SMALL SCALE LNG LIQUEFACTION AND NGL RECOVERY IS SUPERCOOL

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ABSTRACT

Conventional wisdom holds that small natural gas liquefaction plants (producing less than 100,000 gallons per day of LNG) cannot be built and operated economically. This is primarily due to high capital and maintenance costs typically associated with this type plant.

Thus, the economies of scale have historically led to the installation of single, large scale LNG liquefaction plants that can cost hundreds of millions of dollars and which usually require long haul transportation of the product to the end-user.

S-Con and BDL Fuels have developed a new modular plant design for LNG production of 10,000 to 250,000 gallons per day that can handle gas compositions ranging from pure methane to gas containing 13 GPM of heavy hydrocarbon and 25% nitrogen.

The plants are designed to pre-treat the gas, recover essentially 100 percent of the ethane (C₂) and heavier hydrocarbon components into a Y-Grade quality NGL product and liquefy the methane product into LNG, as well as reject any excess nitrogen (N₂) that might be contained in the inlet gas stream.

In its simplest form, feed for the plant is pipeline quality gas. However, with the new SUPERCOOL process, the plant is also designed to process raw, untreated gas, recovering essentially 100% of the contained NGL, generating vehicular-grade LNG and rejecting N₂ to pipeline or LNG specifications.
INTRODUCTION

Background

Over the last ten (10) years or so, oil and gas production from Shale plays across the United States has grown exponentially. It all started back in the 1990’s in the Barnett Shale and has expanded to include the Haynesville, Eagle Ford, Marcellus, Utica, Bakken and numerous other fields across the country. Gas production has increased to such an extent that prices have been driven down and there is no place to take all of the production. We have gone from a country that, only a few short years ago, was ready to build billions of dollars of LNG import terminals, to a country that is now trying to figure out how it can either export LNG and/or utilize this new abundance of fuel to help make the United States energy independent.

Of course, with every new opportunity, new challenges and obstacles appear to temper our good fortune. Most of these new areas of energy production have either no or little infrastructure, or the wrong type, to handle the new gas volumes and/or the liquids contained in them and, thus, no way to get products to market. Also, while the Shale plays produce a lot of gas, many also supply a tremendous amount of oil, which is usually the driving force for producing the field. Where there is no infrastructure for the produced gas streams, the gas is often flared. Enter the State and Federal Regulators.

While the States have a vested interest in keeping oil production in full force, they also have regulations regarding flaring of gas that will be enforced. Many of these regulations allow for flaring produced gas over a specified time, while the necessary infrastructure is put into place, allowing oil production to continue. Many of these areas are fast approaching the time limit and the infrastructure has not yet been put in place, risking the shutdown and loss of oil production from these fields. And even in the cases where the States are amenable to allowing the production to keep flowing, the Federal Regulators are never far away and are always more than happy to insert themselves into the discussion.

Along with everything above, America (and the World) continues to try and develop cleaner, more efficient and more economical energy supplies. Wind and solar energy may be clean, but they are not efficient or economical as a major source of energy and they will not supply more than 10% - 15% of America’s energy needs in the foreseeable future. That being said, a great deal of the Planet is already using CNG and/or LNG as a primary fuel source; the United States is well behind the curve on fully utilizing this source of energy.

Supply and Demand

One of the biggest impediments to utilizing CNG and LNG for Consumer Fuel has been the inability to bring the Producer and the Consumer together, where the Producer can be certain of a market demand for the product and the Consumer can be certain he will have a reliable supply of the product if he spends the extra money necessary to run his car or truck on LNG or CNG. It has been the perfect Catch-22 since most LNG has been produced at large, centralized locations which are not necessarily
near a local consumer market and requires long-haul transportation with the associated costs. This thought process has been due, in large part, to the belief that small (<100,000 gallons per day) LNG production plants could not be built economically because of:

- The large footprint associated with the typical, large scale LNG plant design
- The amount of expensive rotating equipment associated with the typical, large scale LNG plant design
- The infrastructure required to bring large volumes of gas to the LNG facility

With the introduction of S-Con’s SUPERCOOL Process, the economic viability of small scale LNG Liquefaction Plants is now a reality. These plants can be installed virtually anywhere and are designed to produce truckable liquid products with little or no emissions into the atmosphere. In one step, the SUPERCOOL Process can address:

- Providing “local infrastructure” for small scale production from any gas stream
  - SUPERCOOL can be designed to process as little as 1 MMSCFD
  - SUPERCOOL can process pipeline quality gas or 13 GPM wellhead gas and deliver “transportation grade” LNG in either case
  - LNG/CNG loading stations can be set up essentially anywhere a gas supply is available
    - Required footprint for the SUPERCOOL Plant is almost always less than 50 feet x 75 feet (not including storage or loading facilities). See Figure 1.
- Elimination of flaring gas, thus improving revenue and the environment at the same time
  - SUPERCOOL recovers essentially 100% of the inlet hydrocarbons, so there is no harmful waste gas streams
  - Plants are fully modularized and can be moved from one location to another
  - Product can be used as fuel for drilling, trucking and other associated production equipment
- Providing local CNG/LNG supply at multiple locations, taking the gas from production facilities or off transmission pipelines that criss-cross the country
  - Eliminates having to transport product hundreds of miles to market
  - Consumer can be certain of supply since produced at the sales point
  - Numerous smaller plants located within a region provides flexibility and reliability in case one plant is down
  - Elimination of transportation costs and having readily available supply will continue to keep price to the Consumer low, while at the same time enhancing the Producer’s bottom line
DISCUSSION

In the Beginning

In 2009, three friends (with vast experience in the area of LNG) were discussing the significant rise in domestic gas production and the call for converting this abundance of gas into LNG for both export and use by the American consumer. Like everyone else, they initially believed that this could only be accomplished in large “mega-plants” which could make millions of gallons per day of LNG and then transport the product to the end users. But then one of them asked the question, why can’t smaller plants (10,000 – 20,000 gpd) be built closer to the gas supply and closer to the final Customer? After thinking about it and eliminating the self-imposed obstacles, they concluded that smaller plants were a viable option, if you could overcome the large footprint and amount of major equipment required; but how do you do that?

There are numerous ways to produce LNG, but every one of them relies on some type of refrigeration system or combination of systems (i.e. cascade type refrigeration, mixed refrigerant, closed loop nitrogen vapor, partial LNG vaporization and recycle, etc.) and every one requires a lot of equipment and power to make that happen, none of which is conducive to small plant economic feasibility. That is when the light went off --- bring in the refrigerant to the plant, let it be a consumable and you don’t have to worry about
all the equipment. Of course, you can’t just release hydrocarbon into the atmosphere and not expect someone to notice; but you can vent nitrogen without anyone raising the least bit of a fuss. Thus, BDL Fuels embarked down the path to determine if using liquid nitrogen as a refrigerant was feasible and how to best use it to produce a quality LNG product.

In 2011 BDL filed a patent for, among other things, the use of liquid nitrogen refrigerant for the production of LNG. The patent application was published in October of 2011. Once the patent was filed, BDL decided it was time to put the theory into practice and moved forward with the design and construction of a pilot plant.

Keeping things as simple as possible, BDL felt the best way to attack this new process design was to process a small volume (1.0 – 1.5 MMSCFD) of pipeline quality gas that could be treated for water and carbon dioxide removal, using an inlet molecular sieve system, before being totally condensed and sub-cooled against the liquid nitrogen refrigerant. The pilot plant was completed in 2012 and has been operated and proven on several occasions. In late 2012, BDL had S-Con refurbish the pilot plant in order to make some enhancements to the operation and to bring the plant up to all ASME and NEC Code requirements. The plant is currently being readied to be put into full-time operation.

Several key aspects of the pilot plant include:

- Enclosure of entire plant is in an 8’ x 40’ connex building
- Capability of mol sieve pretreatment system to remove up to 2% CO₂
- Use of vaporized nitrogen refrigerant to regenerate the mol sieves
  - Nitrogen is vented to atmosphere, along with any desorbed CO₂ and water vapor
  - Due to volume/mass/dryness of nitrogen available, it is not necessary to heat the regeneration gas above 350F
- Use of liquid nitrogen is the key to the process, as it:
  - Allows total condensation of LNG product at relatively low pressure (200 – 350 psig), reducing compression requirements
  - Allows for sub-cooling of LNG and elimination of flash when going to storage
  - Eliminates need to use part of LNG product as refrigerant, thus eliminating a hydrocarbon waste or recycle stream
- 100% condensation of treated gas stream results in approximately 11,000 gallons of LNG product per MMSCF of feed
- Direct connect of liquid nitrogen truck line to plant inlet and LNG product line to tanker truck at plant outlet

**Liquid Nitrogen is Key**

As stated above, the use of liquid nitrogen as the refrigerant is the key to making the process work as efficiently as possible. Nitrogen vapor has a lowly average heat capacity of only 0.25 Btu/lb-F, whereas liquid nitrogen has a heat of vaporization of over 85 Btu/lb. Therefore, by use of liquid nitrogen, the LNG product can be efficiently sub-cooled and the vaporized nitrogen refrigerant can then be used in the sensible heat cooling of the inlet gas stream (See Figure 2). While there is a temperature “pinch” that
must be overcome, if nitrogen vapor were used throughout a significantly larger volume of nitrogen would be required to condense the LNG (see Figure 3). This is one of the main reasons that a portion of LNG product is typically used as refrigerant in “typical” designs. It should also be pointed out that the “typical” LNG plant design is only able to chill the LNG product to a temperature slightly above the temperature of the vaporizing refrigerant; thus, you will always have a portion of the final LNG product flash when let down to atmospheric storage pressure. By using liquid nitrogen for product sub-cooling, the SUPERCOOL process allows the LNG to be sub-cooled to a point that there is no flash and no product loss or recycle and no need to use a portion of LNG as refrigerant. Finally, it is also possible to use either liquid nitrogen, or cold nitrogen vapor, as the condensing medium for any methane vapor that evolves off of LNG storage, thereby eliminating vapor recovery systems that are usually required.

Also, since the process is based on total condensation with refrigerant only (without any rotating equipment) and because liquid nitrogen is much colder than the condensing LNG stream, the inlet gas to the plant can enter at much lower pressures than what is typically required. Thus, inlet compression requirements are much less than for other processes and, since there is no low pressure hydrocarbon recycle streams, there is no recycle or residue gas compression required.

Along with being much more efficient as a refrigerant when in liquid form, it is also much easier to transport volumes of nitrogen as a liquid rather than as a vapor. For a plant producing 15,000 gallons per day of LNG, less than 20,000 gallons per day of liquid nitrogen is required. Thus, two nitrogen transport trucks per day can be used to generate one and a half LNG transport loads.

Figure 2
What About Processing Raw Wellhead Gas?

Forming “small” quantities of LNG from pipeline quality gas at numerous locations for local markets brings the LNG and CNG market home to the Consumer and makes the idea of utilizing a cleaner, cheaper fuel, with a readily available supply, very appealing. But what about the Producers in the field that have to flare their gas because there is no infrastructure by which they can get the gas to market? Most of this is rich, associated gas, produced as part of oil production, and can contain a substantial amount of recoverable hydrocarbon liquids. However, since there is no infrastructure, the gas is flared in order to keep the oil production going. Not only is the Producer losing a potentially large revenue stream from the flared liquids, most States have laws and regulations on the books that limit the time and/or amount that gas can be flared, before being faced with the possibility of fines and penalties, or worse, shutting off the oil. Up to this point, most States have worked with the Producers to avoid these scenarios, but it is only a matter of time before the Federal Government begins to pressure the States to enforce these regulations more rigorously.

One option would be to build the infrastructure necessary, but this might require several hundred miles of pipeline, compression facilities, etc., in order to gather enough gas to send to a central gas plant. While this may be feasible for large volumes of gas, it generally is cost prohibitive to proceed down this path for gas volumes less than 10 or 15 MMSCFD.

Another option to flaring the gas would be to liquefy the stream and truck it to market. However, this has its own set of problems. First, heavy-end hydrocarbons tend to freeze below certain temperatures. Second, it is often difficult to get permission to
truck a product with a vapor pressure of 500 psig or more on public roads. At S-Con, we began to study ways to design and install a small portable plant at a production site. This plant needs to generate truckable and saleable product streams while greatly reducing or eliminating emissions into the atmosphere. Use of liquid nitrogen seemed a perfect fit, but the problems outlined above had to be overcome; thus the invention of the SUPERCOOL Process.

S-Con expanded upon the BDL process to incorporate fractionation of the NGL from the LNG, nitrogen rejection from the LNG and extensive heat integration with the process streams within the plant. The SUPERCOOL Process still utilizes a molecular sieve pretreatment system for removal of CO₂ and water vapor from the inlet gas stream and still utilizes vaporized nitrogen as the regeneration gas. The big differences lay within the Cold Box itself and how the gas stream is separated into its component parts. A patent application was filed, as a Continuation in Part to the BDL patent, in November 2012.

After pretreatment, the inlet gas enters the processing plant, between 250 psig and 350 psig, where it is partially condensed to the point where essentially 100% of the butanes and heavier components are liquefied. It should also be noted that approximately 90% of the CO₂ remaining in the gas after pretreatment is also recovered in the Cold Separator liquid stream; this allows the inlet CO₂ content into the plant to possibly reach 200 – 300 ppmv, without fear of freezing up the plant. Nitrogen refrigerant, along with several process streams, are used as the cooling mediums for the inlet gas stream. The liquid and vapor are separated in a Cold Separator, the same as any standard cryogenic gas processing plant, with the liquid being fed to the Demethanizer tower. The vapor off the Cold Separator is routed to a second exchanger where it is totally condensed and sub-cooled before being fed to the top of the Demethanizer as column reflux. Again, nitrogen refrigerant and various process streams act as the cooling mediums to condense the Cold Separator vapor stream. The fractionation process is essentially the same as in any standard cryogenic gas processing plant, but by operating at relatively low inlet pressure and sub-cooling the reflux, there is no flashing of the reflux into the Demethanizer, resulting in more efficient fractionation and higher product quality. Essentially 100% of the ethane and heavier components is recovered out the bottom of the Demethanizer, while still meeting specifications for C1/C2 ratio in the product stream. The NGL Product is pumped, heated through process heat exchange and routed to sales (either by truck, pipeline or reinjected into the gas stream). The Demethanizer overhead vapor product consists of nitrogen, methane and trace amounts of ethane.

The Demethanizer overhead vapor is then routed to the process exchanger, where it is totally condensed and fed to the Nitrogen Rejection Unit (NRU) Column where excess nitrogen is removed from the final LNG product, or Residue Gas stream. The NRU Column is a reboiled tower with partial condenser. Reboiler heat is provided by process streams, such as the Demethanizer overhead vapor stream. The Condenser cooling medium is provided by liquid nitrogen refrigerant, along with any rejected nitrogen off the top of the NRU. By utilizing liquid nitrogen as the condensing medium, it is possible to regulate the amount of reflux and meet whatever LNG product spec is desired, while also limiting the hydrocarbon content in the overhead nitrogen stream to less than 0.10%. Thus, unlike typical NRU designs, the performance of the SUPERCOOL NRU is not contingent upon the amount of nitrogen contained in the gas.
stream. If there is a significant amount of nitrogen in the inlet gas, less liquid nitrogen refrigerant is required; whereas, when there is less nitrogen present, additional nitrogen refrigerant is utilized to supplement the condenser. The bottom product from the NRU column is an LNG product that will meet all product specifications, whether it be for sale as vehicular grade LNG or as residue gas.

The LNG from the NRU Column can be handled in one of two ways (or a combination of the two). As the SUPERCOOL Plant is first and foremost set up as an LNG production unit, the base operation of the plant takes the LNG product and sub-cools the stream to between -265F and -275F before it is reduced in pressure and sent to LNG storage. Liquid nitrogen is utilized to sub-cool the LNG. By sub-cooling the liquid stream, there is no flash of vapor as the product enters the storage tank; as a matter of fact, the sub-cooled liquid helps to re-condense any methane vapors that may have weathered within the storage tank. Sub-cooling the LNG product is another advantage that SUPERCOOL provides which is not generally available in other types of plant designs.

In other instances, where a gas pipeline may exist and/or there is no market for LNG, the LNG stream from the NRU can be pumped to 300 – 400 psig, routed back through the process exchangers and vaporized, acting as the process refrigerant and greatly reducing the demand for nitrogen refrigerant in the system. This type of operation would make the most sense when the inlet gas is too rich in heavy-hydrocarbons or contains too much nitrogen to be fed directly into the sales pipeline.

The third option is to operate such that the plant provides both a sub-cooled LNG product stream and a Residue Gas stream. This is easily accomplished in the SUPERCOOL Plant and would be most useful when a sales gas point is available and the Producer is trying to develop an LNG market. As the market demand increases, the plant is slowly converted to full LNG production and, if the LNG market begins to lag, simply change the operation back to producing Residue Gas. This operation can be done on-line, without disruption to plant operation.

Sounds Too Good to be True; What Else Can It Do?

SUPERCOOL can handle any natural gas stream, from “pipeline quality” gas to 13 GPM gas. In any case, the SUPERCOOL design will recover essentially 100% of the ethane-plus hydrocarbon component as a salable NGL product, while producing a high quality LNG product. The SUPERCOOL design also is designed to handle up to 25% nitrogen and still deliver a methane product that will meet vehicular grade LNG standards or Sales Gas pipeline specifications. The heat integration throughout the system is such that the nitrogen requirement remains relatively constant, no matter the gas composition, though the distribution of refrigerant within the plant will vary. In the case where pipeline gas is being liquefied, a good rule of thumb is that 11,000 gallons of LNG will be produced for every MMSCF processed. As the gas gets richer the LNG production is reduced, but is more than replaced by the recovered NGL’s.

S-Con has developed three basic sizes for the SUPERCOOL Plant; 1.5 MMSCFD, 5 MMSCFD and 10 MMSCFD, with the possibility of a 20 MMSCFD plant in the future. Therefore, the SUPERCOOL Plant can be designed to supply as little as 5,000 gallons per day of LNG, to over 100,000 gallons per day. In all cases, the SUPERCOOL Plant itself has exactly the same footprint, though the Pretreatment system
will grow slightly as the gas input rate increases. In every case, the plant is fully modularized and portable from one location to the next. Also, since the plant is fully modularized, each plant is fully assembled and tested at the S-Con Shop Facility before shipment; thus, field work is shortened and unexpected problems should be minimized.

Since there is no long lead-time rotating equipment in a SUPERCOOL Plant, and the entire plant system is designed for relatively low pressures (MAWP of 500 psig or less), S-Con can have all Major Equipment in-hand much quicker than other plant designs. This allows S-Con to start building the plant sooner and, thus, have any size SUPERCOOL Plant up and running in approximately twelve months, which is six to twelve months sooner than most other LNG plants can be in operation.

For the smallest size plant, S-Con recommends trucking in the liquid nitrogen refrigerant, whereas it appears more economical to install an Air Separation Unit (ASU) or Nitrogen Liquefier for the larger size plants. If an ASU or Nitrogen Liquefier is to be used, the Customer then must decide if they wish to own the unit or have the ASU Vendor Build, Own and Operate the plant (which ASU Vendors are eager to do). The decision on whether to build a full scale ASU or the Nitrogen Liquefier is usually dependent on whether or not there is a merchant market for the other air components (i.e. Oxygen and Argon). Also, if an ASU or Nitrogen Liquefier is used, it is usually economic to recover the spent nitrogen refrigerant from the SUPERCOOL Plant and recycle it back to ASU/Liquefier. In the case where the nitrogen is trucked in to the site, the spent nitrogen refrigerant is vented to atmosphere, along with any CO\textsubscript{2} and water recovered from the Pretreatment system.

**What Are the Downsides to This Process?**

There are a couple of things every Customer needs to know. First, the nitrogen refrigerant source of supply needs to be identified. The Air Separation industry is a mature industry and there are numerous plants throughout the United States and many of these plants have excess liquid nitrogen capabilities looking for a merchant market. If the nitrogen is to be trucked in, an agreement should be made with the Supplier as soon as possible in order to lock in a price that can be used in determining overall project economics. If an ASU or Nitrogen Liquefier is to be provided, these units currently take 14 – 16 months to build from scratch. However, ASU Suppliers are anxious to get into this market as well; and it is possible to start up the SUPERCOOL Plant on trucked in nitrogen until the ASU/Liquefier is completed. The matter of who is responsible for the plant operation also needs to be determined.

Second, since the SUPERCOOL Plant recovers essentially 100% of the ethane component, the overall NGL Product stream may be too rich in ethane and exceed acceptable vapor pressure limitations for an over-the-road truckable product. If there is no NGL pipeline available to accept this stream, then something else must be done. When this is the case, a Deethanizer can be incorporated into the facility design to drive off enough ethane so the remaining NGL can be trucked from the site. However, the problem then falls to what can be done with the ethane product. It may be possible to burn the stream as fuel, though that may not always be an alternative either. Another solution that has recently received some attention is the possibility of installing a “Gas-to-Liquids” (GTL) plant that can convert ethane to natural gasoline. This is not an
inexpensive solution, but may have tremendous upside and could possibly be combined with other portions of the overall SUPERCOOL Plant facility.

Finally, like every cryogenic LNG Plant, the presence of sulfur compounds will be problematic and could plug equipment. If sulfur, specifically H₂S, is present in the inlet gas stream, it is recommended that this be removed using an amine plant upstream of the Pretreatment system.

**Money Talks; What are the Economics?**

Since the SUPERCOOL Plant is specifically designed for smaller volumes of LNG production and there is a limited amount of Major Equipment, the capital costs associated with SUPERCOOL are significantly less than the “typical” LNG Plant. In order to compare SUPERCOOL to a typical LNG plant, on an apples-to-apples basis, we will make the following assumptions:

- 10 MMSCFD of inlet gas at 300 psig and 100F
  - Gas Composition (mol %)
    - Nitrogen - 1.25
    - Carbon Dioxide - 1.25
    - Methane - 92.80
    - Ethane - 4.55
    - Propane - 0.15

- LNG Product Specifications
  - Composition (mol%)
    - Nitrogen - 2.00 Max
    - Methane - 95.00 Min
    - Ethane - 5.00 Max

- Customer will purchase Nitrogen Liquefier for SUPERCOOL Plant
- No LNG Storage is included in the evaluation
- Assume NGL product and any “waste gas” or recycle stream will be recompressed back to 300 psig and sent back into the pipeline

The above assumptions are made to give the “typical” LNG plant every benefit so as not to put a cryogenic plant in front of the plant, nor require a NRU.
TABLE I

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Thus, even with a total capital cost that is $7.5 million less than the “typical” LNG plant, the SUPERCOOL Plant will produce an additional $13,000 per day in revenue at the same inlet conditions.

This is a simplified analysis, and does not include costs such as additional operator attention and maintenance because of the rotating equipment in the typical LNG plant. Nor does it include debt service on the additional $7.5 million CAPEX or the fact that the SUPERCOOL Plant will be up and running 6 – 12 months sooner.
SUMMARY

The abundance of natural gas production in North America (and the World) creates an opportunity to provide a cleaner, more cost effective energy source that can help provide a greater sense of energy independence. The question has been how to effectively bring this into the marketplace and make it readily available to the Consumer.

Until now, most raw gas has been processed in Gas Plants, designed to remove heavy-end hydrocarbons, so the residue gas can be sold into a pipeline and transported to markets across the Country. In cases where there is no infrastructure to process and/or sell the gas, it has oftentimes been flared or shut-in.

In cases where LNG was produced, gas was/is taken off pipelines or a cryogenic gas plant tailgate, at a central location, and liquefied at a mega-plant capable of producing several hundred thousand gallons per day, or more. The LNG was/is then transported, via truck or rail, to distribution locations. This manner of operation is inefficient, expensive and has limited availability to the Consumer.

With the introduction of the SUPERCOOL Process, small LNG Liquefaction plants (less than 100,000 gallons per day) can be affordably installed almost anywhere a natural gas source exists, creating a reliable supply of clean, inexpensive energy to essentially any local Consumer market. The ability to install the SUPERCOOL Plant at any location, on any quality gas stream, also provides:

- The Producer an easy way to get his product to market, without having to possibly deal with landowners for pipeline right-of-ways, the cost of installing pipelines and other typical obstacles that can arise.
- Installation in locations without other infrastructure available, or in place, and eliminate the possibility of having to shut-in oil and gas production due to flaring regulations.
- Ability to take product directly from one well site and use the product as the fuel source for the next door sites that might be doing drilling or other production activities
- Reduction in product transportation costs associated with trucking product possibly hundreds of miles
- Capability to install vehicle CNG/LNG loading stations literally next door to the production facility, thus guaranteeing the supply and availability to meet Consumer demand

LNG and CNG hold the key to America’s energy independence, while providing a cleaner, more environmentally friendly, fuel source. The advent of the SUPERCOOL Process will aid in accelerating the conversion of America to this new alternative.