DEVELOPMENT OF ENERGY GENERATING TEXTILES & FABRICS

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Goal

We're researching and evaluating the engineering of piezoelectric and photovoltaic threads, circuits and interconnections to create energy generating textiles and fabrics for vertical applications across technical textile and specialty fabrics and smart fabrics.

Research outcomes will yield findings clarifying how piezoelectric and photovoltaic fabrics and textiles could be integrated into textile switches, flexible keypads, iPod & iPhone controls, mobile phone interfaces, garment heating systems, fabric sensors and wearable lighting systems, OEM markets, soldier fighting ensemble and equipment, and workplace and residential drapes, among other applications, we anticipate.

Available Technologies

Piezoelectric elements can be produced as thin ceramic threads for energy generation and harvesting.

Photovoltaic elements can be produced in fibrous forms generating 2.79% to 3.27% efficiency values with stainless steel threads or wires exposed to incident light.[1]

Innovative Challenges

Circuits and interconnections remain challenges and technical barriers to engineering energy generating fabrics or textiles with photovoltaic and piezoelectric threads.

Proof of Concept Approaches

We are designing and engineering energy producing textiles and fabrics using these threads.

For piezoelectric (PZT) threads, research and development focus on automated methods to engineer small diameter PZT fibers in a fabric generator and ranges of textile operations to convert PZT yarn into a generator preform, among other form factors.

For photovoltaic threads, we are evaluating woven fabric or textiles, formed as a series of inter-connected PV filaments and creating electrical circuits, which will be interwoven with other non-PV fibers and threads, for distinct, specific energy generating yields and applications.

We are evaluating knitting as well as weaving.

Consequentiality

Economic viability over existing technology

Woven photovoltaic fabrics and textiles constitute manufacturing innovations and technologies to compete in global, photovoltaic markets, currently characterized by national champion, state subsidies to the detriment of U.S. manufacturing,[2] to complement photovoltaic arrays with fabrics and textiles at competitive yields and price points, ideally at $0.50/kW in time,[3] and to create wide varieties of new energy generating textiles and fabrics generating low cost, renewable energy.[4]

Manufacturing productivity improvement

The energy generating fabrics and textiles, which we propose to create, engineer and evaluate, would constitute vertical technologies with applications for technical textile and specialty fabrics, smart fabrics and across many, potential markets in civilian and military sectors.[5]

Technical textiles, defined as "use(s) of fibers, often engineered in fiber, yarn and fabric form, to provide specific technical performance characteristics to meet the final customer/market requirements, either as a final product in themselves or as a component in another product,"[6] constitute $31B US and $120B world wide markets.[7]

Specialty fabrics include awnings and canopies, safety and technical fabrics (including smart fabrics for battlefield, medical monitoring and interactive textiles), industrial and agricultural tarps, fabric structures, fabric graphics (e.g., signage), marine fabrics and geosynthetic materials and narrow fabrics; that is, textiles that are "no more than 12 inches (300mm) in width and are made by weaving, knitting or braiding fibers or yarns with an edge to prevent unraveling." Specialty fabrics constitute a $18.4B market and are projected to grow to $18.9B by 2015.[8]

Smart fabrics, often defined as textiles with radio frequency capabilities principally for medical and battlefield monitoring applications, constitute a category of specialty fabrics and are valued at $700M. Their definition can extend to fabrics incorporating mechanical, thermal, chemical and magnetic stimuli, currently estimated at $300M annual markets with 36% growth rates.[9]

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Endnotes

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[1] Michael R. Lee, Robert D. Eckert, Karen Forberich, Gilles Dennler, Christoph J. Brabec, Russell A. Gaudiana, "Solar Power Wires Based on Organic Photovoltaic Materials," *Science*, Volume 324, April 10, 2009.

[2] For instance, despite U.S. strength exporting solar manufacturing equipment, "the recent strength of Chinese stocks "truly reflects the low cost base of the Chinese solar manufacturers, and it is great to see their positioning, particularly relative to their American and European counterparts," said K. K. Chan, the chief executive of Nature Elements Capital, a Chinese clean energy investment company based in Beijing. He attributed the Chinese industry's low costs not to inexpensive labor in China -- high-technology solar panel manufacturing is not labor-intensive -- but rather to free or subsidized land from local governments, extensive tax breaks and other state assistance." *The New York Times*, September 2, 2011; August 29, September 1, 7, 2011.

A Solar Energy Technologies Program expert evaluation reports "141% rise in global and 93% rise in U.S. installations…during 2009-2010" noting "the U.S. is expected to lead the global growth rate during 2010-2014." It finds 251MW of PV installed in Q1 '11, bringing total U.S. capacity to 2.3GW." At this point in market development, it reports that "51% of capital invested globally in solar in 2010 came from government supported debt: $23b from China Development Bank in Q2 and Q3 '10; $1.85b from the U.S. DOE Loan Program in Q4 '10." "China's draft five-year energy plan calls for 5 GW of solar in next five years and $9.5b in conditional loans to solar projects [are] yet to be finalized by the U.S. DOE loan program." David Feldman, First Quarter, 2011 Solar Industry Update, Solar Energy Technologies Program, EERE, DOE, June, 2011.

It is all quite consequential due to manufacturing's myriad effects in the national economy and culture. Louis Uchitelle, *The New York Times*, September 11, 2011; Andy Grove Q&A, *Technology Review*, Volume 114, Number 5, September/October, 2011, p.28.

[3] Photovoltaic cells, whether fabricated with monocrystalline or multicrystalline silicon, amorphous silicon thin film, copper indium diselenide/copper indium gallium diselenide (CIS/CIGS) thin film, or cadmium telluride (CdTe) thin film, exhibit distinct efficiency yields and price metrics.

Module Price, Manufacturing Cost, and Efficiency Estimates by Technology, 2008 **Technology**	**Price (2008 $/Wp)**	**Manufacturing Cost (2008 $/Wp)**	**Conversion Efficiency**
High-efficiency monocrystalline silicon	$3.83	$2.24	17.5%
Multicrystalline silicon	$3.43	$2.12–$3.11	13.5%
Amorphous silicon (a-Si) thin film	$3.00	$1.80	6.5%
Copper indium diselenide/copper indium gallium diselenide (CIS/CIGS) thin film	$2.81	$1.26	10.2%
Cadmium telluride (CdTe) thin film	$2.51	$1.25	10.0%

Mehta and Bradford 2009 Cited in EERE, Solar Energies Report, 2008, January, 2010

[4] We foresee new textile products for industrial and residential markets. Installed residential pv base costs are US ($6.9/W), Germany ($4.2/W), Japan ($6.4/W). Galen Barbose, Naim Darghouth, Ryan Wiser, "Tracking the Sun IV, An Historical Summary of the Installed Costs of Photovoltaics in the United States from 1998 to 2010, Lawrence Berkeley National Laboratory, September, 2011 http://eetd.lbl.gov/ea/emp/re-pubs.html for LBNL link to publications.

[5] In very real senses, the innovative energy generating fabrics, which we are proposing, are radically new. Every competent expert in commerce or government, whom we contact, remarks on their innovativeness, so much so, they point to projections for markets which we seek to stimulate based on incumbent PV technologies.

For instance, Pike Research offers a number of projections across several sectors. For the built environment in civilian markets, specifically "building-integrated" and "building-applied" photovoltaics," Pike Research forecasts "wholesale revenues rising from $744 million in 2010 to nearly $4 billion in 2016." It notes new products like solar shingles and shingles, which "blend into rooftops and crystalline-silicon (c-Si) solar panels in various shapes, sizes, colors, transparencies, and patterns that appear to seamlessly blend into a building's structure." For military markets, solar photovoltatic projects will comprise a critical component of U.S. military market adoption of "wind, biomass, geothermal, hydrokinetic energy, biofuels and synfuels, fuel cells, microgrids, smart meters" among other renewable energy technologies "growing from $1.8 billion per year in 2010 to $26.8 billion by 2030." Pike Research also notes doubling stationary fuel cell shipments 2008-2010 and expanding markets. Pike Research, "Building Integrated Photovoltaics," April, 2011, "Renewable Energy for Military Applications," June, 2011, "Fuel Cell Annual Report," "Stationary Fuel Cells," May, 2011.

And, of course, energy generating fabrics and textiles are timeless, too, resonating with myth.

As the full moon climbs the sky, and its risen brightness
shimmers down on the garret bedroom of some young creature
who catches it on her fine dress, and the heart within her
lifts at the sight of that pure radiance, so now Jason…
filled with joy as he hefted the great Fleece in his hands,
and over his fair cheeks and brow the bright glint of its texture
cast a ruddy blush of flame. In size it equaled
the hide of an ox, a yearling….And golden throughout
….heavy the flocks of wool. Brightly the earth
gleamed ever in front of his feet as he strode on forward
Apollonios Rhodios, *The Argonautika: The Story of Jason and the Quest for the Golden Fleece*, IV:168-178 (Peter Green, translator), 1997.

[6] Woon Chang and Peter Kilduff, "The U.S. Market for Technical Textiles," North Carolina State, 2002.

[7] William C. (Bill) Smith, "Technical Textiles 2009, The State of the Industry," June, 2009, www.intexa.com. These comprise approximately 25% of all fibers going into industrial and commercial manufacturing and in the United States and amount to 24M tons for fabric worldwide.

[8] Industrial Fabrics Association International, 2011. IAFI defines and classifies industrial fabrics as "textile products manufactured mainly for their performance and functional properties rather than decorative purposes… such as automotive applications, medical textiles (e.g. scaffolds for tissue engineering), geotextiles (e.g., reinforcement of embankments), agrotextiles (e.g., textiles for crop protection), and protective clothing (e.g. protection against extreme heat for fire

fighters; cut or stab protection in the industrial workplace, and bullet resistant vests for military and law enforcement personnel); traditional markets include awnings, tents, marine (fabric for boats), tarps and truck covers, fabric graphics and also includes smart fabrics used in applications such as those in the military, fire and law enforcement and in aerospace applications." IFAI, July 2011.

[9] S. Lam Po Tang and G*.K. Stylios,* "An Overview of Smart Technologies for Clothing Design and Engineering," *International Journal of Clothing Science and Technology*, Volume 18, Number 2, 2007, p.108.