

## REFERENCES

Aasberg-Peterson K., Christensen T.S., Dybkjaer I., Sehested J., Østberg M., Coertzen R.M., Keyser M.J. and Steynberg A.P., 2004. Synthesis Gas Production for FT Synthesis. *In: A.P. Steynberg and M.E. Dry, Eds, Fischer-Tropsch Technology*, p.258-405. Elsevier, Amsterdam. (Studies in Surface Science and Catalysis, Vol. 152)

Alpern B., Nahuys J. and Martinez L., 1984. Mineral Matter in Ashy and Non-washable Coals – Its Influence on Chemical Properties. *In: M.J.Lemos de Sousa,Ed., Symposium on Gondwana Coals, Lisbon, 1983, Proceedings and Papers. Comunicações dos Serviços Geológicos de Portugal, Lisboa, T.70, Fasc.2, p. 299-317.*

van Alphen, C., 2005. Factors Influencing Fly Ash Formation and Slag Deposit Formation (Slagging) on Combusting a South African Pulverised Fuel in a 200 MWe Boiler, 332 pp. The Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg. (Ph.D. Thesis).

ASTM D1857, 2004. Standard Test Method for Fusibility of Coal and Coke Ash. ASTM International, West Conshohocken, PA. (See: [www.astm.org](http://www.astm.org))

ASTM D3302, 2007. Standard Test Method for Total Moisture in Coal. ASTM International, West Conshohocken, PA. (See: [www.astm.org](http://www.astm.org))

ASTM D3682, 2001. Standard Test Method for Major and Minor Elements in Combustion Residues from Coal Utilization Processes. ASTM International, West Conshohocken, PA. (See: [www.astm.org](http://www.astm.org))

ASTM D4239, 2002. Standard Test Methods for Sulphur in the Analysis Sample of Coal and Coke Using High Temperature Tube Furnace Combustion Methods. ASTM International, West Conshohocken, PA. (See: [www.astm.org](http://www.astm.org))

ASTM D4749-87, 2002. Standard Test Method for Performing the Sieve Analysis of Coal and Designating Coal Size. ASTM International, West Conshohocken, PA (See: [www.astm.org](http://www.astm.org))

ASTM D5016, 2003. Standard Test Method for Sulphur in Ash from Coal, Coke, and Residues from Coal Combustion Using High-Temperature Tube Furnace Combustion Method with Infrared Absorption. ASTM International, West Conshohocken, PA. ( See: [www.astm.org](http://www.astm.org))

ASTM D5373, 2002. Standard Test Methods for Instrumental Determination of Carbon, Hydrogen, and Nitrogen in Laboratory Samples of Coal and Coke. ASTM International, West Conshohocken, PA. (See: [www.astm.org](http://www.astm.org))

Baker, G., 2007a. E-mail communication – 30/05/2007.

Baker, G., 2007b. E-mail communication – 03/10/2007.

Baker, G., 2007c. Personal communication.

Benson, S.A., 2007. Lignite and Fixed Bed Gasification. Microbeam Technologies Inc., Confidential Presentation to the Sasol Visitors. Grandforks, North Dakota, USA.

Benson, S.A. and Holm, P.L., 1985. Comparison of Inorganic Constituents in Three Low-Rank Coals. *Industrial and Engineering Chemistry Product research and Development*, Vol.24, p.145-149.

Benson, S.A., Jones, M.J. and Harb, J.N., 1993. Ash Formation and Deposition. In: L.D. Smoot, Ed., *Fundamentals of Coal Combustion for Clean and Efficient Use*, p.299-373. Elsevier, Amsterdam. (Coal Science and Technology Vol. 20).

Boardman, R.D. and Smoot, L.D., 1993. Pollution Formation and Control. In:

L.D. Smoot, Ed., *Fundamentals of Coal Combustion for Clean and Efficient Use*, p.433-506. Elsevier, Amsterdam. (Coal Science and Technology Vol. 20).

BP Statistical Review of World Energy, 2007. (See: [www.bp.com](http://www.bp.com) accessed 08/02/2008).

Bunt, J.R., 2006. A New Dissection Methodology and Investigation into Coal Property Transformation Behaviour Impacting on a Commercial Scale Sasol-Lurgi MK-IV Fixed Bed Gasifier, 165 pp., North-West University. (PhD Thesis).

Bunt, J.R. and Waanders, F.B., 2008a. An Understanding of Lump Coal Physical Behaviour (density and particle size effects) Impacting on a Commercial Scale S-L FBDB Gasifier. *Fuel*, Vol.87, 13/14, p. 2856-2865.

Bunt, J.R. and Waanders, F.B., 2008b. Identification of the Reaction Zones occurring in a Commercial-Scale S-L FBDB Gasifier. *Fuel*, Vol.87, 10/11, p. 1814 - 1823.

Bunt, J.R. and Waanders, F.B., 2008c. An Understanding of the Behaviour of a Number of Element Phases Impacting on a Commercial-Scale Sasol-Lurgi FBDB Gasifier. *Fuel*, Vol.87, 10/11, p. 1751–1762.

Bunt, J.R., Joubert, J.P. and Waanders F.B., 2008. Coal Char Temperature Profile Estimating using Optical Reflectance for a Commercial Scale S-L FBDB Gasifier. *Fuel*, Vol.87, 13/14. p. 2849-2855.

Collot, A.G., 2002. Matching Gasifiers to Coal. *IEA Clean Coal Centre*, 65 pp.

Dittus, M. and Johnson, D., 2001. The Hidden Value of Lignite Coal. In: *Proceedings of the Gasification Technologies Conference*, San Francisco, USA.

van Dyk, J.C., 2006. Manipulation of Gasification Coal Feed in Order to Increase the AFT of the Coal to Operate the Gasifiers at Higher Temperatures, 147 pp. North-West University. (PhD Thesis)

van Dyk, J.C., 2008. Quantification and Validation of Oxygen Capture in Mineral matter of North Dakota Lignite in Fixed Bed Gasification Process, 15 pp. Sasol Technology R&D. (Unpublished Internal Report).

van Dyk, J.C., Keyser, M.J., and van Zyl, J.W., 2001. Suitability of Feedstocks for the Sasol-Lurgi Fixed Bed Dry Bottom Gasification Process, *Proceedings of the Gasification Technologies Conference*, San Francisco, USA.

van Dyk, J.C., Waanders. F.B. and van Heerden, J.H.P., 2008. Quantification of Oxygen Capture in Mineral Matter during Gasification. *Fuel*, Vol.87, 12, p.2735-2744.

Fagerstrom, B., 2007. Operation and Maintenance of the Lurgi MK IV Gasifier at Dakota Gasification Company. In: *Proceedings of the Gasification Technologies Conference*, San Francisco, USA.

Falcon, R.M.S. and Snyman, C.P., 1986. An Introduction to Coal Petrography: Atlas of Petrographic Constituents in the Bituminous Coals of Southern Africa, 27 pp. Geological Society of South Africa.

Finkelman, R.B., 1994. Abundance, source and mode of occurrence of the inorganic constituents in coal. In: Kural, O. (Ed.), *Coal*. Istanbul Technical University, Istanbul, pp. 115– 125.

Gary, M., McAfee, R., Wolf, C.L. (Eds.), 1972. *Glossary of Geology*. American Geological Institute, Washington, DC, 805 pp.

Glover. G., 1988. An Experimental Study of the Physical and Chemical Processes Occurring Within a Lurgi Mark IV Coal Gasifier with a View to

Determining an Optimization Path. Part 1: Rationale and Preliminary Observations, 65 pp. (Sasol Technology R&D Internal Report).

Glover, G., 1991. An Experimental Study of the Physical and Chemical Processes Occurring Within a Lurgi Mark IV Coal Gasifier With a View to Determining an Optimization Path. Part 2: The Sasol One Gasifiers, 42 pp. (Sasol Tehnology R&D Internal Report).

Gluskoter, H.J., 1965. Electronic low-temperature ashing of bituminous coal, *Fuel*, Vol.44, p. 285-291.

Goblirsch, G.M., Benson, S.A., Karner, F.R., Rindt, D.K. and Hajicek, D.R., 1984. AFBC bed material performance with low-rank coals. In: W.R. Kube, E.A. Sondreal, and C.D. Rao, Eds, *Twelfth Biennial Lignite Symposium: Technology and Utilization of Low-Rank Coal Proceedings*, p.557-58. (DOE/METC/84-13, 2)

Harvey, R.D., Ruch, R.R., 1986. Mineral matter in Illinois and other US coals. In: Vorres, K.S. (Ed.), *Mineral Matter in Coal Ash and Coal*. American Chemical Society Symposium Series 301, pp. 10– 40.

Hebden, D and Stroud, H.J.F., 1981. Coal Gasification Processes. In: Elliot, M.A. (Ed.) *Chemistry of Coal Utilisation*, Second Supplementary Vol., Wiley-Interscience, p. 665-784.

Higman, C. and van der Burgt, M., 2003. *Gasification*, 391 pp. Elsevier, Amsterdam.

Huggings, F. E., Huffman, G. P., Lytle, F. W. and Greegor, R. B., 1983. An EXAFS Investigation of Calcium in Coal. In: *Proceedings of the International Conference on Coal Science*, p.679-682.

International Committee for Coal and Organic Petrology (ICCP), 2000. The new inertinite classification (ICCP System 1994). *Fuel*, Vol.80, 4, p.459-471.

ISO 562: 1998. Hard Coal and Coke – Determination of Volatile Matter. International Organization for Standardization – ISO, Geneva, 1988. (See: [www.iso.org](http://www.iso.org))

ISO 589: 2008. Hard Coal – Determination of Total Moisture. International Organization for Standardization – ISO, Geneva, 2008. (See: [www.iso.org](http://www.iso.org))

ISO 1171: 1997. Solid Mineral Fuels - Determination of Ash. International Organization for Standardization – ISO, Geneva, 1997. (See: [www.iso.org](http://www.iso.org))

ISO 5068-1: 2007. Brown coals and lignites - Determination of Moisture Content - Part 1: Indirect Gravimetric Method for Total Moisture. International Organization for Standardization – ISO, Geneva, 2007. (See: [www.iso.org](http://www.iso.org))

ISO 7404-2: 1985. Methods for the Petrographic Analysis of Bituminous Coal and Anthracite - Part 2: Preparation of Coal Samples. International Organization for Standardization – ISO, Geneva, 1985. (See: [www.iso.org](http://www.iso.org))

ISO 7404-3: 1984. Methods for the Petrographic Analysis of Bituminous Coal and Anthracite - Part 3: Method of Determining Maceral Group Composition. International Organization for Standardization – ISO, Geneva, 1984. (See: [www.iso.org](http://www.iso.org))

ISO 7404-5: 1994. Methods for the Petrographic Analysis of Bituminous Coal and Anthracite - Part 5: Method of Determining Microscopically the Reflectance of Vitrinite. International Organization for Standardization – ISO, Geneva, 1994. (See: [www.iso.org](http://www.iso.org))

ISO 11760: 2005. Classification of Coals. International Organization for Standardization – ISO, Geneva, 2005. (See: [www.iso.org](http://www.iso.org))

Krishnudu, T., Madhusudhan, B., Narayan Reddy, S., Seshagiri Rao, K. and Vaidyeswaran, R., 1989a. Moving Bed Pressure Gasification of some Indian Coals. *Fuel Processing Technology*, Vol.23, 3, p. 233-256.

Krishnudu, T., Madhusudhan, B., Reddy, S.N., Sastry, V.S.R., Seshagiri Rao, K. and Vaidyeswaran, R., 1989b. Studies in a Moving-Bed Pressure Gasifier : Prediction of Reaction Zones and Temperature Profile. *Ind. Eng. Chem. Res.*, Vol.28, p. 438-444.

Lancet, M. S. and Curran, G.P., 1982. Process for Producing Synthesis Gas from Wood. United States, Conoco Inc. (Stamford, CT) Patent No.4334894, available from <http://www.freepatentsonline.com/4334894.html>

Li, Z., 2004. Coal Based Ammonia Plants, New Technology and Trend in Ammonia Production in China. *In: IFA Technical Conference, Beijing, China.*

Madhusudhan, B., Narayan Reddy, S, Krishnudu, T., Mallikarjunan, M.M, Anjaneyulu, T.S.R., Khaleel Akmal, M.A., Seshagiri Rao, K. and Vaidyeswaran, R., 1989a. Residence Time Distribution Studies on the Flow of solids in a Moving Bed Pressure Gasifier. *Indian Chem. Eng.*, Vol XXXI, 4, p.65 -68.

Mangena, S. J., 2006. Internal Sasol Technology R&D Report, 16 pp. (Unpublished).

Matjie, R.H., van Alphen, C. and Pistorius, P.C., 2006. Mineralogical Characterisation of Secunda Gasifier Feedstock and Coarse Ash. *Minerals Engineering*, Vol.19, p.256-251.

Matsuoka, K., Suzuki, Y., Eylands, K.E., Benson, S.A. and Tomita, A., 2006. CCSEM Study of Ash Forming Reactions during Lignite Gasification. *Fuel*, Vol.85, 17/18, p.2371-2376.

Morgan, M.E., Jenkins, R.G. and Walker Jr., P.L., 1980. Inorganic Constituents in American lignites. *Fuel*, Vol.60, 3, p.189-193.

Murphy E.D., 2005. Mineral Resources of North Dakota: Coal. Available on [www.dmr.nd.gov/ndgs/Mineral/nd\\_coal.asp](http://www.dmr.nd.gov/ndgs/Mineral/nd_coal.asp) --Accessed on 08 /04/2008.

Nankervis, J.C. and Furlong, R.B., 1980. Phase Changes in Mineral Matter of North Dakota Lignites Caused by Heating to 1200°C. *Fuel*, Vol.59, 6, p.425-430.

Pinheiro, H.J., Pretorius, C.C. and Boshoff, H.P., 1999. Analysis of Coal Product Samples of South African Collieries 1998 – 1999. In: H.J.Pinheiro Ed., *Coal Bulletin*, 113, p.64 -89. (ISBN 0-7988-5438-3).

Pistorius, P.C., 2006. Pyrometallurgy 700. *In: Course Notes*, University of Pretoria.

Quann, R.J. and Sarofim, A.F., 1986. A Scanning Electron Microscopy Study of the Transformations of Organically Bound Metals during Lignite Combustion, *Fuel*, Vol.65, 1, p.40-46.

Radovic, L.R., Steczko, K., Walker, P.L. and Jenkins, R.G., 1984. Combined Effects of Inorganic Constituents and Pyrolysis Conditions on the Gasification Reactivity of Coal Chars. *Fuel Processing Technology*, Vol.10, 3, p.311-326.

Roeger, A. and Jones Jr., J.E., 1983. Testing Kentucky Coal to set Design Criteria for a Lurgi Gasification Plant. *Presented at the Fifth Annual Industrial Energy Conservation Technology Conference and Exhibition, Houston, Texas.*

Ruppert, L.F., Kirschbaum, M.A., Warwick, P.D., Flores, R.M., Affolter, R.H. and Hatch, J.R., 2002. The US Geological Survey' National Coal Resource Assessment: The Results. *International Journal of Coal Geology*, Vol.50, 1/4, p.247-274.

SANS 5924, 1978. Moisture Content of Coal Samples Intended for General Analysis (vacuum-oven method). South Africa Bureau of Standards. (See: [www.sabs.co.za](http://www.sabs.co.za))

SANS 6073, 1984. Yields of Tar, Water, Gas and Coke Residue from Coal by Low Temperature Distillation. South Africa Bureau of Standards. (See [www.sabs.co.za](http://www.sabs.co.za))

Schober, H. H., 1995. Lignites of North America, 696 pp., Elsevier, Amsterdam. (Coal Science and Technology Vol. 23).

Slaghuis, J. H., 1993. Coal Gasification, Study Guide for the National Diploma in Fuel Technology, 202 pp. (ISBN 0-620-17788-8).

Smith, K.L., Smoot, L.D. and Fletcher, T.H., 1993. Coal Characteristics, Structure, and Reaction Rates. In: L.D. Smoot, Ed., *Fundamentals of Coal Combustion for Clean and Efficient Use*, p131-298. Elsevier, Amsterdam (Coal Science and Technology Vol. 20)

Srinivasachar, S., Helble, J.J., Boni, A.A., Shah, N., Huffman, G.P. and Huggins, F.E., 1990a. Mineral Behaviour during Coal Combustion, 1. Illite Transformations. *Progress in Energy and Combustion Science*, Vol.16, p. 293-302.

Srinivasachar, S., Helble, J.J. and Boni, A.A., 1990b. Mineral Behaviour during Coal Combustion, 1. Pyrite transformations. *Progress in Energy and Combustion Science*, Vol.16, p. 281-292.

Stach, E., Mackowsky, M.-Th., Teichmüller M., Taylor, G.H., Chandra, D. and Teichmüller, R., 1982. Stach's Textbook of Coal Petrology, Third revised and enlarged edition, 535 pp. Gebrüder Borntraeger, Berlin.

Sýkorová, I., Pickel, W., Christanis, K., Wolf, M., Taylor, G.H. and Flores, D., 2005. Classification of huminite –ICCP System 1994. In: A. Cook, P. David,

W. Pickel, Eds, Marlies Teichmüller Symposium. *International Journal of Coal Geology*, Vol.62, 1/2, p.85-106.

Taylor, J.C., 1991. Computer Programs for Standardless Quantitative Analysis of Minerals Using the Full Powder Diffraction Profile. *Powder Diffraction*, Vol.6, p.2-9.

The Coteau Properties Company, 2008. Freedom Mine Fact Sheet. Available on [www.nacoal.com/operations/Coteau\\_freedomfacts\\_b1FD0.pdf#1FD0.pdf](http://www.nacoal.com/operations/Coteau_freedomfacts_b1FD0.pdf#1FD0.pdf) -- Accessed on 09/04/2008.

Tromp, P.J.J., 1987. Coal Pyrolysis: Basic Phenomena Relevant to Conversion Process, 183 pp. University of Amsterdam. (PhD Thesis)

Turna, O., 2007. S-L FBDB Gasification for Fuels and Chemicals. In: *Proceedings of the 2<sup>nd</sup> International Freiberg Conference on IGCC and XtL Technologies*. Freiberg, Germany.

Turna O., 2008. Personal communication.

University of Wyoming - The Science and Mathematics Teaching Center, 2002. Wyoming Coal. Available on <http://smtc.uwyo.edu/coal/swamp/default.asp> -- Accessed on 10/06/2008.

Unsworth, J., Cunliffe, F., Graham, S.C. and Morgan, P.A., 1987. Ash formation during pulverised coal combustion 1: Aerodynamic influences. *Fuel*, Vol.66, 12, p.1672-1679.

van de Venter, E.G., 2007. Update on the Sasol-Lurgi Technology Company Business Activities and the Application of the S-L FBDB Gasification Technology. In: *Proceedings of the Gasification Technologies Conference*, San Francisco, USA.

Wagner, N.J., 2007. North Dakota Gasifier Turn-Out Investigation: Petrographic Carbon type Analysis, 29 pp. (Unpublished Report)

Ward, C.R., 2002. Analysis and Significance of Mineral Matter in Coal Seams. *International Journal of Coal Geology*, Vol.50, 1/4,135-168.

Watt, J.D., 1969. The Physical and Chemical Behaviour of Mineral Matter in Coal under Conditions Met in Combustion Plants, BCURA Industrial Laboratories, Leatherhead, Surrey, Part II.

## APPENDIX 1

### 1a. Data used for the Evaluation of the "Bernice" Gasifier Fuel Bed

Table A1. Proximate analyses, Fischer tar and CO<sub>2</sub> char reactivity data from the "Bernice" gasifier bed samples.

| Sample number | % Ash (db) | % Fixed carbon (db) | % Volatile matter (db) | % Fixed Carbon Conversion | Volatile matter (kg/100kg ash flow) | Fixed carbon (kg/100kg ash flow) | % Fischer Tar (ad) | Fischer Tar (kg/100kg ash flow) | CO <sub>2</sub> Char reactivity (h <sup>-1</sup> ) |
|---------------|------------|---------------------|------------------------|---------------------------|-------------------------------------|----------------------------------|--------------------|---------------------------------|----------------------------------------------------|
| Feed          | 12.5       | 45.2                | 42.2                   | -                         | 336.5                               | 197.2                            | 6.1                | 48.5                            | 37.9                                               |
| 27            | 18.0       | 43.9                | 38.2                   | -                         | 212.1                               | 243.0                            | 5.5                | 30.7                            | 39.5                                               |
| 26            | 17.9       | 43.4                | 38.7                   | -                         | 216.5                               | 301.2                            | 6.0                | 33.5                            | 41.7                                               |
| 25            | 14.5       | 43.8                | 41.7                   | -                         | 287.0                               | 311.2                            | 5.8                | 40.0                            | 35.1                                               |
| 24            | 13.3       | 41.4                | 45.3                   | -                         | 340.5                               | 386.3                            | 6.8                | 51.2                            | 40.3                                               |
| 23            | 10.9       | 42.1                | 47.0                   | -                         | 430.5                               | 283.6                            | 6.1                | 55.9                            | 39.8                                               |
| 22            | 14.0       | 39.7                | 46.3                   | -                         | 331.1                               | 379.5                            | 6.0                | 43.1                            | 40.3                                               |
| 21            | 12.8       | 48.6                | 38.6                   | -                         | 300.9                               | 327.7                            | 6.2                | 48.1                            | 37.4                                               |
| 20            | 13.5       | 44.3                | 42.2                   | -                         | 312.6                               | 410.5                            | 6.0                | 44.2                            | 39.0                                               |
| 19            | 10.7       | 44.1                | 45.1                   | -                         | 420.0                               | 345.3                            | 5.5                | 50.9                            | 34.6                                               |
| 18            | 13.1       | 45.4                | 41.5                   | -                         | 315.4                               | 280.7                            | 6.1                | 46.3                            | 33.3                                               |
| 17            | 15.5       | 43.6                | 40.8                   | -                         | 262.9                               | 383.1                            | 5.6                | 35.9                            | 29.7                                               |
| 16            | 13.1       | 50.3                | 36.6                   | -                         | 278.8                               | 340.3                            | 4.8                | 36.5                            | 32.3                                               |
| 15            | 15.3       | 52.0                | 32.7                   | -                         | 213.7                               | 341.2                            | 4.9                | 31.9                            | 35.4                                               |
| 14            | 16.5       | 56.4                | 27.1                   | -                         | 164.1                               | 388.1                            | 3.4                | 20.4                            | 35.4                                               |
| 13            | 15.4       | 59.7                | 24.9                   | -                         | 161.5                               | 388.1                            | 2.6                | 16.8                            | 35.0                                               |
| 12            | 16.8       | 61.5                | 21.8                   | -                         | 129.7                               | 366.5                            | 2.6                | 15.4                            | 32.2                                               |
| 11            | 21.2       | 62.4                | 16.4                   | 0.0                       | 77.2                                | 293.6                            | 0.8                | 3.7                             | 30.4                                               |
| 10            | 26.9       | 59.1                | 14.1                   | 7.0                       | 52.4                                | 207.3                            | 0.2                | 0.9                             | 35.5                                               |
| 9             | 34.0       | 51.4                | 14.6                   | 17.6                      | 43.1                                | 151.4                            | 0.5                | 1.6                             | 40.5                                               |
| 8             | 39.2       | 49.5                | 11.4                   | 20.6                      | 29.0                                | 126.3                            | 0.1                | 0.3                             | 50.3                                               |
| 7             | 63.9       | 25.6                | 10.5                   | 58.9                      | 16.4                                | 40.1                             | 0.0                | 0.0                             | 56.6                                               |
| 6             | 66.6       | 23.2                | 10.2                   | 62.9                      | 15.4                                | 34.8                             | 0.0                | 0.0                             | 57.8                                               |
| 5             | 78.4       | 12.1                | 9.6                    | 80.6                      | 12.2                                | 15.4                             | 0.0                | 0.0                             | -                                                  |
| 4             | 84.0       | 5.3                 | 10.7                   | 91.5                      | 12.7                                | 6.3                              | 0.0                | 0.0                             | -                                                  |
| 3             | 90.7       | 1.5                 | 7.8                    | 97.6                      | 8.6                                 | 1.7                              | 0.0                | 0.0                             | -                                                  |
| 2             | 90.9       | 1.2                 | 7.9                    | 98.0                      | 8.7                                 | 1.3                              | 0.0                | 0.0                             | -                                                  |
| 1             | 88.6       | 1.8                 | 9.5                    | 97.0                      | 10.7                                | 2.1                              | 0.0                | 0.0                             | -                                                  |
| Ash           | 91.5       | 1.4                 | 7.1                    | 97.7                      | 7.7                                 | 1.5                              | 0.0                | 0.0                             | -                                                  |

Table A2. Ultimate analyses data (dry basis) from the "Bernice" gasifier bed samples.

| Sample number | %C (db) | %H (db) | %N (db) | %S (db) | %O (db) | C<br>(kg/100kg ash flow) | H<br>(kg/100kg ash flow) | N<br>(kg/100kg ash flow) | S<br>(kg/100kg ash flow) | O<br>(kg/100kg ash flow) |
|---------------|---------|---------|---------|---------|---------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Feed          | 69.3    | 3.35    | 1.05    | 1.4     | 12.4    | 321.6                    | 23.2                     | 3.9                      | 1.9                      | 97.4                     |
| 27            | 63.1    | 4.55    | 0.76    | 0.4     | 11.5    | 353.9                    | 24.6                     | 4.4                      | 4.4                      | 56.3                     |
| 26            | 63.3    | 4.39    | 0.79    | 0.8     | 12.8    | 434.9                    | 31.8                     | 6.5                      | 5.4                      | 71.2                     |
| 25            | 63.2    | 4.62    | 0.94    | 1.0     | 15.7    | 473.7                    | 34.7                     | 7.1                      | 7.1                      | 108.0                    |
| 24            | 63.0    | 4.62    | 0.94    | 0.8     | 17.3    | 599.5                    | 43.6                     | 9.4                      | 6.9                      | 129.3                    |
| 23            | 65.4    | 4.75    | 1.02    | 0.8     | 17.2    | 454.9                    | 32.2                     | 7.4                      | 8.5                      | 155.9                    |
| 22            | 63.6    | 4.51    | 1.03    | 0.9     | 15.9    | 505.2                    | 35.1                     | 8.2                      | 8.9                      | 111.4                    |
| 21            | 64.7    | 4.50    | 1.05    | 1.1     | 15.8    | 480.3                    | 32.9                     | 7.6                      | 8.2                      | 123.7                    |
| 20            | 64.9    | 4.45    | 1.02    | 1.0     | 15.1    | 617.9                    | 42.7                     | 9.5                      | 8.5                      | 111.0                    |
| 19            | 66.4    | 4.59    | 1.02    | 0.8     | 16.4    | 502.0                    | 32.6                     | 7.6                      | 8.6                      | 151.9                    |
| 18            | 66.0    | 4.28    | 1.00    | 0.8     | 14.8    | 411.9                    | 27.6                     | 6.1                      | 6.9                      | 111.6                    |
| 17            | 64.0    | 4.28    | 0.94    | 0.9     | 14.4    | 521.4                    | 27.2                     | 7.7                      | 5.9                      | 92.1                     |
| 16            | 68.4    | 3.57    | 1.01    | 0.9     | 13.0    | 437.3                    | 28.1                     | 6.4                      | 7.7                      | 97.9                     |
| 15            | 66.9    | 4.30    | 0.98    | 0.7     | 11.8    | 402.5                    | 22.0                     | 5.4                      | 5.6                      | 76.5                     |
| 14            | 66.5    | 3.63    | 0.90    | 0.5     | 11.9    | 462.1                    | 21.5                     | 5.7                      | 4.5                      | 70.8                     |
| 13            | 71.1    | 3.32    | 0.87    | 0.6     | 8.7     | 419.4                    | 16.9                     | 5.7                      | 4.6                      | 55.8                     |
| 12            | 70.4    | 2.12    | 0.82    | 0.6     | 8.7     | 324.8                    | 10.0                     | 4.9                      | 4.2                      | 50.8                     |
| 11            | 69.0    | 2.12    | 0.72    | 0.4     | 6.6     | 244.2                    | 5.4                      | 3.4                      | 2.9                      | 29.7                     |
| 10            | 68.3    | 1.50    | 0.52    | 0.5     | 1.2     | 182.8                    | 4.4                      | 1.9                      | 2.7                      | 3.4                      |
| 9             | 62.1    | 1.50    | 0.53    | 0.5     | 1.3     | 139.6                    | 2.7                      | 1.6                      | 1.9                      | 3.8                      |
| 8             | 54.7    | 1.04    | 0.43    | 0.4     | 4.3     | 53.9                     | 1.0                      | 1.1                      | 1.3                      | 10.7                     |
| 7             | 34.4    | 0.66    | 0.27    | 0.3     | 0.4     | 47.4                     | 1.0                      | 0.4                      | 0.7                      | 0.5                      |
| 6             | 30.8    | 0.64    | 0.25    | 0.4     | 0.5     | 47.4                     | 1.0                      | 0.4                      | 0.9                      | 0.5                      |
| 5             | 18.4    | 0.41    | 0.13    | 1.0     | 1.5     | 23.5                     | 0.5                      | 0.2                      | 1.1                      | 2.3                      |
| 4             | 12.9    | 0.36    | 0.09    | 1.0     | 1.7     | 15.3                     | 0.4                      | 0.1                      | 1.1                      | 2.1                      |
| 3             | 3.3     | 0.29    | 0.03    | 1.0     | 4.2     | 3.7                      | 0.3                      | 0.0                      | 1.1                      | 5.1                      |
| 2             | 4.6     | 0.39    | 0.04    | 1.0     | 3.1     | 5.1                      | 0.4                      | 0.0                      | 0.9                      | 3.6                      |
| 1             | 4.6     | 0.29    | 0.02    | 1.0     | 5.1     | 5.2                      | 0.3                      | 0.0                      | 0.6                      | 6.2                      |
| Ash           | 4.8     | 0.02    | 0.05    | 0.8     | 3.6     | 5.2                      | 0.0                      | 0.1                      | 0.8                      | 3.1                      |

Table A3. PSD, Ergun index, density and AFT data from the "Bernice" gasifier bed samples.

| Sample number | +25 mm (%) | -25+6.3 mm (%) | -6.3 mm (%) | Ergun Index | Bulk Density (ton/m <sup>3</sup> ) | *Particle Density (ton/m <sup>3</sup> ) | DT (°C Oxidizing) | FT (°C Oxidizing) | DT (°C Reducing) | FT (°C Reducing) |
|---------------|------------|----------------|-------------|-------------|------------------------------------|-----------------------------------------|-------------------|-------------------|------------------|------------------|
| Feed          | 61.2       | 35.2           | 3.5         | 12.7        | 0.74                               | 1.2                                     | 1185              | 1257              | 1200             | 1260             |
| 27            | 44.1       | 20.6           | 35.3        | 4.0         | 0.79                               | 1.3                                     | 1263              | 1313              | 1250             | 1350             |
| 26            | 37.0       | 30.8           | 32.1        | 3.8         | 0.70                               | 1.2                                     | 1249              | 1324              | 1190             | 1250             |
| 25            | 23.8       | 44.7           | 31.5        | 3.8         | 0.73                               | 1.2                                     | 1260              | 1296              | 1250             | 1290             |
| 24            | 10.8       | 48.8           | 40.5        | 3.0         | 0.71                               | 1.2                                     | 1254              | 1310              | 1190             | 1290             |
| 23            | 7.0        | 32.9           | 60.1        | 2.2         | 0.75                               | 1.3                                     | 1257              | 1299              | 1190             | 1220             |
| 22            | 7.3        | 35.1           | 57.6        | 1.9         | 0.78                               | 1.3                                     | 1257              | 1324              | 1170             | 1240             |
| 21            | 10.4       | 29.9           | 59.7        | 1.8         | 0.79                               | 1.3                                     | 1221              | 1291              | 1220             | 1250             |
| 20            | 4.3        | 21.7           | 73.9        | 1.5         | 0.81                               | 1.4                                     | 1232              | 1291              | 1240             | 1300             |
| 19            | 6.2        | 25.3           | 68.6        | 1.7         | 0.81                               | 1.4                                     | 1235              | 1293              | 1220             | 1260             |
| 18            | 6.7        | 20.8           | 72.5        | 1.5         | 0.80                               | 1.3                                     | 1257              | 1307              | 1210             | 1300             |
| 17            | 6.5        | 19.6           | 73.9        | 1.4         | 0.81                               | 1.4                                     | 1229              | 1318              | 1230             | 1280             |
| 16            | 5.4        | 20.8           | 73.8        | 1.6         | 0.80                               | 1.3                                     | 1207              | 1268              | 1250             | 1300             |
| 15            | 5.9        | 21.1           | 73.1        | 1.4         | 0.79                               | 1.3                                     | 1232              | 1271              | 1300             | 1330             |
| 14            | 2.2        | 18.0           | 79.8        | 1.3         | 0.80                               | 1.3                                     | 1221              | 1252              | 1250             | 1300             |
| 13            | 2.4        | 12.9           | 84.7        | 1.2         | 0.79                               | 1.3                                     | 1252              | 1291              | 1290             | 1320             |
| 12            | 1.6        | 12.5           | 85.9        | 1.2         | 0.78                               | 1.3                                     | 1241              | 1296              | 1260             | 1300             |
| 11            | 1.4        | 12.1           | 86.6        | 1.2         | 0.77                               | 1.3                                     | 1260              | 1291              | 1230             | 1320             |
| 10            | 1.9        | 13.3           | 84.8        | 1.3         | 0.78                               | 1.3                                     | 1229              | 1266              | 1280             | 1310             |
| 9             | 2.7        | 14.7           | 82.5        | 1.3         | 0.81                               | 1.4                                     | 1232              | 1271              | 1180             | 1260             |
| 8             | 2.6        | 16.8           | 80.6        | 1.3         | 0.85                               | 1.4                                     | 1224              | 1266              | 1190             | 1240             |
| 7             | 8.9        | 17.5           | 73.6        | 1.3         | 0.92                               | 1.5                                     | 1218              | 1274              | 1220             | 1270             |
| 6             | 7.0        | 21.2           | 71.8        | 1.5         | 1.07                               | 1.8                                     | 1221              | 1268              | 1190             | 1250             |
| 5             | 7.3        | 23.7           | 69.1        | 1.5         | 1.22                               | 2.0                                     | 1218              | 1263              | 1200             | 1250             |
| 4             | 8.8        | 24.9           | 66.3        | 1.7         | 1.43                               | 2.4                                     | 1221              | 1274              | 1190             | 1250             |
| 3             | 7.0        | 28.3           | 64.7        | 1.7         | 1.54                               | 2.6                                     | 1191              | 1252              | 1180             | 1230             |
| 2             | 9.1        | 29.4           | 61.6        | 1.9         | 1.53                               | 2.5                                     | 1188              | 1257              | 1180             | 1230             |
| 1             | 9.1        | 28.0           | 62.9        | 1.8         | 1.53                               | 2.5                                     | 1185              | 1257              | 1180             | 1230             |
| Ash           | 14.2       | 31.3           | 54.5        | 1.8         | 1.44                               | 2.4                                     | -                 | -                 | -                | -                |

\* = Bulk density x 0.6

Table A4. Carbon particle type and char morphology data from the "Bernice" gasifier bed samples.

| Sample number | Coal (vol%) | Total Carbon Particles (vol%) | Heated Minerals (vol%) | Porous Char (vol%) | Dense Char (vol%) | Devolatilized Coal (vol%) |
|---------------|-------------|-------------------------------|------------------------|--------------------|-------------------|---------------------------|
| 27            | 81.4        | 8.4                           | 10.0                   | 1.4                | 4.4               | 2.6                       |
| 25            | 85.2        | 11.0                          | 3.8                    | 2.2                | 2.0               | 6.8                       |
| 22            | 83.0        | 13.4                          | 3.6                    | 2.2                | 3.6               | 7.6                       |
| 20            | 70.4        | 21.2                          | 8.4                    | 2.2                | 6.4               | 12.6                      |
| 18            | 72.4        | 24.2                          | 3.4                    | 3.4                | 11.8              | 9.0                       |
| 16            | 60.2        | 36.0                          | 3.8                    | 7.8                | 10.4              | 17.8                      |
| 15            | 59.4        | 34.4                          | 5.6                    | 6.0                | 11.2              | 17.2                      |
| 14            | 44.6        | 48.2                          | 7.0                    | 8.4                | 19.4              | 20.4                      |
| 13            | 32.0        | 55.6                          | 10.8                   | 8.4                | 31.6              | 15.6                      |
| 12            | 26.8        | 66.0                          | 7.0                    | 12.0               | 31.8              | 22.2                      |
| 11            | 15.8        | 74.4                          | 8.2                    | 16.4               | 43.4              | 14.6                      |
| 10            | 13.6        | 76.8                          | 8.6                    | 15.2               | 46.8              | 14.8                      |
| 9             | 7.4         | 72.4                          | 19.2                   | 10.2               | 53.0              | 9.2                       |
| 8             | 8.6         | 70.4                          | 20.2                   | 14.4               | 44.8              | 11.2                      |
| 7             | 6.0         | 58.6                          | 35.0                   | 11.4               | 42.4              | 4.8                       |
| 6             | 4.6         | 52.8                          | 41.8                   | 12.8               | 37.0              | 3.0                       |
| 5             | 0.8         | 38.2                          | 60.6                   | 6.8                | 29.0              | 2.4                       |
| 3             | 0           | 10.6                          | 89.0                   | 2.2                | 8.2               | 0.2                       |
| 1             | 0           | 7.0                           | 93.0                   | 1.0                | 5.8               | 0.2                       |

Table A5. Temperature profile data in the "Bernice" gasifier

| Sample number | Average Temperature (°C) | Surface Temperature (°C) | Peak Temperature (°C) |
|---------------|--------------------------|--------------------------|-----------------------|
| Feed          | 232                      | 264                      | 265                   |
| 27            | 270                      | 283                      | 288                   |
| 26            | 318                      | 525                      | 814                   |
| 25            | 323                      | 650                      | 773                   |
| 24            | 317                      | 628                      | 745                   |
| 23            | 316                      | 502                      | 566                   |
| 22            | 315                      | 625                      | 750                   |
| 21            | 349                      | 687                      | 722                   |
| 20            | 337                      | 576                      | 691                   |
| 19            | 321                      | 601                      | 686                   |
| 18            | 397                      | 748                      | 781                   |
| 17            | 432                      | 751                      | 764                   |
| 16            | 407                      | 728                      | 743                   |
| 15            | 346                      | 742                      | 791                   |
| 14            | 398                      | 739                      | 747                   |
| 13            | 439                      | 740                      | 784                   |
| 12            | 417                      | 753                      | 780                   |
| 11            | 560                      | 781                      | 818                   |
| 9             | 620                      | 769                      | 779                   |
| 8             | 586                      | 789                      | 807                   |
| 7             | 601                      | 753                      | 775                   |
| 6             | 607                      | 786                      | 814                   |
| 5             | 610                      | 762                      | 787                   |
| 4             | 638                      | 819                      | 1073                  |
| 3             | 645                      | 785                      | 786                   |
| 2             | 677                      | 770                      | 791                   |
| 1             | 677                      | 847                      | 1045                  |
| Ash           | 327                      | 327                      | 327                   |

Table A5. XRD data (wt %) from the "Bernice" gasifier bed samples.

| Sample number | Bassanite ( $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ ) | Calcite ( $\text{CaCO}_3$ ) | Illite ( $\text{KA}(\text{Al}_2(\text{AlSi}_3\text{O}_{10}))$ ) | Quartz ( $\text{SiO}_2$ ) | Kaolinite ( $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$ ) | Bredigite ( $\text{Ca}_7\text{Mg}(\text{SiO}_4)_4$ ) | Gehlenite ( $\text{Ca}_2\text{Al}_2\text{SiO}_7$ ) | Glauberite ( $\text{Na}_2\text{Ca}(\text{SO}_4)_2$ ) | Melanterite ( $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ ) | Magnetite ( $\text{Fe}_3\text{O}_4$ ) | Gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) | Anhydrite ( $\text{CaSO}_4$ ) | % LTA |
|---------------|-------------------------------------------------------------------|-----------------------------|-----------------------------------------------------------------|---------------------------|---------------------------------------------------------------|------------------------------------------------------|----------------------------------------------------|------------------------------------------------------|-----------------------------------------------------------|---------------------------------------|------------------------------------------------------|-------------------------------|-------|
| B Feed        | 66.9                                                              | 1.1                         | 8.7                                                             | 8.2                       | 15.1                                                          | -                                                    | -                                                  | -                                                    | -                                                         | -                                     | -                                                    | -                             | 16.2  |
| B22           | 62.4                                                              | 11.9                        | -                                                               | 11.1                      | 4.5                                                           | 0.0                                                  | 0.0                                                | 0.5                                                  | 0.4                                                       | 0.9                                   | 8.3                                                  | -                             | 16.6  |
| B17           | 69.0                                                              | 2.9                         | -                                                               | 7.7                       | 8.6                                                           | 1.1                                                  | 0.2                                                | 4.5                                                  | 0.6                                                       | 0.7                                   | 4.7                                                  | -                             | 17.8  |
| B15           | 62.2                                                              | 23.0                        | -                                                               | 6.3                       | 2.6                                                           | 0.0                                                  | 0.0                                                | 2.5                                                  | 0.5                                                       | 0.6                                   | 2.3                                                  | -                             | 21.6  |
| B13           | 42.9                                                              | 39.8                        | -                                                               | 7.2                       | -                                                             | 2.7                                                  | 0.0                                                | 6.6                                                  | -                                                         | 0.8                                   | -                                                    | -                             | 26.0  |
| B11           | 34.8                                                              | 31.3                        | -                                                               | 8.4                       | 2.6                                                           | 0.2                                                  | 0.6                                                | 3.0                                                  | -                                                         | 1.0                                   | 18.1                                                 | -                             | 26.5  |
| B10           | 32.6                                                              | 36.1                        | -                                                               | 6.0                       | -                                                             | 12.1                                                 | 7.0                                                | 4.8                                                  | -                                                         | 1.3                                   | -                                                    | -                             | 35.3  |
| B9            | 13.5                                                              | 18.7                        | -                                                               | 25.1                      | -                                                             | 17.8                                                 | 14.1                                               | 8.0                                                  | -                                                         | 2.8                                   | -                                                    | -                             | 44.6  |
| B7            | -                                                                 | 21.2                        | -                                                               | 11.5                      | -                                                             | 45.2                                                 | 13.8                                               | -                                                    | -                                                         | 8.4                                   | -                                                    | -                             | -     |
| B6            | -                                                                 | 20.5                        | 12.1                                                            | 6.4                       | 1.7                                                           | 26.3                                                 | 13.5                                               | 1.2                                                  | 8.9                                                       | 8.1                                   | -                                                    | 1.5                           | -     |
| B5            | -                                                                 | 30.4                        | -                                                               | 6.8                       | -                                                             | 27.2                                                 | 25.6                                               | 2.6                                                  | 3.8                                                       | 2.9                                   | -                                                    | 0.6                           | -     |
| B4            | -                                                                 | 20.8                        | 7.0                                                             | 5.4                       | -                                                             | 38.4                                                 | 13.2                                               | 1.4                                                  | 4.9                                                       | 9.0                                   | -                                                    | -                             | -     |
| B2            | -                                                                 | 20.2                        | 6.5                                                             | 7.9                       | 0.3                                                           | 38.2                                                 | 11.9                                               | 1.6                                                  | 0.5                                                       | 8.0                                   | 5.0                                                  | -                             | -     |
| B1            | -                                                                 | 14.3                        | 4.5                                                             | 4.0                       | 0.7                                                           | 33.2                                                 | 13.4                                               | 0.7                                                  | 11.3                                                      | 9.8                                   | 8.1                                                  | -                             | -     |
| Ash           | -                                                                 | 10.3                        | 6.0                                                             | 5.4                       | 1.1                                                           | 35.5                                                 | 22.5                                               | 5.6                                                  | 2.1                                                       | 11.4                                  | -                                                    | -                             | -     |

Table A6. CCSEM and SEMPC data (wt %) from the "Bernice" gasifier bed samples.

| Sample number | Akermanite ( $\text{Ca}_2\text{Mg}(\text{Si}_2\text{O}_7)$ ) | Nepheline ( $\text{NaAlSiO}_4$ ) | Iron oxide ( $\text{Fe}_x\text{O}_x$ ) | Unclassified | Pyrite ( $\text{FeS}_2$ ) | Pyrrhotite ( $\text{FeS}$ ) |
|---------------|--------------------------------------------------------------|----------------------------------|----------------------------------------|--------------|---------------------------|-----------------------------|
| B Feed        | -                                                            | -                                | 0.2                                    | 24.9         | 33.6                      | 2.7                         |
| B22           | -                                                            | -                                | 0.5                                    | 27.1         | 14.5                      | 3.8                         |
| B17           | -                                                            | -                                | 0.1                                    | 27.8         | 29.6                      | 2.6                         |
| B15           | -                                                            | -                                | 0.8                                    | 25.6         | 5.7                       | 2.6                         |
| B13           | -                                                            | -                                | 0.4                                    | 22.8         | 20.4                      | 8.6                         |
| B11           | -                                                            | -                                | 1.2                                    | 32.3         | 3.8                       | 4.2                         |
| B10           | -                                                            | -                                | 1.4                                    | 43.4         | 2.2                       | 3.8                         |
| B9            | -                                                            | -                                | 0.5                                    | 35.2         | 1.4                       | 2.5                         |
| B7            | 1.7                                                          | -                                | 1.0                                    | 68.5         | -                         | 0.3                         |
| B6            | 2.0                                                          | 0.7                              | 3.3                                    | 72.2         | -                         | -                           |
| B5            | 2.8                                                          | 0.3                              | 2.1                                    | 79.2         | -                         | -                           |
| B4            | 2.7                                                          | 0.7                              | 6.8                                    | 69.2         | -                         | 0.3                         |
| B2            | 0.8                                                          | 0.8                              | 1.1                                    | 66.7         | -                         | -                           |
| B1            | 3.0                                                          | -                                | 1.7                                    | 73.9         | -                         | 0.3                         |
| Ash           | 1.7                                                          | 2.4                              | 2.4                                    | 65.2         | -                         | -                           |

Table A7. Morphological analysis (wt %) of the "Bernice" gasifier bed samples – elements determined in the organic matrix

| Sample number | Na   | Mg   | Al   | Si   | S    | Ca   | Fe  |
|---------------|------|------|------|------|------|------|-----|
| B Feed        | 11.5 | 5.9  | 3.0  | 15.2 | 29.8 | 34.6 |     |
| B22           | 4.9  | 4.6  | 1.0  | 40.0 | 17.9 | 23.3 | 7.2 |
| B17           | 2.3  | 8.6  | 10.5 | 12.9 | 9.1  | 52.0 | 0.9 |
| B15           | 6.0  | 8.3  | 8.4  | 13.7 | 3.7  | 42.3 | 1.1 |
| B13           | -    | 9.1  | 7.6  | 33.6 | -    | 43.5 | 5.7 |
| B11           | 2.5  | 5.4  | 4.6  | 28.1 | 1.5  | 50.2 | 3.3 |
| B10           | 6.0  | 14.6 | 6.7  | 10.1 | -    | 49.9 | 7.4 |
| B9            | 8.7  | 11.2 | 7.4  | 7.7  | -    | 61.8 | 2.4 |
| B7            | 7.2  | 8.8  | 8.6  | 3.8  | 13.0 | 53.4 | 2.9 |
| B6            | 0.0  | 13.5 | 5.0  | 12.8 | -    | 60.3 | 6.4 |
| B5            | 7.4  | 4.0  | 20.5 | 28.5 | 1.3  | 35.8 | 2.5 |
| B4            | 11.3 | 7.2  | 5.1  | 15.4 | 1.2  | 51.3 | 4.6 |
| B2            | 21.9 | 6.2  | 5.4  | 19.3 | 3.5  | 40.6 | 1.8 |
| B1            | 25.3 | 5.0  | 8.6  | 25.9 | -    | 30.8 | 1.4 |
| Ash           | 6.1  | 4.3  | 4.1  | 47.2 | -    | 33.2 | 2.3 |

Table A8. Morphological analysis (wt %) of the "Bernice" gasifier bed samples – elements determined in the included minerals.

| Sample number | Na   | Mg  | Al   | Si    | S    | Ca   | Fe   |
|---------------|------|-----|------|-------|------|------|------|
| B Feed        | 0.6  |     | 8.0  | 34.6  | 0.2  | 22.5 | 0.4  |
| B22           | 0.0  | 0.0 | 11.2 | 36.9  | 20.1 | 2.6  | 14.5 |
| B17           | 2.7  | 3.6 | 11.7 | 32.1  | 8.1  | 4.5  | 5.7  |
| B15           | 1.4  | 0.6 | 8.6  | 37.3  | -    | 14.8 | 3.4  |
| B13           | 0.9  | 0.0 | 6.8  | 11.5  | 12.0 | 0.4  | 43.2 |
| B11           | 1.2  | 0.0 | 29.3 | 42.1  | -    | -    |      |
| B10           | 0.0  | 0.5 | 15.0 | 17.5  | 17.6 | 0.2  | 22.4 |
| B9            | -    | -   | -    | 100.0 | -    | -    | -    |
| B7            | 5.5  | 0.0 | 30.9 | 31.1  | -    | -    | 1.0  |
| B5            | 3.2  | 0.0 | 29.0 | 29.0  | -    | 1.8  | 8.0  |
| B4            | 6.0  | 0.4 | 8.3  | 47.2  | -    | 0.1  | 0.8  |
| B1            | 40.4 | 0.0 | 1.7  | 2.0   | 11.6 | 3.5  | -    |

Table A9. Morphological analysis (wt %) of the "Bernice" gasifier bed samples – elements determined in the ash/ excluded minerals.

| Sample number | Na  | Mg  | Al   | Si   | S   | Ca   | Fe   |
|---------------|-----|-----|------|------|-----|------|------|
| B Feed        | 0.0 | 0.0 | 3.9  | 67.3 | 0.0 | 0.8  | 2.0  |
| B17           | -   | -   | 22.2 | 30.6 | -   | 1.2  | -    |
| B13           | 2.2 | 3.6 | 3.4  | 17.6 | 5.1 | 21.7 | 8.0  |
| B11           | 1.9 | 4.4 | 7.9  | 16.7 | -   | 26.3 | 6.1  |
| B10           | 2.3 | 4.4 | 6.3  | 17.7 | -   | 39.0 | 4.0  |
| B9            | 3.6 | 1.9 | 11.4 | 22.6 | -   | 23.7 | 6.1  |
| B7            | 2.0 | 3.4 | 5.8  | 10.7 | 0.3 | 30.3 | 18.7 |
| B6            | 4.1 | 2.9 | 8.9  | 18.3 | -   | 30.7 | 10.3 |
| B5            | 5.3 | 1.5 | 8.4  | 13.6 | 1.9 | 40.6 | 12.6 |
| B4            | 4.1 | 1.3 | 7.5  | 17.8 | 0.4 | 17.8 | 15.1 |
| B2            | 3.4 | 1.9 | 11.7 | 19.5 | 0.2 | 31.2 | 3.2  |
| B1            | 2.6 | 1.2 | 5.3  | 23.9 | 0.5 | 14.5 | 4.3  |
| Ash           | 3.1 | 0.6 | 9.7  | 25.6 | 0.4 | 16.3 | 13.7 |

# 1b. Data Used for the Evaluation of the "Albert" Gasifier Fuel Bed

Table B1. Proximate analyses, Fischer tar and CO<sub>2</sub> char reactivity data from the "Albert" gasifier bed samples.

| Sample number | % Ash (db) | % Fixed carbon (db) | % Volatile matter (db) | % Fixed Carbon Conversion | Volatile matter (kg/100kg ash flow) | Fixed carbon (kg/100kg ash flow) | % Fischer Tar (ad) | Fischer Tar (kg/100kg ash flow) | CO <sub>2</sub> Char reactivity (h <sup>-1</sup> ) |
|---------------|------------|---------------------|------------------------|---------------------------|-------------------------------------|----------------------------------|--------------------|---------------------------------|----------------------------------------------------|
| Feed          | 10.4       | 41.8                | 47.9                   | -                         | 461.4                               | 402.8                            | 6.3                | 61.2                            | 38.4                                               |
| 27            | 10.8       | 53.1                | 36.1                   | -                         | 335.4                               | 492.5                            | 4.6                | 43.1                            | 33.1                                               |
| 26            | 9.7        | 51.9                | 38.3                   | -                         | 395.1                               | 535.5                            | 5.5                | 56.8                            | 32.2                                               |
| 25            | 9.4        | 52.2                | 38.4                   | -                         | 407.7                               | 554.4                            | 5.6                | 59.4                            | 29.6                                               |
| 24            | 9.9        | 52.3                | 37.8                   | -                         | 383.1                               | 529.2                            | 4.7                | 48.0                            | 34.8                                               |
| 23            | 9.9        | 52.9                | 37.2                   | -                         | 377.2                               | 537.0                            | 4.5                | 45.3                            | 31.8                                               |
| 22            | 9.8        | 51.5                | 38.8                   | -                         | 397.2                               | 527.0                            | 5.7                | 58.0                            | 36.4                                               |
| 21            | 13.4       | 48.7                | 37.9                   | -                         | 283.4                               | 363.6                            | 5.7                | 42.7                            | 31.6                                               |
| 20            | 10.4       | 50.1                | 39.5                   | -                         | 380.3                               | 482.2                            | 5.8                | 55.6                            | 33.1                                               |
| 19            | 10.7       | 51.9                | 37.3                   | -                         | 347.1                               | 483.2                            | 5.8                | 53.6                            | 32.7                                               |
| 18            | 12.5       | 52.4                | 35.1                   | -                         | 280.3                               | 419.1                            | 6.5                | 52.0                            | 34.4                                               |
| 17            | 13.2       | 54.2                | 32.6                   | -                         | 246.6                               | 410.8                            | 4.4                | 33.1                            | 32.6                                               |
| 16            | 11.8       | 55.8                | 32.3                   | -                         | 272.8                               | 470.9                            | 3.6                | 30.2                            | 36.1                                               |
| 15            | 17.2       | 57.9                | 24.9                   | -                         | 145.1                               | 337.0                            | 3.2                | 18.7                            | 35.1                                               |
| 14            | 19.6       | 59.1                | 21.3                   | 0.0                       | 108.6                               | 302.1                            | 2.2                | 11.0                            | 30.8                                               |
| 13            | 28.5       | 55.0                | 16.5                   | 7.0                       | 58.1                                | 193.2                            | 0.5                | 1.7                             | 33.3                                               |
| 12            | 34.0       | 52.9                | 13.1                   | 10.5                      | 38.4                                | 155.7                            | 0.3                | 0.8                             | 34.5                                               |
| 11            | 35.4       | 53.6                | 11.0                   | 9.4                       | 31.0                                | 151.4                            | 0.5                | 1.3                             | -                                                  |
| 10            | 58.5       | 30.8                | 10.6                   | 47.9                      | 18.1                                | 52.6                             | 0.4                | 0.8                             | 36.7                                               |
| 9             | 60.2       | 29.6                | 10.2                   | 50.0                      | 17.0                                | 49.1                             | 0                  | 0.0                             | 35.4                                               |
| 8             | 62.2       | 26.3                | 11.6                   | 55.6                      | 18.6                                | 42.3                             | 0                  | 0.0                             | 40.2                                               |
| 7             | 72.0       | 16.6                | 11.5                   | 72.0                      | 15.9                                | 23.1                             | 0                  | 0.0                             | -                                                  |
| 6             | 72.9       | 16.4                | 10.7                   | 72.2                      | 14.7                                | 22.5                             | 0                  | 0.0                             | -                                                  |
| 5             | 88.1       | 2.7                 | 9.2                    | 95.4                      | 10.4                                | 3.1                              | 0                  | 0.0                             | -                                                  |
| 4             | 81.1       | 6.9                 | 12.0                   | 88.3                      | 14.8                                | 8.5                              | 0                  | 0.0                             | -                                                  |
| 3             | 81.3       | 7.8                 | 10.9                   | 86.8                      | 13.4                                | 9.6                              | 0                  | 0.0                             | -                                                  |
| 2             | 85.2       | 2.3                 | 12.5                   | 96.1                      | 14.7                                | 2.7                              | 0                  | 0.0                             | -                                                  |
| 1             | 88.1       | 0.1                 | 11.9                   | 99.9                      | 13.5                                | 0.1                              | 0                  | 0.0                             | -                                                  |
| Ash           | 90.2       | 0.5                 | 9.4                    | 99.2                      | 10.4                                | 0.5                              | 0                  | 0.0                             | -                                                  |

Table B2. Ultimate analyses data (dry basis) from the "Albert" gasifier bed samples.

| Sample number | %C (db) | %H (db) | %N (db) | %S (db) | %O (db) | C (kg/100kg ash flow) | H (kg/100kg ash flow) | N (kg/100kg ash flow) | S (kg/100kg ash flow) | O (kg/100kg ash flow) |
|---------------|---------|---------|---------|---------|---------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Feed          | 65.8    | 3.49    | 1.07    | 0.89    | 15.8    | 632.7                 | 33.6                  | 10.3                  | 8.6                   | 154.8                 |
| 27            | 69.8    | 3.76    | 0.98    | 1.51    | 11.8    | 647.9                 | 34.9                  | 9.1                   | 14.0                  | 122.2                 |
| 26            | 67.4    | 4.25    | 1.00    | 1.08    | 16.6    | 694.9                 | 43.8                  | 10.3                  | 11.1                  | 170.8                 |
| 25            | 67.7    | 4.53    | 1.05    | 1.06    | 16.2    | 719.3                 | 48.1                  | 11.2                  | 11.2                  | 172.5                 |
| 24            | 67.2    | 4.42    | 1.10    | 1.05    | 16.3    | 680.9                 | 44.8                  | 11.2                  | 10.6                  | 165.1                 |
| 23            | 67.3    | 4.19    | 1.11    | 1.10    | 16.4    | 682.7                 | 42.5                  | 11.3                  | 11.1                  | 166.8                 |
| 22            | 67.2    | 4.13    | 1.13    | 1.02    | 16.7    | 688.6                 | 42.3                  | 11.6                  | 10.4                  | 171.3                 |
| 21            | 65.6    | 4.04    | 1.11    | 1.21    | 14.6    | 490.4                 | 30.2                  | 8.3                   | 9.0                   | 109.2                 |
| 20            | 66.8    | 3.96    | 1.12    | 1.07    | 16.7    | 642.6                 | 38.1                  | 10.8                  | 10.3                  | 160.8                 |
| 19            | 66.7    | 3.87    | 1.07    | 1.05    | 16.5    | 620.7                 | 36.0                  | 10.0                  | 9.8                   | 154.0                 |
| 18            | 66.7    | 3.82    | 1.08    | 1.22    | 14.6    | 533.5                 | 30.6                  | 8.6                   | 9.7                   | 117.0                 |
| 17            | 67.1    | 3.55    | 1.53    | 1.00    | 13.6    | 508.6                 | 26.9                  | 11.6                  | 7.5                   | 102.9                 |
| 16            | 68.8    | 3.42    | 1.02    | 0.89    | 14.0    | 580.7                 | 28.9                  | 8.6                   | 7.5                   | 118.3                 |
| 15            | 68.9    | 2.92    | 0.96    | 0.86    | 9.1     | 401.4                 | 17.0                  | 5.6                   | 5.0                   | 53.2                  |
| 14            | 66.9    | 2.46    | 0.86    | 0.96    | 9.3     | 341.5                 | 12.5                  | 4.4                   | 4.9                   | 47.4                  |
| 13            | 62.6    | 1.78    | 0.68    | 0.66    | 5.8     | 219.9                 | 6.2                   | 2.4                   | 2.3                   | 20.5                  |
| 12            | 57.9    | 1.31    | 0.56    | 0.52    | 5.7     | 170.4                 | 3.9                   | 1.7                   | 1.5                   | 16.7                  |
| 11            | 57.0    | 1.09    | 0.43    | 0.57    | 5.6     | 160.9                 | 3.1                   | 1.2                   | 1.6                   | 15.7                  |
| 10            | 36.6    | 0.76    | 0.29    | 0.58    | 3.2     | 62.6                  | 1.3                   | 0.5                   | 1.0                   | 5.5                   |
| 9             | 35.3    | 0.69    | 0.26    | 0.62    | 2.9     | 58.6                  | 1.1                   | 0.4                   | 1.0                   | 4.8                   |
| 8             | 33.3    | 0.70    | 0.25    | 0.72    | 2.9     | 53.6                  | 1.1                   | 0.4                   | 1.2                   | 4.7                   |
| 7             | 24.2    | 0.46    | 0.18    | 0.71    | 2.5     | 33.6                  | 0.6                   | 0.2                   | 1.0                   | 3.5                   |
| 6             | 23.7    | 0.57    | 0.21    | 0.75    | 1.9     | 32.5                  | 0.8                   | 0.3                   | 1.0                   | 2.7                   |
| 5             | 9.5     | 0.39    | 0.13    | 0.79    | 1.1     | 10.7                  | 0.4                   | 0.1                   | 0.9                   | 1.3                   |
| 4             | 15.9    | 0.41    | 0.15    | 0.71    | 1.7     | 19.7                  | 0.5                   | 0.2                   | 0.9                   | 2.1                   |
| 3             | 15.2    | 0.39    | 0.13    | 0.66    | 2.3     | 18.7                  | 0.5                   | 0.2                   | 0.8                   | 2.8                   |
| 2             | 12.1    | 0.36    | 0.12    | 0.84    | 1.4     | 14.2                  | 0.4                   | 0.1                   | 1.0                   | 1.6                   |
| 1             | 8.7     | 0.29    | 0.09    | 0.76    | 2.1     | 9.9                   | 0.3                   | 0.1                   | 0.9                   | 2.4                   |
| Ash           | 6.5     | 0.09    | 0.09    | 0.63    | 2.6     | 7.2                   | 0.1                   | 0.1                   | 0.7                   | 2.9                   |

Table B3. PSD, Ergun index, density and AFT data from the "Albert" gasifier bed samples.

| Sample number | +25 mm (%) | -25+6.3 mm (%) | -6.3 mm (%) | Ergun Index | Bulk Density (ton/m <sup>3</sup> ) | *Particle Density (ton/m <sup>3</sup> ) | DT (°C Oxidizing) | FT (°C Oxidizing) | DT (°C Reducing) | FT (°C Reducing) |
|---------------|------------|----------------|-------------|-------------|------------------------------------|-----------------------------------------|-------------------|-------------------|------------------|------------------|
| Feed          | 61.8       | 33.0           | 5.2         | 12.9        | 0.7                                | 1.2                                     | 1310              | 1338              | 1230             | 1300             |
| 27            | 9.6        | 33.1           | 57.2        | 2.0         | 0.7                                | 1.2                                     | 1279              | 1343              | 1210             | 1290             |
| 26            | 3.4        | 41.0           | 55.6        | 2.2         | 0.7                                | 1.2                                     | 1307              | 1349              | 1140             | 1200             |
| 25            | 1.7        | 45.2           | 53.1        | 2.3         | 0.8                                | 1.3                                     | 1266              | 1299              | 1150             | 1260             |
| 24            | 0.6        | 29.9           | 69.5        | 1.8         | 0.8                                | 1.3                                     | 1254              | 1321              | 1160             | 1250             |
| 23            | 1.5        | 16.2           | 82.3        | 1.5         | 0.8                                | 1.3                                     | 1266              | 1291              | 1170             | 1230             |
| 22            | 2.5        | 21.1           | 76.4        | 1.5         | 0.8                                | 1.3                                     | 1257              | 1288              | 1160             | 1230             |
| 21            | 1.3        | 20.3           | 78.4        | 1.4         | 0.8                                | 1.3                                     | 1227              | 1254              | 1150             | 1240             |
| 20            | 2.5        | 15.7           | 81.8        | 1.3         | 0.8                                | 1.4                                     | 1235              | 1288              | 1180             | 1240             |
| 19            | 4.1        | 16.2           | 79.7        | 1.4         | 0.8                                | 1.3                                     | 1254              | 1279              | 1150             | 1230             |
| 18            | 2.1        | 14.3           | 83.6        | 1.3         | 0.8                                | 1.3                                     | 1235              | 1266              | 1160             | 1260             |
| 17            | 1.9        | 12.2           | 85.9        | 1.3         | 0.8                                | 1.3                                     | 1238              | 1304              | 1170             | 1250             |
| 16            | 3.1        | 11.7           | 85.2        | 1.3         | 0.8                                | 1.3                                     | 1254              | 1327              | 1160             | 1235             |
| 15            | 2.0        | 11.0           | 87.1        | 1.2         | 0.7                                | 1.1                                     | 1235              | 1271              | 1150             | 1220             |
| 14            | 4.9        | 11.8           | 83.3        | 1.3         | 0.8                                | 1.3                                     | 1210              | 1249              | 1160             | 1200             |
| 13            | 5.0        | 12.5           | 82.5        | 1.3         | 0.7                                | 1.2                                     | 1188              | 1224              | 1150             | 1190             |
| 12            | 12.7       | 12.2           | 75.1        | 1.5         | 0.9                                | 1.4                                     | 1199              | 1266              | 1155             | 1225             |
| 11            | 16.2       | 15.1           | 68.7        | 1.6         | 0.8                                | 1.3                                     | 1157              | 1241              | 1140             | 1200             |
| 10            | 18.7       | 19.3           | 62.0        | 1.6         | 1.0                                | 1.6                                     | 1152              | 1277              | 1160             | 1215             |
| 9             | 12.6       | 21.0           | 66.4        | 1.6         | 1.0                                | 1.6                                     | 1157              | 1232              | 1150             | 1220             |
| 8             | 7.3        | 23.0           | 69.7        | 1.5         | 0.9                                | 1.6                                     | 1166              | 1252              | 1200             | 1265             |
| 7             | 12.2       | 23.5           | 64.3        | 1.6         | 1.2                                | 2.0                                     | 1143              | 1227              | 1190             | 1255             |
| 6             | 7.0        | 22.9           | 70.2        | 1.8         | 1.2                                | 2.0                                     | 1160              | 1238              | 1180             | 1255             |
| 5             | 8.9        | 26.1           | 64.9        | 1.8         | 1.4                                | 2.4                                     | 1182              | 1218              | 1180             | 1250             |
| 4             | 11.4       | 21.4           | 67.2        | 1.6         | 1.2                                | 1.9                                     | 1129              | 1216              | 1190             | 1250             |
| 3             | 7.7        | 26.5           | 65.8        | 1.8         | 1.2                                | 2.0                                     | 1127              | 1221              | 1200             | 1270             |
| 2             | 6.9        | 23.4           | 69.7        | 1.6         | 1.3                                | 2.2                                     | 1129              | 1216              | 1190             | 1280             |
| 1             | 9.5        | 28.6           | 61.9        | 1.9         | 0.8                                | 1.4                                     | 1127              | 1249              | 1180             | 1240             |
| Ash           | 9.0        | 28.5           | 62.5        | 1.9         | 1.4                                | 2.3                                     | -                 | -                 | -                | -                |

\* = Bulk density x 0.6

Table B4. Carbon particle type and char morphology data from the "Albert" gasifier bed samples.

| Sample number | Coal (vol%) | Total Carbon Particles (vol%) | Heated Minerals (vol%) | Porous Char (vol%) | Dense Char (vol%) | Devolatilized Coal (vol%) |
|---------------|-------------|-------------------------------|------------------------|--------------------|-------------------|---------------------------|
| 27            | 57.6        | 38.0                          | 4.0                    | 2.2                | 17.6              | 20.4                      |
| 25            | 66.2        | 33.2                          | 0.6                    | 2.2                | 11.0              | 22.2                      |
| 23            | 43.2        | 55.2                          | 1.2                    | 2.8                | 14.8              | 40.4                      |
| 22            | 57.8        | 42.0                          | 0.0                    | 1.6                | 9.6               | 32.4                      |
| 21            | 48.4        | 50.0                          | 0.0                    | 2.6                | 11.0              | 39.0                      |
| 19            | 44.2        | 53.6                          | 1.8                    | 4.0                | 15.4              | 38.2                      |
| 17            | 45.0        | 51.6                          | 2.8                    | 5.6                | 23.4              | 27.6                      |
| 15            | 28.6        | 65.2                          | 5.6                    | 6.6                | 33.4              | 31.8                      |
| 14            | 14.8        | 75.4                          | 7.8                    | 10.8               | 43.0              | 32.4                      |
| 13            | 10.8        | 77.2                          | 11.0                   | 18.2               | 57.4              | 19.8                      |
| 12            | 5.2         | 79.8                          | 12.4                   | 19.0               | 63.4              | 16.4                      |
| 11            | 4.8         | 67.4                          | 27.0                   | 18.0               | 58.0              | 9.4                       |
| 10            | 1.0         | 69.6                          | 28.4                   | 18.0               | 63.2              | 6.4                       |
| 9             | 1.0         | 63.0                          | 35.2                   | 22.4               | 53.8              | 8.8                       |
| 8             | 1.6         | 63.0                          | 34.4                   | 12.4               | 53.8              | 9.0                       |
| 7             | 0.2         | 43.2                          | 56.0                   | 8.0                | 40.2              | 3.0                       |
| 6             | 0.0         | 54.2                          | 44.2                   | 7.6                | 51.6              | 2.2                       |
| 5             | 0.0         | 22.4                          | 76.8                   | 5.6                | 21.8              | 0.6                       |
| 3             | 0.0         | 26.2                          | 73.2                   | 4.6                | 24.8              | 1.4                       |
| 1             | 0.0         | 17.8                          | 82.2                   | 3.6                | 17.4              | 0.4                       |