There is a new era in the U.S. with the rise of the shale gas boom that has emerged in this country. Large production increases are occurring from shale gas plays ranging from C1-C4 hydrocarbons, C5s/condensate and “tight oil,” petroleum that consists of light crude oil contained in petroleum-bearing formations of low permeability, often shale or tight sandstone. The plentiful C1-C4 supply versus current demand is driving prices for these molecules down. The recent result is directionally lower prices for methane, ethane, propane and butane, as well as heavier products.

The plentiful supply and low prices for these building block molecules is having a marked effect on downstream industries that use the molecules either as fuel for energy or for raw materials as feeds. Steam crackers are moving to maximally change feedstock from naphthas and gas oils to ethane to make ethylene, and they are experiencing attractive margins.

Ethylene yield is high when using ethane as feed, which results in favorable economics based on the low price of ethane that has been prevalent in recent years. Ethylene producers have already made moves to feed as much ethane as possible within the limits of their existing production facilities. Ethylene producers are also moving to debottleneck existing plants; some such initiatives have already been announced. Additionally, as many as seven new grassroots facilities have been announced or are under consideration, primarily along the Gulf Coast. Two new ethylene plant projects are under review in the Northeast to take advantage of ethane production from the Marcellus Shale Play in Ohio, Pennsylvania and West Virginia.

Ethylene capacity increases totaling more than 7 million metric tons per year have been announced or are under study between the debottlenecking and new initiatives. The debottlenecking projects can be accomplished in a shorter time frame, with the capacity increases continuing through 2013 to 2015. The grassroots capacities are slated to come online through 2016 and 2017. Several of the new ethane crackers will also install additional polyethylene capacity.

**ECONOMIC SHIFT**

Historically, naphtha and gas oils have been used as feed to steam crackers. These feeds typically come from processing crude oils in refineries and, as such, the pricing for naphtha and ethylene is directly related to the price of crude. Ethane production from shale gas plays provides crackers with a new feed source unrelated to the refining of crude oil or worldwide oil markets. This represents a paradigm shift in the economics of ethylene production.

Ethylene is a major building block for numerous chemicals and petrochemicals. Consequently, the shale gas renaissance is affecting a broad spectrum of the chemical industry.
Shifting ethylene production from naphtha and gas oil to ethane as feed has a dramatic effect on the production of other traditional steam cracker byproducts. Propylene, C4, C5 and heavier product yields produced when feeding ethane are low.

The reduction in propylene production is affecting the economics of producing propylene through the “on purpose” route. Numerous propane dehydrogenation projects are already in design, with others being announced. This is just one example of the changing markets and the necessary transition that is taking place in the U.S. as the markets transition.

The total spending for the chemical/petrochemical industry for the period 2013 to 2030 is now estimated at approximately $120 billion. There is an anticipated sharp increase in spending starting in 2014 to peak in 2016-2017 at more than $13 billion. The total spending for the period 2013 to 2017 totals nearly $48 billion.

GLOBAL SUPPLY IMPACT

With the announced ethylene plants slated to come on line by 2017, ethylene will be in greater supply. The economics of supply and demand suggest an oversupply of ethylene produced in the U.S., which will result in lower ethylene prices. A lower ethylene price will swing the economics in favor of producing more derivatives made from ethylene, which will have to be exported from the U.S. to the global marketplace in order to maintain a supply-and-demand balance.

It is estimated that along with ethylene production, ethylene derivatives — including polyethylene, ethylene oxide, ethylene glycol, ethylene dichloride (EDC), vinyl chloride monomer (VCM) and polyvinyl chloride (PVC) — will also see a production increase. This has the effect of increasing the capital spending through 2020 — and beyond.

Where will all this production go? Forecasts call for increased net U.S. exports of the ethylene derivatives.

The combination of lower energy costs and cheap ethane has caused a marked shift in where U.S. stands on the global ethylene production cost curves. An impressive result of the shale gas boom and consequent lower cost of energy and cheap ethane has been the effect on U.S. production cost for ethylene on the global cost curve. Comparing the 2007 and 2012 cost of production curves, it is clear that the shift has brought the U.S. much closer to the lowest cost producers in Canada and the Middle East.

FOCUS ON ETHYLENE DERIVATIVES — EDC AND VCM

Ethylene dichloride (EDC) is one of the ethylene derivatives forecasted to see capacity increases in the United States. EDC is used to produce vinyl chloride monomer (VCM), which, in turn, is used to produce polyvinyl chloride (PVC). The U.S. is likely to increase export of PVC for use in homebuilding and plumbing products worldwide. (Burns & McDonnell will focus on the EDC to VCM value chain in this presentation.)

The process to produce chlorine is energy intensive at 20,200 Btu/pound. Reduced U.S. energy costs represent a significant advantage in lowering the cost of production for chlorine, which is another
advantage in the EDC, VCM and PVC value chain. There are two widely accepted methods for producing EDC: direct chlorination and oxychlorination.

In **direct chlorination**, chlorine and ethylene react to form the EDC molecule; two chlorine molecules are used for each molecule of ethylene. The typical reaction is between the dissolved gases in liquid over an iron chloride catalyst at a pressure of 15-75 psig and 200 to 300 degrees F. The use of high purity reactants is typical to avoid the formation of a broad range of impurities that may further complicate EDC purification. An excess of chlorine is typical to ensure complete ethylene conversion.

In **oxychlorination**, the reaction occurs over a copper chloride impregnated alumina catalyst in the liquid phase at a temperature of approximately 300 degrees F and a pressure of up to 75 psig. The typical fluid bed technique offers heat transfer, prevents hot spots and allows more efficient catalyst regeneration. Ethylene conversion of 93% to 97% can be achieved with selectivity in EDC of 91% to 96%.

The **EDC purification section** removes trace amounts of impurities in the furnace feed, which can inhibit the cracking reactions and cause fouling. In addition, EDC must be dry to prevent excessive corrosion in equipment and piping downstream of the reactor. Therefore, the combined EDC from three sources (direct chlorination, oxychlorination and that recovered and recycled from the cracking step) must be purified to greater than 99%. This combined EDC is washed with water and scrubbed with caustic to remove chlorine, hydrochloride (HCl) and other water soluble impurities, including chloral. The crude EDC and unconverted EDC from the VCM column are combined, dried and purified in two distillation columns. In the first “lights column,” water and lower boiling point impurities are separated as the overhead product. The bottoms product is fed to a “heavies column.” EDC with approximately 99% purity is taken as the overhead product while the heavy impurities leave the column as the bottoms product.

The pure EDC is forwarded to a furnace for thermal cracking to vinyl chloride. A typical furnace consists of a radiant section, a convection section and a stack. The furnace fire box operates at 950 degrees F. The convection uses combustion gases to preheat the feed before entering the firebox.

The vinyl purification section consists of two distillation columns in series, which separate vinyl chloride from EDC, HCl and remaining byproducts. The first column (HCL column) distills the HCL mixture to a pure overhead product that is recycled to the oxychlorination reactor. The HCL column is a trayed column and operates at a pressure of 135 psig. The bottoms product of the HCL column is fed to the second column (VCM column), which operates at 65 psig. A VCM product of greater than 99 wt% is the overhead product of the VCM column. The bottom of the VCM column is recycled to the lights column for repurification.

A brief overview of the economic analysis for EDC/VCM plant investment indicates that the total installed cost for a 300,000 metric ton/year facility is in the range of $450 million to $500 million. With current EDC pricing of $245-$275/ton and assuming an ethylene and chlorine cost of $1,320-$1,362/ton and $275-310/ton, respectively, and assuming the energy, labor, overhead and tax contributions are in the range of $70-85/ton, results in a payback of less than five years. These rough economics do not include cash costs for land, startup or the capital investment required for utilities and infrastructure. Constructing a new EDC plant at an existing facility where existing infrastructure and utilities are present will make the investment more attractive than a pure greenfield site. Debottlenecking an existing EDC facility is likely yield a return on revenue that represents another attractive investment.
Furthermore, installing or debottlenecking existing VCM and PVC facilities make this value chain one of keen interest in the coming low-cost ethylene environment that is predicted.

**CONCLUSIONS**

- The shale gas boom is resulting in high production of C1s-C4s, which has resulted in reduced prices for these chemical and petrochemical building blocks.
- Several new grassroots ethane crackers and ethylene plant debottlenecks to increase ethane feed capacity have been announced.
- Increased ethylene production in the U.S. is forecasted to lower ethylene prices in the long run.
- Ethylene is a central building block in producing various chemicals and petrochemicals.
- A large sector of the U.S. chemical industry will be affected.
- Ethylene derivatives benefit from reduced ethylene prices.
- U.S. exports of ethylene derivatives are forecasted to increase to supply the worldwide market.
- The U.S. can compete in the world chemical and petrochemical market place with the advent of tapping the shale gas plays.
- Chlorine cost of production is and will continue to benefit from the low energy prices in the U.S.
- EDC and VCM are examples chemicals forecasted to benefit as more ethylene production comes on line along with consequent lower ethylene pricing.
- The economics of producing EDC and VCM in a low cost ethylene environment is compelling.
- The EDC to VCM to PVC value chain will benefit. Export of these chemical products to the worldwide market is forecasted to increase.

The shale gas boom has shifted the U.S. energy picture as well as the outlook for chemical and petrochemical production. The U.S. is once again a key actor and leader in the world chemicals stage.

This truly is a new era of technology!

**ABOUT THE AUTHORS**

**Mark W. Lockhart**, PE, is the process technology manager in the chemicals and petrochemicals group in the Burns & McDonnell Houston office. He can be reached at 832-214-1975.

**Elliott Robertson**, PE, is the senior process engineer in the chemicals and petrochemicals group in the Burns & McDonnell Houston office. He can be reached at 832-214-2916.

**ABOUT THIS PAPER**

For additional information about this topic, see the presentation slides that were the basis for this text. They may be downloaded at www.burnsmcd.com/shalegasboom.