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Global energy & emissions reduction potential of chemical process improvements

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ABSTRACT

Current transitions in the global chemical and petrochemical industries provide a unique opportunity to reduce the energy and emissions footprint per unit of production as more efficient technology is brought on-line. They also provide an opening for a revival in industrial R&D focused on improving processes as current technology competes with newer and revived options to address market needs. Over 90% of chemical processes depend on catalysts to efficiently convert raw materials to products. This presents a pivotal opportunity to apply a range of recently advanced capabilities to catalysis and related process improvements. It is also the time to drive emerging technology and game-changers where advances in fundamental science & engineering are needed to lower hurdles and pave the way for next generation technologies.

1. Introduction

More than 95% of all manufactured products rely on chemistry to solve a wide array of problems and provide unique properties for advanced materials. To achieve the highest production efficiency and lowest footprint 90% of chemical processes employ catalysts. Still, the chemical industry consumes 30% of global industrial energy, so improved catalysts and related energy efficiency advances are vital to sustainably employing the global energy supply [1,2].

A recent global chemical industry technology roadmap describes the potential impact of continuous improvements, best practices, emerging technologies, and breakthrough advances to cut energy use and emissions (greenhouse gases (GHG), and other pollutants) [1,2]. Improving the efficiency of olefin production, selectivity of partial oxidation reactions, and alternative routes to feedstocks are among the top opportunities highlighted.

The global chemical industry is in transition as it responds to changes in feedstock availability and type, local resource utilization, and feedstock logistics. In the U.S., the discontinuity of shale gas is prompting a huge wave of investment in state-of-the-art facilities. Ripples in the supply chain include reduced availability of C3, C4 hydrocarbons resulting in the advent of on-purpose plants for those intermediates. In Asia, the drive to use local resources and growth have accelerated coal to chemicals and use of stranded hydrocarbons. The Middle East is increasingly cracking naphtha due to limited availability of gas [3]. Europe is beginning to import natural gas liquids for chemical production, diversifying its reliance on naphtha [4]. Former (Fischer–Tropsch, Houdry process for butadiene) and new technologies (direct conversions) are now being tapped to meet a wide variety of needs across the supply chain [3].

These dramatic supply shifts and changing market needs present a unique opportunity to improve current processes and accelerate progress in future technologies (emerging, game-changers). In parallel, there is a remarkable opportunity to reduce the emissions footprint through a revitalization of industrial catalysis and related process R&D. It also gives an opening to apply advanced capabilities (modeling, high throughput, etc.) and an integrated approach to make step-changes in the understanding of fundamentals so technical hurdles can be lowered.

2. Materials and methods

Publically available data for catalyst impact on process efficiency is limited so a recent roadmap combined information from several complimentary sources [1,2]. Information on the energy use and catalyst impact for the top 40 energy consuming catalytically relevant processes was gathered using a questionnaire sent to chemical manufacturers, catalyst manufacturers, and academic experts. The survey responses were augmented/verified using market research

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data from IHS Consulting, contact with industry experts, and discussions with licensors. Open literature was also used to provide a broad perspective. To compare processes on a similar basis, the specific energy use (SEC) was employed. This is the amount of energy, expressed in GJ/metric ton that an average facility would require to produce a specific product. The impact of catalysts and process improvements were considered as a whole since they are difficult to separate and the integration of efforts is important to emphasize. In this work, process refers to all steps (catalytic and non-catalytic) required to make a product.

Potential improvement opportunities beyond business as usual (BAU) were grouped by;

- II, incremental improvements, small technology advances (e.g. more selective/durable catalysts, optimized reactors, etc.)
- BPT, best practiced technologies, widespread deployment of the best technology demonstrated at scale
- ET, emerging technologies, step-change advances that could realistically be commercialized (e.g. replacement of steam cracking by catalytic process, methanol-to-olefin (MTO) process)
- Game-changers, paradigm shift in the process (e.g. omit intermediate steps, alternative feedstocks, changing basic mechanisms).

In this work, potential energy savings below are given in exajoules (10^{18} J, similar to quadrillion BTUs) and petajoules (10^{15} J) and GHGs are given in millions and billions of metric tons of CO_2 equivalent (Mt CO_2e, Gt CO_2e respectively).

3. Results and discussion

3.1. Industry-wide opportunities and impact

There are thousands of products made by the chemical industry, yet 18 products account for 80% of the energy use and 75% of the GHGs. Some 130 different processes can be used to make those 18 products signaling the complexity of technology use. Fig. 1 shows that five large-volume products dominate the energy use landscape. In this figure, the size of the bubble represents relative GHG emissions as millions of CO_2e tons. Ammonia leads the way on energy use, which is understandable from a production volume perspective as 50% of the world's food production relies on ammonia-based fertilizers. While ethylene is primarily made by steam cracking today, there is progress on catalytic routes, including demonstration plants using catalysts for conversion of naphtha.

The total energy used to make these top 18 products is expected to more than double in the BAU case as chemical production goes up 2–3 times to meet market needs (Fig. 2) such as in high growth

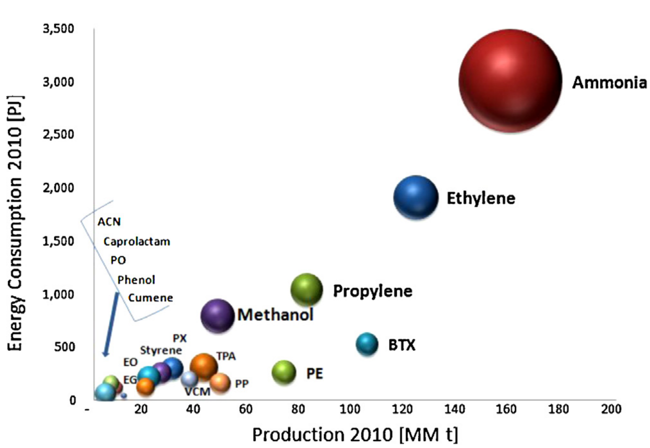

Fig. 1. Energy use of top 18 chemical products [1,2].

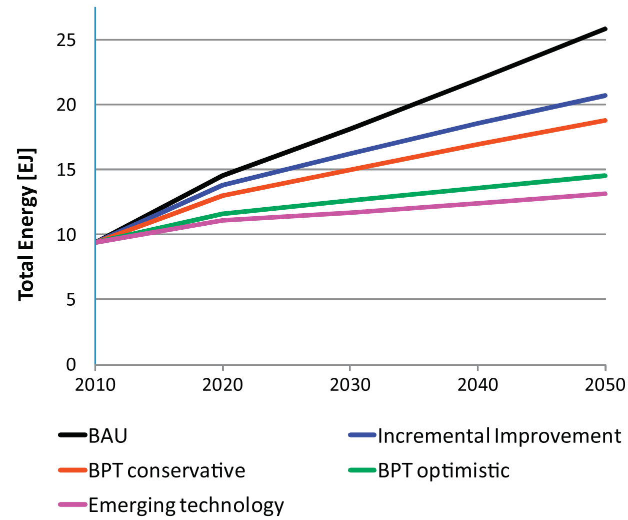

Fig. 2. Projected energy use and potential reductions per scenarios [1,2].

renewables. The potential reductions across all segments noted above could nearly offset the growth. Here the BPT conservative scenario assumes a portion of plants upgrade to BPT whereas the optimistic assumes all plants (new and retrofits) achieve BPT.

The potential reductions in GHGs are shown in Fig. 3. Similarly, the GHG emissions are expected to climb as production grows globally. For some chemical processes, non-energy related GHG emissions are unavoidable as the chemistry instrinsically generates GHGs. Examples would be the stochiometric generation of CO_2 during ammonia production from natural gas where 1 ton of CO_2 is produced per ton of ammonia. This is represented by the black line in Fig. 3.

Compared to BAU, incremental improvements could reduce energy use 20% and GHGs 15% resulting in a savings of 5.3 EJ and 380 Mt of CO_2e by 2050. Increased adoption of BPT (conservative case) could give an additional impact of 6.6 EJ and 560 Mt CO_2e by the same time period. Yet, accelerated BPT adoption is not easy, straight-forward, or quick. The most cost-effective way to implement BPT is during the building of new facilities. Hence, during the current wave of facility construction and subsequent waves (likely with newer technology) it is important that the right investment environment exist for BPT adoption. With catalyst cycle times being years and the need to avoid downstream consequences, it can

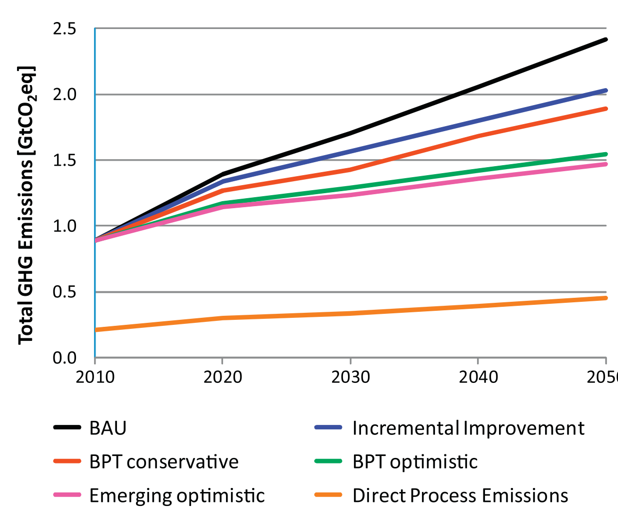

Fig. 3. Projected GHG emissions and potential reductions per scenarios [1,2].