

Nanotechnology and Advanced Materials for Energy

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Materials for Energy as the Next Big Thing

Just as the semiconductor industry exploded in the 1980s, "Cleantech" is now a major field of innovation and disruptive change. Although there have been important innovations in Cleantech software, services, and infrastructure, most of the disruptive change has been in the area of materials-enabled innovation. Nano-structured advanced materials are the cornerstones of photovoltaics, batteries, solid-state lighting, fuel cells, bio-fuels, enzymatic reactors, and other recently funded start-ups, some of which have become newly listed companies.

Introduction

Nanotechnology, advanced materials, and energy are inextricably coupled. Einstein's famous equation $E=mc^2$ formulates a universal law describing the interdependency of matter and energy. Whereas the relationship between information and energy may be unclear, energy and matter are discussed interchangeably.

The discussion of energy is complex. Various branches of sciences and arts have developed their own languages to handle it. Astrophysicists, for example, focus on universe-scale relations, and their language is full of dark matter, dark energy, matter, and antimatter. Planetary-scale scientists focus on global warming, food chains in the ecosystem, and efficiency of solar-energy conversion into biomass. For semiconductor engineers, energy is heat dissipation, power consumption, clocking speed, and reversible computing. For a molecular biologist, energy flows are represented through metabolic pathways, intercellular interactions, and biochemical reactions. Energy is everywhere, and so are advanced materials such as atmospheric plasma, cellulose and soft tissues, low-k dielectrics, super-lattices, non-stoichiometric compounds, proteins, enzymes, etc.

Thus, the advanced materials for energy theme provides a very broad investment mandate that circumvents a significant part of the venture-capital deal flow worldwide. In order to stay within venture-capital conventions, however, we shall follow the current venture-capital definition of Cleantech (energy-thesis subset evolved around generation, transmission, storage, and efficient use of electrical and thermal energy) [**Figure 1**], while focusing on the areas where market readiness for disruptive change and our in-house expertise overlap.

The widening gap between capabilities of existing energy solutions and global demand has created a rare vacuum that venture-capital-funded entrepreneurial companies are rushing to fill. While energy innovations come in different shapes and forms, *materials for energy* are in the forefront of disruptive change in energy generation, storage, and utilization, and nanotechnology is in the forefront of materials innovation.

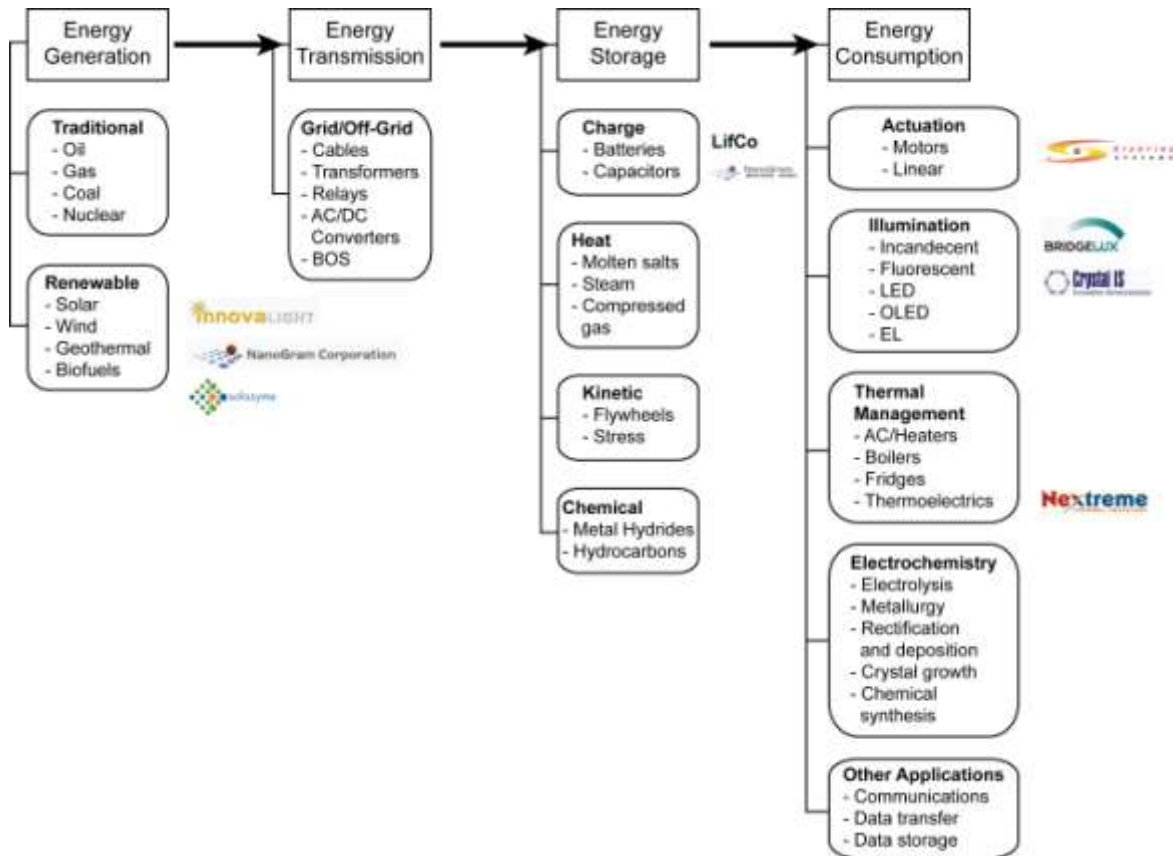


Figure 1. Typical venture-capital-scale picture of the Cleantech space.

Harris & Harris Group and Cleantech

Since 2001, Harris & Harris Group, Inc., ("H&H") has been making new investments exclusively in what MIT terms "tiny technology." These investments have been primarily in the field of nanotechnology. Eight of our 32 current investments, and one of our investments that was acquired, are companies utilizing nanotechnology for Cleantech solutions.

In 1994, we made our first nanotech investment, in Nanophase Technologies, Inc. (Nasdaq: NANX), which went public in 1997. We currently have 32 investments in nanotechnology-enabled companies, and we are not aware of any venture capital firm that has as many such investments as we do. In 1989, before we began investing exclusively in tiny technology, we were the seed investor in our first Cleantech company, Molten Metal Technology; in 1993, we sold our shares in Molten Metal on Nasdaq for net proceeds of \$30,860,765, versus our cost basis of \$110,000.

As a bottoms-up investor, we have never specifically targeted Cleantech investment opportunities; but as of September 30, 2007, our Cleantech investments represent more than 23 percent of our portfolio in terms of value. Since we began investing strictly in tiny technology in 2001, we have invested in nine companies that we classify as Cleantech companies enabled by nanotechnology: BridgeLux, Crystal IS, Innovalight, CFX Battery, NanoGram, NanoGram Devices, Nextreme Thermal Solutions, Solazyme, and Starfire Systems. Along with the rest of the venture-capital syndicate that funded Nanogram Devices, we sold our interest in that company to Wilson

Greatbatch (NYSE: GB) in 2004 for 3.4x our investment of \$813,210 in 14 months. Most of our remaining Cleantech companies have completed rounds of funding subsequent to our initial investment. We now value four of them at a premium to their cost basis, and none have been written down [Table 1].

Company Name	Initial Investment Year	Investment Round	Total Invested	Gain		Comments
				Unrealized*	Realized	
Molten Metal Technology, Inc.	1989	Seed	\$110,000**		\$30,750,765	NASDAQ IPO in 1993 Acquired by Wilson Greatbatch (NYSE: GB) in 2004
NanoGram Devices Corp.	2003	Series A-1	\$813,210		\$1,936,745	
NanoGram Corp.	2003	Series 1	\$2,285,159	\$313,534		
Nextreme Thermal Solutions, Inc.	2004	Series A	\$1,750,000			
Solazyme, Inc.	2004	Series A	\$885,400			
Crystal IS, Inc.	2004	Series A	\$1,299,984	\$19,735		
Starfire Systems, Inc.	2004	Series A-1	\$750,000			
BridgeLux, Inc.	2005	Series B	\$2,520,466	\$328,369		
Innovallight, Inc.	2006	Series B	\$2,500,000	\$3,218,216		
CFX Battery, Inc.	2007	Series A	\$946,528			

* As of September 30, 2007.

** On 11/13/89, H&H invested \$1,000,000 in Molten Metal Technology, \$890,000 of which was returned on 6/1/90 in a recapitalization. On 6/1/90, H&H also loaned \$200,000 at 8.75% to Molten Metal Technology, which was repaid in full with interest on 6/1/92.

Table 1. H&H investment performance in Cleantech space as of year-end 2007.

The common denominator of our current Cleantech portfolio companies is reliance on nanotechnology to develop and build products. We invest in technology-intense opportunities based on unique properties of nano-structured advanced materials.

Nanotechnology and Advanced Materials. The terms *nanomaterials* and *advanced materials* are rapidly converging. Today, these words are often used interchangeably to cover a broad range of nanoscale-engineered material systems such as meta-materials, supra-molecules, non-equilibrium alloys, and hierarchically structured and biomimetic substances.

In general, the properties of condensed matter are defined by chemical composition and the mutual arrangement of underlying building blocks including atoms and molecules. Therefore, any material might be legitimately called a *nanomaterial* because its physical properties are predominantly determined by the nanoscale patterns of comprising atoms. However, the term *nanomaterial* is normally reserved for a subset of materials that are specifically built with some unusual atomic arrangements or for materials with properties strongly determined by surface morphology. The latter usually applies when the particle size is small enough for its surface layer to represent a significant proportion of the particle itself: i.e., the particle is at the nanoscale.

The peer-reviewed scientific journal, *Advanced Materials*, covers a very broad range of materials systems: liquid crystals, semiconductors, superconductors, optics, lasers, sensors, porous materials, light-emitting materials, magnetic materials, thin films, and colloids. Although the original inventions and innovations of these materials systems were often at the bulk scale, the cutting-edge discoveries and improvements in this field today are increasingly made on the nanoscale. Nanoscale material design adds a new dimension to man's toolkit for creating materials with desired properties. Most of the low-hanging fruits based on bulk properties have been picked. To stay ahead of the curve in advanced materials, increasingly one has to innovate at the nanoscale.

Whether a material system is optimized for a semiconductor, optoelectronics, or energy application, its nano-scale design is becoming the most important contributor to a successful outcome.

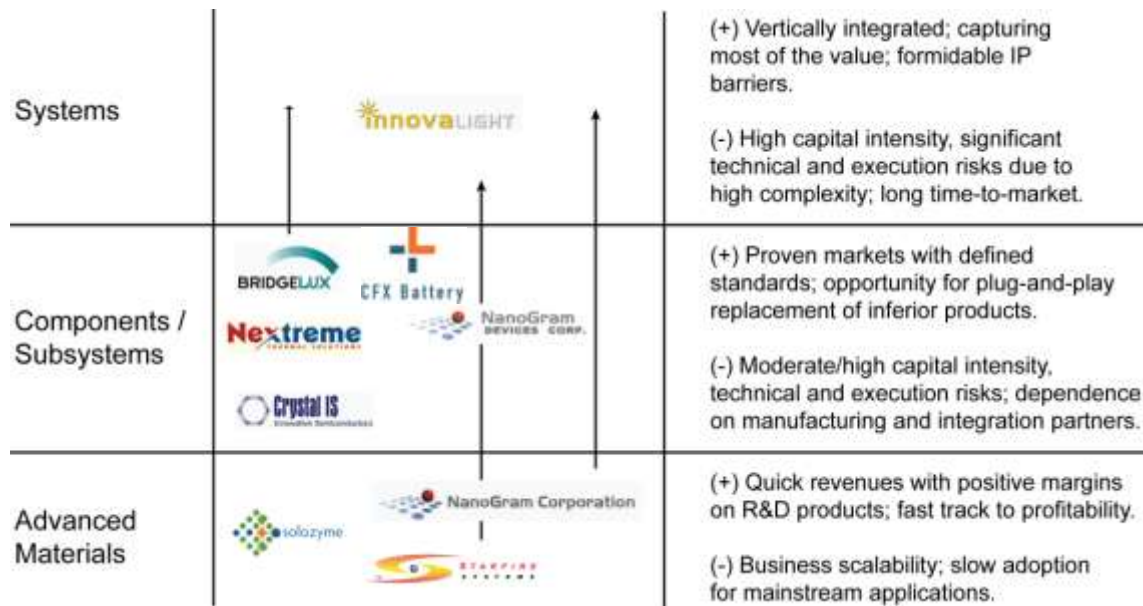


Figure 2. Evolution of current H&H Cleantech portfolio.

On Cleantech valuations and long-term barriers. Cleantech is now attracting significant attention from the public and private markets alike. As an early entrant in the field, we are benefiting from healthy interest in our portfolio companies from other members of the venture capital community, in the form of follow-on investments in these companies [see Table 1]. Although we believe that valuations of Cleantech deals will eventually come under pressure, we think that start-ups built upon *materials for energy* will be less vulnerable because of their IP positions. By contrast, Cleantech start-ups focused on services or integration of off-the-shelf components do not have this competitive barrier.

Conclusion

As an early entrant, we believe that our team at H&H has learned valuable lessons in Cleantech. We have funded *materials for energy* start-ups at all stages of their life cycles, and stayed with our companies all the way through exits. Our portfolio companies have targeted various segments of the value chain, tested different business models, and migrated from one level of integration to another. We do not know all of the answers by any means, but we have learned a lot about technical and execution complexities of these opportunities, usual pitfalls, and avoidable mistakes.

H&H has been one of the most active advanced materials and energy investors of the last decade. In the Cleantech space, we currently have eight such portfolio companies, all enabled by nanotechnology, and we have successfully exited from two Cleantech investments. Owing to our nanotechnology-related advanced materials expertise, academic connections, deal flow, syndication network, and business Rolodex[®], we believe that we are well positioned to increase our investment activity in Cleantech innovations.