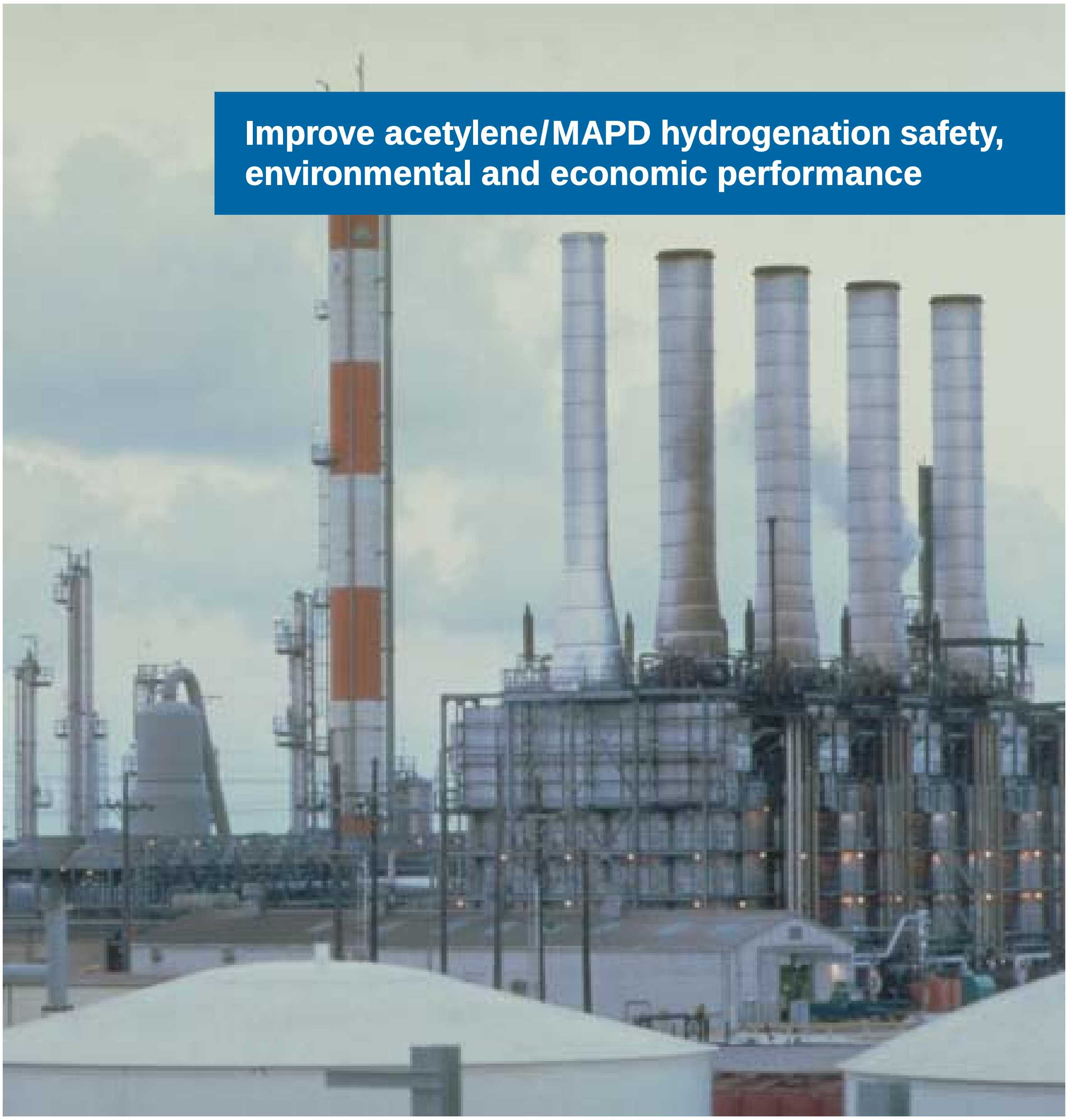
# Industrial$^{IT}$ for Acetylene/MAPD Hydrogenation

## Creating value through integrated solutions




ABB

# Improve acetylene/MAPD hydrogenation safety, environmental and economic performance

## Overview

Petrochemical companies continuously strive to enhance the profitabilty of their ethylene plant operations as they face the ongoing challenges of an increasingly competitive industry. Growing competition from low-cost feedstock producers, tightening environmental regulations, and increasingly volatile feedstock and energy costs all contribute to the necessity of operating plants at maximum efficiency and reliability.

The selective hydrogenation of acetylenes is a key unit operation within the ethylene process and can make a significant contribution to the efficiency gains demanded by this competitive operating environment. Optimization of this critical process step results in enhanced olefin yields, consistent delivery of on-specification product, and lower utility costs, resulting in significant improvements in overall plant operating economics. In addition, the ever present risk of reactor "runaways" and product flaring can be reduced, minimizing operational impact on employees and local communities, while complying with emission legislation.

ABB offers a unique Industrial$^{IT}$ solution for Acetylene/MAPD Hydrogenation Units to assist operating companies in meeting the significant challenges of today's operating environment that are of critical importance from financial and reputation perspectives.

- Our leading technology for acetylene hydrogenation units is multivariable, model-predictive control that exploits our capability for real-time analysis of feed and intermediate streams within multi-converter units. This unique approach can help operators maximize olefin gains and avoid the common problems leading to plant upsets and performance deterioration.
- On-line measurement of conversion and selectivity available in real-time for all catalyst beds delivered by our leading analytical technology.
- Process analytical technology for hydrogen and olefin product quality helps to improve reactor yields and ensure continuous availability of on-specification product.
- A complete service portfolio including field services, on-line support, training and parts/repair in order to maintain the performance of your Industrial$^{IT}$ solution.

## Industrial$^{IT}$ for Acetylene/MAPD Hydrogenation

- Employs our unique capability for real-time, on-line measurement of conversion and selectivity.
- A low cost option to improve olefin selectivity and reduce product flaring incidents.
- Achievable benefits of $2-3M per plant.
- You have the insurance that other leading operating companies are already enjoying the benefits of our acetylene hydrogenation unit technology which reduces your risk and assists in local justification of project expense.
- Allows for simple and synergistic upward migration to the entire family of olefin plant solutions from ABB.
- All elements can be seamlessly integrated into your existing unit.

Operators can obtain a combined analytical and control solution from one vendor, delivering unique synergistic benefits to the operation of acetylene converters. This leads to enhanced unit reliability and selectivity while ensuring safe operation.

## Acetylene Hydrogenation Unit Operations

Operation of acetylene hydrogenation units (AHUs) is a difficult undertaking and subject to the most testing of operating regimes. This is due to a number of industry specific constraints and operating issues that stretch the processing capability of the units.

### Operating issues

- AHUs must be able to deal with feedstocks that routinely vary in both acetylene content and volume due to upstream operating complexities, while maximizing olefin gains and availability of on-specification product.
- They must operate in a safe manner despite the ever-present and real concerns of “thermal runaways” caused by non-routine operations or poor reactor control.
- Operation must meet run-time and selectivity objectives for the catalyst as the formation of heavier by-products adversely impacts olefin yields, operating cycle length and regeneration frequency.

The demands on the acetylene hydrogenation unit are further increased due to ongoing trends within the ethylene industry.

## Industry trends

- Increased cracking feedstock flexibility.
- Proliferation of plant revamps as existing producers preferentially gain additional capacity at lower incremental costs compared to construction of grass roots units.
- A continuing trend towards higher severity cracking operations.
- Ever increasing demands from consumer plants and polymerization technology for improved availability and quality of olefin feedstock.

All of these scenarios result in ongoing demands on the AHU to be more flexible in handling increased and varying acetylene contents, while enhancing unit reliability and olefin quality.

## Environmental issues

The whole petrochemical industry is subject to ever-tightening environmental legislation.

- Regulations continue to drive towards minimizing emissions and much effort is made by operators to improve, monitor and report environmental performance.
- Penalties for non-compliance are expensive from financial as well as reputation perspectives.
- Compliance agencies are reluctant to grant operating waivers for flaring incidents that result in increased emissions over and above permitted levels. Off-specification operation of AHUs commonly results in a number of such incidents on a yearly basis.

Industry trends, complex operating conditions and more stringent environmental compliance all contribute to increasing difficulties of operating acetylene hydrogenation units. To meet these challenges, it is more important now than ever, that these units improve olefin product yields, reliability and operational flexibility.

## Case study 1 – North American Ethylene Plant

A North American ethylene plant has recently installed ABB technology for improved control of acetylene and MAPD hydrogenation units. The variable nature of unit feeds had been causing significant disturbances to the optimum operation of the converters. The problem was compounded by the slow response of existing conventional analyzers and poor performance of inferential measurements. Fluctuations in raw C2 feed and inter-bed acetylene content led to poor hydrogen ratio control which resulted in a number of flaring incidents. As well as the obvious economic penalties associated with such events, the operating company was extremely concerned about the environmental compliance and local community impact of such incidents. To mitigate these events, our real-time analysis technology for feed and inter-bed streams has been employed. The operator is targeting a reduction in flaring of at least two incidents per year coupled with improved olefin yields.

# Meeting the challenges

## What are the options for Acetylene/MAPD Hydrogenation Unit operators?

Further technical developments and improvements in acetylene/MAPD hydrogenation must meet these increasing operational challenges. AHU technology must be highly focused on economic, safety and environmental compliance issues while improving operability of current operations. In the last few years, the first choice of many operators has been to install new technology supplied by the catalyst industry. This approach has been successful in improving many of the operating problems and challenges experienced in AHU operations. However, despite these improvements, a number of historical challenges still exist that significantly hinder the optimum economic and safe operation of these units. In this respect, improved process control of existing assets can further enhance unit operability. Advanced process control is always one of the most efficient, low cost actions that is undertaken by the operators of any process unit. Many of the ongoing operating problems affecting AHUs are a result of less than optimum process control of key unit targets.

Depending on whether the acetylene/MAPD hydrogenation is carried out in front-end or tail-end mode, there are a number of different disturbance variables that affect the operation of the unit.

In addition, process control is more complicated in the case of multiple converter-beds while iso-thermal or adiabatic operation add further individual demands to the implemented control scheme. However, the primary disturbance variables in all configurations are feedrate, raw olefin stream composition (especially acetylene/MAPD content) and in some cases, hydrogen purity.

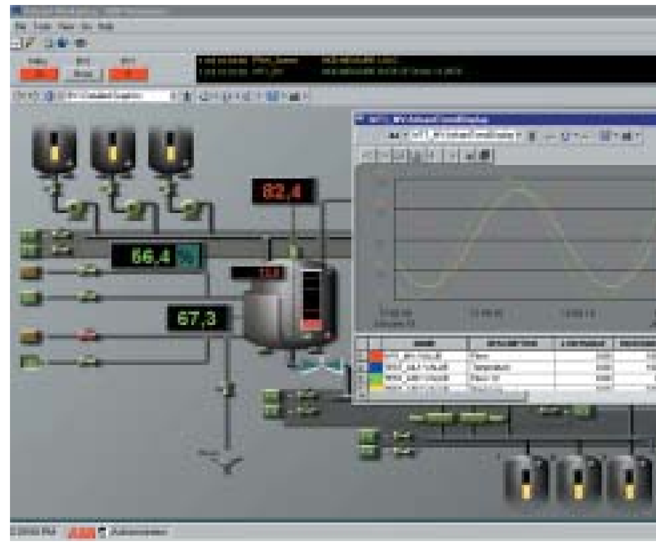
These disturbances are routine occurences within ethylene units and can be caused by:

- Furnace shutdowns
- Severity changes
- Feed-type switches
- Fractionation plant upsets

These variations significantly challenge the ability of the control scheme to continuously achieve:

- Safe unit operation
- On-specification product availability
- Reduced flaring
- Improved selectivity
- Olefin yield gains across the unit
- Low by-product formation
- Acceptable run-lengths and regeneration frequency

These and other common AHU operating challenges that have been experienced for many years in the industry can now be managed by the application of ABB's Acetylene/MAPD Hydrogenation Industrial IT Solution. Operators that have been limited in their ability to deal with day to day upsets due to these uncontrollable disturbances, can now maintain optimum control of AHU unit operations. This leads to significant improvement in unit economic, safety and environmental performance.




# Industrial[IT] for Acetylene/MAPD Hydrogenation

## 1 Hydrogen: Acetylene ratio control

**Common Operating Problems**

- The majority of plants run with poor hydrogen:acetylene ratio control resulting in:
  - – lower reaction selectivity leading to reduced olefin gains (or net losses)
  - – acetylene slippage causing off-specification product and flaring
  - – closer approaches to runaway conditions
  - – higher "green oil" production leading to increased regeneration frequency and shorter catalyst life
  - – product downgrades to ethane (or propane) with associated recycle costs.
- The poor ratio control is further deteriorated by rapid feed compositional changes which are not adequately tracked by the slow analytical response of traditional analyzers. These include changes in acetylenic content as well as heavy ends from upstream fractionation upsets.
- During plant upsets, operators tend to ramp up to excessive hydrogen addition rates in order to absolutely maintain on-specification product. This causes extremely high olefin losses due to greatly reduced selectivity and the reactor is usually held in this condition for far longer than the duration of the initial incident.

**Solution**

Implementation of ABB multivariable control technology driven by our unique capabilty of real-time feed and mid-bed stream characterization, allows these common operating problems to be solved.

Feeds to lead and guard beds are characterized in real-time providing a true hydrogen demand picture leading to optimum hydrogen ratio control. This unique capability is inherently more effective than traditional approaches to ratio control which rely on slow feedback from gas chromatographs. As part of a wider multivariable control scheme, this approach will lead to improvements in olefin yields compared to conventional baseline APC performance. In addition, plant upsets are smoothly managed, eliminating operator initiated overhydrogenation for extended periods of time.

## 2 Conversion and selectivity optimization

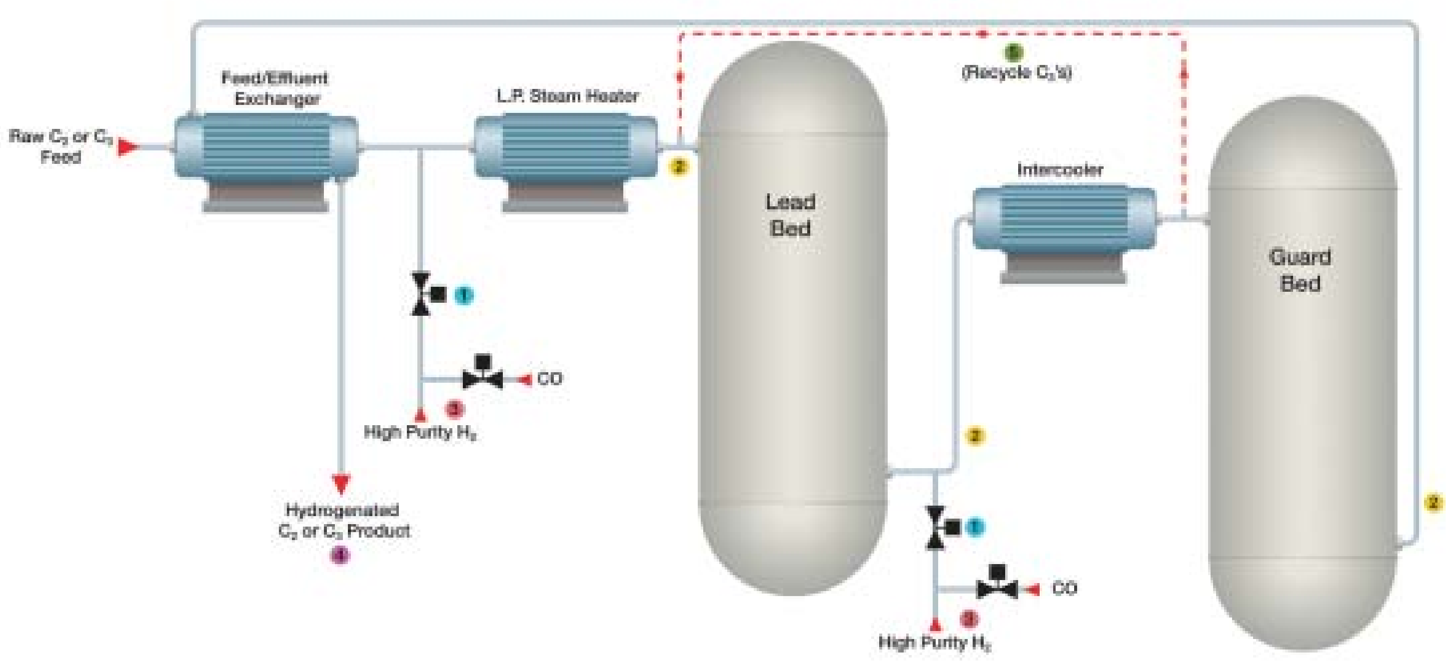
**Common Operating Problems**

- Operators are currently limited in their capability to rapidly and accurately track bed conversion and selectivity performance. Current methods include the use of reactor temperature differentials or slow feedback from gas chromatographs. The sub-optimum performance of these approaches is further compounded when feed composition is subject to rapid changes. The following problems are evident in many units:
  - – Operating campaigns are extended beyond the optimum regeneration point in the cycle as olefin yield losses are not rapidly or accurately determined.
  - – Conversion is concentrated too much on the lead reactor, which as well as reducing selectivity, results in accelerated fouling of the bed and shorter run-lengths.
  - – Heavy ends from upstream fractionation upsets can enter the reactors undetected and cause selectivity losses, catalyst/exchanger fouling and closer approaches to runaway conditions.
  - – Rapid and large ethylene losses cannot be determined quickly enough to definitively indicate runaway conditions.

**Solution**

The implementation of ABB PIR3502 photometer technology allows these common operating problems to be solved. Ethylene, ethane and acetylene content of lead and guard bed feeds can be determined in real-time. In addition, the ethylene and ethane content of guard bed effluent is measured. The analagous components for MAPD hydrogenation units are also determined in real-time by the ABB technology. For the first time, an operator can track conversion and selectivity across the converter beds, in real-time. Furthermore, heavy-ends can be detected in lead bed feed by tracking propylene or butadiene in C2 and C3 hydrogenation units respectively.

The availability of real-time conversion and selectivity data is a key element of ABB's multivariable control approach and results in industry leading safety, economic and environmental performance for acetylene and MAPD hydrogenation units.



## 3 Hydrogen quality

**Common Operating Problems**

- CO spikes in hydrogen feed can occur due to operating problems in upstream methanation or pressure swing adsorption (PSA) units.
- For CO moderated catalysts, poor control of methanation or PSA reactor bypass can lead to sub-optimum catalyst operation and olefin losses.

**Solution**

ABB offers our PGC 2000 gas chromatograph and Advance Optima technology for hydrogen quality measurements. The traditional approach to hydrogen quality measurement in ethylene plants has been gas chromatography and ABB has installed many such units in this duty. Our Advance Optima Uras 14 has also been used extensively for hydrogen quality measurements, providing continuous real-time chracterization. Faster hydrogen quality measurements can rapidly detect process upsets and so prevent catalyst problems and associated operational penalties. The rapid availability of hydrogen quality is a key element of ABB's multivariable control package for acetylene hydrogenation units.

## 4 Hydrogenated $C_2$/$C_3$ product quality

**Common Operating Problems**

- Unreliable analyzer feedback resulting in:
  - acetylene contamination of downstream fractionation tower
  - hydrogen slippage to product which reduces reaction selectivity and requires pasteurization of olefin product in downstream splitter
  - poor selectivity control due to slow feedback of ethylene and ethane content (or propylene and propane in MAPD units)

**Solution**

For these key measurements in the ethylene process, our approach includes our PGC 2000 gas chromatograph for hydrogen and acetylene measurements, and our PIR3502 photometer technology for real-time indication of ethane and ethylene content of the guard bed effluent stream.

The reliability of our technologies for these applications has been rewarded with the leading supply position within the ethylene industry. Operators can rely on the performance of our analytical solutions to help them make operational decisions regarding olefin product quality which can have huge economic implications for the ethylene unit and downstream consumers.

## 5 MAPD hydrogenation

**Common Operating Problems**

- In common with C2 hydrogenation units, these converters commonly operate with poor hydrogen:acetylene ratio control resulting in:
  - lower reaction selectivity leading to reduced propylene gain
  - MAPD slippage causing off-specification product
  - higher "green oil" production
  - product downgrades to propane with associated recycle costs
- The poor ratio control is further deteriorated by rapid feed compositional changes which are not adequately tracked by the slow analytical response of traditional analyzers. This includes changes in MAPD content as well as heavy ends from upstream fractionation upsets.

In addition, unique problems associated with MAPD hydrogenation units include:

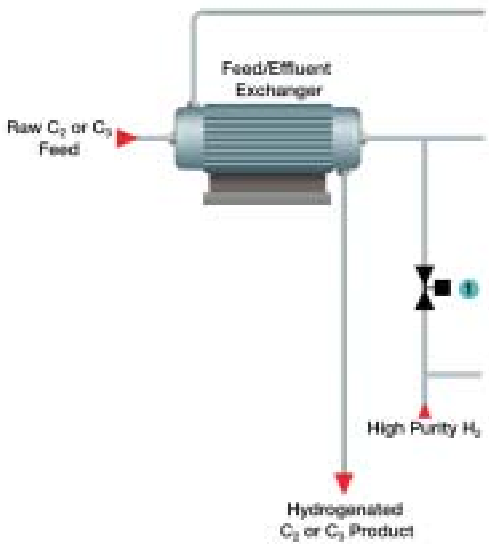
- The strongly exothermic hydrogenation of MAPD components coupled with the presence of heavy ends in the feed cause accelerated by-product formation leading to shorter catalyst run-lengths. Breakthrough of butadiene from upstream fractionation upsets also causes reduced selectivity. This is commonly "solved" by operator induced overhydrogenation which is usually implemented for excessive periods.
- Operating safety demands that the significant exotherms experienced in MAPD hydrogenation be tightly controlled. This is commonly achieved by recycling lead bed product in liquid phase two-bed systems in order to limit the MAPD content in fresh feed. Poor ratio control of this step is common with unnecessary large recycles leading to poor conversion/selectivity control, higher energy costs and risk of over-evaporation of liquid in the reactors. This challenge is further compounded by rapid feed composition changes.
- Less commonly, MAPD hydrogenation is carried out in the vapor phase. These units are well known to exhibit low propylene gains or net losses throughout their operating cycle due to poor selectivity. High green oil production is also a common occurence. These intrinsically poor characteristics of vapor phase C3 systems are further exacerbated by poor control of disturbances in feed composition leading to unacceptable olefin losses and run-lengths.

**Solution**

Implementation of ABB multivariable control technology driven by our unique capabilty of real-time feed and mid-bed stream characterization, allows these common operating problems to be solved.

Feeds to lead and guard beds are characterized in real-time providing a true hydrogen demand picture leading to optimum hydrogen ratio control and efficient management of heavy end breakthroughs. This unique capability also allows liquid recycle ratio control to be precisely controlled as feed and lead bed effluent MAPD contents are determined in real-time. Application to vapor phase systems can mitigate the intrinsically poorer performance of these systems leading to olefin gains and acceptable run-lengths.

# Benefits of Industrial$^{IT}$ for Acetylene/MAPD Hydrogenation




## 1 Hydrogen:Acetylene Ratio Control

Setting hydrogen addition rates based on the real-time characterization of lead and guard bed feeds offers several advantages to the operator. This unique capability from ABB is inherently more effective than traditional APC approaches which rely upon slow analyzer feedback.

- Average hydrogen:acetylene ratios are lowered even in those operations that have already implemented traditional advanced process control in an attempt to improve baseline unit performance.
- Flaring incidents are reduced as the hydrogen ratio is maintained consistently, without dead-time effects, resulting in higher availability of on-specification ethylene product. Annualized savings associated with reduced flaring are in the range of $1 - 2M depending on current baseline reactor performance. (basis: 1 billion pound per annum ethylene unit).
- Ethylene yields are increased due to improvements in olefin selectivity across the converter beds. Implementing traditional APC can improve olefin yields (as a percentage of feed) by up to 0.5%. The enhanced ABB approach can further improve olefin yield gain by another 0.2%. For a billion pound per year ethylene plant this results in average benefits of $1.5 - 2.1M per annum. In addition, ethane recycle is reduced resulting in lower utility costs.
- Less frequent approaches to runaway conditions are experienced as precise hydrogen ratio control avoids overhydrogenation and rapid ethylene consumption.
- Plants can finally realize the expected gains of recent investments in state of the art catalysts by truly exploiting their enhanced capability for lower hydrogen:acetylene ratio operation. Many plants still run hydrogen ratios “on the safe side” despite having implemented capable catalysts.
- Reduce green oil formation and the need for large inlet temperature increases to maintain unit conversion. Lowering by-product formation will improve olefin selectivity and reduce the need for bed regeneration which ultimately leads to shorter catalyst life. In addition, as the catalyst proceeds through its normal operating cycle, optimum hydrogen ratios can be maintained by tracking unit performance in real-time and so avoiding unecessary inlet temperature increases.
- Maintain optimum ratio control during plant upsets when operators have historically ramped up to excessive hydrogen addition rates. This avoids unnecessary overhydrogenation for periods exceeding the lifetime of the “incident”. Real-time determination of acetylene as well as “heavies” allows rapid intervention by the advanced process control scheme.

### Case Study 2 – North American Ethylene Plant

A North American ethylene plant has been using ABB analytical technology for real-time feed and intermediate stream characterization for over 10 years. Like all operators of front-end hydrogenation units, the company had a critical need for rapid CO and acetylene measurements in lead bed reactor feed. The main drivers were prevention of runaway conditions and optimization of ethylene yield gains across the converter. In addition, the capability for determining CO and acetylene in lead reactor effluent was also implemented in order to optimize the guard reactor.

Both analyzers have operated successfully during this period resulting in huge payback for the operating company.

# Benefits of Industrial[IT] for Acetylene/MAPD Hydrogenation

## 2 Conversion and Selectivity Optimization

Many of the benefits associated with optimization of converter selectivity and conversion are coincident with those achieved by tighter hydrogen:acetylene ratio control. However, the operator can gain additional benefits from the real-time tracking of these critical operating variables.

- The optimum balance of run-length management and ethylene yield gains can be achieved by real-time indication of conversion and selectivity throughout an operating cycle. Plants can avoid the all too common problem of keeping a reactor on-line for too long due to delayed or unreliable secondary correlation feedback on reactor performance. These events result in unnecessary olefin yield losses.
- Catalyst poisoning incidents can be rapidly detected and managed as they instantly affect conversion and selectivity of the reactor.
- Real-time conversion and selectivity data allows the operator to distribute conversion more evenly between lead and guard (or multiple) beds which can be beneficial during the course of a catalyst operating cycle. The real-time control reduces the risk of acetylene breakthrough while obtaining benefits in bed lifetime and selectivity.
- Provides primary evidence of an approach to runaway conditions in addition to reactor temperature measurements. The continuous real-time measurement of ethylene and ethane content in reactor effluent streams (all beds), helps avoid unnecessary process interventions or shutdowns due to instrument reliability issues or operator doubt.  More importantly, this capability allows operators to take definitive steps to mitigate potential excursions in their early stages.
- Track heavy ends (propylene and butadiene) in $C_2$ and $C_3$ feeds respectively and avoid reactor fouling, loss of selectivity and approaches to runaway conditions.


## 3 Hydrogen Quality

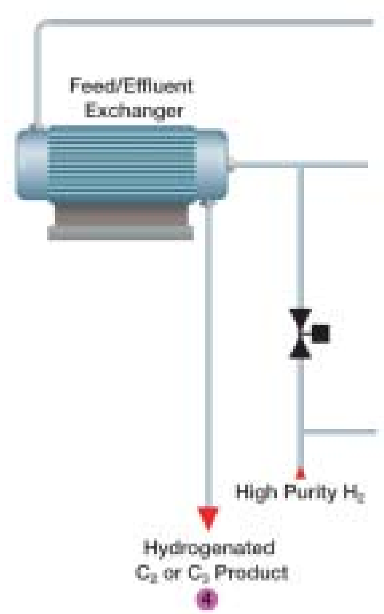
Rapid, on-line determination of $H_2$ quality allows the operator to:

- Prevent off-specification slippage of acetylene to ethylene product due to inadequate hydrogen ratio control.
- Implement optimum control of CO injection systems or methanator bypass rates for CO-moderated catalysts and so increase olefin yields.
- Detect upsets in upstream methanation or PSA systems causing CO spikes.


## 4 Hydrogenated $C_2$/$C_3$ Product Quality

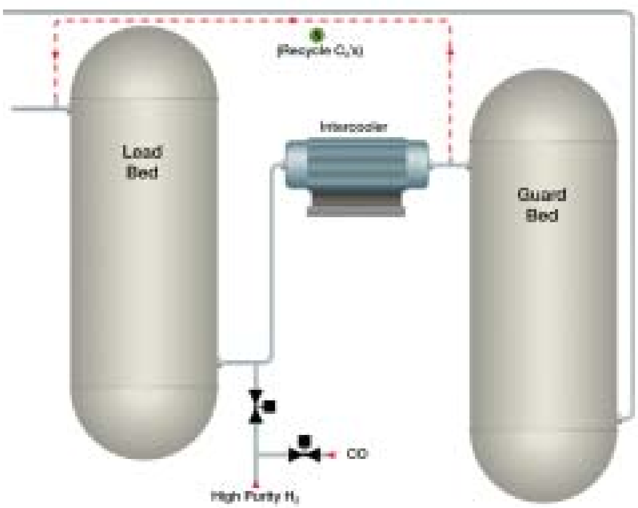
For this key measurement in the ethylene process our approach includes our PGC 2000 gas chromatograph for hydrogen and acetylene measurements and our PIR3502 photometer technology for real-time indication of ethane and ethylene contents.

Operators can rely on the performance of our analytical solutions to help them make operational decisions regarding olefin product quality which can have huge economic implications for the ethylene unit and downstream consumers.



## 4 Hydrogenated $C_2/C_3$ Product Quality (continued)

- Reliably detect acetylene and prevent contamination of downstream fractionation.
- Reduce hydrogen slippage to product which impacts reaction selectivity and pasteurization load of the downstream $C_2$ splitter.
- Optimize selectivity control with real-time feedback of ethylene & ethane content (or propylene and propane in MAPD units).




## 5 MAPD Hydrogenation

The demand for additional propylene as $C_3$ derivative consumption rates increase, makes improved MAPD hydrogenation an important source to help meet predicted product demand. ABB can provide a unique multivariable control approach for optimum control of MAPD hydrogenation units and so increase propylene yield gains across converter beds. Our technology is underpinned by real-time feed and mid-bed stream characterization leading to optimum hydrogen ratio control and:

- Improved reaction selectivity resulting in additional propylene in tandem with lower propane recycle costs.
- Higher availability of on-specification propylene product.

Unique benefits of our approach also include:

- Rapid management of C4 breakthroughs caused by upstream fractionator upsets which reduce selectivity and result in prolonged periods of overhydrogenation due to excessive operator intervention.
- Safer operations by improved management of MAPD hydrogenation exotherms. This is achieved by precise ratio control of recycled lead bed product in liquid phase two-bed systems. Fresh feed and recycle stream MAPD concentrations are determined in real-time allowing precise attainment of target MAPD levels in reactor feed. As well as the primary gain of improved safety, significant economic benefits are attained by eliminating unnecessarily large recycles. This leads to improvements in conversion/selectivity control, lower energy costs and reduction in over-evaporation in the reactors.
- Operating improvements to vapor phase MAPD hydrogenation. The characteristically low propylene gains (or net losses) and high green oil production associated with this process can be significantly improved by application of our unique multivariable control approach. In tandem with improved management of feed disturbances, our technology can turn olefin losses into gains and extend catalyst run-lengths.

## Front End Hydrogenation

Although the majority of ethylene plants employ tail-end hydrogenation schemes, a significant number of front-end hydrogenation units are in operation. These are particularly evident in gas fed crackers where the hydrogenation unit feed can be $C_3$ or lighter but is more commonly $C_2$ and lighter. The front-end approach is attractive for a number of reasons including long cycle lengths, improved energy efficiency and lower capital expenditures.

### Common Operating Problems

- Particularly in front-end de-ethanizer schemes, the operation is sensitive to CO fluctuations.
- Rapid increases in CO can lead to off-specification product for acetylene if the control scheme does not react quickly and manipulate inlet temperatures.
- Rapid decreases in CO are far more serious and will result in temperature excursions (runaways) due to the hydrogenation of ethylene given the abundance of hydrogen in the feed. These events not only result in off-specification product but also limit catalyst cycle lengths and produce large olefin product losses.
- Unplanned slippage of MAPD into the feed of front end de-ethanizer converters naturally tempers catalyst activity. If its presence is not rapidly detected, the control scheme cannot compensate quickly enough to avoid significant activity decreases and potential acetylene slippage to ethylene product.
- In front end de-propanizer fed units, breakthrough of heavy ends in the reactor feed cause accelerated catalyst fouling, further compounding the intrinsically higher rate of green oil formation due to the higher reactor exotherms associated with simultaneous $C_2$ and $C_3$ hydrogenation.

### Solution

Implementation of ABB multivariable control technology driven by *real-time* feed and lead-bed effluent characterization, results in significant improvements in the safety and economic performance of front-end hydrogenation units.

Real-time determination of CO and acetylene in reactor feed and intermediate streams leads to better control of inlet bed temperatures. This approach can mitigate the product quality penalties associated with rapid increases in feed CO content and more importantly, reduce the risks of temperature excursions leading to reactor runaways.

## Acetylene Extraction Units

For those ethylene plants that operate acetylene extraction units, attractive benefits can also be gained by the application of ABB's unique multivariable control technology driven by real-time acetylene measurements.

- Reduce utility and make-up solvent costs in recycle loops
- Minimize ethylene slippage to acetylene product
- Improve safety profile

## Summary

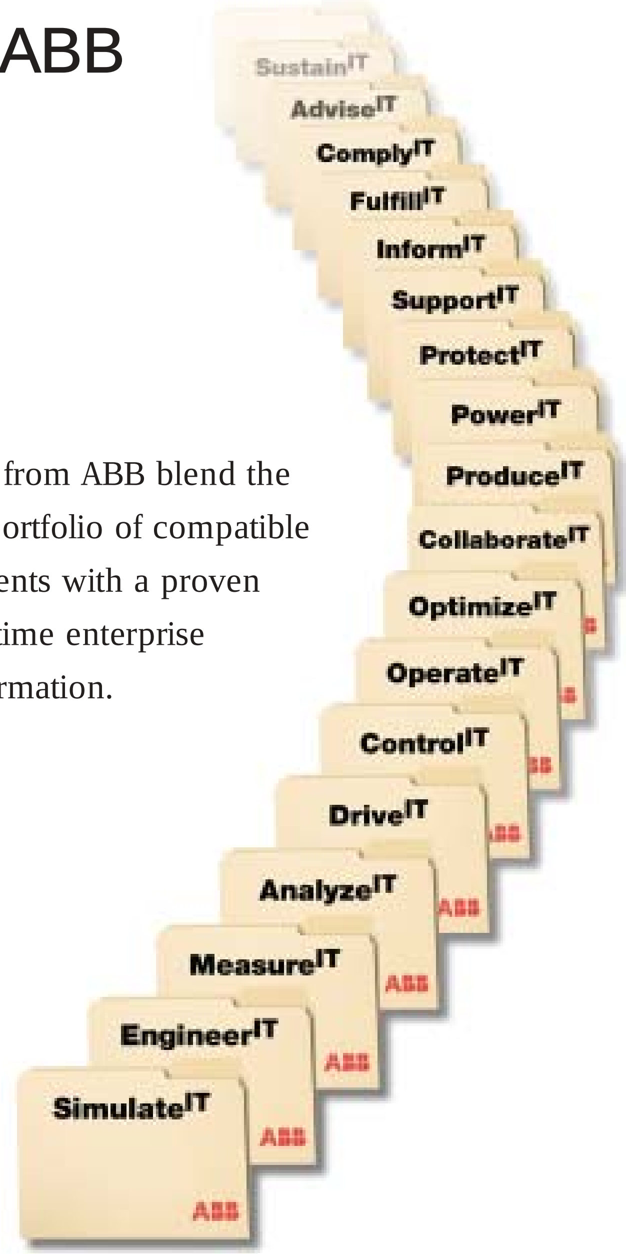
ABB offers a unique Industrial[IT] solution for Acetylene/MAPD Hydrogenation to assist operating companies in meeting the significant challenges of today's operating environment that are of critical importance from financial and reputation perspectives.

- Our leading technology for acetylene/MAPD hydrogenation is multivariable, model-predictive control that exploits our capability for real-time analysis of feed and intermediate streams within multi-converter units. This unique approach can help operators maximize olefin gains and avoid the common problems leading to plant upsets and performance deterioration.
- On-line measurement of conversion and selectivity available in real-time for all catalyst beds delivered by our leading PIR3502 photometer technology.
- Process analytical technology for hydrogen and olefin product quality helps to improve reactor yields and ensure continuous availability of on-specification product.
- A complete service portfolio including field services, on-line support, training and parts/repair in order to maintain the performance of your Industrial[IT] solution.

For the first time, operators can obtain a combined analytical & control solution for acetylene/MAPD hydrogenation from one vendor, delivering unique synergistic benefits to the operation of these important unit operations within ethylene plants. This leads to enhanced safety, economic and environmental performance.

For more information, please visit us at www.abb.com/analytical

# Industrial^IT Solutions from ABB




Industrial^IT solutions from ABB blend the industry's broadest portfolio of compatible knowledge components with a proven architecture for real-time enterprise automation and information.

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