



Energeia

Development of the University of Kentucky – Toyota Research Partnership: Monozukuri: PART II

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In the previous issue of *Energeia*, Dr. Saito explained the meaning of Monozukuri (a Japanese word consisting of 'mono' which means 'products' and 'zukuri' which means 'process of making or creating') and how this Eastern philosophy can be applied to technical problems to benefit all.

COMPUTATIONAL METHOD, GENCHI-GENBA CONCEPT, AND MONOZUKURI

Computational methods not only save time and energy, but also provide details in virtual-reality conditions under well-controlled initial and boundary conditions that may be difficult to

achieve by experiments. However, all computer models include assumptions. Before computer models are applied to simulate the actual problems, they need to be validated against full-scale experiments, scale-model tests or plant-site observation. Validation by more than one of these methods helps researchers enhance their understanding of the problem.

Special emphasis should be given to the importance of plant site observation, known as "Genchi-Genba," an age-old Japanese philosophy in monozukuri. Genchi means exact location; Genba refers to function. The philosophy underlines the importance of interacting with things and problems directly, and in a specific context. It's a way to contextualize problem-solving in a very concrete way. Progress in high-speed computers made it possible for us to simulate and calculate many industrial problems and phenomena in a relatively short time. It should be noted, however, that the

Genchi-Genga concept is the basic concept for all industry problem-solving processes and should be practiced before we conduct computation, analysis or experiments. Toyoda Saikichi reminds us of the value of on-site observation; he once described for an interviewer how he came up with the Toyota auto-activated loom. We should note the absence of advanced technology and computation in his description:

"In my village, every family farmed and each house had a hand-weaving machine. Influenced by my environment, I gradually began thinking about this hand-weaving machine. Sometimes I would spend all day watching the grandmother next door weaving. I came to understand the way the weaving machine worked."

Figure 4 compares the plant site downward airflow measurement (left) with 2-D Computational Fluid Dynamics (CFD) laminar airflow model simulation (right).

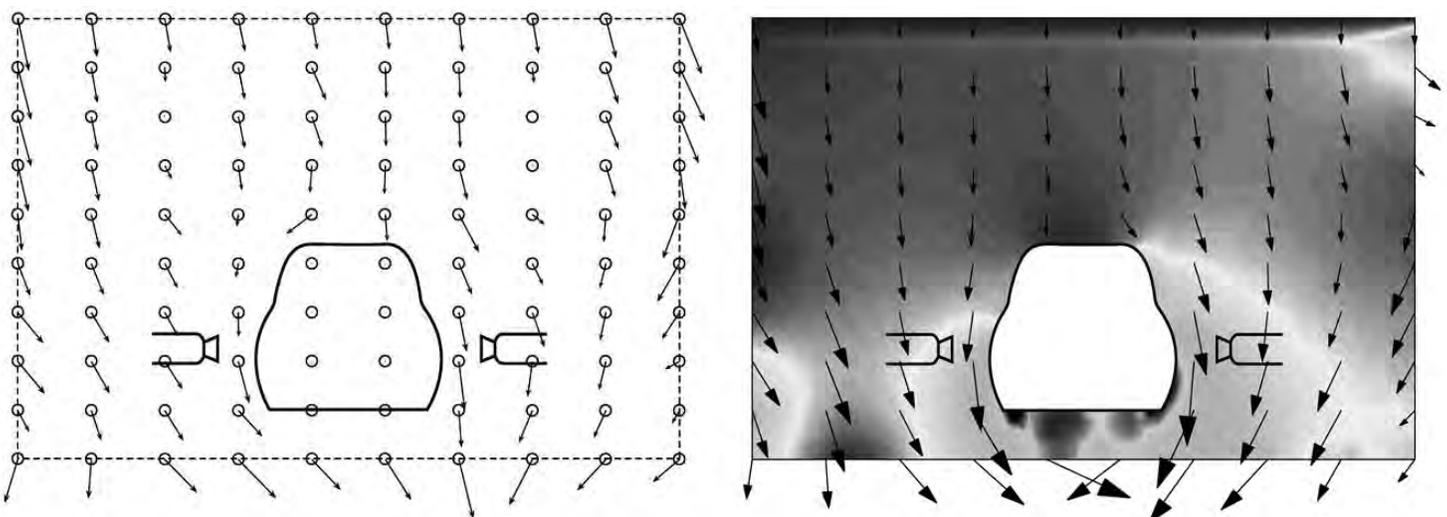


Figure 4. Comparison of a prototype airflow measurement (left) and 2-D laminar Computational Fluid Dynamics (CFD) simulation (right), from A. Salazar, Ph.D. thesis, University of Kentucky, 1998. Color indicates pressure difference inside the booth.

The plant site airflow measurement was conducted by the former members of PE7 team at Toyota Motor Corporation, Motomachi plant (then the general managers, Mr. N. Tanaka and Mr. Y. Tamura kindly provided us with this very useful data) and we conducted the CFD model simulation at IAES. It was very fortunate to have this plant site measurement data to validate our model.

Our simple CFD model simulated the booth airflow profiles with approximately 80 % accuracy. Then, this CFD model was applied to assess an entire airflow structure inside the booth during an actual operation. To assess how accurately our CFD model predicted the actual airflow, we visited a company's paint booth to practice Genchi-Genba. We confirmed qualitative agreement, but also found several miss-matches that required modifications on the CFD model. Taking this step-by-step process of improvement over the past seven years, our CFD model has been upgraded to the transient three-dimensional capability model including the effects of water mist, electric static, and evaporation with better than 95 % accuracy.

VORTECONE INVENTION AS AN EXAMPLE OF TEAMWORK MONOZUKURI

Here I present an example of how scientific and engineering methods worked side by side to develop a new type of wet scrubber that can effectively capture over-spray paint particles. Seven years ago, there was a need to develop a new type of device to capture over-spray paint particles, which have higher capturing efficiency and less energy consumption than products that were already available. All of the wet scrubbers were then designed based on craftsmanship-type experience and categorized as one of three different types: venture type, high-impact type and other type. All of these scrubbers, regardless of type, created high unrecoverable energy loss due to their poor design of fluid dynamics.

Using the above CFD model validated against experiments, we carefully analyzed the wet scrubber that performed best in capturing particles. Prior to our model simulation, we asked the company's engineers why their product worked better than other companies' products, and what mechanism they used to capture fine paint particles of 20 micron diameter. Their explanation was that when air flow carrying the over-

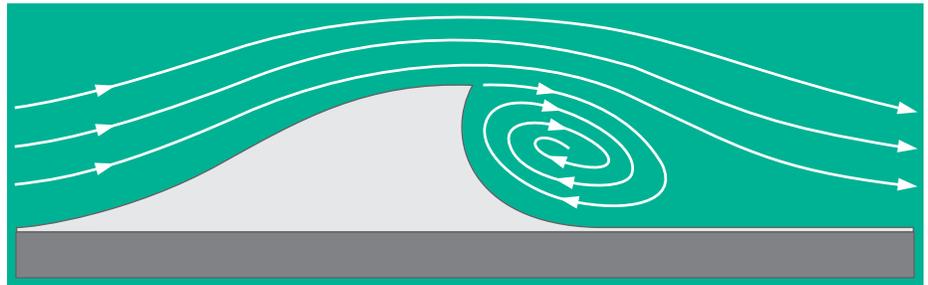


Figure 5. Cross section of a sand dune displaying the flow pattern generated over desert sand.

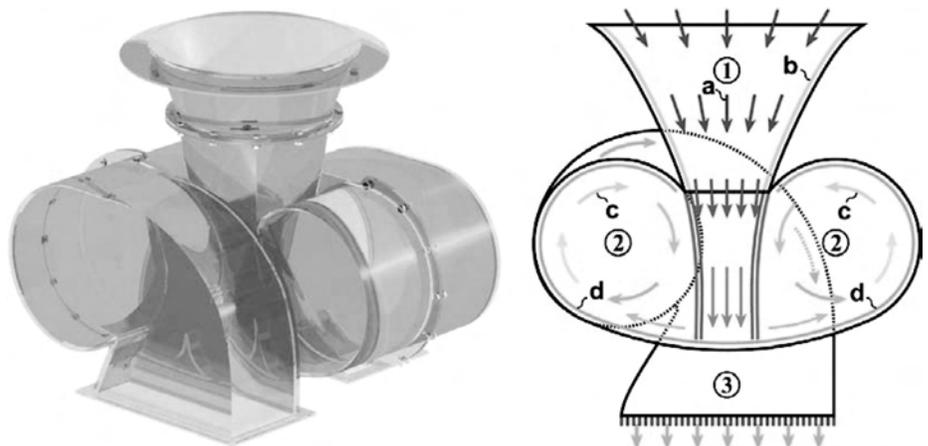
spray paint particles hit a water pool, paint particles penetrated into the water, mixed with water, and were captured by water, but air escaped.

We used our model to simulate the capturing efficiency by the company's suggested mechanism, but failed. During that process, our computer model showed a very interesting vortex flow where particles circulated along the circulation at a least expected location. We carefully analyzed this motion and conducted further calculations that confirmed a newly found vortex mechanism to be very effective in capturing fine paint particles.

Next we considered what might be the best geometry and shape to enhance the vortex while minimizing energy to operate the system. Engineers' creative minds played an important role in this process. We paid attention to a desert where an interaction of wind and fine sand particles creates a special 3-D shape, known as a sand dune. This 3-D crescent shape structure can easily stand against desert storm winds of over 30 m/s. Since sand particles are not

bonded, sand particles would be blown away under a strong wind. Why can the sand dune shape stand against a strong wind? **Figure 5** shows a cross section of the sand dune where the wind blows from left to right. Behind the crescent shape dune, there is a strong circulation which traps the otherwise blown away sand particles, protecting the dune from erosion and also significantly reducing the drag force of air that flows over the dune because the circulation acts as a bearing. The sand dune shape would be most ideal for capturing small particles with lowest energy consumption.

Based on the sand-dune shape, we wanted to build a new type of wet scrubber. As a result, Vortecone over-spray paint scrubber, shown in **Figure 6**, was jointly designed with Toyota and the University of Kentucky. The first prototype was manufactured and tested by Trinity Industrial Corp. in Japan in 1998. The first prototype of Vortecone showed 30 % less energy consumption compared to a traditional type A scrubber, and 37 % less compared to a traditional type B scrubber, while Vortecone's capturing of paint



- ▶ 2 U.S. Patents: US6024796 and US6093250
- ▶ 2 Japanese Patents: JP2004042044 AND JP2005007395
- ▶ 2 European Patents: EP1007219 and EP1258294

Figure 6. Vortecone wet scrubber jointly invented by UK, Toyota and Trinity.

Toyota Research Partnership, (cont.)

mass increased 21 times. Based on these test results, Toyota Motomachi was the first plant to adopt Vortecone scrubbers in the fall of 1998, followed by three other Toyota plants within three years: Takaoka, Tahara, and Indiana. As an additional benefit, the maintenance cycle of three months required for the traditional type scrubbers was extended to one year compared to the type B scrubber.

Based on this success, the University of Kentucky is studying the application of Vortecone to capture fly ash and other combustion by-products from coal-fired power plants. Currently, Kentucky coal-fired power plants use electrostatic precipitators to recover fly ash particles from coal combustion gases. The installed cost of these precipitators varies depending on the fraction of fly ash removed, as dictated by environmental regulations when the plant was granted a permit. New green technology that could either reduce the recovery cost, improve the percent recovered, or both, would improve the market position of coal as a boiler fuel and also help Kentucky's coal-fired utilities update their facilities. This environmentally friendly new green technology for coal-fired power plants, created as spin-off from long-term research collaboration between Toyota and the University of Kentucky, would help enable continued use of coal for power generation in Kentucky and all over the United States.

CONCLUSION

A series of discussions began in the late 1980's through the early 1990's in order to initiate and further develop mutually beneficial research collaboration between the Toyota Georgetown plant and the University of Kentucky. Then Toyota Georgetown plant president was Mr. Fujio Cho, Senior VP was Mr. Alex Warren, VP was Mr. Naoji Tanaka, and the special assistant to President was Mr. Hiro Adachi. All four distinguished Toyota executives shared a common vision to create a win-win-win relationship among industry, university and the state of Kentucky by working together for a common good. This Toyota-UK research collaboration served this purpose and Vortecone can be seen as a product of this effort. The Toyota-UK research collaboration also has grown over the past 13 years, involving more than 10 UK faculty and researchers, and more than 20 UK graduate students. For the year 2004-2005 alone, four Toyota offices (TMC, TMMNA, TMMK, and TTC) funded a total of 12 projects with a total budget of \$1.2M.

Toyota's commitment for long term and sustainable research funding attracted other companies (Nippon Steel, Mitsui Bussan, Ford, Nissan, Honda, Trinity, Admatechs, etc.), Federal agencies (NASA, National Science Foundation, Department of Energy), and the state of Kentucky Economic Development Cabinet to join in investing in UK's research. This group of well-diversified sponsors created a dynamic research environment for faculty, researchers, and students to study a variety of research topics. Some research outcomes are ready to create a spin-off company which will bring in high tech jobs for UK graduates and Kentuckians.

special help, encouragement, and guidance: Mr. Yukio Tamura, Mr. Yasuo Tanigawa, Mr. Ken Kreaflle, Mr. Mark Boire, Mr. Richard Alloo, distinguished members of former TMC PE7, UK Dean Dr. Tom Lester, and Dr. John Walker.

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ACKNOWLEDGEMENTS

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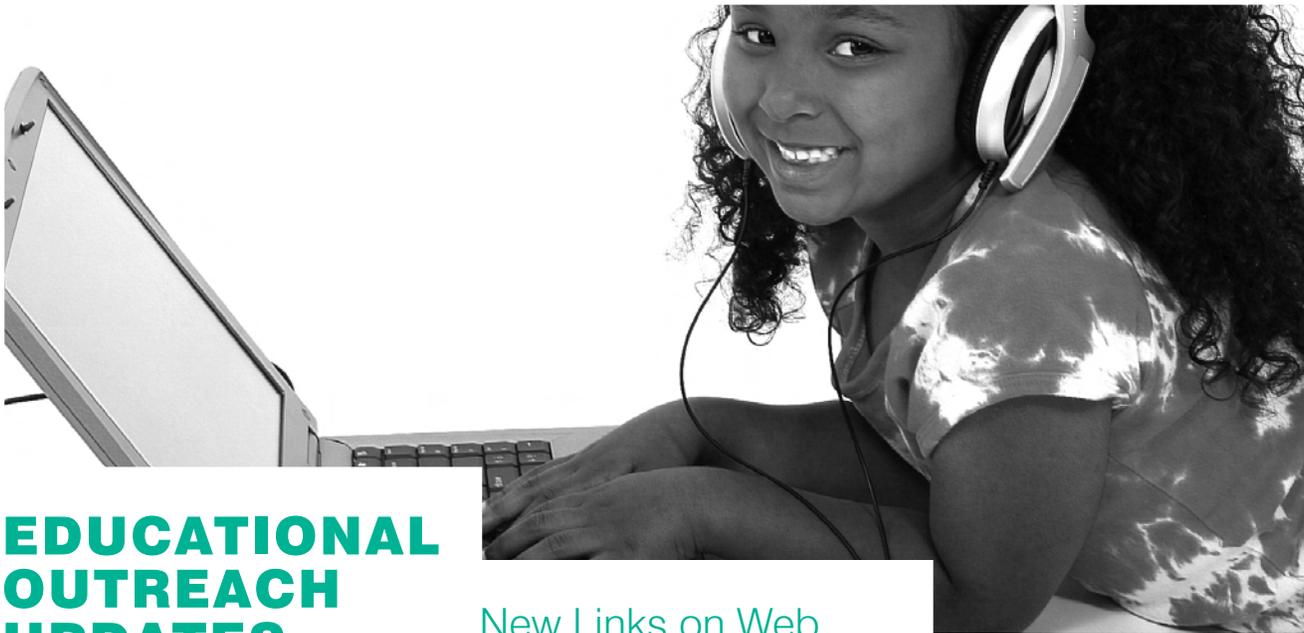
Short Course on the Science of Coal Product Utilization

Monday, May 7th, 2007

8:00 am - 5:00 pm

This short course is being taught in conjunction with the **2007 World of Coal Ash (WOCA)** conference, co-hosted by the University of Kentucky Center for Applied Energy Research and the American Coal Ash Association. It will cover basic information about the science and technology of coal combustion by-products and will be taught by experts from academia and industry. The course that was taught at the 2005 WOCA meeting has been expanded to include two parallel tracks, offering more choices for students, whose knowledge ranges from novice to expert. This course offers Professional Development Credits.

For more information on content, cost, and associated details, go to: <http://www.worldofcoalash.org/registration/shortcourse.html>.



EDUCATIONAL OUTREACH UPDATES

Three New Ways the CAER is Providing Outreach

In addition to our technical work, as a component of the University of Kentucky, the CAER is charged with educational outreach, which takes place in many forms.

New Links on Web

We have pulled together links to many energy education web sites and offer them to our stakeholders for viewing.

If you go to: <http://www.caer.uky.edu/liblinks.shtml> you will find links to energy-education sites for kids, teachers, and the general public. In addition, there are fun links to science fair projects, experiments, and virtual tours. There are also various federal government agencies with more serious educational and informational sites, which are included. If you know of additional links that should be added, please let us know. (mcalister@caer.uky.edu).

Kentucky Ash Education Web Site

Also, in the not-so-distant future we will unveil a new web site dedicated to information and education on coal combustion by-products. The purpose of this site is to educate the layperson or student about what CCBs are, and why they are important to the average individual. It is funded through the university's Commonwealth Collaborative Projects Program; and was selected based on its ability to promote research that addresses Kentucky's ongoing challenges and advancing its future.

Science Experiments On-Line

Since August, 2002 scientists from the CAER have devised and conducted hands-on science experiments with 4th grade students at Russell Cave Elementary School in Lexington, Kentucky. The students have created invisible ink, made generators and thermometers, extracted color from leaves, studied energy and done much, much more. This is a way for our scientists' to share their expertise with the students of the community. As the next step, we are putting some of these experiments on-line for others to use. The experiments will be formatted in Powerpoint and will be downloadable. Educators are encouraged to integrate these experiments into their classrooms. These materials may be utilized for educational, non-commercial use only.

Natural Gas in Crisis

By Peter Savage
The Thinking Companies

We'll look back on the winter of 2005-2006 as the time when the US electric power industry finally got the message that overdependence on natural gas has put it in an uncomfortable, even dangerous, position. For the first time in decades, there was a risk of power outages not caused by falling trees or the machinations of energy traders. Extremely cold weather coupled with short supplies of natural gas might have forced rolling brownouts or blackouts in gas-dependent regions like the Northeast.

Fortunately, that warning has been heeded-better late than never – and US utilities are taking a closer look at their generating mix. The results can only be positive for coal, and for nuclear power in the long run. Under the greatest pressure are power companies and regions with a newly high dependence on gas. California, Texas and New York are especially vulnerable, but even New England boosted its natural gas usage from 13 % of the total in 2000 to 29 % in 2004.

The tight natural gas markets of the 2005-2006 winter may be traced to the triple blows of Hurricanes Katrina, Rita, and Wilma in the Gulf of Mexico. But in reality, natural gas supplies have been tight, and prices rising, for three years. The natural gas industry did a great job of selling its product, but a less than stellar one of replacing diminishing reserves.

How did the electricity industry's overdependence come about? It took a couple of decades, but really accelerated in the late 1990s due to increased deregulation in many important markets. The driving force from the first, however, was that natural gas was abundant, cheap and clean. In hindsight, we've discovered that it is merely clean. With public concerns and the heavy hand of the EPA weighing on the thinking of power companies' management, switching to natural gas at the expense of coal seemed like a no-lose proposition. Coal may have been cheap and abundant, but natural gas was clean.



Put aside the short-term effects of the three recent hurricanes and this is what you see: the US has a natural gas industry whose center of gravity is moving away from the Gulf and heading inland. The natural gas industry also is moving to explore and exploit the kind of reserves it always shunned in the past: natural gas that was too expensive to produce. It has never been a secret that there are considerable reserves of natural gas in such formations as tight sands, gas shales, and coal beds. What has changed is the now almost desperate need to get at them. Such reserves were regarded as non-commercial at \$2-\$3/MMBTU, but they look more attractive at today's natural gas prices of \$6, \$8 and higher.

Improvements in exploration and completion technology – such as 3D seismic surveys and lateral drilling, both fairly recent technologies – have helped turn the Barnett Shale of northern Texas into a boom territory for natural gas production. The same is happening in the Rocky Mountain states. Drillers are now contemplating the possibility that there may be huge,

neglected reserves of natural gas deep below the Appalachian basin and other Midwestern areas that had previously been thought depleted, at least at shallow depths. And there's a good deal of excitement about coal bed methane, and not just in the Powder River Basin.

The reality, after the hype is discarded, is that all of these reserves are expensive to exploit, and that some are, perhaps, even conjectural. Examples of the latter include resources believed to exist in offshore US continental shelf waters, where drilling has been (and continues to be) barred. Disappointing results in deepwater Gulf of Mexico and offshore Nova Scotia production may be telling us that these resources are not what they purport to be. You can't find what is not there.

At present, no less than 50 % of all domestic gas production is coming from what the Energy Information Administration (EIA) calls 'unconventional' sources: sands, shales, and coal beds. It's estimated that about 90 % of exploration dollars are chasing such resources. This situation is not forecast to change in coming years.

If we move beyond the lower 48 states, then we see that Canada – long a reliable supplier of pipelined gas to America – has hit the same problems as the US. Where it once had 30 years' reserves, Canada now has 10 years, despite much higher levels of exploration. Some think that natural gas from the Mackenzie Basin, or even Alaska, will flow south via pipeline and save everyone's bacon. That possibility is unlikely. Construction of both pipelines has been endlessly stalled, and in the meantime, Mackenzie gas is being used to make synthetic crude oil out of oil shale and oil sands.

Another sign of desperation on the part of the natural gas industry is the blossoming of schemes to import liquefied natural gas (LNG) from overseas. Deeply unpopular with residents outside of the US Gulf, terminals to handle the regasification of LNG are proposed for California and along the East Coast. This concept is rashly championed by the US Department of Energy and by

Natural Gas in Crisis, (cont.)

the Federal Energy Regulatory Commission (FERC), which has so far had courts uphold its right to override states' objections to siting these projects.

Our view of LNG importation is that it is folly. The major producers of natural gas – in descending order of importance – are Russia, Iran, and Qatar, followed by a dozen or more nations, nearly all of which are OPEC members. Even if the natural gas were virtually free at its source, it wouldn't be cheaper than \$3-4/MMBTU in a US pipeline. Realistically, both OPEC and a new body – the Gas Exporting Countries Forum, which includes most of the large players – have their eyes on 'price stability' and 'fair prices.' We already learned what that means with crude oil. Unfortunately, some in the US have not learned the lessons of relying on imported energy. Misguided optimists are constructing several new LNG terminals, even as the existing four US terminals run half-empty for want of importers or cheap enough gas to fill them.

This natural gas problem is not just one for the US. In Europe, where various countries have become dependent on natural gas

imported from Russia (or elsewhere), alarm bells are ringing. When Russia cut off natural gas to the Ukraine on January 1, 2006, panic over reliability of the gas supply erupted in Europe and caused energy ministers to rethink fuel mixes. About 30 % of European energy already comes from imported natural gas, and that was set to rise to 50 % by 2025. Clean coal is now a high priority in the latest EC energy policy. France has always had its strongly pro-nuclear policy, and now other nations are reviewing their decisions to walk away from nukes under 'green' pressure. How long will it be before they start to like the look of coal imports again?

It's not as if there aren't better uses for natural gas than power raising, even at the former 'cheap' prices. US chemical companies are hopping mad at the way they've been forced to invest in fertilizer production and other activities overseas to get access to cheap natural gas. What the natural gas industry calls 'demand destruction' has proved to be 'job destruction,' with hundreds of

thousands of well-paid chemical positions lost. Notice, too, that the chemical companies aren't hauling tanker loads of LNG to their now-idled US plants. They know it makes no economic sense!

Ron Savage is a consultant who has 35 years of experience in business, technology and science writing. His degree was in chemical engineering from University College, London, England. Mr. Savage may be reach at: ronin@thinkingenergy.com. A version of this article previously appeared in American Coal, Issue 1, 2006.

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