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COMMENTARY

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Perspective on advanced manufacturing and progress on improvement in societal well-being

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Advances in manufacturing technology, process innovation, and green chemistry are major goals of corporations, research organizations, and the marketplace. When you add goals of enhancing social well-being in both manufacturing and the resulting products, the guidance and results become complex, extend over large boundaries, and involve more disciplines. These more complex, often hidden, challenges often lead to the early adoption of intuitive choices for “what is improvement” (bio must be greener, no toxics leads to safer processes, a cancer-free economy, etc.) This was illustrated in the early development of the building environmental certification system, Leadership in Energy and Environmental Design (LEED), in which architects intuitively formulated sustainability improvements in building design and gave credits to LEED-certified buildings. A number of these credits proved to not be sustainability improvements, and the work of Scheuer and Keoleian[1] demonstrated the need to move away from intuitive guidance on sustainability.

As advanced manufacturing continues to develop and engage with goals of improving and enhancing societal well-being, it will be important to rely less on intuitive approaches and begin to quantify sustainability improvements as a means of developing wider standards for manufacturing technology. Approaches that quantify, analyze, and look more broadly at new chemicals or processes are critical to avoiding regrettable substitutes. Zimmerman and Anastas[2] provide a partial list of such regrettable substitutes (bisphenol S for bisphenol A; 2, 3-pentanedione for diacetyl food flavor). These examples and others led the National Research Council to release a report calling for “informed substitution,” meaning quantitative comparative and broad analyses in seeking improvements in manufacturing and products.[3]

Such quantitative approaches in manufacturing and environmental fields encounter complex challenges of

- collecting quality data,
- geographic location,
- analyses over long time periods,
- larger boundaries for analysis,
- choices of comparisons to measure improvement,
- alternative parameters to measure change in societal well-being (such as disability-adjusted life year, ecotoxicity, or sustainability), and
- how to communicate results, for example, to government policy development or community decision-makers.

However, all of these efforts to move toward more quantitative verification of advanced manufacturing improvement cannot be very effective without data. This is illustrated by issues like our ancestral heritage, the effectiveness of the next cycle of flu vaccines, or molecular links to fight cancer as these challenges would fail without the data of the human or other genomes.

Much of advanced manufacturing, process improvement, and green chemistry are aimed at significant improvement and new approaches to the production of the 100 000 chemicals-in-commerce that underlie all of our global product systems. These industrial chemicals and materials are thus ground zero of the gains in advanced manufacturing. However, to fully assess the environmental, social, and economic improvement of a new technology, one must quantify well beyond a single manufacturing plant. The boundary should extend back to natural resources in the earth and forward to the benefits from customer use and finally to the end of life of products built by these chemicals-in-commerce.

One may also need to examine information about future time segments and global geographic location.

With these wide challenges to better estimate and quantify how manufacturing improves sustainability, a new database should be visualized. Such a database should have high transparency, open access, and show detailed analyses while approaching the size of the 100 000 chemicals-in-commerce. The desired database may thus provide the first answers we need to the demand "*where are the data*" and hence the key to documenting scorecards for improvement in environment and social well-being resulting from developments in advanced manufacturing.

This information would form the core of important sustainability analyses in chemical manufacturing and processing, smart manufacturing, and biological and biochemical manufacturing, which are the focus topics of the *Journal of Advanced Manufacturing and Processing.* With a uniform methodology, each of the 100 000 chemicals to be mapped would have a common file format, all relevant physical properties, and assumptions, thus enhancing the computer integration over value chains and for use in analytics development. It should be noted that the technology to create such a database for chemicals-in-commerce has been successfully developed, while the basic process analyses for macro-shape building (known as unit process life cycle inventory) of chemicals into products is only now beginning.[4] This database also uses high transparency and extensive detail to establish for the user what is available. This stimulates external review and concerns regarding underlying bias.

In conclusion, there are many areas in which the databases described above are needed for advances in manufacturing technology, process innovation, and green chemistry, and these will feed the next phase of analytics development as applied to these data. In large concepts, these impacts are on

- national security;
- engineering, innovation, and manufacturing;
- public health; and
- product design.

An exciting aspect of the path forward is that no one has envisioned the power of creating a fully indexed engineering view of all of industrial chemistry, which is the core of all our consumer, industrial, and military products, capturing what humans have created in the past, present, and future.

CONFLICT OF INTEREST

This commentary represents views developed from 46 years of work in chemical engineering, and hence, the conflict of interest is the author's approach to sustainability and engineering and recent development of the Environmental Genome database, one of the databases referred to herein.

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