HOW NEW MATERIALS FIGURE IN THE DOW

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ABSTRACT

The Dow Jones Industrial Average (DJIA) is comprised of thirty large cap stocks and is intended to be representative of the entire United States economy (except for the transportation and utilities sectors). The editors of the Wall Street Journal change the composition of the DJIA periodically to ensure that it evolves with the U.S. economy. For the past few decades, these changes resulted in the substitution of a few (2 to 4) stocks every two and more recently five to six years. Many of the industries represented throughout the years and today: e.g. Aerospace & Defense, Major Drugs, and Semiconductors, are directly affected by advances in materials science and engineering. Certainly all of the top twenty engineering achievements of the twentieth century (e.g., electronics, telephone, laser and fiber optics; see http://www.ceramics.org/outreach/NAETop20.asp for the complete list) are tied to materials. This paper examines, not only how the public investment in science, engineering, education and technology through agencies such as the National Science Foundation helps create knowledge and sustain prosperity, but also how it might affect the market. No investment advice is provided, but it is interesting to speculate how advances in nanostructures, photonic crystals or synthetic bones might affect our future on several different fronts.

TRANSCRIPT

The following is an edited transcription of an invited talk within The Future of Materials Science and Engineering symposium at the 6th Pacific Rim Conference on Ceramic and Glass Technology in Maui, Hawaii (Sept. 2005).[1]

Many of you in the audience may think of me as the program director of ceramics at the National Science Foundation (NSF) – this makes me an investor in science.[2] I am also a traditional investor – one who invests in companies through the purchase of stocks and mutual funds. As well I am a more reluctant and sometimes highly critical investor that comes with being a taxpayer. What I hope to do is to connect some recent scientific discoveries to big businesses, in particular those in the Dow. And, to a certain extent, I will discuss how new materials drive the economy. In turn, I hope to make you think about investments.

One of my motivations came from this introspective look at the twentieth century's greatest engineering achievements and the role materials, specifically ceramics, played (Table I).[3]

In looking forward, inherently with more error, I will consider a subset of businesses, namely the Dow and in doing so I will begin with a description of the Dow Jones Industrial Average (DJIA), and an examination of the companies to discern those directly impacted by scientific breakthroughs. Obviously the scientific/technological component is significant since Business Week observed in 2005 that 19 of 30 companies in the DJIA had launched nanotechnology initiatives.[4] I will then spend the rest of my time highlighting just a few recent discoveries with a brief look at how they might relate to the Dow companies.

In 1884 a financial journalist named Charles Dow created the basis for the Dow Jones Industrial Average.[5] The initial index was comprised of only 11 stocks, most of which were railroad companies. Later the Railroad Average (subsequently renamed the Transportation Average) and the Utilities Average were created. As a result, the Dow Jones Industrial Average was modified to be representative of the entire United States economy except for the transportation and utilities sectors. It wasn't until October 1, 1928 that the Dow was modified to consist of thirty stocks as it does to this day.[6] The DJIA continues to evolve and in the past few decades two to four stocks have been changed: initially every two years and more recently, only every five to six years.

The Dow is widely viewed as the world's most popular stock market index. One indication of its appeal is the extensive website and following of the Dogs of the Dow – a stock pricing strategy devoted to selecting high dividend stocks. However, the Dow isn't without its critics.[7] There tend to be two points of contention for using the Dow as a barometer of the US stock market. "First, the Dow is comprised of thirty large cap stocks. Critics argue that this is hardly representative of the broader US economy. Second, the Dow is a price-weighted index as opposed to a capitalization-weighted index. The weakness in this is that a high price stock can have a disproportionate impact on the overall value on the Dow. However, proponents of the Dow argue that in the end, the Dow has a high correlation to the broader and capitalization-weighted indices such as the S&P 500 and New York Stock Exchange Index and therefore conclude that these concerns are negligible at best."[5]

According to the market guide, the companies in the Dow can be categorized by both their sector and industry (Table II). Clearly three-quarters of these sectors include technology as a critical component and more than half of the individual stocks (19 of 30) have technology filling an essential role in all or some of their products and/or business.

Let me clarify a bit. Some companies, e.g., Coca-Cola use technology for its product. One can think about the evolution of containers that Coke has been sold in: initially a glass bottle, then aluminum cans and now also plastic bottles. However, it was only the change from a fountain-only to a container business back in 1886 that Coca-Cola attributes its recognition today.[8] I will not consider these companies further, but rather, I will focus on those with some critical dependence on scientific and technological evolution now.

In terms of industries, there are eleven to consider with respect to the DJIA in addition to conglomerates: semiconductors, communication services, computer hardware, aerospace & defense, auto & truck, construction/machinery, metal mining, chemicals, oil & gas, major drugs and household products.

I begin with my first example from Intel's in-house research on sensors.[9] They have observed the sensitivity of unpackaged chips to biological molecules and are considering ways to exploit it. They can be credited with two recent innovations: (i) a unique laser microscope based on Raman spectroscopy that can be used to detect disease and improve human health, and (ii) a system for positioning biological molecules in three-dimensions for further detailed analysis.

At the University of Pennsylvania, in Charlie Johnson's laboratory they use a 'chip dip' nano process.[10] First they create large batches of small-diameter nanotubes in solution and then separate out the semiconducting nanotubes. Integrated circuits then have a patterned adhesive coating that collects the nanotubes into specific regions to form an electronic circuit. In addition to Intel this development has relevance to Hewlett-Packard and IBM.

It is irresistible (here in Maui) to talk about our friend the gecko and how it has helped with a recent discovery. In addition to eating roaches and mosquitoes,[11] these creatures are known for their ability to walk up walls. They owe this prowess to their remarkable footpads: each covered in microscopic elastic hairs with split ends (for greater surface coverage). Polymer scientist Ali Dhinojwala at the University of Akron with the support of the NSF has created a similar carpet of carbon nanotubes that function with 200 times the gripping power of a gecko foot.[12] Potential applications including dry adhesives for microelectronics, information technology, robotics and space have interest to companies such as IBM, Hewlett-Packard, Honeywell and Boeing.

I don't know how many of you enjoyed great ride comfort and cornering ability in a GM car on your way along route 30 from the airport; General Motors claims their new shock absorbers utilizing a magnetorheological fluid should deliver this quality.[13] The shock absorbers work on the basis that the silicone-based fluid containing 3 to 10 micron diameter iron spheres becomes more viscous when bumps are hit since a surrounding magnetic field aligns the spheres.

GM might also have interest in a related development concerning bicycles weighing less than one kg with excellent stiffness and strength properties. One team in the latest Tour de France competition rode on bikes designed by a Swiss Manufacturer BMC.[14] Apart from the threading on the bottom bracket, the bikes were based entirely on a carbon nanotube technology with fibers embedded in a resin. The use of moulding technology meant machining after manufacture and the risk of damage to carbon fibers was completely avoided. Interestingly the post-race press coverage emphasizes not the bike, but the advantage the team had through a new wireless communication tool that allowed them to keep abreast of the tour including where their teammates were positioned.[15]

Caterpillar designs, manufactures, and markets earthmoving machinery, construction machinery, material handling machinery, and engines.[16] Is there a new business opportunity for them with the discovery of bendable concrete by Li and co-workers at the University of Michigan? This new fiber-reinforced concrete is 500 times more resistant to cracking and 40% lighter in weight.[17] Tiny fibers comprise ~2% of the volume and the other materials in the concrete itself are designed for maximum flexibility.

Kenneth Klabunde at Kansas State University devised the nano-engineering techniques that led to the development of FAST-ACT, a toxic-chemical cleaner, and subsequently to the founding of a small company, Nanoscale Materials, Inc.[18] The product's large surface area from nanoparticles composed of magnesium, titanium and oxygen rapidly breaks down hazardous materials. Will either 3M or Dupont partner with this new company?

Alternatives to fossil fuels hold a high interest today. A multidisciplinary team supported through the NSF's small business innovation research (SBIR) program is working on a battery with an enduring nature.[19] Its fuel, tritium, is a hydrogen isotope that releases electrons in a process called beta decay. It is more efficient and less expensive than similar designs with easier manufacturing requirements.

Hydrogen production and storage are receiving a lot of attention today. The vision for a hydrogen economy is based on two expectations: (i) that hydrogen can be produced from domestic energy sources in a manner that is affordable and environmentally benign, and (ii) that applications using hydrogen—fuel cell vehicles, for example—can gain market share in competition with the alternatives.[20] Domestic sources of energy for hydrogen production include fossil fuels, such as natural gas and coal; renewable energy resources, such as solar radiation, wind, and biomass; and nuclear energy.[21] Certainly success with hydrogen will affect Exxon Mobil Corporation, which operates as a petroleum and petrochemicals company.[22]

Switching strides now, I move to one of my last three topics, drugs. Science magazine featured drug discovery in its July 29th issue.[23] A few things caught my eye, e.g., one statement made was that, "Training is suboptimal, industry scientists typically learn on the job, not in universities". No doubt this is often true. However, efforts at the University of Southern Mississippi in cooperation with the University of Mississippi within an NSF-sponsored interdisciplinary graduate education research traineeship program (IGERT) focus on entrepreneurial, medicinal and polymer science interests.[24] As well, the University of California at Davis has a unit called the Biotechnology Program, within their Office of Research to serve as an administrative home to a number of programs which link academia to biotechnology industries and government agencies.[25] Of special note is the Designated Emphasis in Biotechnology graduate program[26] and the Advanced Degree Program (ADP) for corporate employees. Other connections to training are made when individuals move from industry to academia. One example is James Wells, cofounder of South San Francisco-based pharmaceutical company Sunesis and pioneer in developing new drug discovery and protein engineering technologies, who was appointed professor in both schools of pharmacy and medicine at the University of California San Francisco (UCSF).[27] He will direct a new center to boost drug discovery at the California Institute for Quantitative Biomedical Research, headquartered at UCSF's Mission Bay campus. Interestingly in Science magazine, the key touted was in identifying druggable compounds: molecules that might bind to targets that could block or enhance a biochemical process that leads to a particular pathological state or impairment.

Drug delivery is a growing area of interest and study. In the first example, researchers at UCLA are working with naturally occurring nano-capsules, known as vaults.[28] Recently it has been shown that vaults can function as nanoscale Trojan Horses, carrying foreign molecules past cellular membranes that are expressly designed to keep such interlopers out. In future experiments, they hope to bioengineer vaults that will hone in on specific cell surface receptors, so they are directed to enter only certain types of cells. In the second example, materials scientists working with biologists at the University of California - Santa Barbara have developed "smart" bio-nanotubes — with open or closed ends (as determined by an applied electrical charge) — that could be developed for drug or gene delivery applications.[29]

Self-cleaning surfaces, those that repel water, e.g., are found in nature. An example is the lotus or water lily. In 2004, researchers at MIT developed a superhydrophobic coating using a combination of microporous polyelectrolyte multilayers and silica nanoparticles.[30] More recently, using a similar approach, an Ohio State University researcher, Bharat Bhushan has built the first computer model that calculates the best bumpy surface for different materials and applications.[31] He is excited mostly about what his technology could do for microelectro-mechanical systems (MEMS) (in terms of reducing friction between moving parts).

My last example, organic light emitting diodes (OLEDs), involves new product technology. Toni Marechaux of the National Academies provided a comprehensive list of the stages involved this morning.[32] This example will give only a brief glimpse of some of the issues involved. OLEDs promise to bring increased performance and lower electric bills.[33] However, to bring innovative light and power products into the marketplace requires a sophisticated plan for penetrating the many diverse markets where each one has unique price/performance requirements. When a new market is penetrated, it must be used to refine the technology to enable movement to the next one. An example of an entry market for OLEDs is cell phones with their high volume and low margin. Already Osram Opto Semiconductors[34] has unveiled new colors and display formats for this rapidly growing market. OLEDs also have a potential for high-end plasma television sets. Samsung is proud to introduce their most advanced technologies.[35] Their line-up includes a 40” OLED ultra-slim design television using an amorphous silicon backplane, and new LED backlight and mobile display technologies. In the longer term, OLEDs may also meet general lighting needs starting with the industrial market where cost-accountability of operation is higher.

So, in closing this leaves us with the big question: Where should one make investments? Advances in materials and technologies may serve as a guide.

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Table I. Ceramic Materials Contribute to National Academy of Engineering's Top 20 Engineering List

Top Achievements	Examples of How Ceramics Contribute
1. electrification	Electrical insulators for power lines, insulators for industrial/household applications
2. automobile	Engine sensors, catalytic converters, spark plugs, windows, engine components, electrical devices
3. airplane	Anti-fogging/freezing glass windows, jet engine components
4. safe water supply and treatment	Filters
5. electronics	Substrates and IC packages, capacitors, piezoelectrics, insulators, magnets, superconductors
6. radio and television	Glass tubes (CRTs), glass faceplate, phosphor coatings, electrical components
7. agricultural mechanization	Refractory ceramic containers make melting and forming of ferrous and non-ferrous metals possible.
8. computers	Electrical components, magnetic storage, glass for computer monitors
9. telephone	Electrical components, glass optical fibers
10. air conditioning and refrigeration	Glass fiber insulation, ceramic magnets
11. interstate highways	Cement for roads and bridges, glass microspheres used to produce reflective paints for signs and road lines.
12. space exploration	Space shuttle tile, high-temperature resistant components, ceramic ablation materials, electromagnetic and transparent windows, electrical components, telescope lenses
13. Internet	Electrical components, magnetic storage, glass for computer monitor
14. imaging: X-rays to film	Piezoceramic transducers for ultrasound diagnostics, sonar detection, ocean floor mapping and more, ceramic scintillator for X-ray computed tomography (CT scans), telescope lenses, glass monitors, phosphor coatings for radar and sonar screens
15. household appliances	Porcelain enamel coatings for major appliances, glass fiber insulation for stoves and refrigerators, electrical ceramics, glass-ceramic stove tops, spiral resistance heaters for toasters, ovens and ranges
16. health technologies	Replacement joints, heart valves, bone substitutes, hearing aids, pacemakers, dental ceramics, transducers for ultrasound diagnostics, ceramic scintillator for X-ray computed tomography (CT scans) and many other applications
17. petroleum and natural gas technologies	Ceramic catalysts, refractories and packing media for petroleum and gas refinement, cement for well drilling, drill bit coatings for well drilling
18. laser and fiber optics	Glass optical fibers, fiber amplifiers, laser materials
19. nuclear technologies	Fuel pellets, control rods, high-reliability seats and valves, containerization components, spent nuclear waste containment
20. high-performance materials	Ceramic materials were cited for their advanced properties such as wear, corrosion and high temperature resistance, high stiffness, lightweight, high melting point, high compressive strength, hardness, and wide range of electrical, magnetic, and optical properties

Table II. List of the DJIA companies alongside their sector and industry designations. Bold font indicates companies with a technological interest.

Stock Symbol	Company	Sector	Industry
BA	**Boeing**	**Capital Goods**	**Aerospace & Defense**
HON	**Honeywell**	**Capital Goods**	**Aerospace & Defense**
GM	**General Motors**	**Consumer Cyclical**	**Auto & Truck Manufacturers**
KO	Coca-Cola	Consumer/Non-Cyclical	Beverages (Non-Alcoholic)
DIS	Disney	Services	Broadcasting
DD	**DuPont**	**Basic Materials**	**Chemicals**
SBC	**SBC Communications**	**Services**	**Communications Services**
VZ	**Verizon**	**Services**	**Communications Services**
HPQ	**Hewlett-Packard**	**Technology**	**Computer Hardware**
IBM	**International Business Machines**	**Technology**	**Computer Hardware**
GE	**General Electric**	**Conglomerates**	**Conglomerates**
MMM	**Minnesota Mining & Manufacturing**	**Conglomerates**	**Conglomerates**
UTX	**United Technologies**	**Conglomerates**	**Conglomerates**
CAT	**Caterpillar**	**Capital Goods**	**Construction & Agriculture Machinery**
AXP	American Express	Financial	Consumer Financial Services
AIG	American International Group	Financial	Insurance
PFE	**Pfizer**	**Health Care**	**Major Drugs**
JNJ	**Johnson & Johnson**	**Healthcare**	**Major Drugs**
MRK	**Merck**	**Healthcare**	**Major Drugs**
AA	**Alcoa**	**Basic Materials**	**Metal Mining**
C	Citigroup	Financial	Money Center Banks
JPM	JP Morgan Chase	Financial	Money Center Banks
XOM	**ExxonMobil**	**Energy**	**Oil & Gas - Integrated**
PG	**Procter & Gamble**	**Consumer/Non-Cyclical**	**Personal & Household Products**
MCD	McDonald's	Services	Restaurants
WMT	Wal-Mart	Services	Retail (Department & Discount)
HD	Home Depot	Services	Retail (Home Improvement)
INTC	**Intel**	**Technology**	**Semiconductors**
MSFT	**Microsoft**	**Technology**	**Software & Programming**
MO	Altria	Consumer/Non-Cyclical	Tobacco

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[2] The National Science Foundation makes a public investment in science, engineering, education and technology to help create knowledge and sustain prosperity. With an annual budget of about $5.5 billion, it is the funding source for approximately 20 percent of all federally supported basic research conducted by America's colleges and universities. In many fields such as mathematics, computer science and the social sciences, NSF is the major source of federal backing. NSF is joined by many others in many others in federal funding (e.g., DoE, DoD and NIH), as well as private and industrially backed funds. The National Science Foundation (NSF) is an independent federal agency created by Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…"

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