

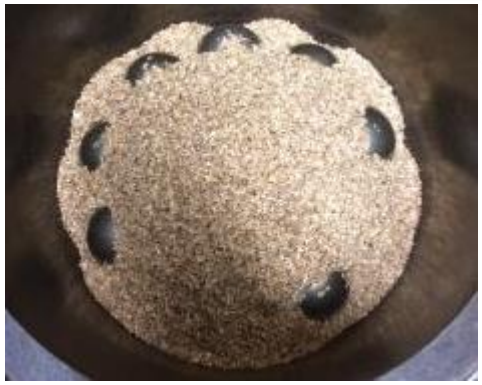

10th European Conference on Coal Research and its Applications

Bond Index & Hardgrove Grindability Index Tests for Biomass & Coal

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Tuesday 16th September 2014

BF2RA

Research Councils UK Energy For a Low Carbon Future

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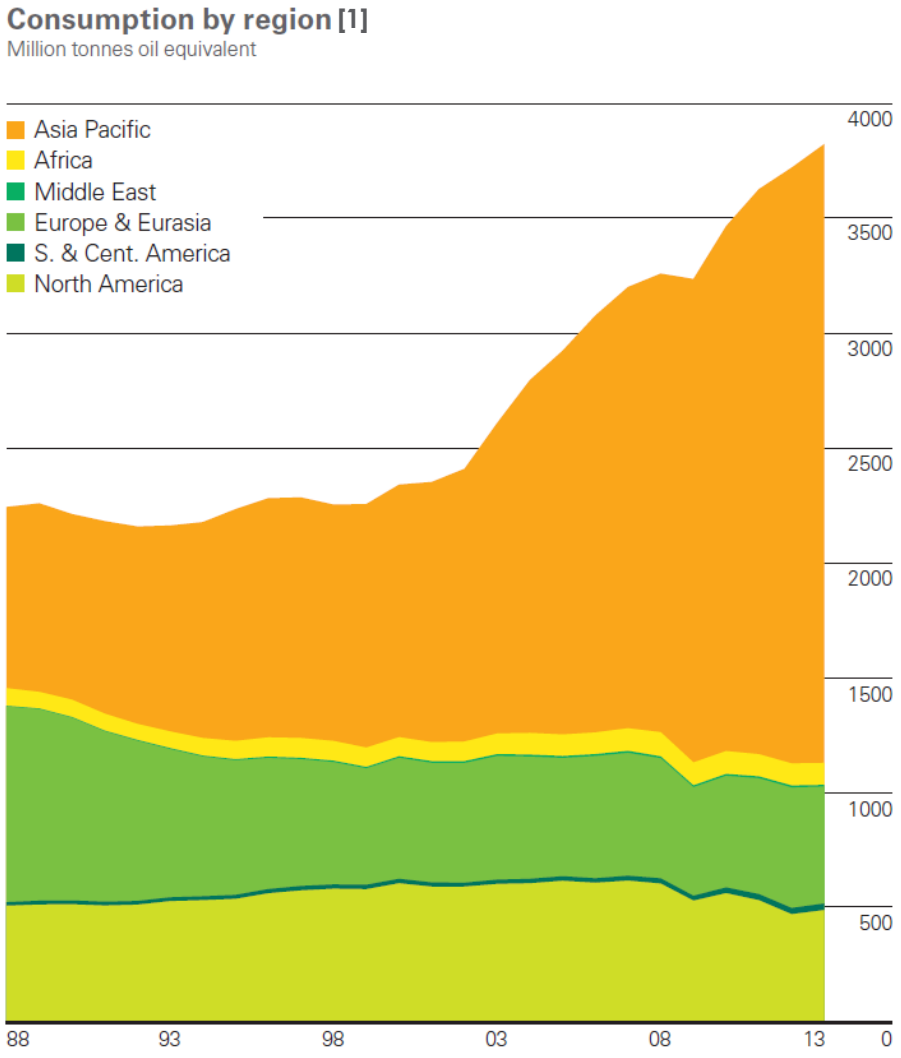
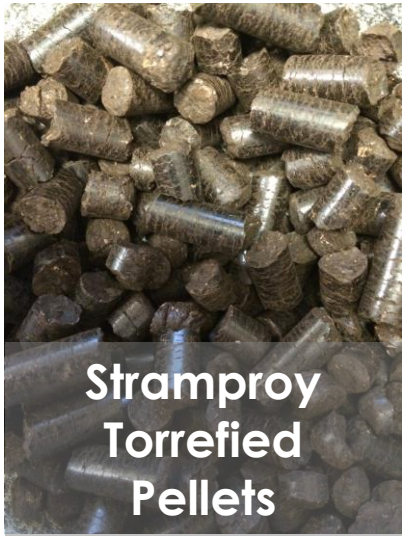
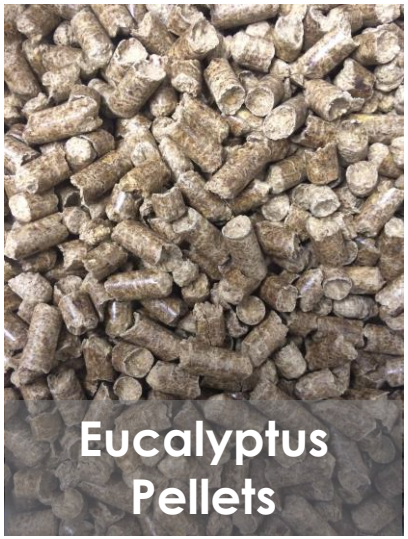
Status of Coal

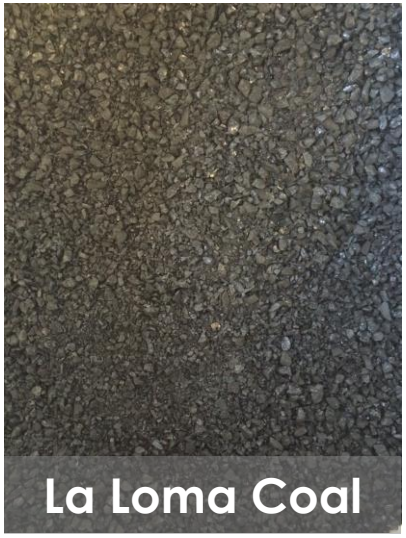
- Coal produced 36% of all UK electricity generation in 2013 [2]
- EU regulations reducing NO_x, SO_x, and particulate emissions
- UK government legally bound to cut CO_2 emissions by 80% by 2050
- Nine oil and coal power plants closing by 2016 and ten nuclear power facilities to close by 2035
- Biomass co-firing reduces NO_x emissions and extends the life of coal fired plants

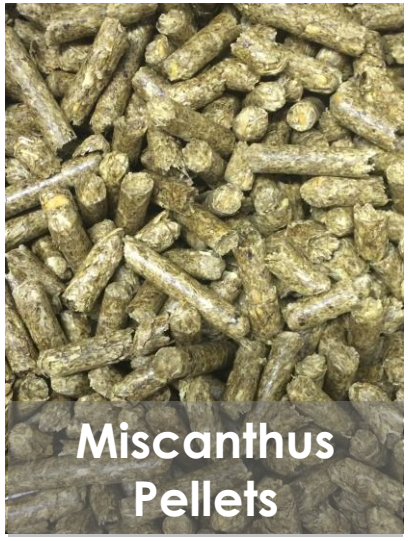


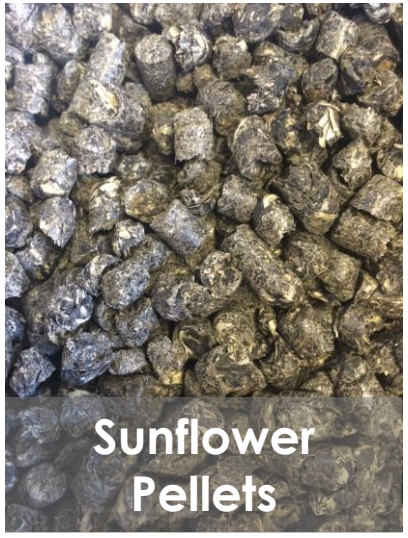
Samples Tested





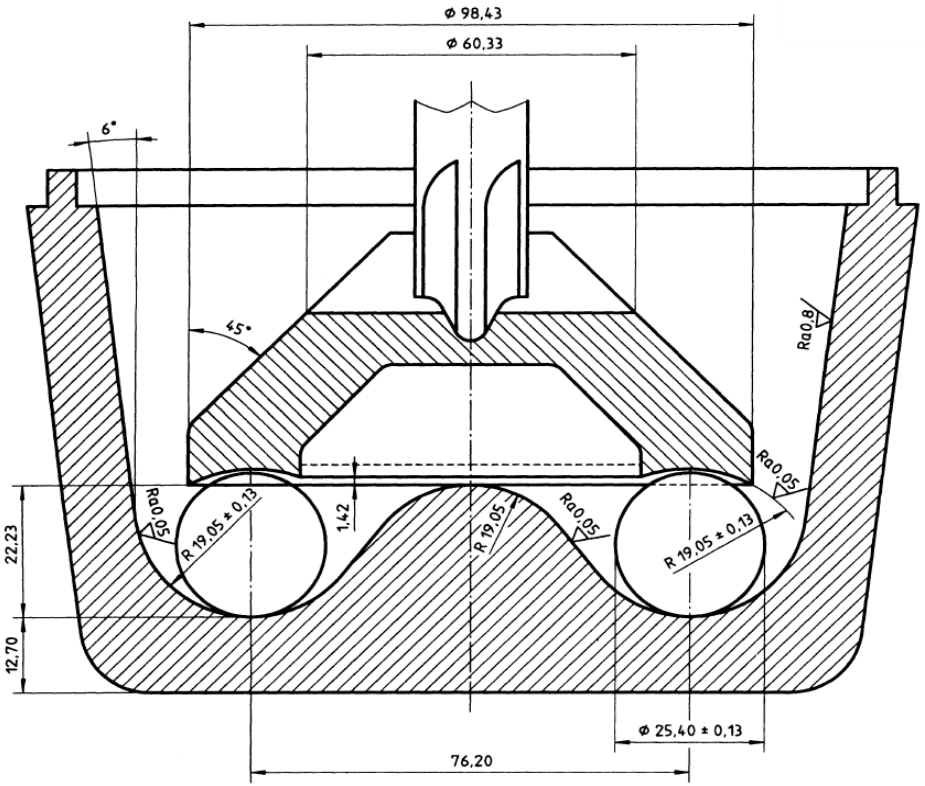






Standard Grindability Test for Coal

- Most widely used grindability test for coal is the Hardgrove Grindability Index Test (HGI) [3]
- The HGI of binary coal blends cannot be predicted from the weighted average of the individual coals in the blend [4, 5]
- HGI values become an ineffective measure of grinding behaviour as coal properties move away from the norm [6]



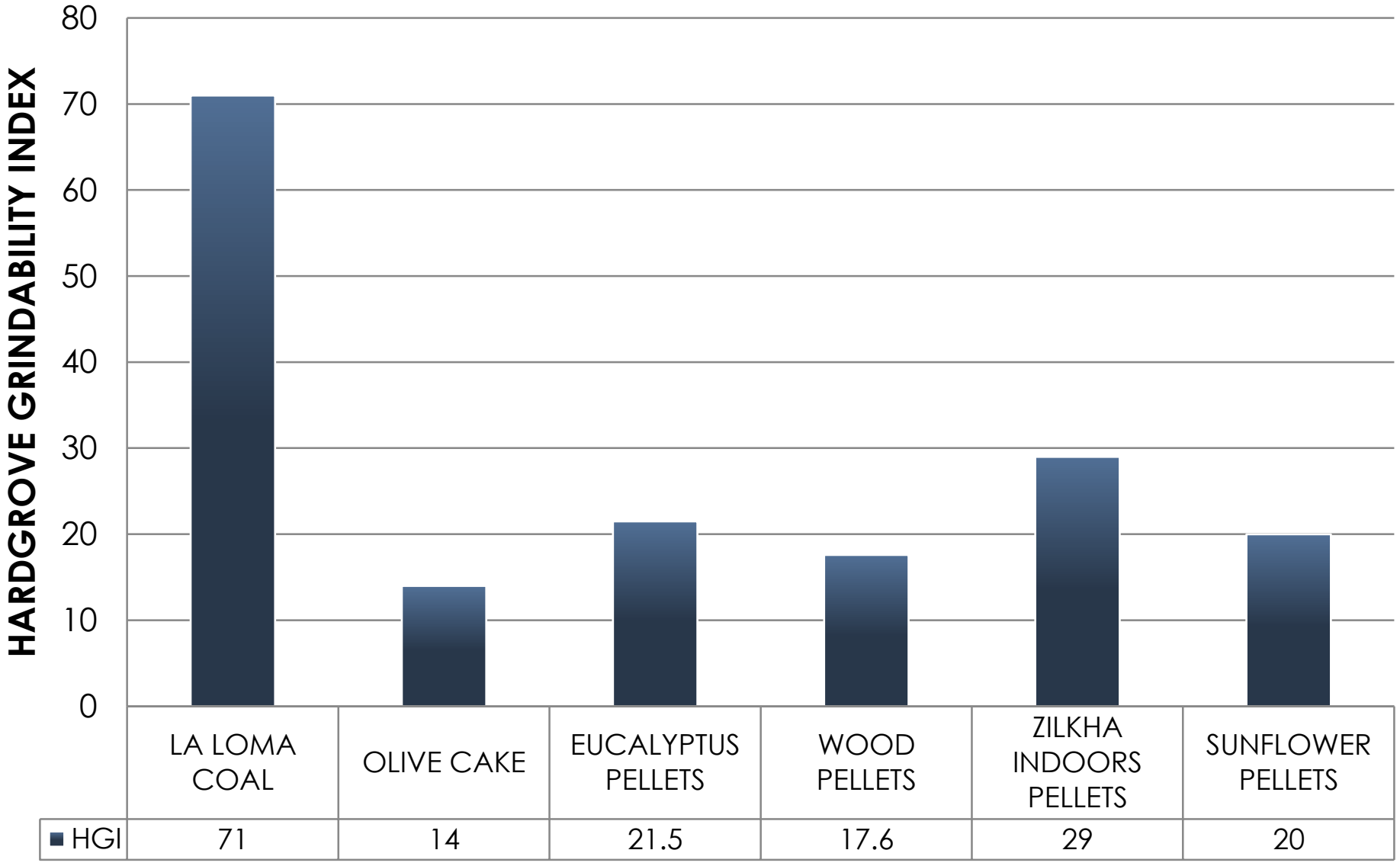
Hardgrove Grindability Index (HGI)

- Test conducted according to BS 1016-112:1995 [3] and conducted at Environmental Scientific Group, Bretby, UK
- 50g ± 0.01g of sample (1.18mm-600µm) milled for 60 revolutions.
- The sample sieved with 75µm sieve size and mass *m* (g) is calculated:

$$m = 50 - m_1$$

- where m_1 is the mass (g), retained on the 75µm sieve.
- HGI found from calibration chart base on value of *m*

HGI Results


HARDGROVE GRINDABILITY INDEX
80
70
60
50
40
30
20
10
0
LA LOMA COAL
OLIVE CAKE
EUCALYPTUS PELLETS
WOOD PELLETS
ZILKHA INDOORS PELLETS
SUNFLOWER PELLETS
HGI
71
14
21.5
17.6
29
20

HGI Conclusions

- HGI is a poor grindability test for biomass
- Pre milled size is unrepresentative of biomass (1.18mm-600µm)
- 75µm is too small a target particle size for biomass
- Milling is a volumetric process, and HGI favours denser materials, giving favourable results to coal like La Loma
- Good indicator of milling performance for vertical spindle mill for coal
- Potential for method to be modified in larger mill for biomass

Theories of Comminution

All work indices are derived from the general comminution energy equation proposed by Walker et al. [7] which relates the net specific energy *E*, the characteristic dimension of the product x, the exponent *n*, and a constant C related to the material:

$$dE = -C\frac{dx}{x^n}$$

The 3 Theories of empirical size reduction:

- **Rittinger's:** The energy required for size reduction is proportional to the new surface area generated [8]
- **Kick's:** The equivalent relative reductions in sizes require equal energy [9]
- **Bond's:** The net energy required in comminution is proportional to the total length of the new cracks formed [10]

Bond Index Test

- Test conducted on a Bond Index testing mill (Bico-Braun, USA)
- 700ml of sample milled for 100 revolutions.
- New number of revolutions is calculated to produce fines equal to 1/3.5 of the total charge of the mill.
- The **Bond Work Index W_i** expresses the resistance of the material to grinding to a specified product size (kWh/ton)
- The **Work Input *W*** gives the power required by the mill to grind the product to the required product size (kWh/ton)

Bond Index Equations

- Bond Work Index Equation is:

$$W = 10W_i\left(\frac{1}{\sqrt{P_{80}}} - \frac{1}{\sqrt{F_{80}}}\right)$$

Where W is the work input (kWh/t), W_i is the Work Index (kWh/t), and F_{80} and P_{80} are the 80% passing size of the feed and product (μm) respectively.

- Bond Work Index W_i can be found through the following equation:

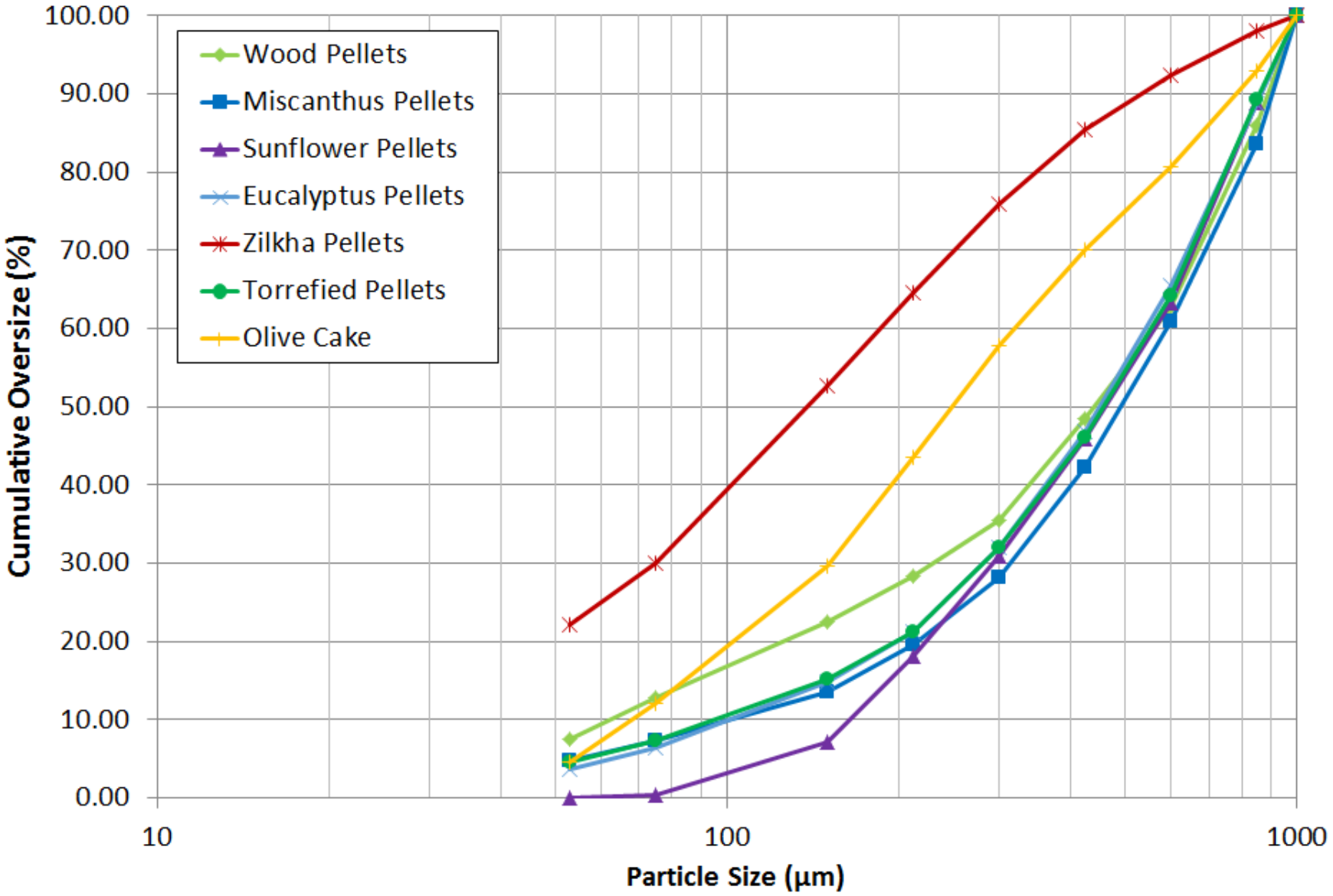
$$W_i = \frac{44.5}{P_1^{0.23}G^{0.82}\left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}}\right)}$$

Where P_1 is the target sieve size (μm), G is the grindability (net g/rev).

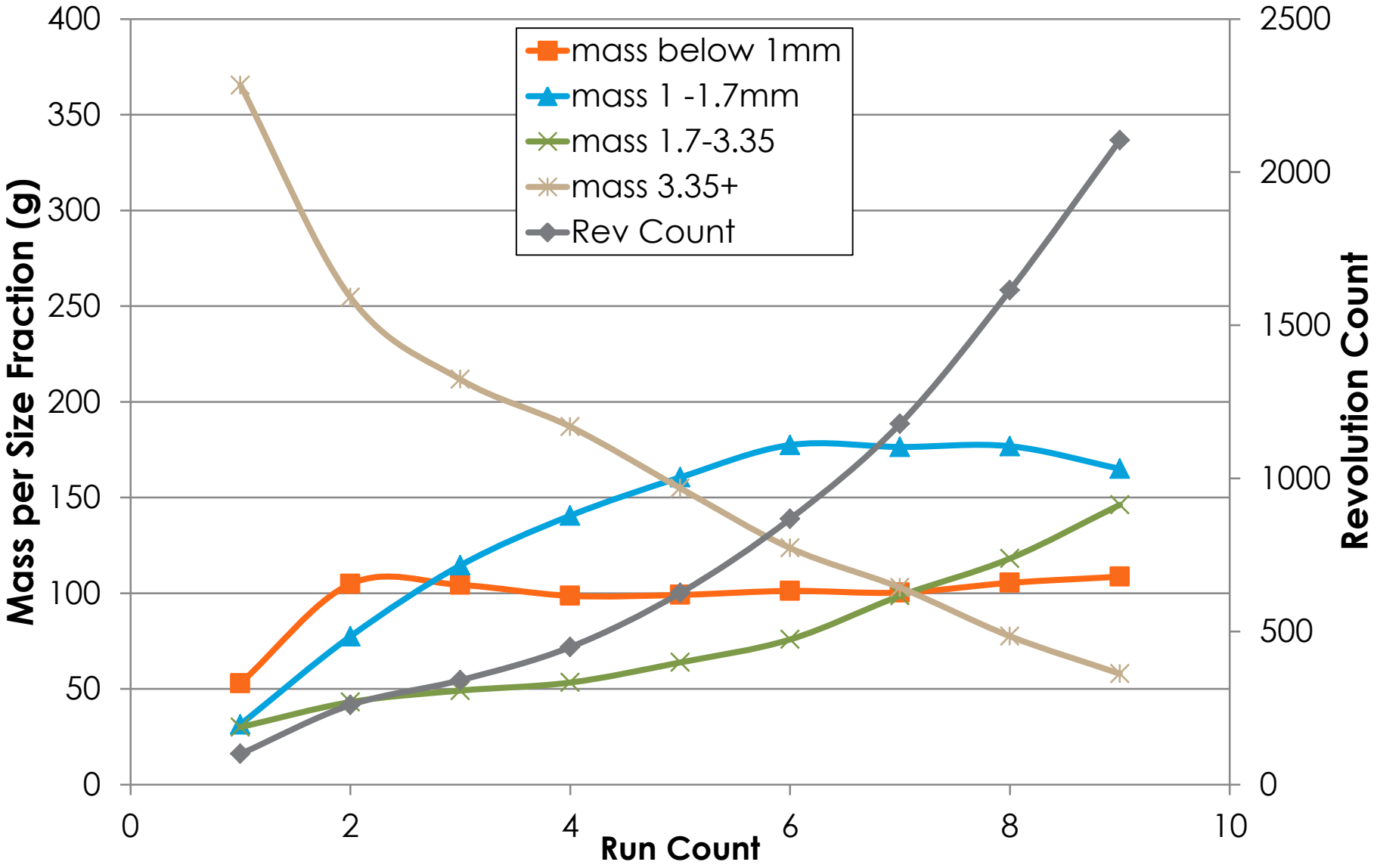
Bond Index Results

Sample	HGI	F80 (µm)	P80 (µm)	Target (µm)	Grindability per rev	Final rev count	Bond Index KWh/ton	Power to grind to product size (kWh/ton)
Wood Pellets	17.60	8400	786	1000	0.053	2141	413.03	102.29
Miscanthus Pellets	-	6290	811	1000	0.057	2168	425.87	95.85
Sunflower Pellets	20.00	8620	764	1000	0.059	1699	366.32	93.08
Eucalyptus Pellets	21.50	8390	757	1000	0.340	411	87.28	22.25
Zilkha SE Pellets	29.00	5910	355	1000	0.283	556	63.86	25.62
Stramproy T Pellets	-	8000	758	1000	1.655	60	16.30	4.10
Olive Cake	14.00	3712	590	1000	0.202	390	136.24	33.75
La Loma Coal	70.50	2709	77	90	0.664	242	23.35	22.11

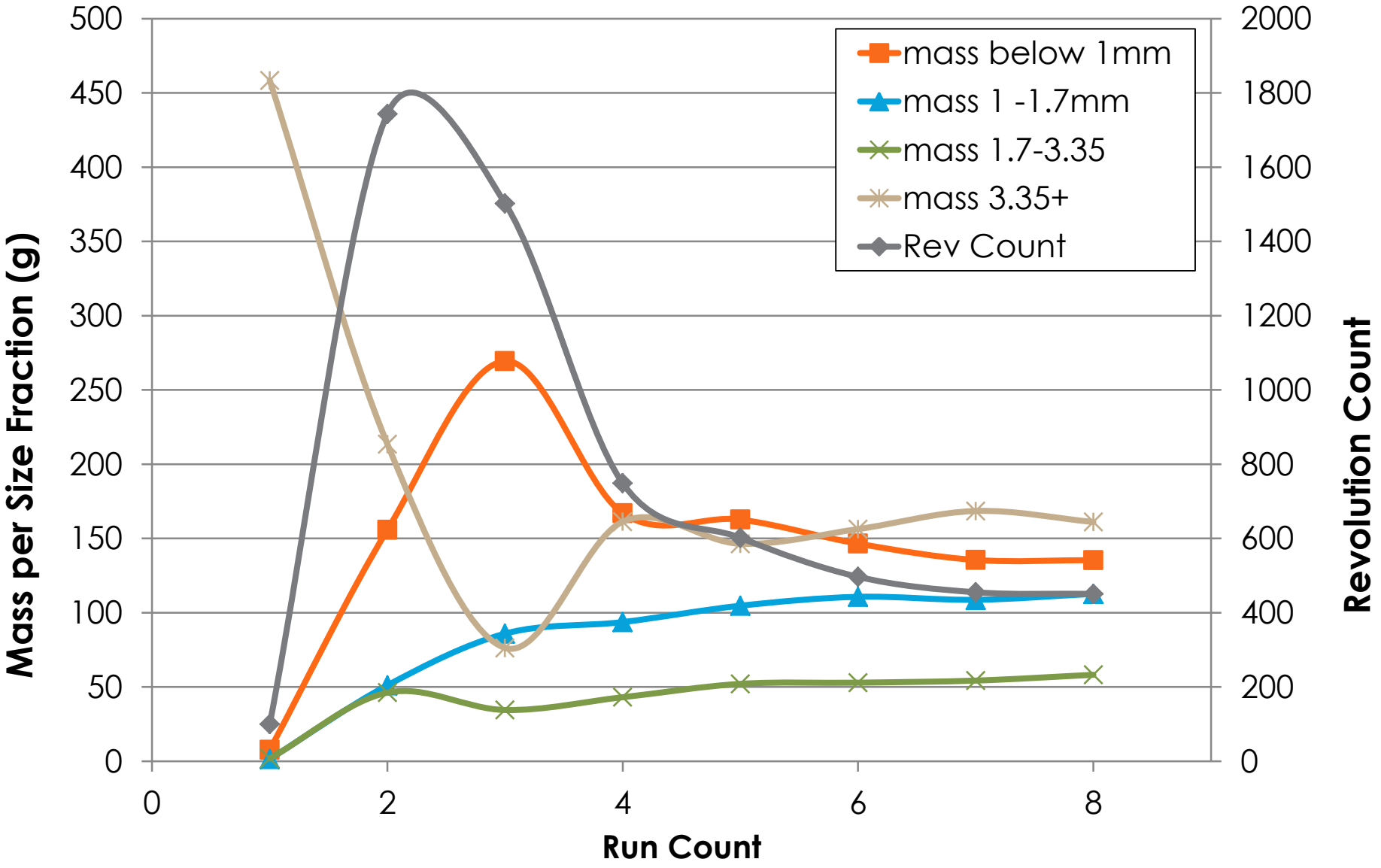
Biomass Particle Size Distributions



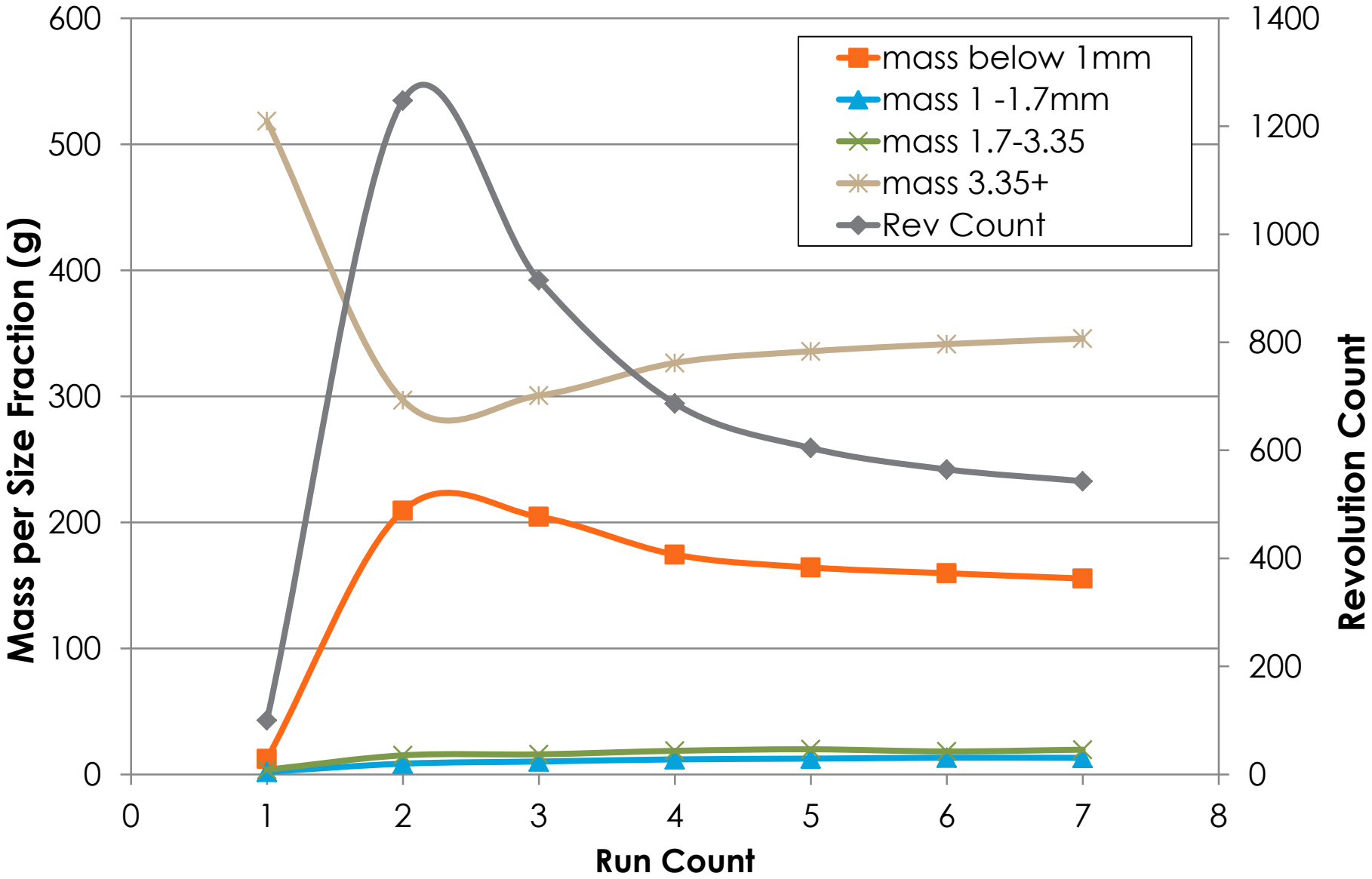
Wood Pellets



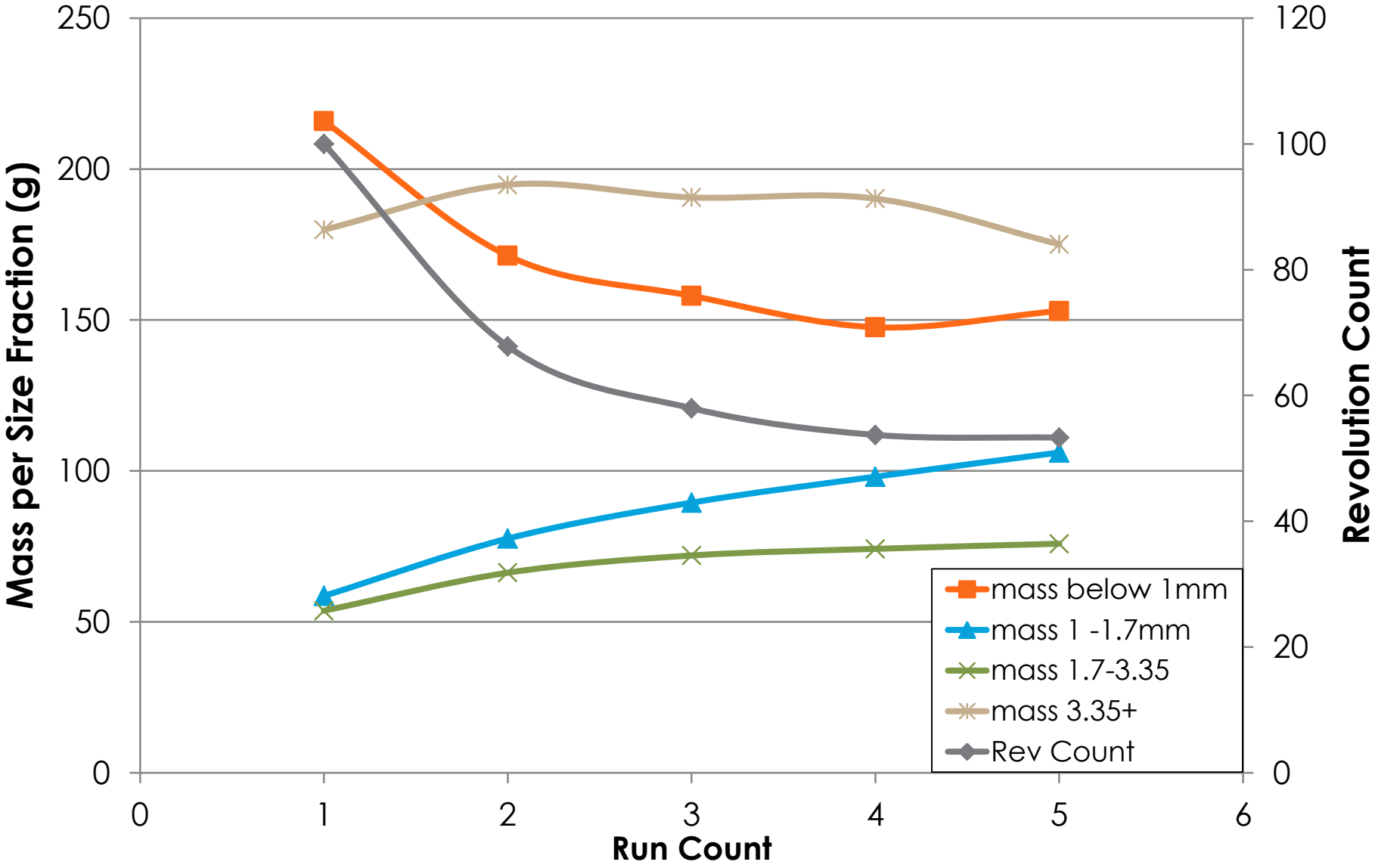
Eucalyptus Pellets



Zilkha Steam Exploded Pellets



Stramproy Torrefied Pellets



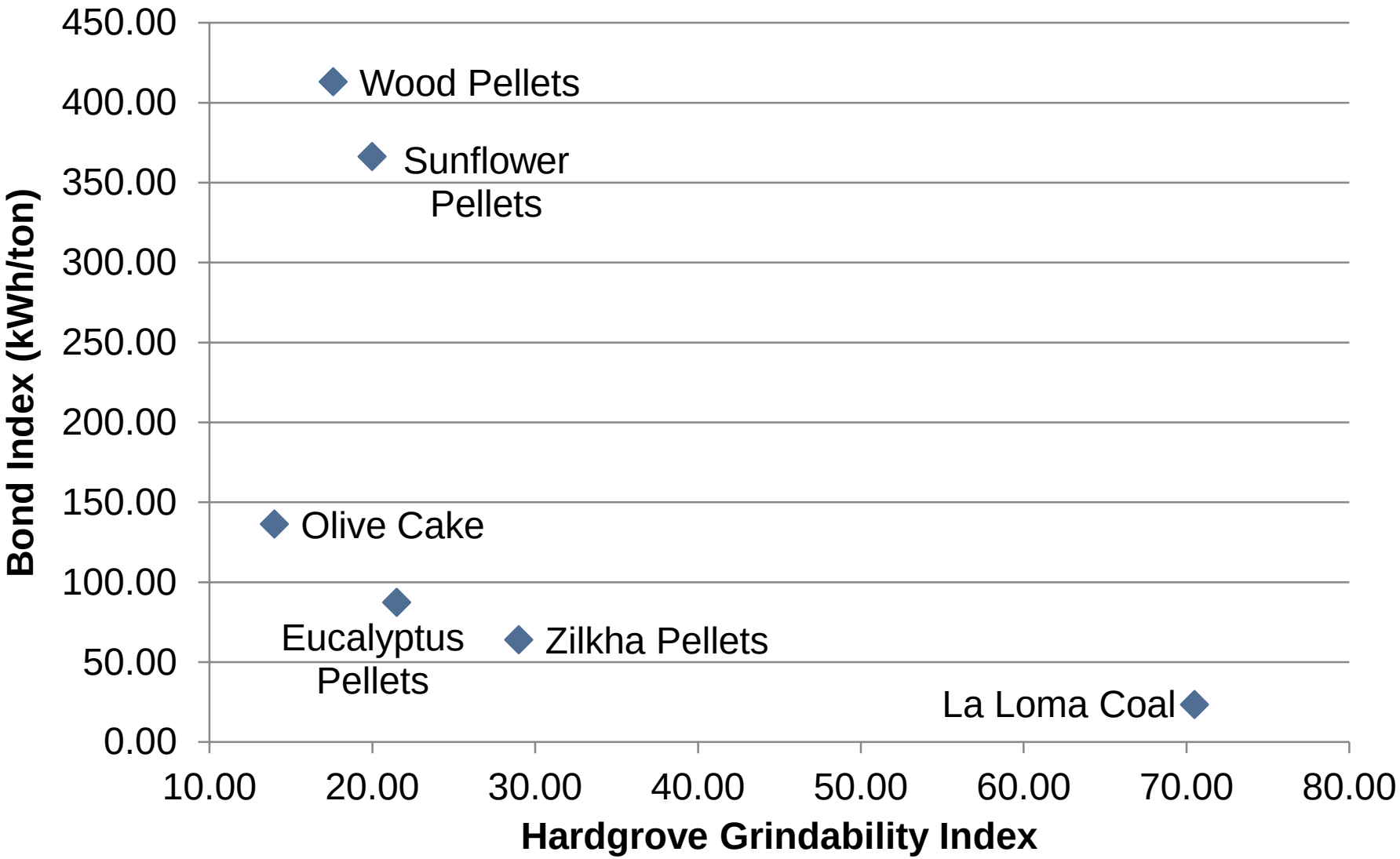
Bond Index Conclusions

- Bond Index Test can be used on biomass to analyse the grinding performance and behaviour of biomasses in a tube and ball mill
- Allows analysis of impact of different target particle size on grindability
- Mimics mill chocking and shows impact of pellet particle size on milling behaviour
- Matching P_{80} to classifier particle size critical in optimising mill performance
- Pre-densified particle size of pellets has large impact on grindability and energy consumption in ball and tube mill

HGI vs Bond Index Test

	Bond Index	HGI
Mill Comparison	Tube & Ball mill	Babcock mill (ring-ball)
Target Particle Size	Any size below 3.35mm	75µm
Particle Size Range	<3.35mm (powder) or pellet size	1.18mm-600µm
Mass constriction	Volume – 700ml	Mass – 50g
Output	kWh/ton	HGI Index
Suitable materials	Any	Good quality coals

HGI vs Bond Index Test



Conclusions & Recommendations

- HGI is a poor test of grindability for biomass
- Standard grindability test for ring-roller/ball mill is required for biomass
- Bond Index test can be used for biomass for analysing grinding performance of biomass in tube and ball mill
- Matching P_{80} to classifier particle size critical in optimising mill performance
- Pre-densified particle size of pellets has large impact on grindability and energy consumption in ball and tube mill
- Need to improve pellet specifications to ensure pre-densified particle size is close to the classifier target size

Thank you for listening

The author would like to thank the University of Nottingham, the Biomass and Fossil Fuel Research Alliance (BF2RA), and EDF Energy plc for their support during this project.

Questions?

References

[1] BP p.l.c. BP Statistical Review of World Energy June 2014 2014:45.

[2] Department of Energy & Climate Change. Digest Of United Kingdom Energy Statistics 2014. London: 2014

[3] The British Standards Institution, 1995. *BS 1016-112: 1995 Methods for Analysis and testing of coal and coke — Part 112: Determination of Hardgrove grindability index of hard coal.* Milton Keynes: BSI.

[4] Vuthaluru, H.B. et al., 2003. Effects of moisture and coal blending on Hardgrove Grindability Index of Western Australian coal. *Fuel Processing Technology*, 81(1), pp.67–76.

[5] Rubiera, F., Arenillas, A., Fuente, E., Miles, N. & Pis, J J. 1999. Effect of the grinding behaviour of coal blends on coal utilisation for combustion. *Powder Technology*, 105, pp.351–356.

References continued

[6] Australian Coal Association Research Program (ACARP), 2008. *ACARP Hardgrove Grindability Index*. [pdf] Brisbane: Australian Coal Association Research Program (ACARP). Available at: http://www.acarp.com.au/Downloads/ACARPHardgroveGrindabilityIndex.pdf

[7] Walker WH, Lewis WK, McAdams WH, Gilliland ER. Principles of Chemical Engineering. New York: McGraw-Hill; 1937.

[8] Von Rittinger PR. Lehrbuch der Aufbereitungskunde. Berlin: Ernst and Korn; 1867.

[9] Kick F. Das Gesetz der proportionalen Widerstande und seine anwendung felix. Leipzig: Verlag von Arthur Felix; 1885.

[10] Bond FC. The Third Theory of Comminution. Trans AIME 1952;193:484–94.