R&D challenges and solutions for OGP Downstream industries

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The petroleum refining, petrochemical and chemical industries face an array of difficult technical challenges, including environmental issues. ABB is responding to these challenges with a proven R&D strategy built on two cornerstones: one is process intensification through multi-functional reactors, integrating catalysis and reaction engineering, and the other promoting collaborations through strategic R&D alliances. We are focusing on 'value growth' and promoting innovation. The chosen R&D strategy is working and we are well positioned to increase our chances of success in the coming decade.

Process improvements, new technology and innovation are required to address the driving forces and technical challenges faced by the refining, chemical and petrochemical industries.

Generating sufficient profit has become very difficult for many oil companies. As the automotive industry successfully develops more fuel-efficient engines, consumers are demanding cleaner and more powerful (high octane) transportation fuels, while legislation is imposing stricter environmental regulations. As a consequence, a great need is emerging for new and improved refinery technologies that will reduce production costs and increase profit. The refinery industry would clearly benefit from an infusion of innovation.

Around the world, environmental protection is becoming a top priority and has already absorbed large capital investments by industry. When confronted with expensive after-the-fact solutions (such as wastewater treatment and sulfur and nitrogen oxides removal from gaseous exhaust streams), new preventative technology often emerges.

We believe that R&D addressing the following areas could potentially have a significant impact on the OGP (Oil, Gas & Petrochemicals) Downstream industry:

- More selective catalyst materials that increase production of desired products
- Better catalysts for the production of cleaner transportation fuels
- Better process control to reduce energy consumption
- Development of new chemistries that use lower cost raw materials
- New processes involving fewer steps, thus lowering investment costs
- Processes for sulfur dioxide removal as well as nitrogen oxide removal, preferably without injection of ammonia
- Development of processes that produce fewer byproducts and have less environmental impact
- Processes for the collection and neutralization of volatile organic compounds from flue gas and exhaust gases
- Solutions for the removal of difficult-to-remove organic compounds from waste water

Table 1: Market and technology trends

Key markets	*Market drivers*	*Technology trends*
Petroleum refining	Cleaner transportation fuels Heavier crudes	Hydroprocessing and complex catalyst systems
Basic petrochemicals	Plastics/ fibers growth	Evolving technology Economy of scale New catalytic routes
Chemical intermediates	Housing and transportation growth	New reaction systems Direct routes from alkanes
Polymers & fibers	GDP growth plus new applications	New catalysts
SynGas	GTL[1], fertilizers and hydrogen demand growth	New reactor systems
Onshore gas Processing	Gas field development	Plant size Evolving technology

[1] GTL Gas-to-liquids

The specific trends and challenges facing the OGP Downstream industries are summarized in *Table 1*.

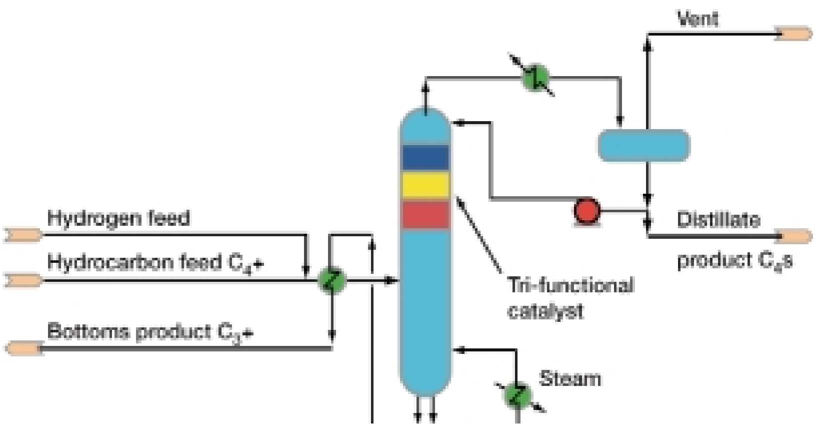
Process intensification and collaboration are the fundamentals of our R&D strategy

To become more competitive and increase our chances of success in the future, R&D related to the challenges outlined above must deal with a series of difficult technology issues. Given realistic financial and manpower constraints, defining priorities is of utmost importance in a climate calling for accelerated innovation and increased speed in moving technologies into the marketplace.

ABB concentrates on large volume commodity products, investing significantly more income into R&D relative to the majority of petroleum and chemical companies, which generally have modest R&D budgets (typically 2-5% of the total) and emphasize value conservation and cost cutting to maintain profitability. On the other hand, we do not invest in R&D at levels which are typical in pharmaceutical companies and which emphasize fundamental studies, innovation and new developments deemed to be necessary for the survival and well-being of the company. At ABB, there is a balanced view regarding R&D for the OGP Downstream industry. Significant amounts go towards innovation, basic research and exploratory efforts, but most of the available resources (typically 55-65%) is invested in improving existing technologies of core importance to ABB's current business.

Economically speaking, R&D projects must be executed with a high degree of efficiency and, from a scientific standpoint, we must produce top quality results. In other words, we must produce more and better results with a shorter time between lab and industrial implementation. This is, obviously, an extremely difficult but not impossible task, given ABB's vision to focus on 'value growth' in its R&D efforts. In OGP Downstream R&D efforts, this is primarily achieved by:

- Emphasizing process intensification through multi-functional reactors, integrating catalysis and reaction engineering
- Promoting collaborations through strategic R&D



1 Flow diagram for CD*Hydro*® process

Process features

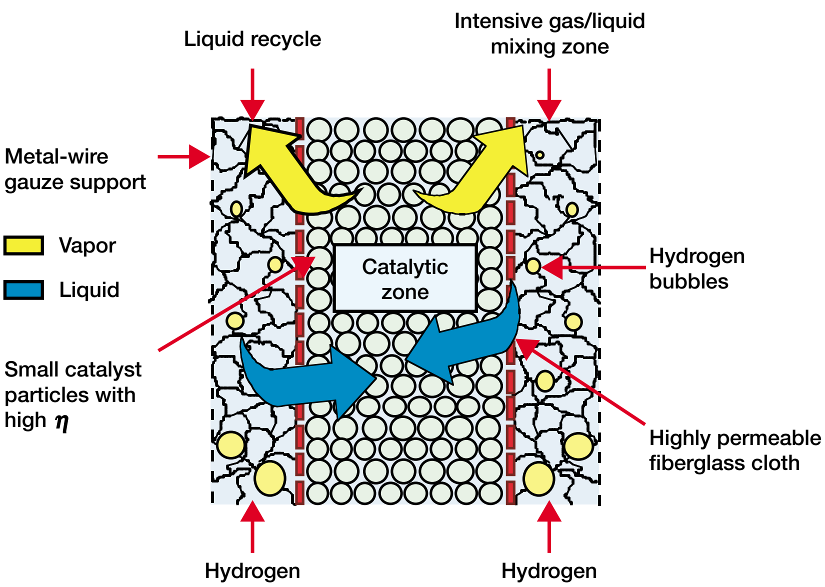
- *Replace trays with catalyst internals*
- *Add hydrogen to feed*
- *Tri-functional catalyst*
  Butadiene hydrogenation
  Butene-1 isomerization
  Sulfur conversion
- *No catalyst fouling*

CD*Hydro*® technology

The following example illustrates how process intensification, as described, can create innovative technology for the future. Catalytic distillation combines reaction and distillation in a single vessel. This technology was developed and commercialized by CDTECH, a partnership between ABB Lummus Global Inc. and Catalyst Research and Licensing, a CRI International company. For this discussion, the CD*Hydro*, hydrogenation process has been selected. This is currently being used in conjunction with a tri-functional catalyst that is capable of butadiene hydrogenation, 1-butene isomerization to 2-butene and the conversion of sulfur-containing compounds in the presence of co-fed hydrogen.

1 is a simplified flow diagram of this process and 2 shows the detail of the catalytic distillation zone of the fractionation tower. Small catalyst particles, packed in the inner core, are kept in place by a highly permeable fiberglass cloth that allows an essentially unrestricted inward and outward transport of reactants and products, both liquid and vapor. During catalytic distillation, catalyst fouling is suppressed because the constant liquid flow over the catalyst particles washes potential 'coke' precursors off the catalyst sites. The external annulus of metal wire gauze mechanically supports the catalyst zone and provides effective counter-current gas/liquid mixing. Novel proprietary reactor internals have been recently developed to further improve catalyst loading in relation to reactor volume and mass transfer characteristics.

2 Principles of CD*Hydro*® process



The first commercial plant using CD*Hydro* technology was brought onstream by Shell at its Norco refinery in Louisiana, USA in February 1994. The startup was flawless and extremely fast, with product diene content within pre-established specification within 14 hours. Overall, butadiene was reduced 99.7%, while at the same time, the 2-butene content of the bottom product was increased by 20%. As expected, catalyst fouling has been practically negligible, and after more than 50 months of continuous operation the catalyst is still performing like new.

The CD*Hydro* process has also been commercialized for the selective hydrogenation of reformate fractions to remove benzene, and commercial operation has been initiated for the selective hydrodesulfurization of C6 fractions from FCC reactors (CDHDS® process).

A second example of process intensification is the Gasoline Alkylation technology described later in this issue of *ABB Review*. Both the CD*Hydro* process and Gasoline Alkylation illustrate that our process intensification approach is a powerful R&D concept that is working well in creating new technology for the OGP Downstream industry.

Industry and university collaborations

With the technology challenges described above in mind and the pressures on R&D to perform better, ABB has been selective in forming strategic R&D alliances. With increased global competition, being first into the market with a new or an improved technology can offer distinct advantages. Typical examples of successful technology partnerships are listed in *Table 2*. By alignment of competencies, we have been able to put together R&D teams with added strength, capable of increasing the speed of projects, while saving resources.

With respect to accelerating innovation, collaborations with universities can offer major advantages. Universities usually work at the cutting edge of new technology and consequently, these collaborations can considerably reduce the gap between basic and exploratory applied research.

Table 2: Typical ABB process/catalyst alliances

Process	Description	Process partner	Catalyst manufacturer
Hydrocracking	Hydrogenation	Chevron	Chevron/ABB JV
LC-fining	Resid hydrocracking	Amoco/ Occidental	Davison, Criterion, Crosfield
Ethylbenzene	Aromatic alkylation	UOP/CR&L	UOP or other
Styrene	Dehydrogenation	UOP	UCI
Maleic anhydride	Oxidation	Lonza	Lonza
Polyethylene	Ethylene polymerization	NOVA	
Polypropylene	Propylene polymerization	Targor	Targor
$C_4/C_5/C_6$ isomerization	Paraffin isomerization	Akzo Nobel	Akzo Nobel
Catofin	Paraffin dehydrogenation	UCI	UCI

ABB currently works with several universities on a variety of catalysis and reaction engineering projects. Topics now under investigation include catalytic routes to lower olefins, development of novel mesoporous materials, and advanced low-pressure drop, high-energy input reactors. Furthermore, we are initiating projects related to homogenizing heterogeneous catalysts and to high temperature, high mass-flow inorganic membranes.

ABB's zeolite catalyst synthesis technology and the micro-engineered catalysts (MEC), also described later in this issue of *ABB Review*, are pertinent examples of successful collaborations with universities.

Enhancement of our core competency

We cannot rapidly adjust to the changing market situation without changing ourselves. Consequently, we are eager to adopt new tools and apply cutting-edge concepts. Our R&D efforts focus on new developments in reaction engineering and catalysis as the foundation of our process intensification R&D strategy.

In reaction engineering, we are growing our competency in applying computational fluid dynamics (CFD) to solve issues with reactor systems in our current technology portfolio. For example, we apply CFD in creating new pyrolysis heaters for olefins production. In working with selected universities, we are also engaged in developing several alternative reactor systems that can provide advantages by improving inter-phase mass and/or heat transfer, while maintaining ultra-low pressure drop. The MEC system is a recent example of such a novel reactor system. Other advanced reactor systems utilizing this approach are currently being considered for funding in the near future.

Catalysis has been identified as a key area where competency growth is required. With appreciable success, we have already been pursuing catalyst pore structure engineering as an important area. In many technologies, 3-level pore structure control offers possibilities to improve the yield as well as the stability of the catalyst. The article on zeolite catalysts synthesis illustrates a recent success along these lines.

The use of '*in situ*' techniques to obtain information on changes in the catalyst under actual reaction conditions is beginning to be used routinely in catalyst research. This information, available to us through university collaborations, can be used in a powerful way to design improved catalysts. In this context, computational modeling will be used more and more in catalyst development, especially for homogeneous catalysts and zeolites. For most heterogeneous catalysts, however, the utility of these techniques will be limited by the catalysts' complexity.

We expect that the introduction of combinatorial and high throughput methodologies will revolutionize catalyst development in the coming years. Most likely, this new approach will be more useful for catalyst optimization than for catalyst discovery. In order to have access to combinatorial and high throughput methodologies, we will probably choose to work with a smaller startup company before adopting this approach for in-house experimentation.

From a business standpoint, it is becoming evident that through advanced catalysts we have an opportunity to grow our revenues substantially. In order to do so, larger investments and more resources are required.

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