ASX ANNOUNCEMENT 6 March, 2018

UNIQUE, HIGH-QUALITY CRYSTALLINITY OF MCINTOSH GRAPHITE CONFIRMED BY A US DEPARTMENT OF ENERGY NATIONAL LABORATORY

Overview

Hexagon Resources Limited (ASX:**HXG**), (Hexagon or the Company) is very pleased to report on recent test work results which highlight the unique properties of the crystalline lattice of graphite coming from its McIntosh project in Western Australia.

Independent testing conducted by Argonne National Laboratory (**ANL**) which is operated by the US Department of Energy has confirmed unique, near all-hexagonal preferred crystal orientation of purified McIntosh natural crystalline flake graphite material. Demonstrating superior crystallinity aspects of the McIntosh material is vital in terms of successfully competing with premium quality synthetic graphite products.

ANL has described the McIntosh material as "HOPG-like", which is extremely rare in the world of natural graphite and is very promising for the utilisation of McIntosh material in a number of value added applications from advanced battery systems to friction, nuclear, thermal management and electrical applications, to name a few. HOPG is an acronym for "highly oriented pyrolytic" graphite and is characterised by the highest degree of three dimensional atomic ordering. This is a very high value synthetic graphite product selling for approximately US$30,000/tonne with 30,000 to 40,000 tonnes traded per year.

In order to carry out the testing, ANL, based in Illinois, USA, utilised a dedicated synchrotron facility, Advanced Photon Source (**APS**).

Commenting on the results, Managing Director, Mike Rosenstreich said: "This test work is a continuation of Hexagon's strategy to find high value applications for the very rare qualities that the McIntosh graphite is being shown to possess. Each tier of test work gives us a better understanding of the applications our material is suitable for and thus the markets that we can address, which other natural graphite often does not qualify for and where we can out-compete synthetic on a cost basis."

"We now have proof that our flake is differentiated from other natural graphite projects. This puts us on a straight path towards accelerating our dual strategy of riding the energy/tech wave but also displacing synthetic graphite – because our material is good enough to do that."

"These exciting results from such a highly reputable lab is another building block on the way to early establishment of a pilot processing and technology demonstration facility which is something we are planning to do, tentatively in Australia."

Introduction

Hexagon is forging ahead on its dual marketing strategy of participating in new demand for battery and technological applications as well as positioning to displace synthetic graphite in a number of premium value markets. These latest results for crystallinity further support the technical credentials of the McIntosh graphite material to achieve those objectives.

In 2017 the energy materials market for graphite in all battery systems (i.e. lithium-ion, lithium primary, alkaline, NiMH, zinc-air etc.) was estimated at between 150,000 and 200,000 tonnes, of which approximately 60% comprised natural graphite. The Company is aware that premium quality synthetic graphite is retaining its stronghold positions in both traditional and new high-growth energy related sectors and continues to command pricing generally in excess of US$20,000 / tonne.

Hexagon, working closely with its US based partner, NAmLab[1] is undertaking the work intended to phase-out synthetic graphite from certain market niches and moving the advanced McIntosh brand product formulations into those sectors which were previously unattainable by natural crystalline flake graphite products because they could not meet those specifications.

Background

The paramount question when comparing natural flake graphite and premium quality synthetic graphite is the crystallinity of the materials. It is well known that poor crystallinity is a fundamental weakness of all synthetic graphite. Existing technologies for adjusting the crystallinity by applying extreme heat to precursors of synthetic graphite are costly and inefficient.

The majority of the world's major synthetic graphite manufacturers operate outdated Acheson Furnaces which have seen little design change since they were invented in the late 1800s and are based on resistive heating of petroleum coke. By way of example a major European manufacturer operates Acheson furnaces on a batch basis processing 20 tonnes of coke over a period of 20 days at temperatures of up to 3,000 degrees Celsius. The lengthy exposure to ultra high temperatures is aimed to:

a. remove impurities from the petroleum coke; and
b. to convert the coke into graphitised carbon i.e. leading to the alignment of the individual graphene layers to form a crystalline lattice of graphite.

As a result of this heat-intensive graphitisation process, parameters of the crystalline lattice become somewhat aligned to resemble that of graphite, but those manufacturers have to deal with non-uniform heat treatment using this technology. At the end of the graphitisation process the resultant synthetic graphite crystalline lattice structure comes close to that of natural graphite but the lattice comprises blocks made out of stacks of aligned graphene basal planes. There is hardly any product on the industrial synthetic graphite market which has very large La and Lc parameters, referring to the length and thickness of graphite crystal, respectively. These parameters are shown in Figure 1, below.

It is important to understand that interruptions of a basal plane due to insufficient stack alignment result in increased electrical resistance in the graphite macromolecule, which in turn, leads to substandard electrochemical performance. Moreover, graphitic materials with a crystallite size of less than 400 nm (La and Lc) are believed to be unsuitable for intercalation by lithium ions, rendering such graphite unfit for the purpose of active materials in the anode of lithium-ion batteries.

Most natural crystalline flake graphite, which originates as mined minerals, do not require "graphitisation" as that has already occurred over the course of millions of years under the influence of temperature and pressure in the Earth's crust. Therefore, manufacturers of natural flake graphite do not need to invest in graphitisation to form the crystallite of graphite macromolecules. Consequently, natural crystalline graphite flakes will always offer a lower cost alternative to the premium quality synthetics.

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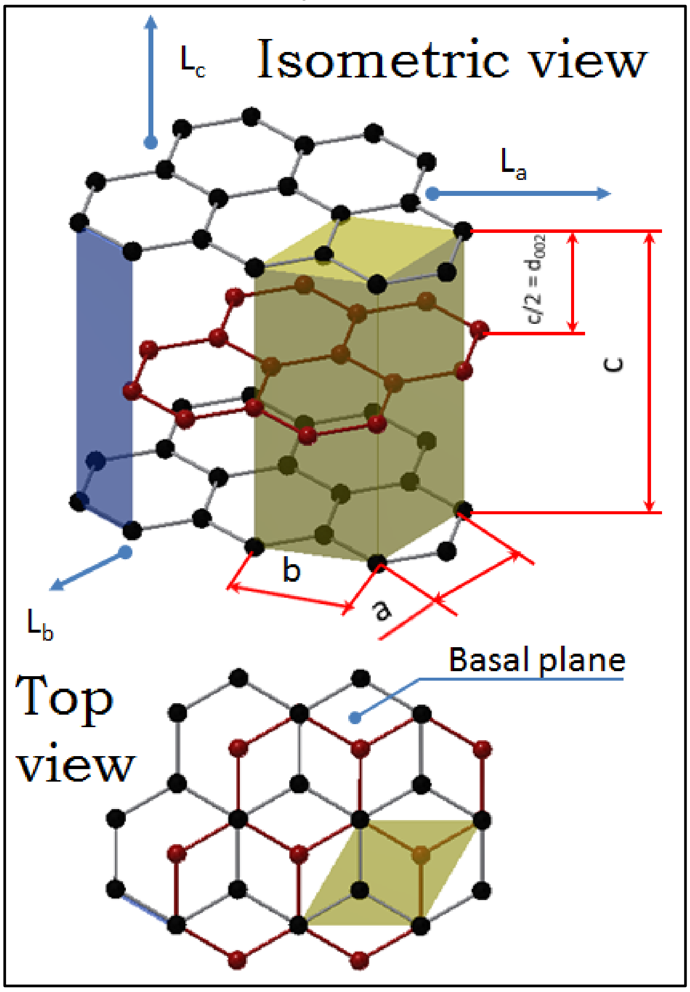
[1] *NAmLab refers to Hexagon's US based technical partner undertaking much of the test work in relation to end-user applications. Given that NAmLab and Hexagon are developing proprietary process methods NAmLab prefers to remain anonymous.*

However, very importantly, not all natural graphite deposits are similar. X-ray diffraction (**XRD**) techniques to examine at an atomic scale the crystal lattice of graphite become a critical tool in identifying flakes, which are more promising than others for value-added applications as reported below with respect to Hexagon's McIntosh flake graphite.

Figure 1: Schematic Representation of Graphite Crystal lattice, comprising various aligned graphene layers in a true hexagonal arrangement and illustrating the key measurement criteria which are referred to as part of Table 1, below.



Results

Hexagon is very pleased to report on recent test work results highlighting the unique properties of the crystalline lattice of its refined graphite which has originated from its McIntosh project in Western Australia. The crystal structure data generated provides Hexagon with rare hard data which is requested by all leading lithium-ion, lead acid and alkaline battery manufacturers. Hexagon is able to clearly demonstrate that its graphite is natural crystalline flake and not synthetic graphitised material and offers higher electrical conductivity, greater reversible capacity towards lithium ion intercalation, and better lubricity in terms of movement (sliding) of its graphene layers.

During recent lithium-ion cell cycling test work utilising Hexagon's processed McIntosh flake graphite, being undertaken by NAmLab, several unique features were observed such as; near theoretical reversible capacity and the ability of flake material to retain very high stability upon long-term cycling. These unexpected but highly favourable attributes were investigated further with rare access to ANL's dedicated synchrotron facility APS to undertake atomic scale examination of the purified McIntosh flake's crystalline lattice. This independent testing has confirmed unique, near all-hexagonal preferred crystal orientation of purified McIntosh material. Argonne has described the McIntosh material as "HOPG-like[2]", which is extremely rare in a natural flake graphite marketspace and is very promising for the utilisation of McIntosh material in a number of value added applications from advanced battery systems to friction, nuclear, thermal management and electrical applications, to name a few.

The Argonne facility is located in Illinois, USA and operated by the US Department of Energy. The APS is considered to be the ultimate source of the most accurate XRD data to examine materials at an atomic scale. The results obtained in an APS beam by far supersede those available from any XRD analysis performed on bench-scale instruments in university laboratory settings. There are less than 30 similar APS facilities worldwide and availability is highly selective and with long waiting times; however, Hexagon was able to secure "beam time" based on the unique features of the McIntosh flake material.

Technical Discussion

In terms of direct relevance to Hexagon's marketing strategy, much of the utilisation of graphite in new battery or electronic applications or in more traditional uses such as electrodes in the electric arc furnaces for steel making is dependent on its electrical properties; such as its high conductivity and stability at high temperatures.

To assess these electrical aspects, it is important to understand the detailed atomic structure of the materials planned to be utilised. In simplified terms, large crystallite size, defined by La and Lc parameters of the crystalline lattice within mostly-hexagonal lattice orientation, such as the flake coming from McIntosh, would be preferred for unrestricted movement of electrons, yielding preferentially greater electrical conductivity. Materials with a high degree of rhombohedral phase and increased turbostratic disorder, such as the majority of other natural crystalline flake graphite on the market, would be less preferred for electrical applications since their crystalline lattice is full of "interruptions" of the "electron paths", therefore leading to higher resistance in electrode matrixes. In the case of synthetic graphite, the large turbostratic disorder becomes an important performance-limiting factor; the macromolecules of these graphitic materials also generally exhibit short crystallite size, which limits their use in the premium performance electronic markets. Indeed, very fundamental atomic scale attributes can be linked to graphite's performance in certain value added applications, and therefore they are often included as part of the specification of some of these materials since the industry is looking for this data (refer to Table 1).

The crystal structure data generated with Hexagon's material provides a rare glimpse into the nuances of the crystalline lattice of purified McIntosh flake. The reported lattice parameters are requested by all leading lithium-ion battery manufacturers. Hexagon is able to clearly demonstrate that its graphite is natural crystalline flake, whose lattice is near all hexagonal without appreciable amounts of turbostratic disorder or rhombohedral phase. Furthermore, Hexagon's material naturally features a preferred orientation of basal planes resembling highly oriented pyrolytic graphite (HOPG), with minimum presence of amorphous component and a rhombohedral phase. It is due to these unique characteristics that McIntosh flake offers to the end users better electrical conductivity, greater reversible capacity towards lithium ion intercalation, enhanced thermal management characteristics, and better lubricity. The difference with HOPG, with an approximate market price in the order of US$30,000 / tonne is that Hexagon graphite is positioned to be available

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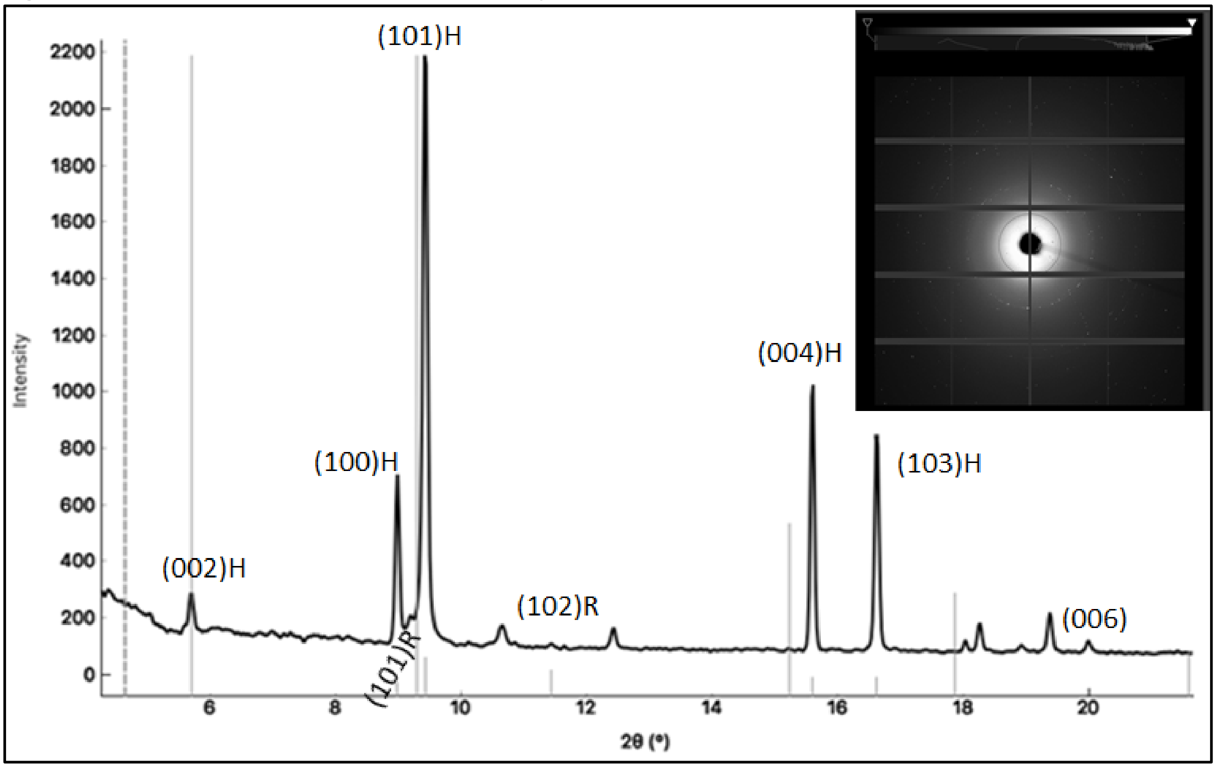
[2] *HOPG is an acronym for highly oriented pyrolytic graphite and is characterised by the highest degree of three dimensional atomic ordering. This is a very high value synthetic graphite product selling for approximately US$30,000/tonne.*

in large industrial quantities. Whilst the global scale of the HOPG market is approximately 30,000 to 40,000 tonnes, this grade is predominantly only used by university researchers, as well as in semiconductor and nuclear industries due to its high price and limited availability.

Figure 2 is the XRD scatter plot for the McIntosh purified material from the ANL APS. It illustrates several unique properties through the relative height of the diagnostic peaks. The most striking difference with other natural crystalline flake graphite on the market are reduced 002 and increased (100), (101), (004) and (103) peaks, resembling the HOPG diffraction pattern. Also, there are several amorphous peaks which ANL APS XRD experts have identified as those of a glassy carbon type. The presence of these peaks makes Hexagon's McIntosh flake very unique in the market of natural crystalline flake graphite.

Figure 2: APS XRD Scatter Plot for McIntosh purified flake.



In reviewing the crystal lattice data presented in Table 1, please refer to the notional schematic by Figure 1, an approximate representation of the layers of graphite macromolecules and presenting the key measurements being determined through the APS and incorporated into various end-users' specifications. The key crystal lattice properties include: the thickness (Lc) and the length (La) of the crystallite, and the inter-layer spacing between the graphene layers (d_{002}). Table 1 provides the comparisons with the premium quality synthetic graphite available from Imerys Graphite & Carbon of Bodio, Switzerland, a leading commercial provider of battery ready synthetic graphite and used commercially for conductivity enhancement applications in the advanced battery systems.

Table 1 - Comparing Product Specifications for leading synthetic graphite with McIntosh purified, natural crystalline flake graphite results.

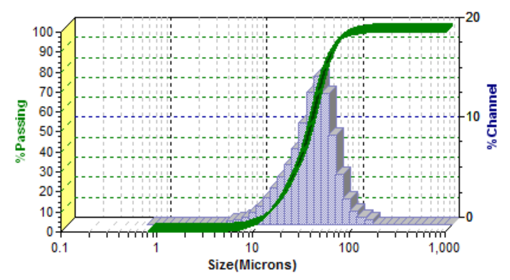
Source of Technical Data Sheet	Specified Crystalline Lattice Attributes	
	La and Lc (nm)	d_{002} interlayer spacing (nm)
McIntosh Sample	>5,500 (La); >1,000 (Lc)	0.3351
TIMREX® KS44	100 (Lc); >100 (La)	0.3354-0.3358
TIMREX® KS15	80 (Lc); > 90 (La)	0.3356
TIMREX® BNB90	35 (Lc)	0.3359

The Lc/La parameters for purified McIntosh flake are so large that they had to be estimated from laser diffraction rather than by a calculation of XRD patterns which would not have been accurate enough (see Figure 3). NAmLab thoroughly sonified the sample looking specifically for the smallest size particle (graphite macromolecule), which would be produced from the McIntosh material. The finest particle was 5.5 micrometres, or 5,500 nm (La) and more than 1 micrometres thick (i.e. Lc > 1,000 nm). Only 0.34 wt% of the flake broke down to this size and the balance of the particles had a greater crystallite size, which was confirmed by a laser diffraction histogram presented in figure 3.

Figure 3: Laser diffraction pattern of sonicated purified flake in size fraction of -140 mesh.

Data	Value	%Tile	Size(um)
MV(um):	38.1	10	14.91
MN(um):	11.84	20	20.97
MA(um):	27.51	30	26.43
CS:	2.18E-01	40	31.25
SD:	18.23	50	35.68
		60	40.17
Mz:	36.45	70	45.19
si:	18.69	80	51.61
Ski:	0.1467	90	62.48
Kg:	1.065	95	74.56

Sonified Hegagon concentrate after thermal purification to 99.99971 wt%C



Size(um)	%Chan	% Pass
418.6	0	100
352	0	100
296	0	100
248.9	0	100
209.3	0	100
176	0	100
148	0.44	100
124.5	0.75	99.56
104.6	1.36	98.81
88	2.59	97.45
74	5	94.86
62.23	8.91	89.86
52.32	13.13	80.95
44	14.84	67.82

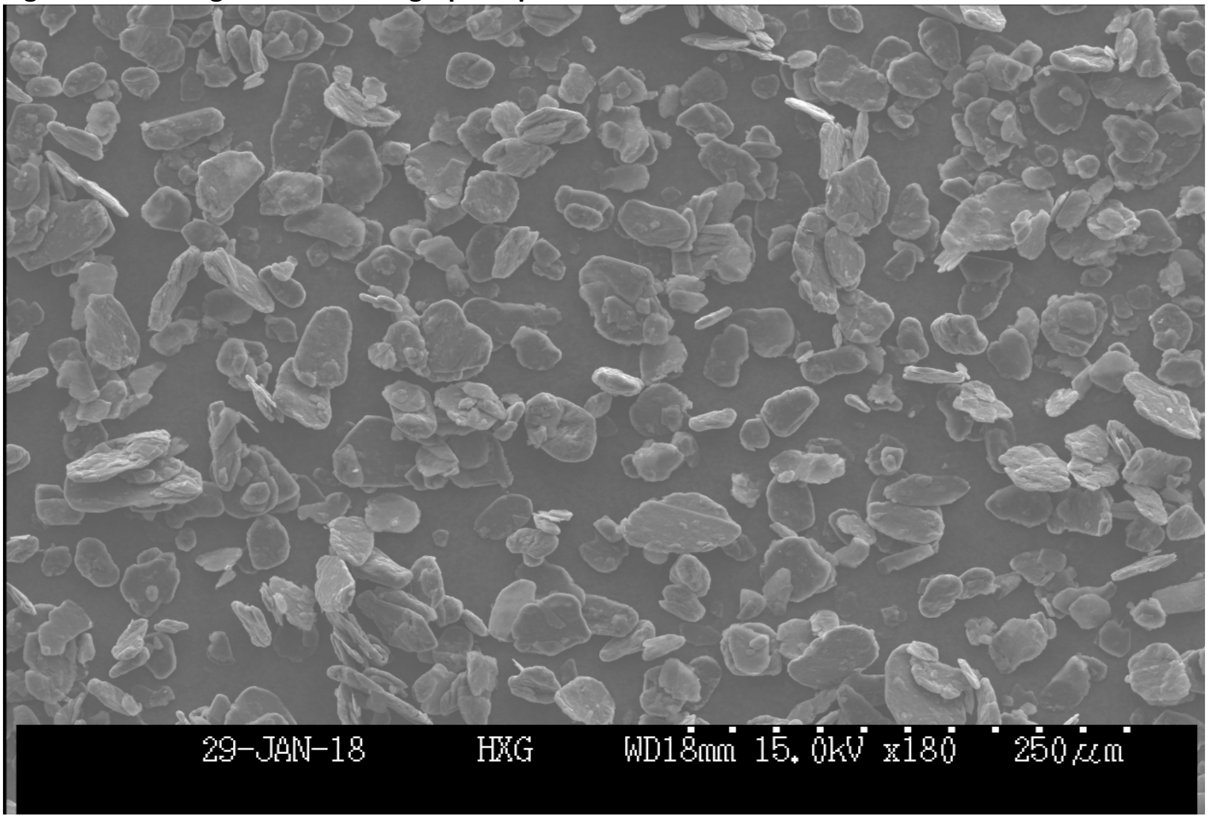
Size(um)	%Chan	% Pass
37	13.29	52.98
31.11	10.23	39.69
26.16	7.66	29.46
22	5.98	21.8
18.5	4.8	15.82
15.56	3.74	11.02
13.08	2.7	7.28
11	1.81	4.58
9.25	1.17	2.77
7.78	0.76	1.6
6.54	0.5	0.84
5.5	0.34	0.34
4.62	0	0
3.89	0	0

Results of Lc/La were further corroborated by SEM of a -140 mesh Hexagon's refined flake presented in Figure 4).

The perfect d_{002} value of 0.3351 nm for the McIntosh graphite interspacing distance ensures excellent, highly efficient intercalation of Li ions to and from the anode thus enhancing the charging and discharging efficiency and capacity of the Li Ion battery system.

The SEM reveals the appearance of classic natural crystalline flake graphite which is comprised of well-defined graphite particles (macromolecules in a sense of structural crystallography). The SEM micrograph in Figure 4, illustrates solid flakes with a crystalline lattice, which is very obviously uninterrupted. The straight, inter-layer path is considered to be an advantage with this material for electrical and thermal conductivity, lubrication, thermal management and battery active materials applications.

Figure 4. Scanning Electron Micrograph of purified McIntosh flake at <140 mesh size fraction.



Conclusion

The crystal structure information generated provides Hexagon with rare hard data which is requested by all leading lithium-ion battery manufacturers.

Hexagon is able to clearly demonstrate that its graphite is natural crystalline flake and not synthetic graphitised material, and offers near all hexagonal crystalline lattice with preferred HOPG-like orientation and only minor presence of the amorphous component. The amount of turbostratic disorder and rhombohedral phase in McIntosh graphite is negligible. Flakes are defined by excellent crystallinity and given their demonstrated exceptional purity level of greater than 99.999 wt% C, the Company can see a very clear path for application of this material as enabling technology for value-added applications, where the value-proposition to the end users is to provide specialised technological characteristics. These include: higher electrical conductivity, greater reversible capacity towards lithium ion intercalation, superb thermal management properties and better lubricity for ultra-purified material.

Hexagon's Managing Director, Mike Rosenstreich commented "the preliminary crystal lattice study of the purified sample of McIntosh flake is very encouraging especially coming from the US Argonne National Laboratory's APS instead of more subjective bench scale XRD results adding real credibility to another excellent set of technical properties with our McIntosh flake. The results fall within what is required for LiB anode, alkaline and lead acid battery cathode markets and indicate several unique properties, again reinforcing the unique and clean attributes of the McIntosh flake. With the XRD data from ANL we have found an effective differentiating tool between the McIntosh flake and other flakes available on the market. The all-Hexagonal structure of crystalline lattice of the McIntosh flake supports very well our name of Hexagon Resources and underpins the value proposition of our "brand" to our customers."

“These enhanced atomic scale features reported today compliment the “easy “and low cost purification and micronising aspects of our material - and end users and investors are starting to appreciate the importance of this compared to the largely irrelevant mining type parameters many people still use to rank graphite deposits. Mining aspects such as grade and strip ratio are almost irrelevant when it comes to the costs associated with secondary processing such as purification or size reduction and the enhanced electrical properties on offer. The ability of our flake to compete with premium quality synthetic graphite, let alone the super-premium HOPG graphite, opens vast prospects into markets that sell based on performance rather than cost. In these markets the costs of graphite is US$30,000 / tonne and a welcome boost to our ultimate business model.”

“Our test work is clearly continuing to highlight a unique flake material suitable for a range of high-purity, premium priced end-uses which underpins our dual strategy of supplying the high growth energy and technology sector as well as to displace synthetic graphite in high-purity applications which is a huge and lucrative market.”

COMPETENT PERSONS’ ATTRIBUTIONS

Exploration Results and Mineral Resource Estimates

The information within this report that relates to exploration results, Exploration Target estimates, geological data and Mineral Resources at the McIntosh and Halls Creek Projects is based on information compiled by Mr Shane Tomlinson and Mr Mike Rosenstreich who are both employees of the Company. Mr Rosenstreich is a Fellow of The Australasian Institute of Mining and Metallurgy and Mr Tomlinson is a Member of the Australian Institute of Geoscientists. They both, individually have sufficient experience relevant to the styles of mineralisation and types of deposits under consideration and to the activities currently being undertaken to qualify as a Competent Person(s) as defined in the 2012 edition of the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves and they consent to the inclusion of this information in the form and context in which it appears in this report.

Metallurgical Test Work Outcomes

The information within this report that relates to metallurgical test work outcomes and processing of the McIntosh material is based on information provided by a series of independent laboratories. Mr Rosenstreich (referred to above) in association with highly qualified and experienced researchers at NAmLab, planned, supervised and interpreted the results of the test work. The NAmLab principals have sufficient experience relevant to the types of test work under consideration and to the activities currently being undertaken to qualify as a Competent Person(s) as defined in the 2012 edition of the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves and have consented to the inclusion of this information in the form and context in which it appears in this report (Please refer footnote 1 at the base of page 2).

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