

Coal, Just Not for Burning

by

Michael D. Campbell, P.G., P.H., CPG

M. David Campbell, P.G.

Jeffrey D. King, P.G.

Henry M. Wise, P.G., CPG

This is the rest of the story. As industry has begun to pull carbon dioxide out of the atmosphere and store it in underground reservoirs, we also have the option to not burn the coal of fossilized dead forests. Alternative sources of energy to generate electricity are available. We also have the option to prevent the destruction of the living forests (and their associated ecosystems) that produce much of the oxygen that humans and other organisms need to exist. The carbon in coal can also be used to make other common “clean” products. Coal may then become “clean coal” after all and not just an oxymoron with visions of becoming germane economically.

China, Australia, Russia, India, the Asia Pacific region, and the United States have large coal resources, but they are currently committed for burning to generate electricity, putting huge quantities of particulates, carbon dioxide, carbon monoxide, mercury and other contaminants into the atmosphere (see Figure 1).



Figure 1 - A Coal-Fired Power Plant

The United Nations has formalized bold opposition to burning coal in a recent press release¹⁰, but the Asia Pacific region is largely dependent at present on coal, rather than wind and solar resources, and even these currently have serious drawbacks²⁵.

Coal in its most common natural form is composed primarily of carbon consisting of decomposed and fossilized organic material from plants and animals that lived millions of years ago. This material has been metamorphosed into rock or densely packed sediment by heat and pressure from being buried thousands of feet below the surface. Coal forms in stages, starting with organic mud, progressing through metamorphism successively (given sufficient heat and overlying pressure) to lignite, bituminous coals, and ultimately anthracite coal (the metamorphic version of carbon). Graphite forms as a result of organic material or limestone undergoing even greater heat and pressure at depth over an even longer period of time.

In discussions with an associate a few months ago (James L. Conca, Ph.D.), as we were finishing a report on our investigations of using nuclear systems to generate electricity to power the 2nd space race that has just begun ^{4, 5, page 182}, we realized the importance of carbon-based materials that were on the verge of replacing many products made of less sturdy materials, especially those applications requiring materials that provide superior strength and protection from radiation. These materials have applications in products on Earth as well.⁷

A shift in the paradigm is afoot it seems. Carbon derived from coal is becoming more important than wood and petroleum products as feedstock to make common products that society uses every day. Carbon formulations can replace wood, some metals, and some plastics, the latter once considered to be “the future” by a family

friend providing advice in the movie *The Graduate*. The new material of the future comes from coal and other carbon-rich materials such as graphite. One word, carbon, will carry many present graduates to a rewarding future but plastics will still be needed as well.

We re-discovered the merit of using carbon products to replace the need to harvest trees and produce petroleum that are used currently to manufacture wood-based and plastic-based products, such as furniture, utility poles, building construction materials, and a host of other products. Carbon-rich natural resources no longer need to be burned for the purpose of generating electricity but can be used as a feedstock to formulate carbon fiber and carbon nanotubes and cages (microscopic structures of *graphene* that we'll define later) that are already used in reinforced plastics, heat-resistant carbon composites, many cell-phone components, batteries, fishing rods, golf club shafts, bicycle frames, sports car bodies, the fuselage of the Boeing 787 *Dreamliner*, and pool cue sticks. Carbon is also used to reinforce concrete and gray cast iron and many other products, such as carbon rods used as a neutron moderator in nuclear reactors to control the rate of fission.

Carbon is also used in components for heating nuclear fuel and in the cool-down process, and can absorb heat up to 3,000 degrees Celsius (that's about 5,432 degrees Fahrenheit) without any significant signs of deterioration.²² Refractory crucibles for high-temperature are also made of graphite as well as in the manufacture of electrodes for many industrial applications, e.g., the aluminum and steel smelting industries.

Chairs and other furniture could be made from reformulated coal that could seat an

elephant, last a hundred years, and be of any form and shape conceived of by the designer, even the cushions that go with them. Using high-carbon materials formulated for building materials would also minimize building fires and damage by high winds, and even replace gypsum wallboard to improve energy conservation within homes and interior strength of materials.

Even as we move off-world in the coming decades, carbon products of high density and strength will likely become more useful in exploration activities to protect human habitation and electronics from radiation and from various types of inherent stresses in orbit or encountered in building structures on or under the surface of the Moon, asteroids, and even Mars.⁸ Some form of carbon material will also be needed to make the 28,000 miles of carbon-fiber belts required in building the first space elevator, see Figure 2.^{5, page 201}



Figure 2 - Artist's Conception of the Space Elevator
Hoagland¹⁵

The production of carbon for use in consumer products would likely maintain or increase employment in the current coal and graphite industry and in the associated new carbon-based industries that formulate and manufacture new carbon products.

Underground mining of coal could be put off until it could be accomplished by robotic miners without the need for the continuous presence of humans underground in typically

methane-rich and therefore potentially explosive and otherwise unhealthy environments.

It is apparent that coal and associated carbon-rich natural resources such as lignite can be converted to high-grade carbon through industrial heat and pressure, producing material similar to the naturally occurring anthracite coal and graphite.^{18, 24, and 33}

Graphite is a natural mineral that consists of carbon that forms only two bonds with other carbon atoms. This means it has free electrons, and for that reason it is a good conductor of electricity as well as a strong material. In addition, graphite exists in layers. This enables one layer to slip over another layer, making graphite an excellent lubricant. Also, since there are free electrons to absorb light, graphite is black. Blocks of formulated, fine-grained carbon (like *carbon black* used in copying machines) could also be used in new 3-D printing that has been developed recently to make all manner of large and small products out of carbon materials.

Graphite is composed of thousands of layers of graphene. It is used in pencil “leads” (the lead’s hardness is adjusted by altering the associated clay content). One can split the microscopic layers of graphene in graphite by marking with a pencil on paper and applying *Scotch Tape* over the mark and then pulling off the tape. You will see a graphene layer showing on the tape and on the paper.²³ For scale, there are still thousands of layers of graphene below those one can see.

There are other forms of carbon, but these are not commonly available on Earth. These forms include *Buckminster fullerene* and several cage and tubular varieties that can be made artificially and offer promise for

future applications.⁹ Meteorites also contain graphene in the form of “buckyballs”, and lunar soils consisting of meteorite impact dust will likely also contain large amounts of graphene (and *carbyne* to be discussed later), in addition to helium-3.^{5, page 182}. It is clear that these carbon materials are becoming increasingly important natural resources and are useful resources driving the expansion of a new carbon-based industry, not only in the nuclear industry but in many other industries as well.²⁶

Graphene appears at the atomic-scale like chicken wire made of carbon atoms and their covalent bonds (see Figure 3). Most importantly, graphene is the strongest material widely available in nature.¹

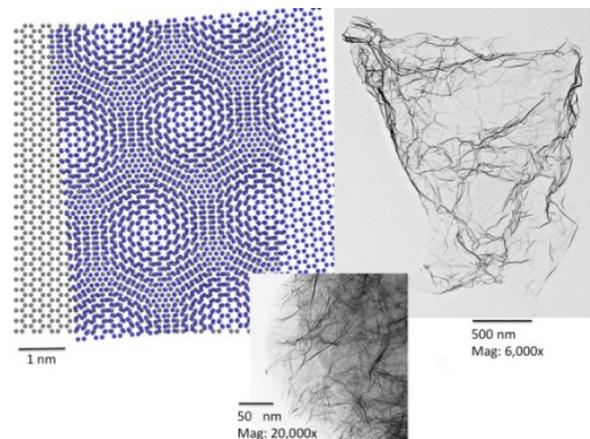


Figure 3 - The regular framework structure of carbon atoms in graphene sheets. (TEM images). Image credits - NIST (National Institute of Standards and Technology) and Cabot Corporation³

The regular structure of stacked graphene sheets show patterns within larger periodic Moiré patterns (see Figure 3). Discontinuities and defects in the stacked sheets can produce subtle strains, bulges or wrinkles as seen in transmission electron micrographs of graphene nanoplatelets consisting of only a few layered graphene sheets.

These structures impart different properties to materials that can enhance performance in composites, batteries, electronics, and many other products (see Figure 4).

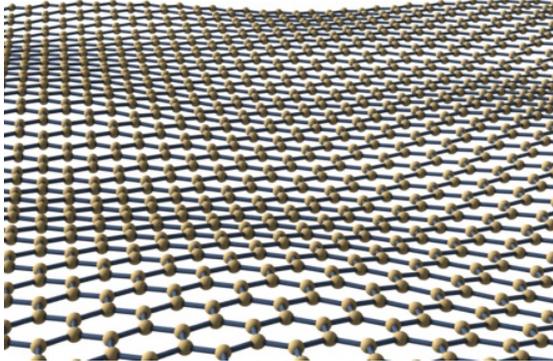


Figure 4 - Chicken Wire Pattern with Variations in the Grid.

Graphene is an incredible submicroscopic material, and is:

- the strongest material in nature (200 times stronger than steel by weight),
- able to be mixed with other materials like plastics and cements,
- highly flexible,
- the thinnest useable material in the world (100,000,000 stacked sheets is less than an inch),
- a better heat and electricity conductor than copper,
- a material that can replace silicon in semi-conductors,
- a material that revolutionizes solar-power collection, and
- a material that dramatically improves the performance of lithium-ion batteries.

The race is now on to commercialize graphene as an integral part of the nanotechnology industry. China is leading the race at present. American companies have entered the race as well, especially since

there are substantial security implications and increasingly important applications of graphene.¹¹ Its ultra-thin structure allows for sheets of the material to be stacked to increase energy storage and possibly double the current capacity of the new ultracapacitors.¹² A graphene-based core additive has been developed for various types of high-energy density lithium-ion battery applications. This is a new technology platform that helps lithium-ion battery manufacturers achieve superior performance.³

Graphene-based products are in development and are actively being studied in Europe, but Asia and the U.S. are currently leading when it comes to patent publications - even though it was pioneered in Britain.⁹ Universities, corporations (IBM and others) and governments in Asia, Europe and North America are leading the effort. Industry and Wall Street are beginning to gear up for a new materials future (Example: Cabot Corporation,² and others^{1 and 21}).

In another university-Industrial effort, a successful demonstration of a new direct carbon fuel cell design was carried out recently at the University of Queensland and by Direct Energy in Australia.³¹ The demonstration indicated the apparent commercial integrity and viability of the unit, together with its scalability. The carbon fuel cells operate through a simple electrochemical reaction without excessive fumes and without combustion.

The University researchers have refined the extrusion and manufacture of the fuel cell tubes to commercial grade quality. These tube extrusions contain the essential anode, electrolyte and cathode materials that are the key component in the

conversion of gasified coal to power. A relatively small unit can replace large boilers, turbines and generators – noise free, no moving parts, minimal emissions and using half the amount of coal for the same output (which means double the electrical efficiency of a traditional coal-fired power plant).³² This is another approach to using carbon but without combustion to generate electricity; the costs for such clean energy appear to be reasonable after all.

So it is now apparent that carbon can be used to generate power and manufacture everyday products including those utilizing microscopic electronics that will have a large impact on society in the years to come.^{14 and 29} But that's not the whole story. The strongest known material in the world may have recently been replaced with an even stronger material.

Researchers from Rice University have calculated the properties of a little-studied form of carbon known as *carbyne*, and they've determined that it should have a specific strength surpassing that of any other known material.^{1 and 16}

The new study shows that *carbyne*, made up of a chain of carbon atoms linked by alternate triple and single bonds or consecutive double bonds, is actually twice as strong as graphene, and exhibits unusual characteristics that make it appealing for a wide range of uses.^{17 and 20} However, *carbyne* has also been detected in interstellar dust and meteorites, likely the result of the high temperatures and pressures experienced in those environments, and the Rice study indicates synthesizing it here on Earth has proven to be difficult. It may

be in more abundance on the lunar surface and on passing asteroids. Sampling will tell us when we visit those sites sometime this decade.

New technology being developed using old resources (i.e. coal and graphite) is paving the way in some unexpected directions.¹⁰ They will likely be important to industry for years to come in producing new building materials, developing new nanotechnology for the electronics industry, or in the field of medicine. The possible uses are vast. Flat screen TVs as thin as *Saran Wrap*... nanotechnology devices that would put the power of a supercomputers in the palm of your hand... and very small brain implants that may combat Alzheimer's¹⁹, as well as a graphene-scale radio²⁸, to name just a few new applications under development today.

The carbon present in refined coal tar has been used for many years in the manufacture of industrial chemicals, such as creosote oil, naphthalene, phenol, and benzene. Ammonia gas recovered from coke ovens is used to manufacture ammonia salts, nitric acid and agricultural fertilizers. Thousands of different products have coal or coal by-products as common household constituents: soap, aspirins, solvents, dyes, plastics and various fibers, such as rayon and nylon.²⁷

Coal is also an essential ingredient in the production of specialist products, such as:

- **Activated carbon** - used in filters for water and air purification, in kidney dialysis machines, and in gold and silver recovery operations associated with mining,

- **Carbon fiber (Graphene Assemblies)** - an extremely strong but light weight reinforcement material used in construction, mountain bikes and tennis rackets, etc.,³³
- **Silicon metal** – carbon is used to produce silicones and silanes, which are in turn used to make lubricants, water repellents, resins, cosmetics, hair shampoos and toothpastes, etc.

Not only are many products derived from reformulated coal useful in the world today, but by moving away from burning coal, the transitioning to additional nuclear power systems in the form of either large-scale plants or in the form of small modular reactors that will soon be coming down the road on a trailer truck or rail-road car, will finally come into their own, driven by the merits of their economy and outstanding safety record (see Figure 5).



Figure 5 - A Nuclear Power Plant with Water-Cooling Towers and the Beginning of the Electrical Grid in the Area.

The alternative energy sources of wind and solar will continue to be tested to determine if they can have a significant place in the energy picture (after government subsidies are removed), and whether they can be scaled up to meet the needs in other than remote areas away from national power grids and meet the

operation and maintenance demands of their moving parts. The transition from burning coal to other reliable energy sources (like natural gas and nuclear power) will likely be slow because industry cannot change quickly unless companies are placed on an emergency footing. However, a large number of coal-fired plants are still in the planning stage for construction in the U.S.³⁰ Such changes in our energy usage may not become widespread in this decade, but they certainly will be apparent in the decades ahead.

So, in the big picture, coal has been used since the days of the cave man.⁶ Coal (in making steam) drove the industrial revolution. It is useful today, and will be more so in the foreseeable future in driving a new, repurposed carbon industry, but just not for burning.

About the Authors:

Michael D. Campbell, P.G., P.H., CPG-03330, is the Executive Vice President and Chief Geologist /Hydrogeologist for I2M Associates, LLC, Houston and Seattle.

M. David Campbell, P.G. is a Project Manager and Senior Geologist for I2M Associates, LLC, in Fort Pierce, Fla.

Jeffrey D. King, P.G. is President and CEO for I2M Associates, LLC in Seattle.

Henry M. Wise, P.G., CPG-07697, is the Remedial Services Senior Specialist for SWS Environmental Services, La Porte, TX.

For more about the Authors, see:

<http://www.i2massociates.com/Downloads/AbouttheAuthorsFeb2014Coal.pdf>

For the References in separate PDF: See:

<http://www.i2massociates.com/Downloads/2014AIPGRefs.pdf>

References

1. Anon, *Science Daily*, "Graphene News". December 13, 2013. Accessed Internet on December 13, 2013 via: http://www.sciencedaily.com/news/matter_energy/graphene/
2. Cabot Corporation, 2013, "New Product Development: Graphenes," Accessed Internet on December 13, 2013. via: <http://www.cabot-corp.com/New-Product-Development/Graphenes>
3. Cabot Corporation, 2013, "Cabot Launches First Graphene-Based Additive to Improve Energy Density of Lithium-Ion Batteries," Accessed Internet on December 13, 2013. via: <http://investor.cabot-corp.com/phoenix.zhtml?c=94559&p=irol-newsArticle&highlight=&ID=1788701>
4. Campbell, M. D., and W. A. Ambrose, 2010, "Significant Uranium and Other Discoveries on the Moon May Indicate New Space Race is Afoot," A Press Release, April 16, 2010, Accessed Internet on December 10, 2013 via: <http://www.mdcampbell.com/SpaceRace04172010.pdf>
5. Campbell, M. D., J. D. King, H. M. Wise, B. Handley, J. L. Conca, and M. David Campbell, 2013, "Nuclear Power and Associated Environmental Issues in the Transition of Exploration and Mining on Earth to the Development of Off-World Natural Resources in the 21st century," in *Energy Resources for Human Settlement in the Solar System and Earth's Future in Space*: AAPG-EMD Memoir 101, (eds) W. A. Ambrose, J. F. Reilly II, and D. C. Peters, eds., pp. 163–213. Accessed Internet on December 11, 2013 via: <http://www.i2massociates.com/downloads/Memoir101-CHAPTER09Rev.pdf>
6. U. S. Department of Energy, 2014, "A Brief History of Coal Use," Accessed Internet on February 11, 2014 via: http://fossil.energy.gov/education/energy_essons/coal/coal_history.html
7. Conca, J. L., 2013, "Coal Doesn't Have To Die - We Can Make Furniture Out of It," Accessed Internet on December 11, 2013 via: <http://www.forbes.com/sites/jamesconca/2013/07/14/coal-doesnt-have-to-die-we-can-make-furniture-out-of-it/>
8. Conca, J. L., 2013, "Beyond Earth's Atmosphere: Energy Needs For Space Colonization," Accessed Internet on December 8, 2013 via: <http://www.forbes.com/sites/jamesconca/2013/05/05/beyond-earths-atmosphere-energy-needs-for-space-colonization/>
9. Dodson, B., 2013, "Graphene: Electronics – 'New lithium/sulfur battery doubles energy density of lithium-ion,'" *GizMag*, December 1, 2013. Accessed Internet on December 7, 2013 via: <http://www.gizmag.com/tag/graphene/>
10. Edmonds, R., 2013, "Windows Phone Central: Nokia Embracing New 'Miracle Material' for Future Hardware Development," Jan 28, 2013, Accessed Internet on December 6, 2013. via: <http://www.wpcentral.com/nokia-investing-new-material-future-hardware-development>
11. Figueres, Christiana, 2013, "Speaking to the International Coal and Climate Summit, organized by the Polish government and the World Coal Association, Executive Secretary of the UN Framework Convention on Climate Change, Warsaw, 18 November 2013. Accessed Internet on December 5, 2013 via: https://unfccc.int/files/press/press_releases_advisories/application/pdf/pr20131811_cop19_coalassociation.pdf

12. Graphite Investing News, 2013, "Featured Stock: Grafoid Inc. – A Global Graphene Platform," Accessed Internet on December 13, 2013. via: <http://graphiteinvestingnews.com/2951-grafoid-graphene-research-investment/>
13. Graphene Energy, Inc., 2013, Corporate Website, Accessed Internet on December 1, 2013. via: <http://www.grapheneenergy.net/technology.html>
14. Graphene-Info.com, 2013, "Graphene-Info is the Web's Leading Resource on Graphene Material Technology, Accessed Internet on December 6, 2013 via: <http://www.graphene-info.com/>
15. Hoagland, R. C., 2005, "Moon with a View: Or, what did Arthur know . . . and when did he know it? Part 5," Accessed Internet on February 7, 2014 via: <http://www.enterprisemission.com/moon5.htm>
16. International Science Times, 2013, "Carbyne Beats Graphene As World's Strongest Material: What Can The 'Super' Substance Do For Engineering?" Accessed Internet on December 9, 2013 via: <http://www.isciencetimes.com/articles/5919/20130820/strongest-material-carbyne-property-graphene.htm>
17. Kastrenakes, J., 2013, "New form of carbon said to be strongest material ever found," in *The Verge* August 15, 2013. Accessed Internet on December 6, 2013 via: <http://www.theverge.com/2013/8/15/4625542/carbyne-determined-strongest-material-ever-found>
18. McLeod, C., 2013, "Scientists Create Graphene Quantum Dots from Coal, in Graphite Investing News, December 9, 2013. Accessed Internet on December 6, 2013 via: <http://graphiteinvestingnews.com/4728-scientists-create-graphene-quantum-dots-from-coal/>
19. Money Morning Staff, 2013, "Massive Breakthrough For Graphene Investors," in *Money Morning*, Accessed Internet on December 11, 2013 via: <http://moneymorning.com/active-premiums/graphene-forecast/>
20. Owano, N., 2013, "Carbyne is stronger than any known material," in the WebLog, August 20, 2013. Accessed Internet on December 10, 2013 via: <http://phys.org/news/2013-08-carbyne-stronger-material.html>
21. Plimsoll Publications, 2013, "Carbon & Graphite Global - Industry Report," Accessed Internet on December 6, 2013 via: <http://www.reportlinker.com/p01908632-summary/Carbon-Graphite-Global-Industry-Report.html>
22. Prasher, R., 2010, "Graphene Spreads the Heat," *Science* 9 April 2010: Vol. 328 no. 5975 pp. 185-186 DOI: 10.1126/science.1188998. Accessed Internet on December 7, 2013 via: <http://www.sciencemag.org/content/328/5975/185.short>
23. *PRNewsWire*, 2013, "Global Carbon and Graphite Industry," March 18, 2013. Accessed Internet on December 6, 2013 via: <http://finance.yahoo.com/news/global-carbon-graphite-industry-173600016.html>
24. Updates on Graphite Exploration and Mining:, 2013, Accessed Internet on December 15, 2013 via: <http://graphiteinvestingnews.com/category/feature-articles/> and [I2M Web Portal](http://www.i2mwebportal.com/)
25. Clemente, F., 2013, "IEA recognizes reality: Coal is the path out of poverty in Southeast Asia," November 6, 2013. Accessed Internet on December 18, 2013 via: <http://energy-facts.org/>
26. *New Scientist*, 2013, "Graphene Search Results," Accessed Internet on December 18, 2013 via: <http://www.newscientist.com/search?doSearch=true&query=Graphene>

27. World Coal Association, 2013, "USES OF COAL," Accessed Internet on December 27, 2013 via:
<http://www.worldcoal.org/coal/uses-of-coal/>
28. *New Scientist*, 2014, "First Graphene Radio Broadcast is a Wireless Wonder," Accessed Internet on February 7, 2014 via:
<http://www.newscientist.com/article/mg22129553.100-first-graphene-radio-broadcast-is-a-wireless-wonder.html>
29. *Red Orbit*, 2013, "Scientists: Coal Is Better, Cheaper For Making Graphene Quantum Dots," Accessed Internet on February 7, 2014 via:
<http://www.redorbit.com/news/science/113022163/coal-graphene-quantum-dots-gqd-medical-imaging-120613/#Mo9pgbRO2RfJEX2z.99>
30. Ambrose, W. A., 2013, "Unconventional Energy Resources: 2013 Review," Chapter 1: COAL – See Figure 3, Accessed Internet on February 15, 2014 via:
http://www.i2massociates.com/Downloads/EMD_AAPG_2013_NRR_online.pdf
31. Direct Energy Holdings Pty Ltd., 2014, SHAREHOLDER UPDATE – February 25, Accessed Internet on February 27, 2014 via:
[http://www.i2massociates.com/Downloads/DE_Shareholder_Update_2_26a\(2\).pdf](http://www.i2massociates.com/Downloads/DE_Shareholder_Update_2_26a(2).pdf)
32. Direct Energy Holdings Pty Ltd., 2014, Corporate Website, Accessed Internet on February 27, 2014 via:
<http://www.dehpl.com/>
33. Ruquan Ye, Changsheng Xiang, Jian Lin, Zhiwei Peng, Kewei Huang, Zheng Yan, Nathan P. Cook, Errol L.G. Samuel, Chih-Chau Hwang, Gedeng Ruan, Gabriel Ceriotti, Abdul-Rahman O. Raji, Angel A. Martí, and James M. Tour, 2013, "Coal as an Abundant Source of Graphene Quantum Dots," Accessed Internet on February 28, 2014 via:
<http://www.nature.com/ncomms/2013/131206/ncomms3943/full/ncomms3943.html>