unit or the thermal oxidiser, and if so, there is no description of its modus operandi, input and output flows, operating parameters, process consumables, and environmental emission points.

13.3.2. If it is the same unit, page 38 of Application Support Document_30/10/14 describes a contradiction, namely that it "discharges <u>directly into the pyrolysis char combustion plant units to ensure complete destruction of any VOC's</u>." This contrasts with the statement in the odour management plan (page 19 of SOL0213CPP01_OMP_Nov/14), where it is stated that "All emissions from the thermal oxidiser are exhausted directly <u>into the atmospheric side</u> of the common pyrolyser duct and released to atmosphere." Thus one statement says that the gases enter before and one after.

13.4. The unit, according the Annex 1b (document "APC-ThermPure"), captures pollutants using a filter system. No details are provided on how this filtrate is disposed of, or how frequently this disposal will be required.

13.5. No details of mass balance (inputs and outputs) are provided for this unit.

Water Treatment Plant Thermal Oxidiser

Page 19 of SOL0213CPP01_OMP_Nov/14 describes what appears to be a separate combustion reactor associated with the Waste Water Treatment Plant: "The water treatment plant is fitted with a small dedicated thermal oxidiser plant specifically for the odour destruction of the non-condensable gases relating to the water treatment / condensing plant."

13.6. Mass and energy balances are needed for this unit along with data on its atmospheric emissions.

Pyrolysis Thermal Oxidiser/Cyclonic Combustion Furnace

These units have been discussed to some extent in Section 7. Air is used for combustion, but there are also unspecified quantities of exhaust gases, and in one case oil, designated for input (c.f. Section 7.16, 7.13, 3.12.12, 4.4, and 13.3). As with the majority of the proposal, the absence of adequate mass and energy balances into the design limits an adequate appraisal of the potential for environmental impact:

13.7. Since "…all impurities are retained in the solid by products (char) of the pyrolysis stages" (page 50 of Application Support Document_30/10/14), this means that the char contains "all the impurities", and so when this char is burnt, as is the function of the unit, toxins which become gaseous or form airborne particulate matter will be emitted as smoke and gas. Temperature and residence time will significantly influence the fate of char contaminants.

13.8. Modelling is used to support a proposed residence time of 2 seconds inside the retort and thermal oxidizer (Table 6.7 of Application Support Document_30/10/14). This refers to Appendix B2, but there is no Appendix B2. However a document titled "CFD", which is identical to the Appendix B2 described in a previous submission can be inferred to be the reference. In this document, the details are sparse and completely insufficient to base any such judgement. The whole of the information in the modelling document (Annex B2 CFD Modelling) comprises just three screen prints. It is not apparent that temperature is shown – the key for the colours in the

second diagram have the same labels as the previous diagram "flight time" rather than "temperature". Of crucial importance are also the input parameters of the model which are not given. What is the flow velocity, what is the size of the reactor, etc? This document does not substantiate anything.

<u>Heat Recovery Steam Generator (HRSG)</u>

This is nominally assigned for the generation of autoclave steam, and described as "effectively a boiler" (page 61 of Application Support Document_30/10/14). The huge energy demands required and the plant's ability to meet them have been discussed in Section 7.

13.9. Information about the HRSG is very sparse. It is not clear whether this is a tangible process component in its own right or whether it is part of something else. There is also an almost total absence of information on how heat is transferred to it. This affects energy balances (of it and anything that it is connected to) and material audits.

13.9.1. Page 5 of Formal Response to Schedule 5_5thNov14, merely describes that there are two HRSGs "associated with the pyrolysis plant".

13.9.2. In Table 6.7 IED/WID Compliance Statement (Application Support Document_30/10/14), it is stated that "All heat from the pyrolyser will be passed through a Heat Recovery Steam Generator (HRSG)". This is interesting because of the fact that **"all heat"** is said to pass through the HRSG, so therefore note the discrepancies with information contained in Section 7 of this report.

13.9.3. Page 34 of Application Support Document_30/10/14 describes the HRSG as "connected to the pyrolysis unit".

13.9.4. In Annex D of SOL1211VT01 End of waste submission, merely describes the HRSG as a place where arsenic, cadmium and zinc cool and "reform to a microsolid".

14. Environmental Fate of Metals and Other Substances

Contradictions and unscientific assertions still remain in the most recent documents, with implications for assessing whether the plant could cause harm to human health and the environment and early onset of systemic corrosion.

14.1. In Table 8 "End fate of metals" (Formal Response to Schedule 5_5thNov14), the fate of **cadmium** is described as "boiled in pyrolyser and condensed in fly ash." This cannot be correct as the material will have been exposed to higher temperatures in the upstream thermal oxidiser.

14.2. Table 7 of Formal Response to Schedule 5_5thNov14, states that the class 3 elements bromine, chlorine, fluorine mercury, iodine, nitrogen, sulphur **"Will not be present in char"**. <u>They are present in the char</u> (see Appendix 7).

14.3. Table 7 of Formal Response to Schedule 5_5thNov14, states that the class 2 elements chromium, cobalt, copper, nickel, vanadium, arsenic, cadmium, lead, thallium, zinc, etc **"Will not be present in char". <u>They are present in the char</u>** (see Appendix 7).

14.4. Accompanying text on page 26 of Formal Response to Schedule 5_5thNov14 describes how bromine, chlorine, fluorine, iodine, nitrogen, sulphur "are all water soluble and removed in the water treatment stages of the autoclave or scrubbed in the syngas clean up stages. This is an erroneous simplification for it overlooks that these elements form and comprise non-soluble gaseous or solid compounds, many of which are gaseous and/or liquid acidic substances that are known pollutants or are highly corrosive to process vessels and pipes.

14.5. The application is confused with the ultimate fate of boron. Table 7 (of Formal Response to Schedule 5_5thNov14) describes that it **"Will not be present in char".** On the next page of the same document, it is stated that "boron….is **retained in the vitrified char".**

14.6. Why is carbon listed as one of the elements that "will not be present in char" (Table 7 of Formal Response to Schedule 5_5thNov14)? Carbon is essentially the main component of char.

14.7. It is stated on page 23 of Formal Response to Schedule 5_5thNov14 that "metals constitute approximately 0.1% of the total mass of the dry fibre", and on page 24 of the same document that

"the presence of toxic metals in the autoclave fibre is extremely low". The fibre samples in fact contain extremely high inorganic mineral content (see sections 11.2 and 5.1).

14.8. Page 9 of SOL0213CPP01_OMP_Nov/14 proposes that "All emissions from the thermal oxidiser are exhausted directly into the atmospheric side of the common pyrolyser duct and released to atmosphere." This is a peculiar statement, as what exactly is the "common pyrolyser duct"? The only gaseous outlet from the pyrolyser is the syngas stream". Where these gases go are a mystery. Obviously these will be gases that will contain contaminants.

Further Comments Specific to Chlorine

14.9. Table 7 of Formal Response to Schedule 5_5thNov14 describes that chlorine "will not be present in char". But, the char analysis (Appendix 7) shows chlorine in the two samples analysed at **concentrations of 1.48% and 1.29% (as received) and 3.2% and 3.63% (dry ash free).**

14.10. In its discussion on the fate of chlorine, the application has overlooked that many of the hydrocarbons formed from biomass gasification and pyrolysis are chlorinated. Elsewhere in the application this is substantiated (Table 2Cc, in SOL1211VT01 End of waste submission document).

14.11. SOL1211VT01 End of waste submission document is still valid, Annex D states that it has zero content in the biofibe/biofibre because it is "stripped out in pre-stage conditioning". It is not clear what this means. If it means the autoclave, then this is superfluous because the waste from the autoclave will go directly to the char combustion units anyway.

Further Comments Specific to Mercury.

14.12. The application does not seem to have considered that mercury can form mercuric salts which will pass through to the thermal oxidiser and then be heated above their boiling points to be passed as atmospheric emissions.

14.13. Table 8 (Formal Response to Schedule 5_5thNov14) states that there will be no mercury emissions from the thermal oxidiser/char combustion, but yet mercury will be "volatised in pyrolyser". This is erroneous since the thermal oxidiser is both upstream of, and of higher temperature than, the pyrolysis retort, thus mercury will most likely be volatised and emitted with the thermal oxidiser stack gases.

14.14. In Table 7 (and also repeated on page 24) of Formal Response to Schedule 5_5thNov14, the ultimate fate of mercury is given as "treated through the APC thermal oxidiser, all ash disposed to landfill". Because of mercury's low boiling point, this fate is highly unlikely and so mercury will NOT be retained in ash. Where it goes then is confused, with either:

14.14.1. the exhaust from the APC unit "discharges directly into the pyrolysis char combustion plant" (page 32, Formal Response to Schedule 5_5thNov14), or

14.14.2. According to Annex 1b, pollutant emissions are captured using a "filter system". No details are provided on this filter system, how this filtrate is disposed of, or how frequently this disposal will be required.

14.15. SOL1211VT01 End of waste submission shows contradictory fates for mercury:

14.15.1. Table 2Cc - "retained in char". This lacks credibility since the temperature of the thermal oxidiser is well above that of mercury's boiling point.

14.15.2. Annex D states that mercury "Boils and forms a gas phase metal within the retort, but then "**Settles as a sludge at bottom of oils separation tank**". This is concerning, for no oils separation tank has been mentioned elsewhere in the proposal.

Further Comments Specific to Arsenic

14.16. Arsenic is not listed (and therefore its fate is not described) in Table 8 (Formal Response to Schedule 5_5thNov14) or Table 3.8 (Application Support Document_30/10/14). Arsenic is however present in the fibre at concentrations of 5-5.5 mg/kg (Table 3.6, Application Support Document_30/10/14, and Appendix 7, fibre data) and also in the char (Appendix 7, char analysis – 7.3

and 7.4 mg/kg). No recent explanation has therefore been given as to its fate. This therefore leaves just SOL1211VT01 End of waste submission, which gives the following contradictory outcomes:

14.16.1. "Boils and forms a gas phase within the retort" (Annex D).

14.16.2. "Boils of *[sic]* to gaseous form in Secondary Converter" (Annex D). Nb., what a "secondary converter" is has not been described.

14.16.3. "Reformed to micro solid as cooled in HRSG" (Annex D).

14.16.4. "collected in ceramic filters" (Annex D).

14.16.5. "collected in dolomite tower" (Annex D).

14.16.6. "retained in char" (Table 2Cc).

15. Engine NOx Emissions

15.1. The permit application repeatedly states that the engines have a "maximum guaranteed [NOx] emission limit of 250mg/m^3" ("s butler" dated 4th March 2014, pages 1 and 2 of "Formal Response to Schedule 5_5thNov14", and also page 60 and Table 4.1 of "Application Support Document_30/10/14"). This value was seemingly also used as an input parameter for air emissions modelling (c.f. page 10, Appendix 1A/Entron Air Quality Assessment_24.10.14). Upon scrutiny, this performance value cannot be substantiated, and moreover there is evidence to refute it.

15.1.1. Formal Response to Schedule 5_5thNov14 refers to a Rolls Royce Bergen engine, and that confirmation of its performance (with respect to 250mg/m^3) is provided in Appendix 2. Appendix 2 contains two documents and neither confirm performance:

15.1.1.1. The technical data sheet does not show NOx emissions corresponding to this value, and the engine performance described refers to natural gas.

15.1.1.2. The second document "Rolls Royce Engine Emissions.pdf" reports NOx emissions of 475mg/m^3 (Table 5), again, on natural gas.

15.1.2. There is an old (from 2009) Excel graph provided in Appendix A3 of SOL1211VT01 End of waste submission, but no description or link is given regarding what engine this relates to, or what the fuel/air mixtures, and engine load settings were. This graph appears in an appendix titled "Pyrolyser Air Emissions Sampling", but it actually relates to sampling from an unknown and unrelated **gasifier** system. It cannot be used as a comparator. Not only are gasifiers higher temperature and cleaner gas emitting systems than pyrolysers, but this analytical report **does not state that it is for engine exhaust monitoring**. To compare NOx concentrations from a gasifier (or pyrolyser producer gas with those from an engine exhaust is unsound, as the NOx from a gasifier is in oxygen limited conditions and so NOx concentrations will be substantially lower.

16. In-line Sorbent System

This unit is described as being necessary to reduce dioxin formation (page 65 of Application Support Document_30/10/14) and for acid gas neutralisation (p.98 and p.104) and in the Revised BAT Assessment_ SOL0514CPP01 assurances are given that it will "remoave *[sic]* any trace acid gas content within the emissions."

16.1. The permit dossier is inconsistent about where this unit is situated. This is important in respect of its operating temperature (not stated) and gas density (hence particle concentration and capture efficiency).

16.1.1. The component is shown as situated *after* the heat recovery banks but *before* the ceramic filtration and NOx reducing catalyst unit (document file by VaporoTech titled "Clean Power -9", "simple pyrolysis unit exhaust schematic"), and also on page 66 of Application Support Document_30/10/14.

16.1.2. On page 63 of Application Support Document_30/10/14, it is stated that this unit will be placed "upstream of [therefore *before*] the heat recovery generator and ceramic filtration plant". This

contradicts the process flow diagram contained in the document "Clean Power -9", "simple pyrolysis unit exhaust schematic".

16.1.3. In document titled "Sorbent Injection" the system is placed *after* the selective catalyst reduction system, not *before* (as in document file by VaporoTech titled "Clean Power -9", "simple pyrolysis unit exhaust schematic").

16.1.4. In Figure 3.10 of Application Support Document_30/10/14, the inline sorbent system is shown as within a separate gas outlet from the pyrolysis retorts. This appears to be a mistake, as it should be part of a process line that comes from the charcoal burners (same Figure). This appears to be the first and only mention of **two** distinct gas outlets from the pyrolysis retorts.

16.1.5. Figure 3.13 of the Application Support Document_30/10/14, shows the "Sorbent Injection Plant". Nothing can be discerned from this figure as the detail is too small and there is no key to what the components are.

16.2. It is not clear what quantity of waste (spent sorbent plus captured pollutants) will be generated.

16.2.1. Page 63 of Application Support Document_30/10/14, qualifies just "very low usage of hydrated lime".

16.2.2. No lime is mentioned in the Process Consumables/Raw Materials usage tables (Table 4.1 of Formal Response to Schedule 5_5thNov14, and Table 3.4 of Application Support Document_30/10/14). Sodium bicarbonate is included at a quantity of 1200 T per annum, 100% of which is "collected in fly ash". However, the waste summary (Table 4.6 of Application Support Document_30/10/14) describes a total volume of fly ash for the whole site of much less: "800 T per annum".

17. Exhaust Emissions Testing

17.1. The gas emissions testing report (Annex A3 – Pyrolyser Air Emissions Sampling, SOL1211VT_02 End of waste submission) does not appear to be sufficiently relevant to this permit application.

17.1.1. It was obtained in 2009 and no details of the type of system used to create the syngas is given. It is stated only "Gasifier" operated by First Power Ltd. The proposal for pyrolysis and autoclave at Washwood Heath **IS NOT A GASIFIER**. Gasifiers operate at higher temperature, they come in a variety of types (updraft, downdraft, fluidized bed, air gasification, steam gasification, etc), and the quality of syngas varies greatly. Gasifiers produce a much higher purity synthesis gas than a pyrolyser (3, 7).

17.1.2. There is an absence of information regarding the operating system, feedstock composition, and feedstock provenance to provide the necessary assurance.

17.1.2.1. No details of the fuel/feedstock are given. It is stated only "Material B".

17.1.2.2. Feedstock is stated as "N/A".

17.1.2.3. No details of the operating temperatures are given and no details of ancillary process stages are provided. This is a significant omission for these factors will completely alter the synthesis gas composition.

17.1.3. In view of the above, a newer analysis giving thorough methodology details of the feedstock, and operating system which should be identical, or at least very similar to the one proposed, would seem necessary.

17.2. On page 103 of Application Support Document_30/10/14, under section 6.2.5 Legislative Requirements, there is the following statement: "The combustion temperature and residence time, and the oxygen content of the stack gases have been validated under the most unfavourable operational conditions". There is no evidence to support this statement, and since this facility and no other similar facility has been built, it is difficult to imagine how this statement can be made.

18. Baghouse Filter

It is not clear what this process component is and there are discrepancies regarding whether it is included or not. In SOL1211VT01 End of waste submission (Table 2A), it is clearly shown as a mid-stage in the dry

syngas cleaning system (Table 2A) where dust from "filter bag waste" is sent directly back into the pyrolysis retorts. Application Support Document_30/10/14 also indicates that there is a fabric/baghouse filter, e.g. "The actual acid gas neutralisation takes place in the duct and on the surface of the filter bags" (page 98), and in Section 6.2.6 a description is given about what will happen if "filter bags fail".

18.1. No modus operandi of this unit, and material throughputs are given. There is no technical specification document.

18.2. In Appendix D of SOL1211VT01 End of waste submission the fate of selenium as "retained within gas train baghouse".

18.3. No details of pressure drop and frequency of cleaning methods is given.

18.4. No explanation is given regarding how the captured particulates will be disposed of.

Yours Faithfully,
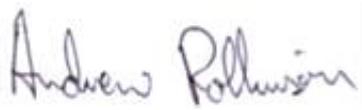
Dr Andrew Rollinson

[BSc (hons), MSc, PhD, MRSC, AHEA]

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