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# NO LONGER A BY-PRODUCT: THE NASCENT SHIFT TO INTENTIONAL FEEDSTOCKS

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OMNOVA is an innovator of emulsion polymers, specialty chemicals, and decorative and functional surfaces for a variety of commercial, industrial and residential end uses.

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## Ethylene Feed Review

To begin, let's have a review of the past several years of raw material discussions here. Speakers to this conference since 2006 have been addressing this group about the significance of the Ethylene feed slate shift from Naptha to light feeds. By way of a quick review, the chart below illustrates the impact of lighter feeds on the key co-products from the Ethylene cracking process:

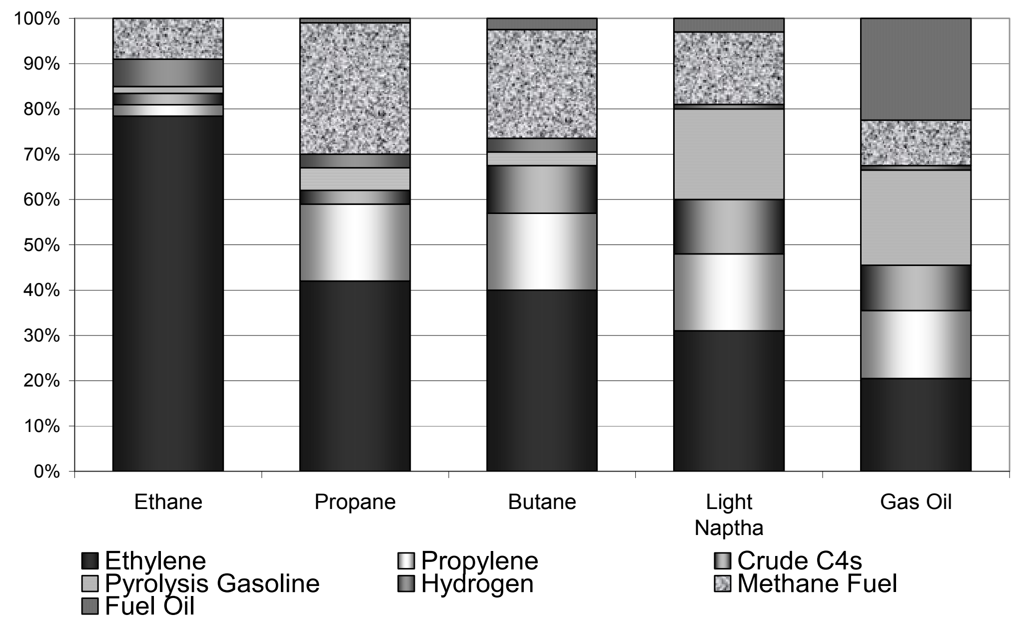



**Figure 1. Ethylene Cracker Yields by Feed Slate**

Historically, the traditional Ethylene cracker feed in the U.S. is Naptha, from the refining process. When cracking Naptha, the product yield is approximately one-third Ethylene, with Pyrolysis Gasoline (20%) and Propylene (15%) the next largest volume co-products.[1] Crude C4 and Methanol are also important in the downstream production of materials used in adhesives, saturants, resins, and tackifiers.

The economics of an Ethylene cracker have been much the subject of discussion in the understanding of the raw materials that support your market. A discussion of the Oil-to-Gas Value ratio has been the basic fundamental driving the decision of the Ethylene producer to run heavier (when oil is cost advantaged) or lighter (when gas is cost advantaged) feeds, along with the value of the by-, or "co"-products. What is *different* now is that this discussion has almost become unimportant. Lighter feeds are here to stay.

Production of natural gas liquids (NGLs) set an all-time record in 2010, topping 2 million barrels per day and representing a 29% growth rate since 1990 (1.550 to 2.001 mmb/d.) (Figure 2). Ethane and Propane production account for most of the increase in NGLs during the past five years.[2]

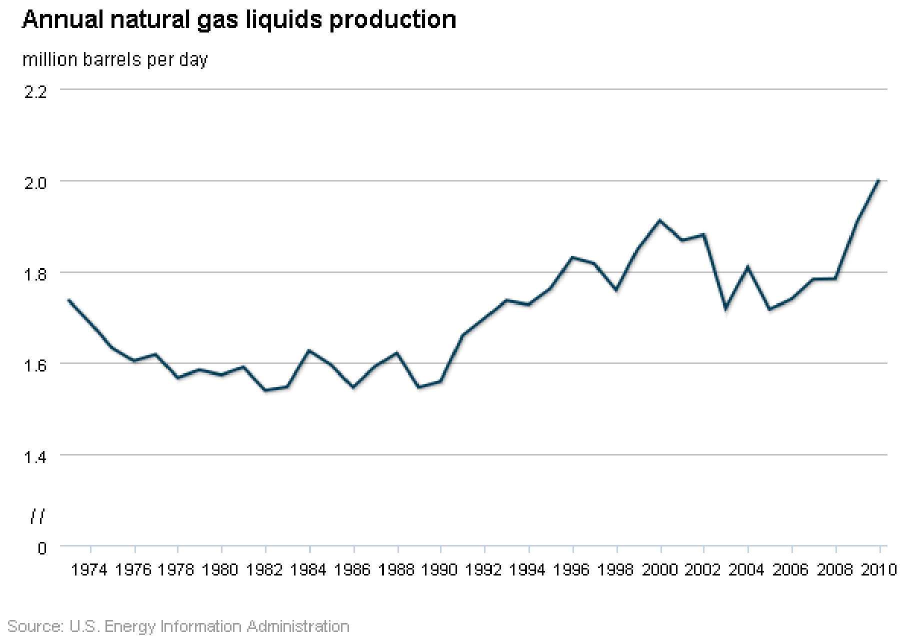



**Figure 2. Annual Natural Gas Liquids Production**

The abundant supply of Ethane as a result of this tremendous increase in NGL production has certainly been a positive for Ethylene producers. Instead of a 30% yield, the cracker is now able to produce nearly 80% Ethylene – at the expense of Propylene – used to make Acrylic monomers, PyGas – a key feedstock for Benzene used to make Styrene, and Crude C4 – feedstock for Butadiene. Acknowledging this, the National Petroleum Council has made the clear statement "Ethane is poised to be the dominant feedstock for the petrochemical industry for the foreseeable future."[3]

There is little change in the feed slate now; the change has already occurred. Today, it is estimated that Ethane and other light feeds represent nearly 90% of the feeds used by US crackers.[4] The discussion now is not about how long the structural tightness might last nor whether the demand for Ethylene will drive an emphasis on lighter feeds. Keeping in mind that there will always be by-products of oil refining, there is little expectation that the major source of feed will go heavy again, "for the foreseeable future." What we have now seen is somewhat of a "Cinderella" transformation in what may have been derisively referred to even in the near past as by-products. Propylene, Butadiene, and Benzene will no longer rely simply on the economics of Ethylene for the determination of their supply. The environment that has brought us a dearth of "by-products" has ushered in a new economic dynamic that supports the investment of on-purpose technologies.

Clearly, from the perspective of the now disadvantaged co-products, alternative technologies are needed to address these fundamental changes. Most of these technologies are not new; the historical challenge is that the economics of the alternatives have not been viable in the past given the growing demand for gasoline from the refineries, spurring ever-increasing production of by-product Naptha, which has been feeding our Ethylene crackers for the past several decades. But now, the entire dynamic has changed. Today's talk will specifically explore the impact on Acrylic monomers via Propylene, on Butadiene, and on other avenues the industry has been exploring to balance supply and demand.

**Glut of Natural Gas Liquids – lots of Propane for Propylene**

Only 40% of US Propylene comes from steam crackers, with the balance from refineries as a by-product of gasoline production.[5] As a result of lighter feeds, the US has probably lost 5-6 billion pounds of Propylene, with an additional loss of about 500 million to 1 billion pounds on the refinery side because of weaker gasoline demand.[6] Gasoline demand in the U.S. has declined steadily since 2007[7]. (Figure 3)

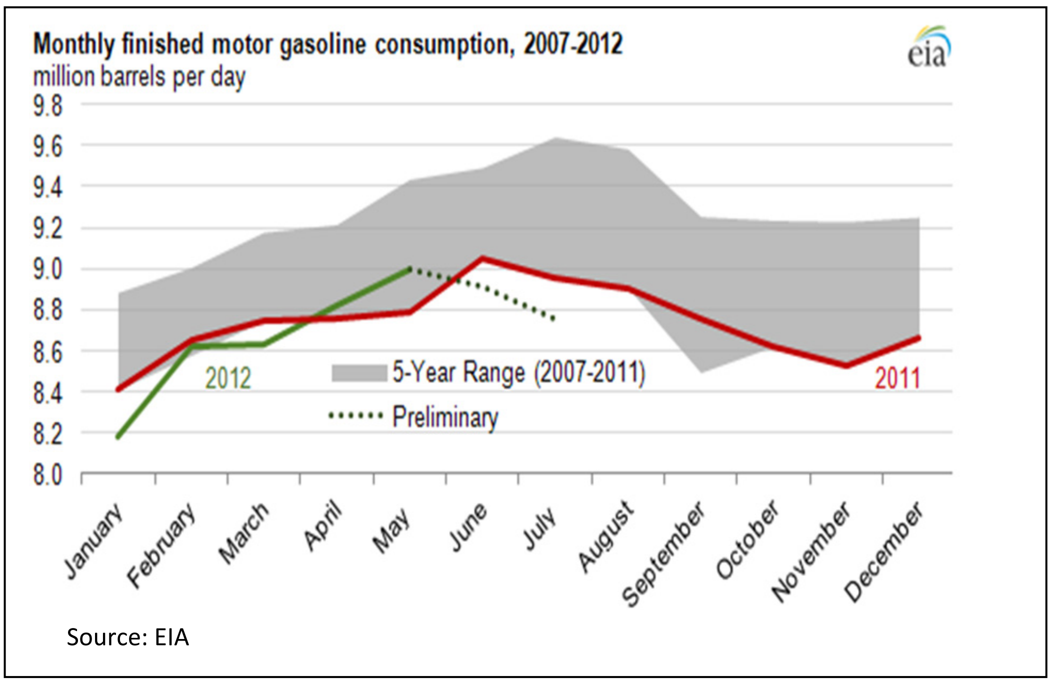


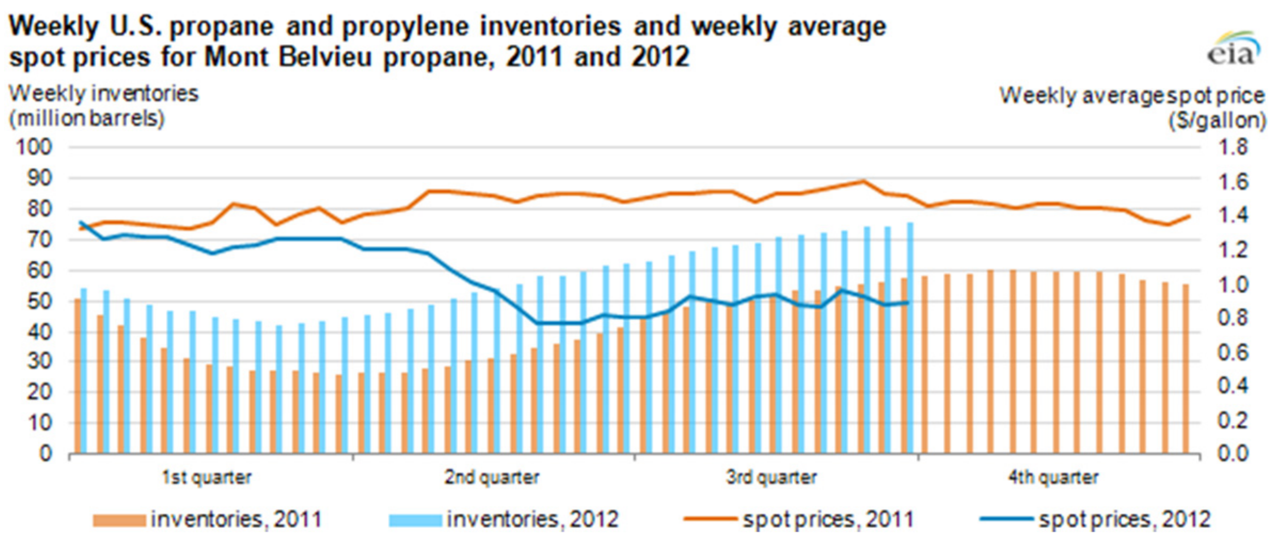

**Figure 3. U.S. Monthly Finished Motor Gasoline Consumption, 2007-2012**

Two-thirds of the world's Propylene is used to make polypropylene, with the remainder primarily consumed in the production of Acrylonitrile, Propylene Oxide, alcohols, Cumene, and Acrylic Acid. [8] The Acrylic Acid is used directly in the production of polymers, and is also a key component in acrylic emulsions used in adhesives and tackifiers.

While there have been efforts to increase Propylene yields from steam crackers, it has become apparent that other technologies will be more successful by approaching the problem directly through on-purpose production: Propane dehydrogenation, olefin metathesis and Methanol-to-Propylene. The most significant of these is Propane dehydrogenation (PDH), which already supplies more than 4 million tons of Propylene annually to the global market. [9] PDH yields are 85% Propylene from Propane. [10]

From the perspective of on-purpose production, the industry swing to lighter feeds is not all doom. As we've seen, there has been a tremendous growth in the Natural Gas Liquids (NGL) stream from the processing of natural gas – (this stream is 40% Ethane and 30% Propane.) So while the supply of Propylene is curtailed by the refinery sluggishness and steam crackers switching to ethane, there is a new and relatively untapped supply of Propane. The value of these liquids, the "liquids boost" is especially important in the development of shale gas. The high NGL content of many shale plays has made it economical for operators to continue aggressive development of shale gas resources during periods of low natural gas prices. Thus, the very phenomenon that creates a "shortage" for traditional feeds also supports the use of new technologies to supply those downstream derivative requirements.

So, in the past, why has the shortage of Propylene from steam crackers had such an impact on the market? One reason is that traditionally the PDH units that were in existence were throttled when the spread in the price of Propane to Propylene declined. For example, PDH plants in Europe often shut down in the winter months when the demand for Propane for heating increased. A larger limiting factor on wide-based exploitation of PDH technology is the investment cost. Since its utilization was based not only on demand for Propylene, but on the dynamics for Ethylene, producers were hesitant to invest. The estimated capital requirement for a 550 kta PDH plant on the US Gulf Coast is US$490 million. The capital cost is lower in China, but now the lower Propane prices because of the rise of NGLs in the U.S. provide a greater net margin to U.S. producers[11] and – for all the reasons stated above – this is a sustainable advantage! The U.S. Propane prices continue to drop supporting the PDH investment[12] (see Figure 4), and the U.S. near-to medium-term has US Propane supply outpacing demand through 2017.[13]




Source: EIA

**Figure 4. Weekly U.S. Propane and Propylene Inventories and Weekly Average Spot Prices**

So, with the massive glut of Propane, petrochemical producers are gearing up for the supply of alternative Propylene. Figure 5 illustrates the capacity that has come on-stream since 2008 and is planned through 2017. As you can see, a considerable portion of this new capacity is in China, where the cost economics are justified not only by the global feedstock availability, but also by demand growth[14]. Conversely, the capacity identified in the U.S. and Europe is specifically addressing the reduction in output from traditional production routes. The U.S. capacity that came online in 2010 nominally replaces 24% of the entire amount expected to be lost.

From North America to Europe to Asia, the sentiment seems to be that on-purpose Propylene production will be more than adequate to compensate for the decline in supply from refineries and steam crackers. One European petrochemical industry executive stated, "Propylene consumers in Europe do not need to be too concerned about the shift to lighter feedstocks in the region, which could result in lower Propylene production... on-purpose production can compensate." [15] Historically Propylene prices were about 15% lower than Ethylene (see Appendix for historical price table). It is anticipated that long-term the traditional cost relationship of Ethylene and Propylene will never return, but Propylene will be available, and perhaps in overabundance.

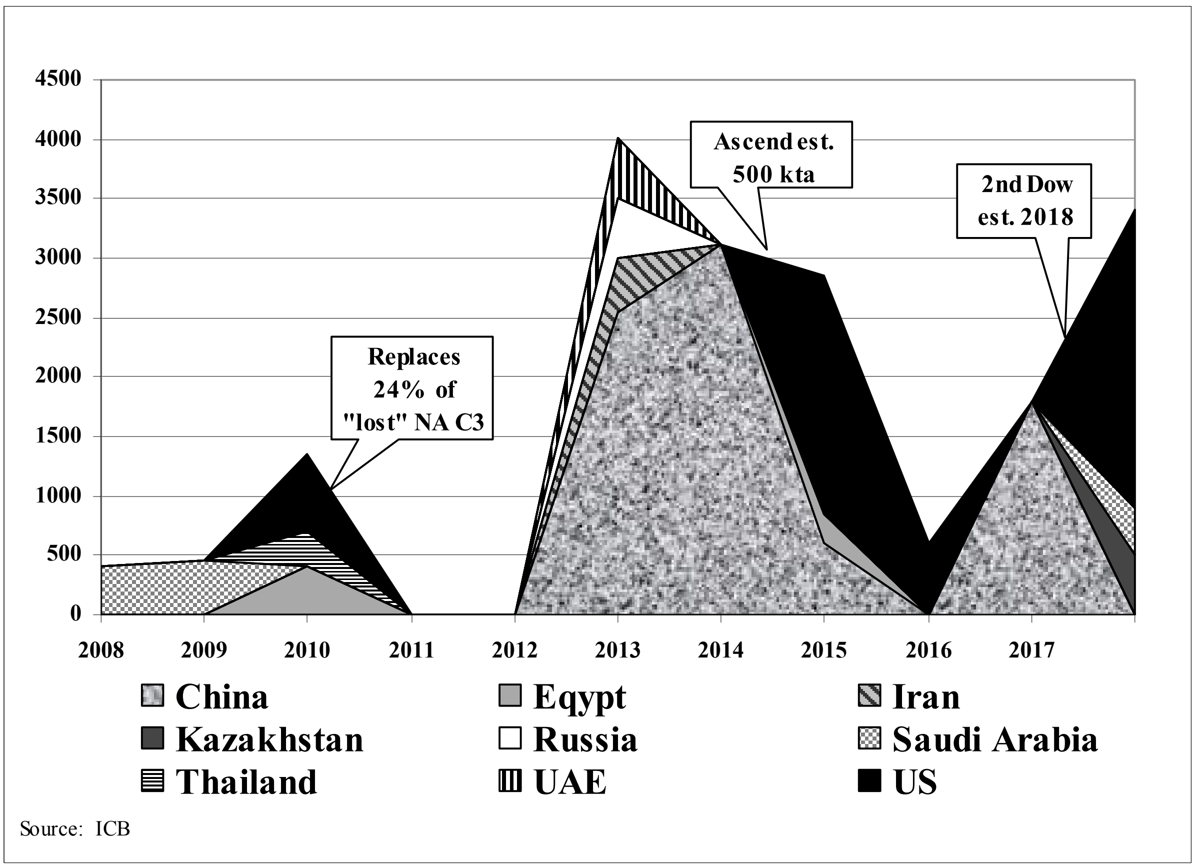



**Figure 5. World PDH Capacity Additions (000 kta)**

PDH accounts for about 75% of the on-purpose production of Propylene, with Olefin Methathesis (which uses Ethylene and butylene) and the Methanol-to-olefin route two other methods for on-purpose production. While these two additional technologies are viable alternatives, recent industry movements indicate that they will not economically compete with PDH, based on costs and availability of butylene and Methanol. In January 2013, LyondellBasell cancelled plans for a 500 kta expansion of its existing methathesis unit, and already some of the announced PDH capacity has been called into question as the announced capacity in the U.S. currently far exceeds the industry loss. The Methanol route is still a strong potential as there has also been an industry resurgence in investment in Methanol production (which is beyond the scope of this article.), but again, there seems to be no shortage (nor incremental incentive) once all the intended PDH plants come online.

Two key take-aways from this analysis are that the current reduction in the supply of Propylene that has resulted from light feed cracking and refinery underutilization have already been answered in part by the existing PDH units - and more are on the way. Secondly, there will not only be enough Propane to feed on-purpose Propylene production, but North America will ultimately have to build out export capacity in order to keep the Propane inventory in balance. While Propylene is currently higher-priced than Ethylene, the markets have yet to equilibrate around the new on-purpose Propylene production model. What is clear is that these plants will lead to a new dynamic on Propylene pricing – one based on gas, not oil. From shortages of Propylene to a glut of Propane to the conversion of that glut to a secure source of Propylene, it seems clear that not only will the polypropylene producers be assured of supply, but the U.S. is positioned to become advantaged in the world in other downstream derivatives markets based on the base economics of Propylene supply. This bodes well for all of us producing or consuming Propylene derivatives – Acrylic Acid, acrylic monomers, or acrylic emulsions.

**Who Moved My Butadiene?**

To set the stage for what is happening globally with Butadiene, it is helpful to have a look at the global demand distribution. As you can see in Figure 6, 50% of world demand is in Asia, with the majority of that in NE Asia. Europe and N. American each account for about another 20%, with the balance in the other regions of the world.[16]

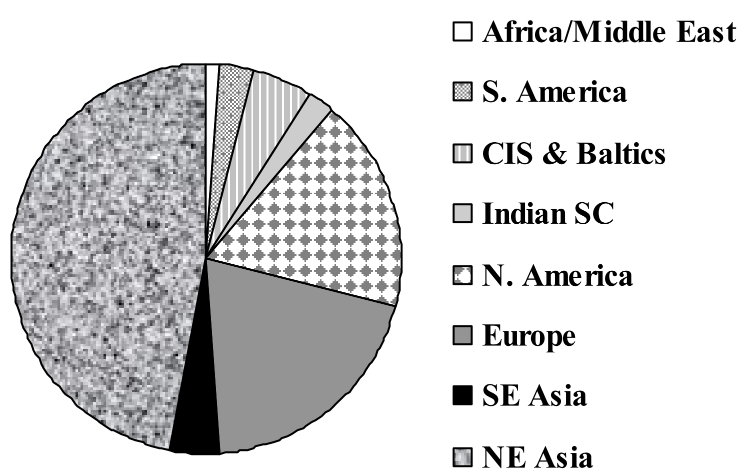



**Figure 6. World Butadiene Demand 2012**

Butadiene has also been impacted by the Ethylene cracker feed shift, and the industry is struggling to meet the supply versus demand gap. The global market is experiencing declining availability of crude C4 (Butadiene) from the Ethylene cracking feed slate change. Because the proportion of crude C4 produced in a steam cracker – regardless of feed – is much less relative to Ethylene, Propylene or Benzene, the Butadiene supply is more subject to the whims of other markets, and the impact was felt sooner and more dramatically for Butadiene than for other Ethylene co-products. In 2011, more than 97 percent of finished Butadiene will be extracted from crude C4 produced in Ethylene crackers. In this way, the Butadiene market is currently different from other petrochemical commodities, (such as Propylene), which have always been able to look to refineries and on-purpose production for incremental supply.[17]

Starting as early as 2004, reduced operating rates and the massive wave of Ethylene supply from light feeds that came on-stream in the Middle East began to reduce Butadiene supply. Both reduced operating rates of crackers globally, as well as the feed slate impact as illustrated by the "Butadiene Ratio" (*i.e.,* the amount of Butadiene produced per unit of Ethylene produced, Figure 7), have had a negative impact.

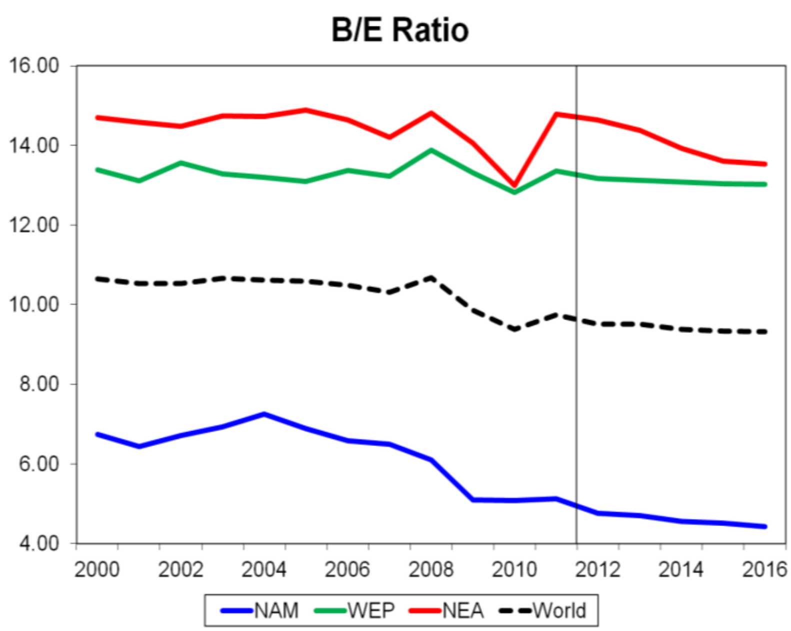



**Figure 7. Butadiene-to-Ethylene Ratio**

While the net amount of available feed has been growing since 2009, the total reflects significant declines in North America and Western Europe, offset by the growth in Northeast Asia and other parts of Asia and the world, which is brought about primarily by new Naptha crackers in China. (Figure 8)

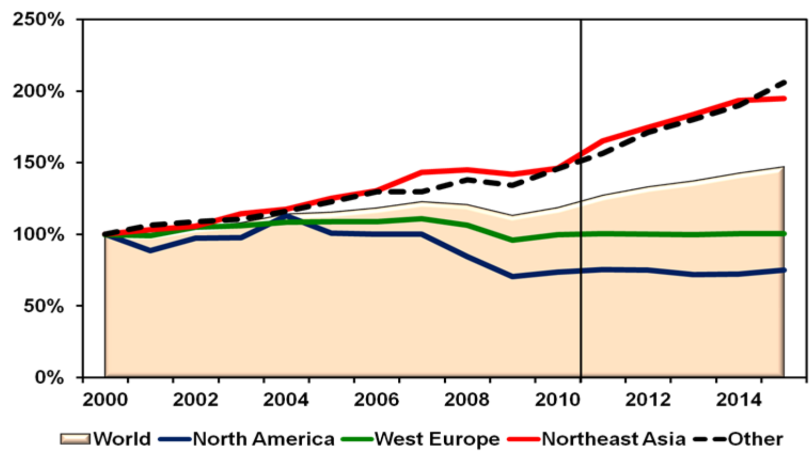



**Figure 8. Feed Available to BD Producers**

This reduction in feed in North American and Western Europe, both current and projected, highlights a long-term supply imbalance, when coupled with the expectations of demand growth of 3-4%. By 2020, the global gap will be 3.3 billion pounds, or about 9.8% of total global demand (Figure 9). This problem is further compounded in that the crude Butadiene is often not located in a logistically economical relationship to the Butadiene refining capacity.

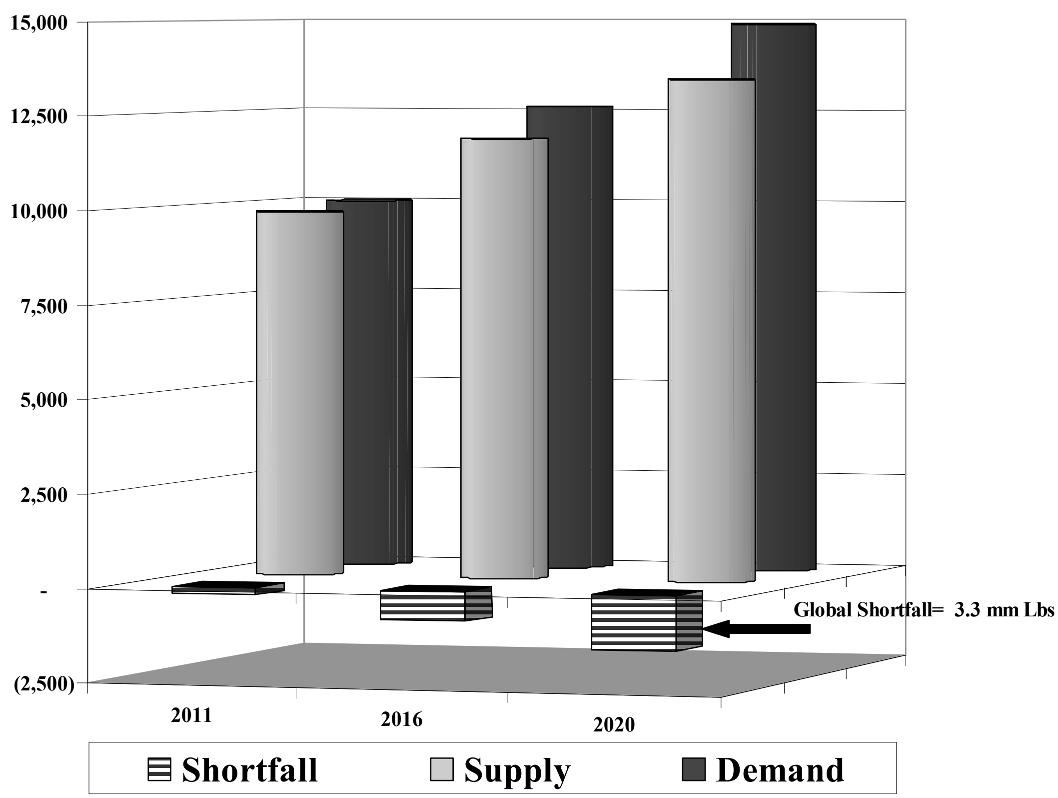



**Figure 9. Global Butadiene Supply and Demand through 2020**

There are expectations that new Naptha cracker capacity outside the U.S. will provide some relief for the current situation, but it seems clear that the U.S. will be a long-term importer of Butadiene, with support from on-purpose production. The fact that "contained Butadiene," the Butadiene contained in crude C4s that is not being extracted, surpasses demand by 20% worldwide, could, in theory, encourage a flood of Butadiene extraction investment downstream of existing crackers. However, investments are not being made because of the inability of crackers to supply enough crude C4 to large-scale Butadiene plants because many of those crackers are small.[18]

The other source of Butadiene is dehydrogenation of butane or butylenes, often referred to as "on-purpose." Producing Butadiene from butane or butylenes is not a new concept. Before the mid-1970s this was the dominant Butadiene production route. However, the rise of naphtha based Ethylene production and the relatively inexpensive route to co-product based Butadiene forced most of the on-purpose units to shut down by the early 1980s. There are two "on-purpose" systems that have been used to produce refined Butadiene. The Oxo-D process uses butylenes, and is the more economical of the two on-purpose technologies. The Houdry process is believed to be more costly, but can convert either butylenes or butane – and can process fractions from either steam crackers or refineries.[19]
One of the emerging trends in the global Butadiene markets is the renewed interest in this on-purpose production. On-purpose Butadiene has always remained in Russia, where its economics are supported by stranded butane feed stocks. Additionally, some on-purpose production was run from time to time in the U.S. and other locations through the early 2000's.[20] The on-purpose share of global Butadiene production has been in the 2-3 percent range in recent years. However, there are currently projects under evaluation or construction in China and the U.S. The volume will remain relatively small, with total production still only just over 6 percent of the global total by 2016.[21]

The new on-purpose production will come primarily from China also (the source of the crude C4), with 870 kta of Butadiene production announced for commissioning by 2014, and a further 200 kta announced with unspecified start-up dates (Figure 10). Some consumers of Butadiene have announced plans for captive production, such as Japanese consumer who is considering building a 500,000 kta plant in Japan for start-up in 2014. This new production will subtract from the global demand, vs. adding to supply – but with the same net result for the market balance.

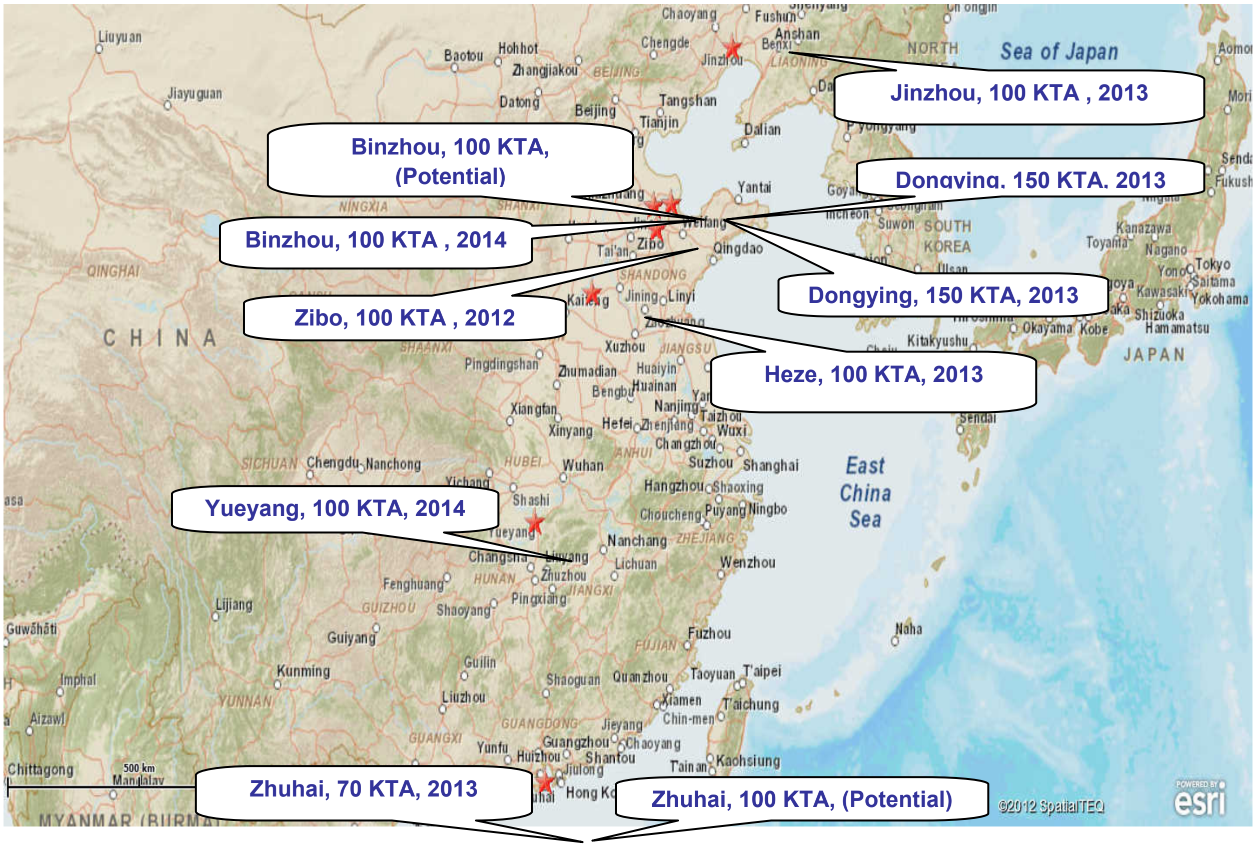



**Figure 10. Announced BDH Butadiene Capacity in China**

By 2016, this incremental volume will be joined by at least one on-purpose plant in the U.S. The U.S. will remain a net importer throughout this horizon, with an increasing share of imported material in the overall supply structure, until the U.S. based on-purpose production is started. At that point, it is anticipated that the import portion of supply will level off or even decline, depending on the final capacity added in the U.S. For logistics purposes, it is important to note that a significant portion of U.S. imports come from Canada, although volume from Asia has become important to the U.S. supply portfolio, and will continue to gain in importance. There is even some argument for the U.S. capacity additions to have a "disproportional market influence,"[22] if all the contemplated capacity is added. If this occurs, it may allow the U.S. Butadiene price to drop relative to the rest of the world and improve the global competitiveness of North American derivative production. Thus the small additional capacity would drive big changes in the global markets. We are all keeping a close watch on the U.S. developments.

Where the new production is, there will be a spot market. However, in the U.S., the macro environment clearly suggests the execution of a long-term contract strategy. In North America, buyers of course, will need to monitor the Asian market, and we will be influenced by it to a small extent. However, U.S. buyers with a contract market approach will ultimately experience more security because of that approach to the supply/demand dynamic. Contract supply will flow – from traditional sources, including imports and domestic on-purpose production. (Figure 11)

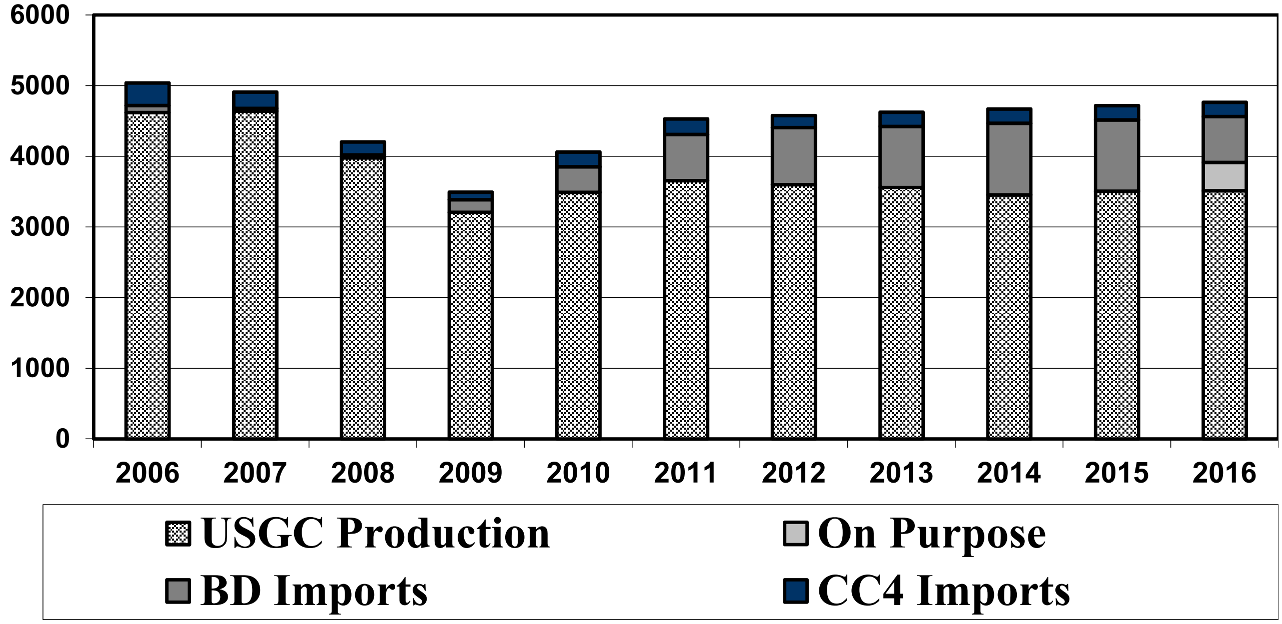



**Figure 11. North America Butadiene Supply Balance to 2016**

**Bio-Based Feedstock Opportunities**

The concept of "on-purpose" production in these two discussions is focused on the management of the downstream output of oil or gas – using macroeconomic assumptions on the economics to bring it out of the ground.

But we should not leave an examination of intentional feedstocks without noting some of the new technologies for bio- or organic-based feedstock production. This approach moves entirely away from the fractions of extracted product – whether it be oil or gas – and instead seeks a renewable source for production of the same downstream molecules. Bio-based chemicals currently hold a market share of 1-3%, which could rise to nearly 9% by 2020.

Although seven petrochemicals, namely Methanol, Propylene, Ethylene, Butadiene, Benzene, toluene and xylene, can be made from biological feedstocks, the success of these bio-based chemicals will ultimately rely on the market economy, particularly regional economics. Cost-competitiveness will be critical in regional markets. [23] While the bio-refining complex is well in place to support bio*fuels* requirements, according to the World Economic Forum, "Biomass for chemicals is a strategic option, not the unique or default path to be pursued." There are certain transformations where bio-routes make sense and certain routes where efficient (process chemistry) approaches work best.[24]

Bio-Based production of Propylene is still in very early stages from a commercial standpoint, but there are a number of technologies proposed. These technologies use various bio-based materials to produce Methanol, Ethanol or Propanol, which are then converted to Propylene. In the case of Propylene, once the Propanol is derived, the steps to Propylene all use known technology. [25] Since 2010, polyethylene has been produced in Brazil in a 200 kta plant which uses ethanol from sugarcane as the raw material. A long-term goal seems to be to develop a technology to make Propanol from sugar, and then convert that to Propylene. While there is no known commercial bio-based Propanol at present, completion of designs for a 30 kta polypropylene plant based on sugar technology have also been announced.[26] While these developments are being driven by the downstream demand for polypropylene and polyethylene, once the technologies are fully commercialized they both alleviate the demand pull as well as offer additional options if and when the economics support them.

Moving beyond Propylene to downstream Acrylic Acid, one global enzyme company is producing enzymes to turn agricultural waste into advanced biofuels and has partnered to convert renewable raw materials into Acrylic Acid.[27] Another player in bio-Acrylic Acid is a venture firm founded in 2007, which claims to already be producing "pre-commercial" scale demonstration quantities of sugar-based bio-Acrylic Acid, with an expectation of entering the commercial market in 2016.[28]

For Butadiene, there are several known bio-based routes which are touted to be cost competitive with conventional or on-purpose routes and may become a factor within a decade. [29] In July 2012, an Italian producer announced a joint-venture for bio-based production of Butadiene. The company's partners are a technology firm and a downstream consumer of Butadiene. The intention is to license the technology once it is commercialized, with the objective of being able to modify the enzymatic technology to produce a specific monomer. [30] Thus, theoretically it could ultimately be used to produce a variety of different monomers.

Other projects are underway with technologies to convert industrial waste gas carbon monoxide into Butadiene, with initial commercialization is expected in 2016. The proposed technology includes both a 2-step process to make Butadiene from 2,3-butanediol (2,3 BDO), and ultimately the development of a direct single step process to produce Butadiene directly through a process of gas fermentation.[31] While the parties state that "direct production of Butadiene is a long-term aspiration," there are clearly interested parties putting capital behind these efforts. Any success in these ventures is anticipated to create some stability in the monomers value chain.

This is by no means an exhaustive list of the biochemcial projects underway. There is a myriad of ventures, both small and large, that seek to enter the value stream of basic and intermediate chemicals with renewable resources. As we know from the old English proverb: "Where there's a will, there's a way," and it seems clear that there is no shortage of "will" in addressing the longer-term needs of our global economy.

For us, the near-term is covered by both conventional technology and incremental improvements; the intermediate term (the next two to five decades) is addressed by the anticipated advantage North America will experience as a result of plentiful shale gas resources, and for the longer term, we can watch the unfolding bio-chemical industry with interest.

## Appendix

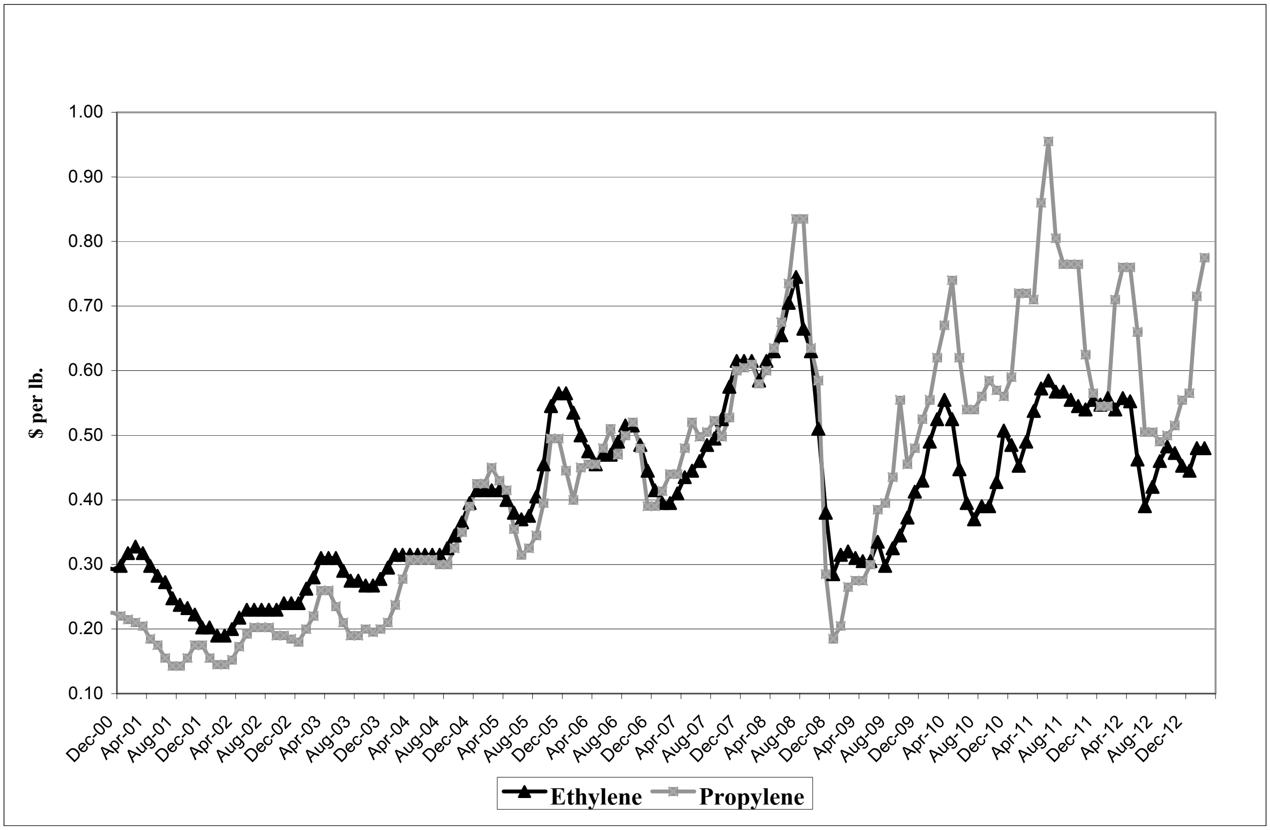



**Figure A**. **Ethylene Net Transaction Contract vs Propylene Chemical Grade Contract**[32]

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