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In this issue:

- Graphene could change the world
- An AIM listed firm with a big future
- Every British tech investor needs to pay attention

Miracle Matter

Stronger than steel... smarter than silicon... more valuable than gold.

Eoin Treacy, Investment Director

There's a material – discovered right here in Britain – with such incredible qualities that there's almost no industry it won't revolutionise in the coming decades.

A strand of this material would be lighter than a single human hair... but it's 200 times stronger than steal, and harder than diamond

It's also translucent... and stretchy.

Not only that, it's "smart" – far more so than silicon. It can help process information at the quantum level.

And on top of *that,* it's one of the most electrically conductive materials ever discovered.

It's also virtually indestructible.

As we learn more about it, this material could change the way multiple major industries operate. So versatile are its properties that it could be the basis of the next generation of microchips, smartphones, oil and gas pipelines, optical computers, cancer treatments, sports equipment, surgical implants... the list is endless.

Now what if I told you this "Miracle Matter" was a form of carbon, and that it's going to save the world?

Considering the element has been vilified to the point where it is almost improper to utter its name in polite company, that might sound like a bold statement. But in this case I think it's justified.

That's because this material is no ordinary carbon. It's graphene. If the pace of innovation around it keeps up, and I'll explain in a moment why it should actually *accelerate*, then this claim will not only be justified but will seem obvious. The idea that it'll save the world may actually be an understatement.

Today I want to show you why that is. I want to introduce a new Aim-listed way of playing it to our portfolio. As you'll see in a second,

Britain is right at the epicentre of the graphene industry. I think every tech investor in the country should consider having some exposure to it tucked away in their portfolio.

Let's look at why.

An accidental discovery in a Mancunian laboratory

The UK is at the forefront of research into the manufacturing and usefulness of graphene.

The first attempts to study graphene date from 1859, but it was not until the advent of powerful microscopes that interest in the material really took off. In 2002, Professor Sir Andre Geim and Professor Sir Kostya Novoselov of the University of Manchester began to work on how to ablate layers of graphite to get down to less than ten layers. Two years later, on a Friday night, they cracked it (they actually made the breakthrough by accident). They discovered and isolated a single atomic layer of carbon for the first time.

The pair received the Nobel Prize in Physics in 2010 in recognition of their breakthrough.

I'll let one of graphene's pioneers, Professor Novoselov, describe its properties in full, just so you know, I'm not exaggerating. He said:

This is the one material which combines all those properties in one. It conducts electricity better than copper, it's stronger than diamond, it's more transparent than many other materials, more impermeable to other gases than any other membrane, so in one material we [have] all those superlatives and we never had it in any other material before.

The wondrous discovery that isolating graphene represented, meant the Nobel Committee wasted little time awarding the prize and graphene has since been responsible for the EU's single largest research initiative. A hard commitment of €1 billion to develop mass manufacturing techniques and commercial applications kickstarted the industry.

That's important because while software companies like Uber or Airbnb can quite easily achieve billions in funding, it's harder for physics and chemistry applications to gain the same level of investor interest.

The reason is simple: time.

Software is comparatively cheap to deploy and the profit potential is large. The profit potential for physical and chemical applications is equally large, but the time to get products ready for market creates uncertainty. That is why government support for such endeavours is often essential.

What makes graphene so compelling is the fact that is has so many commercial and industrial applications. That means funding and research could come from all over the world in an attempt to unlock its potential.

Why graphene is the most important material of the 21st century

Graphene is a single-atom-thick lattice of carbon and its properties are truly astounding.

It has potential applications both in its own right and when melded with other materials in the medical, electronics, light processing, sensors, chemical and environmental sectors. I could talk for hours about its applications. Instead, I'll pinpoint a handful I see as particularly important.

Unbreakable bones

I know this is going to sound like *Star Trek* but bear with me. It is envisaged that graphene's strength and malleability will allow it to be used as a substrate to grow bones on.

That means we will be able to grow new limbs that are stronger than the originals. In tandem with companies that are already 3D printing organs, a future where we can print off whole new limbs is not that far off.

The Nobel Committee wasted little time awarding the prize to graphene's discoverers

Superfast processors

If you're a frequent reader of this letter I'm sure you've heard of Moore's Law. (For the uninitiated, it is the trend where the number of transistors on a silicon chip has doubled every 18 months for decades.)

Right now the smallest transistor is 14 nanometres wide and 10 nanometre wide transistors are on the way.

However, that's where Moore's Law runs into challenges. It is theoretically impossible to create a transistor smaller than 7 nanometres.

At least, when you use silicon that's the case. The simple fact is quantum mechanics gets in the way through a process called quantum tunneling, which allows electrons to drift between atoms and can switch a gate from off to on or vice versa.

Enter graphene. In October researchers at the Lawrence Berkeley National Laboratory announced they have succeeded in building a transistor with a gate length of just 1 nanometre. They achieved that feat using carbon nanotubes on a molybdenum disulphide substrate – and carbon nanotubes are manufactured from graphene.

Therefore graphene represents the last chance for the electronics sector to keep Moore's Law going for another five years before it has to truly deploy other kinds of chips.

I've previously written to you about the promise of quantum computers and particularly for problems revolving around statistics and ascertaining the best possible outcome from a given situation. However, if it comes down to getting the quickest computation, then graphene is likely to play a role in optical computing.

Optical computing

Optical computers will require chips to store information as photons of light rather than electrons, and the atomic scale of graphene makes it one of the only candidates for the foundation of such computers.

A team at Swinburne University of Technology in Australia tried this, and it manufactured a lens using graphene oxide that can split photons. It is also cheap. Here's what Science Alert had to say:

... Well, think of it this way: the new lens could be used to build devices capable of viewing, manipulating, monitoring, and trapping the tiniest particles in real time. In other words, it has the potential to revolutionize the technology used in medical diagnosis and treatment, imaging, sensing, and even computing.

Innovations like these will allow us to create phones that can be rolled up. Personally, I can't wait for this. I bought the iPhone 7 because its large screen is easier on my 40-year-old eyes. Unfortunately it keeps falling out of my pocket, which is a drag.

Smaller, lighter, stronger lenses mean satellites can also be smaller, more powerful and therefore cheaper.

Desalination

Last month the team at Manchester University announced that they have come up with a new and potentially even more compelling use for graphene: desalination.

It turns out that you don't need to have single-layer lattices of graphene if you want to create graphene oxide. By sandwiching graphene oxide between two

pieces of epoxy, the researchers only allowed it to expand into the gaps between the atoms when water passed through it. That narrowed the space through which salt could pass through and they created a low-energy, cheap desalination engine.

I'll admit it's a bit more complicated than that. But with the stress the global water system is under and the potential for billions of more people over the coming decades, we need cheap solutions for desalination.

In short, graphene can do a lot. It could be the basis of the very small (nanotechnology), the very smart (quantum computing) or the very strong (bones, oil pipelines, etc). It'll probably be all three.

The discovery of graphene created a new industry

Remember, graphene was first isolated back in 2004. So what is the team at the University of Manchester doing now?

The team created graphene by ablating graphite, which led other scientists to ask what other materials might be capable of forming single-atom thick structures. That has led to an explosion in the number of "two-dimensional" materials.

Some examples are graphyne, which is made from benzene and similar to graphene. Borophene is made from boron. Germanene is made from germanium and exhibits a concave lattice structure. Silicene is made from silicon. Stanene is made from tin. Phosphorene is made from phosphorus and with high electron motility could have highly attractive semiconductor applications, while 2-D materials have also been both isolated and theorised for molybdenum, rhodium and palladium.

Graphene was first isolated by physicists, but some of its most promising applications are in the chemistry field. As chemists move further into the field of study they are combining different 2-D structures to create completely novel materials. Here is a Professor Novoselov again:

Imagine we had graphene and we went to other two dimensional structures and crystals so we had those two dimensional layers. But now in principal it is in our power to put one on top of another and the question is what would be the properties of this sandwich? And they we can add a third and fourth one and more and more and more and properties of those sandwiches would be really really complicated.

And you can also take a look at it from a different perspective... what we have done historically is to use materials with properties given to us by nature but when we combine two-dimensional structures we create new structures with new properties and we can design those properties at our wish. We can create one layer which is conductive, another layer which is superconductive, another layer which is ferromagnetic, next one which is insulated and so on and so on."

There has been a great deal of media attention on graphene for the last few years, not least because so much capital is being allocated to finding commercial applications for it. But the big obstacle to growth has been the cost of producing graphene in large quantities.

There is still work to be done, but the reason I'm writing to you now is because the pace with which discoveries are being made is so rapid that the obstacle of cost is increasingly close to being solved...

Graphene's time has come

In 2013 graphene was the most costly substance in the world at $1,000 per milligram. Today it's closer to $100.

Last month a South Korean team created an organic light-emitting diode (OLED) display using transparent electrodes made from graphene. At 370mm

In short, graphene can do a lot

x 470mm that's about the same size as a 19-inch monitor and used graphene electrodes thinner than 5 nanometres. That holds out the possibility of unbreakable phone displays and truly wearable electronics. The bigger point is the size of the graphene lattice created. It's orders of magnitude larger than anything we've seen before.

It seems like every week we hear of new cheap ways of creating graphene, many of which can be performed with little more than a battery and tools available in one's kitchen. The challenge is isolating the lattice so it can be combined with other materials to form useful products.

A common argument against investing in graphene holds that it takes decades not years for the commercial application of new materials to be realised. There is some weight to that argument so it is worth addressing it.

Graphene is an exciting new material and the full potential for its applications are not yet fully understood, which is part of the reason it is so exciting. In order for a new material to be implemented into the product cycle of major corporations, sufficient data is required to ensure them against the risk of product failure.

In the short term we already see evidence of graphene being used in the materials field to begin to displace carbon fibre. Since both are based on layering carbon atoms, and the integration of carbon fibre with other materials is already well understood, there is ample potential for graphene to be introduced in the short term. For example, Head introduced its graphene XT Speed Pro line of tennis racquets last year.

While it is arguable just how much graphene is in these products and whether the content is for marketing purposes, the reality is that graphene is already in the product cycle. The only question now is how quickly it will build market share.

More importantly is the impending limit on Moore's Law. Within five years it will have reached its logical limit. The global semiconductor business does nearly $350 billion annually in sales alone. The growth is predicated on getting better, more powerful and cheaper products to consumers on a timely basis.

The companies concerned cannot wait decades. They need to experiment, take risks and invest heavily in innovation. More than any other factor that will contribute to the lead time for mass production of graphene to shorten.

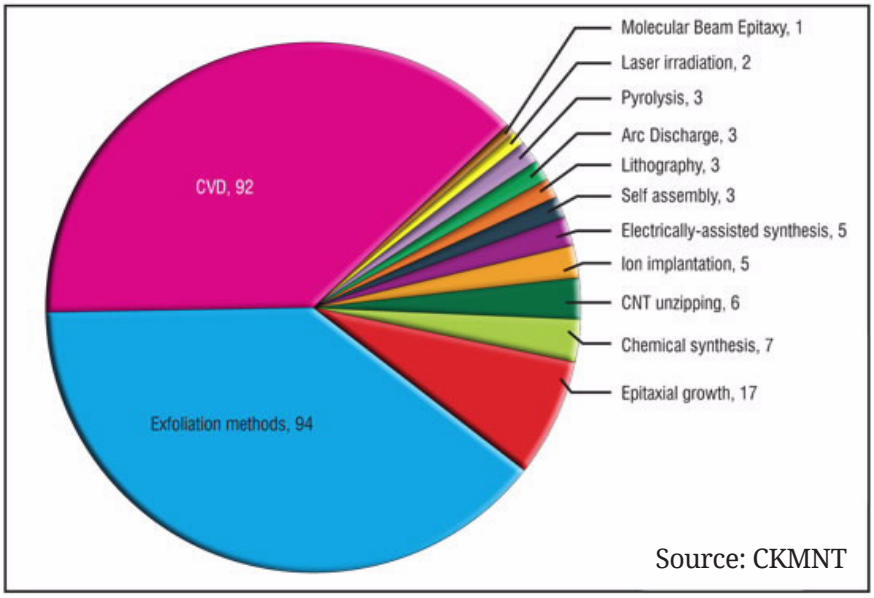
For example, chemical vapour deposition (CVD) and exfoliation are by far the most popular methods for producing graphene, as the chart below shows. That's where the cost argument comes up because these are comparatively expensive or inefficient methods respectively.

Our graphene pick – an Aim-listed moonshot

The UK has a number of avenues for investing in graphene, not least because it played host to the original team that isolated it.

Nevertheless, this is a competitive sector which is growing at a compound annual rate of 44% so we can logically expect the appetite of companies to invest to increase.

There are three primary avenues for investing in graphene. The first is by taking a position in a graphite miner since they produce



Source: CKMNT

the raw material for graphene production. The second is to back a company which is developing the machinery to mass produce graphene. The third is to invest in a company which is developing commercial relationships to bring graphene into the active global product cycle.

I am recommending you buy a company doing number three. It's called **Haydale Graphene Industries (HAYD:LN).** It's an Aim-listed company with a market cap of 34.66 million GBP and I am placing it in the moonshot category because it does not yet have earnings to speak of.

The primary business of the company is as an enabler to the utilisation of graphene in a wider number of applications. Through the company's patented process and third-party verification of its process, it is in a solid position to continue to grow its business. As a leader in facilitating commercial applications for graphene it is in a very favourable position to continue to benefit from the exponential growth of this new sector.

From the company's last annual statement we have learnt that it has grown 30% year on year, earning £1.92 million from reactor sales, grants and consulting. That represented a loss of £3.36 million following spending on operating activities and increasing capacity. The company ended the year with £2.86 million in the bank.

In the year to June 2016 the company had signed agreements with companies like Huntsman Advanced Materials to develop a new range of graphene-enhanced Araldite resins, as well as SHD Composites to launch graphene-loaded resin-impregnated woven fabrics. It also set up and commissioned a pipe testing facility with the aim of developing graphene-enhanced polymer pipes for the oil and gas industry.

The company also entered into a joint venture with the Saudi Arabian Amiantit Company to develop the next generation of glass fibre pipe for water and sewage applications. It signed a commercial tie up with Dowton Electronic Materials Co. Ltd. in Taiwan to manufacture Haydale-branded graphene-enhanced screen printable ink which will be aimed at the bio-medical market.

One of the company's primary growth plans is to secure its intellectual property. With that aim in mind it has secured patents in Europe, China and South Korea and has opened centres of excellence in all of these jurisdictions as well as North America.

To develop commercial applications for the graphene it treats with its patent-pending process in-house,, the company has a manufacturing plant in South Wales and commercial offices in Reading. But its list of foreign clients and patent approvals show just what a global business it is.

It is building relationships with major manufacturing companies all over the world and has seen revenues grow steadily since the company's launch.

Haydale should grow with the graphene sector not least because it has a great deal of expertise in how to bring this wonder material to commercial utility. I recommend buying the share up to 200p. The share has been mostly range bound for 18 months and the June earnings announcement could be a catalyst for bullish news, which is why I am recommending you buy it now.

Haydale has some impressive clients

My 12-month target is 300p while my five-year target is 1,000p based on the assumption that the company can continue to growth revenues at a compound annual growth rate of at least 30%.

The risks with this investment are that this is a small-cap share so it could be easier to buy than sell. The additional risk is that since this is such a new sector there is still uncertainty about the best route to commercialisation. Since Haydale relies on its competitive

advantage as a consultant, it is at risk of a more innovative piece of technology making that expertise obsolete.

That said, I think given the incredible properties graphene possess, that it's a risk worth taking. It's a moonshot. But it's exactly the kind of moonshot we want: if it comes off, it'll change the world and our portfolios. It's a BUY for me.

Your questions answered

Question from reader:

I've been a subscriber for a few months now and had a chance to evaluate and follow all recommendations. Have made a lot of investments but not all.

I notice that Alkane Resources is now a HOLD in the portfolio; surely, given the price, it should be an even stronger buy?

And secondly, I'm getting concerned that the overall market is becoming very complacent. Would you apply stops to all positions in the event of a major setback or would you ride it and look to buy more of certain things in to weakness?

Many thanks

Thank you for subscribing and for these questions which I'm sure may be of interest to other subscribers.

Our minimum buy level for Alkane Resources is 30 cents, and I am reluctant to reduce it because I do not wish to encourage investors to double down on what is likely a losing position in the short term.

In that regard I am very conscious of the fact that I am thinking first of veteran subscribers who may have bought earlier, rather than the many newer subscribers who might be thinking of buying now.

In short, I continue to believe Alkane Resources offers excellent leverage to the rare earths metals sector and that it represents a promising recovery candidate. Nevertheless, the uncertainty that has been a feature of the precious metals markets over the last few months has a taken a toll. There are indications gold is showing renewed signs of life, and as long as it is trading above $1,250 then gold miners should begin to see profits accrue.

Medium term, the ramping up of rare earth metal production, which has been funded by gold revenues, remains the clear competitive advantage Alkane Resources possesses.

Regarding the medium-term outlook, there is no denying that we are moving out of the most favourable season for stockmarket returns and that the technology sector has been among the better performing in the wider market. Therefore I am keeping a close eye on performance. I agree the risk of a somewhat larger pullback than we have seen in six months is a risk between now and the end of September.

The stocks which have performed best and have clear overextensions relative to their trend means are those at greatest risk of a pullback. I would not write to you with a blanket order to introduce stops unless I believed we were close to an imminent multi-year top. Otherwise I will write to you with updates on individual positions when the timing is right.

As always, rest assured I'll be in touch if there's anything urgent you must do with our positions. I monitor the portfolio closely. The guidance there reflects my thinking. If something falls below my buying range, I recommend waiting until it re-enters and has momentum on its side once again.

Name:	**Haydale Graphene Industries**
Ticker:	**HAYD**
Current price (02/05/2017):	**178.50 GBp**
Market cap:	**34.66M GBP**
52-week high/low:	**214/145 GBp**
Buy up to:	**200p**
One-year forecast:	**300p**
Five-year forecast:	**1,000p**

Data as of 02.05.2017

Five-year performance data: | 180.48 2015 %| 2016 -11.36 %

Please note, full five-year performance figures are not available.

Meet our experts face to face on 15th May

On Monday 15th May, we're doing something we've never done before...

We're gathering our top tech experts together for an afternoon of "closed door" meetings about the biggest technology opportunities in the world today.

That means the most important new trends... and the specific stocks you need to own to play them.

Even better, we'd like to offer a handful of our readers the chance to join us...

Claim one of the limited places here.

Capital at risk.

Energy

Company	Ticker	Rec Date	Price Then	Price Now	Gain/ loss %
Orocobre Ltd	ORE. AX	07/04/16	A$ 2.92	A$ 3.10	6.16

Technology

Company	Ticker	Rec Date	Price Then	Price Now	Gain/ loss %
Cyberdyne	7779	30/05/16	JPY 2,353	JPY 1571	-33.32
IBM	IBM LN	07/06/16	$153.33	$158.84	3.59
SAIC	SAIC US	05/07/16	$58.17	$73.46	26.22
Garmin	GRMN US	02/08/16	$55.75	$51.83	-7.03
2U INC	TWOU: US	06/02/17	$33.25	$46.13	38.74
Cisco Systems Inc.	CSCO: US	03/04/17	$33.80	$33.97	0.5

Medical

Company	Ticker	Rec Date	Price Then	Price Now	Gain/ loss %
Intuitive Surgical	ISRG	07/04/16	$ 626.12	$ 839.57	34.09
Terra Tech Corp	TRTC	11/11/16	$0.41	$0.21	-48.18
Autodesk	ADSK	01/11/16	$70.10	$91.98	31.21
Abcam	ABC	07/03/17	913p	857p	-5.56
Zynerba Pharmaceuticals Inc	ZYNE: US	03/04/17	$20.10	$21.86	8.76

Moonshot

Company	Ticker	Rec Date	Price Then	Price Now	Gain/ loss %
SolarWindow	WNDW	07/04/16	$3.96	$2.70	-31.82
Alkane Resources Ltd	ALK: AU	05/09/16	AU$ 0.31	AU$ 0.25	-18.03
Editas	EDIT: US	07/03/17	$21.02	$20.27	-4.75
Haydale Graphene Industries	HAYD	02/5/17	178.5p	178.5p	0

For the full portfolio including live prices, please visit the *Frontier Tech Investor* subscriber area. **You can view that by following this link.**