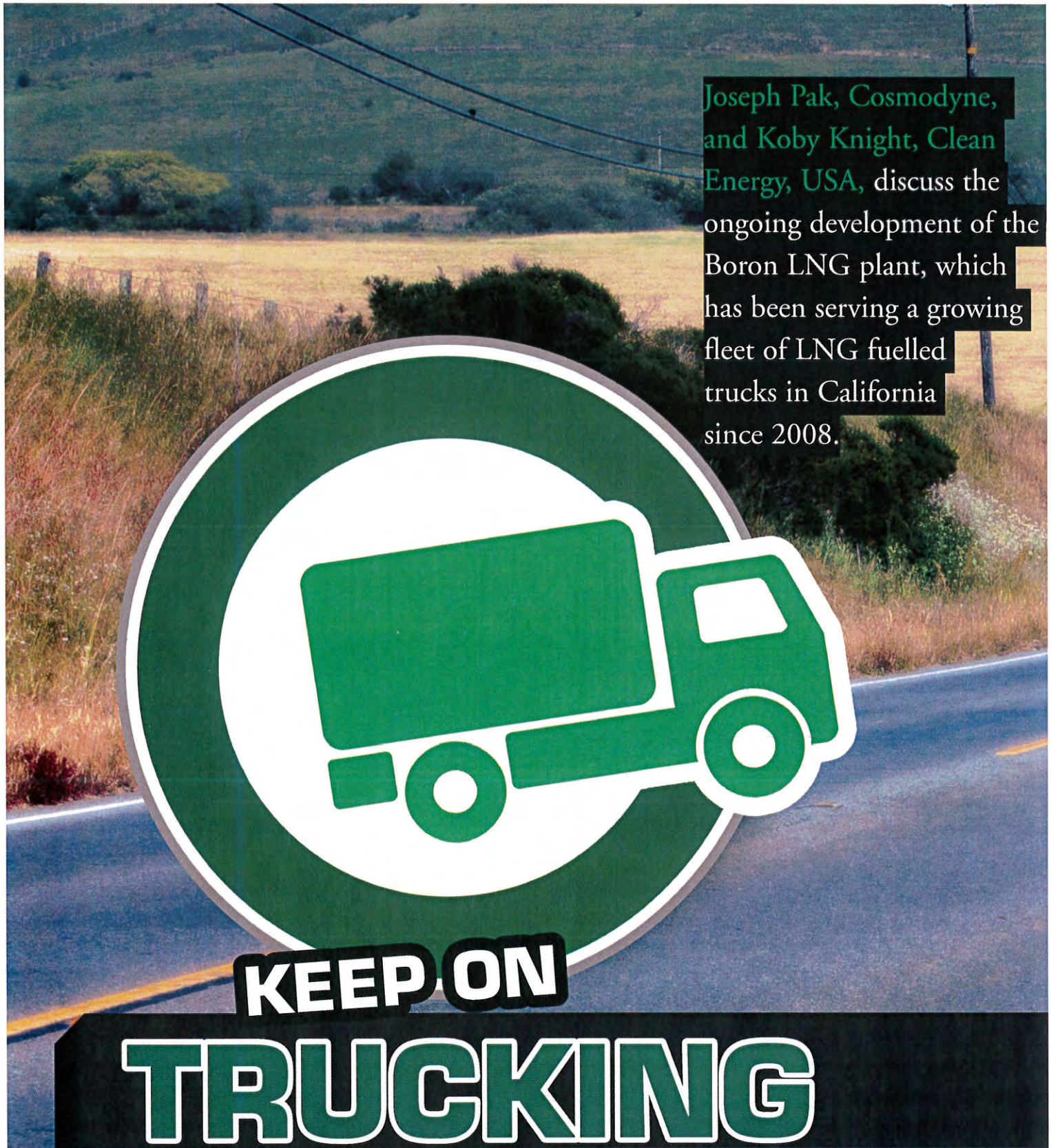

Joseph Pak, Cosmodyne, and Koby Knight, Clean Energy, USA, discuss the ongoing development of the Boron LNG plant, which has been serving a growing fleet of LNG fuelled trucks in California since 2008.

KEEP ON TRUCKING

Clean Energy's Boron LNG plant, the first commercial LNG plant in California, was announced in 2005 to serve heavy duty natural gas vehicle fleets, including Clean Energy's commitment to provide vehicle grade LNG for the Port of Los Angeles and Long Beach's Clean Truck Programme. The plant broke ground in 2007 in Boron, California, approximately 125 miles from Los Angeles and was commissioned in 2008 with an initial capacity of 168 000 gal./d. The Boron plant capacity will be expanded to 252 000 gal./d with the installation of the third train in early 2013 to meet the growing market demand.

Plant description

The Boron LNG plant is on an 8 acre plot next to Rio Tinto's Borate mining operation. It is comprised of four main sections: gas pretreatment; liquefier; storage and trailer filling; and utilities and ancillary.

The gas pretreatment system consists of an amine system and two-vessel molecular sieve dryers that remove the CO_2, H_2O and other impurities in the feed gas before liquefaction.

The natural gas liquefier utilises Cosmodyne's nitrogen closed loop expander process. There are two cold boxes, each liquifying 84 000 gal./d of natural gas. The LNG product is stored in a 1.5

million gal. flat bottomed storage tank. The heavy hydrocarbons (C_2+) are removed from the feed stream via a demethaniser column to meet the LNG vehicle grade specification. The waste stream from the demethaniser column is further processed in the demethaniser bottoms fractionator (DBF) and the resulting LPG is stored in a pressurised storage tank to be trucked off site.

There are two LNG trailer loading stations, each designed to fill a 10 000 gal. trailer in less than an hour, as well as a single dispenser for LNG vehicle fueling.

The electrical power and cooling water is provided by the neighbouring Rio Tinto power plant. Some of the waste streams coming off the pre-treatment system, the lighter hydrocarbon product from the DBF, and the boil-off gas from the storage tank, are taken as fuel gas by the Rio Tinto power plant for its power generation turbines. A flare system is included in case the waste streams have to be handled by Clean Energy during emergencies. A single building houses the main control room, personnel offices and maintenance warehouse. All electric switchgears, motor starters and MCC are in a separate climate-controlled pre-fabricated trailer.

An instrument air compressor system, evaporative cooling tower for cooling water supply, hot oil supply, and liquid nitrogen storage tank provide the necessary utilities for the operation of the plant.

The plant is centrally monitored by a custom Wonderware SCADA package in the main control room. It is also remotely monitored at the company's corporate office in Seal Beach, CA, as well as from its Willis Texas LNG plant. It is protected by fire extinguishers and an alarm system. Gas leak detectors are also installed around the plant and spill containment areas, as required by the codes.

The plant, including the gas treatment system and all utilities, was designed to add a third train to increase the total capacity to 252 000 gal./d. It was also designed for easy installation of the third train with appropriate tap points and branches fabricated into all the piping for easy connections and integration.

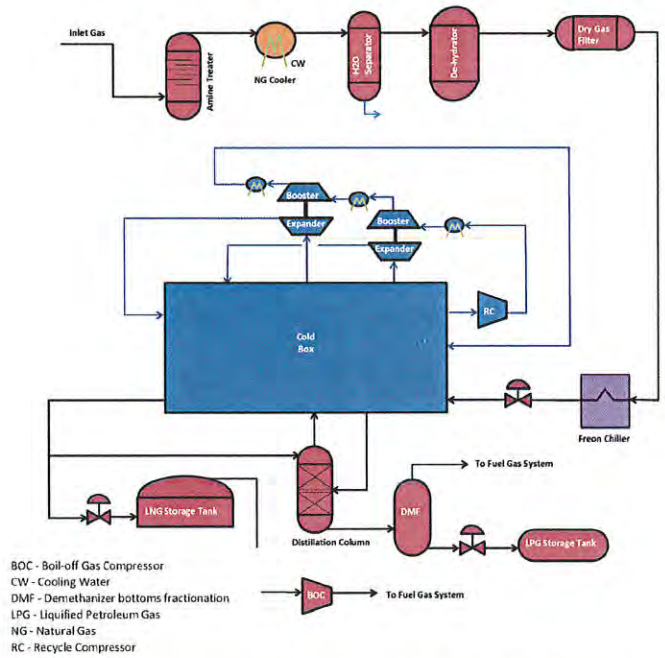

Figure 1. Simplified process flow diagram of the Boron LNG plant.

Table 1. Advantages of natural gas as a vehicle fuel in the US

Cleaner
Compressed natural gas (CNG) and LNG are two of the cleanest burning alternative fuels available. Natural gas vehicles (NGVs) emit up to 30% less greenhouse gases than gasoline or diesel vehicles.
Abundant
North America has at least a 120 year supply of natural gas, according to a June 2008 study. There are more than 13 million NGVs worldwide, with about 112 000 on US roads today. 25% of all new transit buses currently on order nationwide are natural gas powered.
Cheaper
The use of natural gas fuel reduces costs significantly for vehicle and fleet owners. Natural gas averages up to US$ 1.50 less per gallon than diesel or gasoline (depending upon local markets).
Domestic
98% of natural gas consumed in North America is domestically-produced. Increasing use of NGVs reduces dependence on foreign oil and enhances the US's energy security.

Gas supply

The Mojave gas pipeline is the natural gas supply source located at the Boron LNG plant fence. A typical Mojave pipeline gas composition and supply pressure is shown in Table 2.

Gas treatment system

Mojave pipeline natural gas first enters the amine system to remove CO_2 and contaminants such as H_2S. This treated gas (feed gas) is cooled in the water cooler and a gas separator will remove any free liquids. The feed gas subsequently flows through an adsorption bed (dehydrator) where water vapour is removed. After leaving the adsorption system the feed gas passes through a filter to trap any adsorbent dust carryover. It is then cooled down in the mechanical pre-chiller unit to reduce the liquefaction load.

Liquefaction

From the gas treatment section, the feed gas stream enters the warm section of the main heat exchanger in the cold box where the gas stream is cooled and then flows into the demethaniser column. Here the methane enriched cold vapour with less than 1% ethane content rises to the top of the column, and the relatively warm heavy hydrocarbon liquid flows to the bottom of the demethaniser column. The heavy hydrocarbon liquid stream is further processed in the demethaniser bottoms fractionator and stored in a pressurised LPG tank. The overhead methane enriched gas from the top of the column flows back into the main heat exchanger where it is further cooled and condensed to a temperature of -263 °F. A portion of the liquid provides reflux to the demethaniser column and the balance is delivery as LNG product.

The low temperature refrigeration (cold source) at the cold box main heat exchanger is provided by the closed loop gaseous nitrogen refrigeration system (reverse Brayton cycle), which incorporates a recycle nitrogen compressor and two turboexpanders. The nitrogen gas is first compressed through an integral geared three-stage

centrifugal compressor. The recycle nitrogen compressor discharge pressure is further compressed by booster compressors directly mounted on the expander shaft. These compressors utilise the available energy from the highly efficient, near-isentropic expansion occurring at the turboexpanders, which produce the required low temperatures at each point in the process. The nitrogen is cooled after each stage of compression by shell and tube water coolers.

LNG storage tank

The LNG storage tank is a double wall open top with suspended deck type. Chicago Bridge & Iron erected the 1.5 million gal. tank on a reinforced concrete ring wall. The tank was designed per API 620, as well as wind load and seismic criteria per NPFA and URS report. The tank dimensions are over 88 ft in diameter and 51 ft in height. The boil off gas from the tank is compressed and sent to the fuel gas system for Rio Tinto's gas turbines. The ACD centrifugal cryogenic pump system supplies the LNG from the storage tank to the trailer loading system.

Figure 2. Trailer loading kiosk.

Figure 3. Gas treatment system.

Table 2. Typical feed gas composition

Composition	Average (MOL %)
Methane (CH_4)	94.78
Ethane (C_2H_6)	3.17
Propane (C_3H_8)	0.61
n-Butane	0.10
i-Butane	0.11
n-Pentane	0.02
i-Pentane	0.04
C_6+	0.04
N_2	0.58
CO_2	0.55
H_2S	0.6 PPM
Supply pressure	825 psig (average)

Trailer loading system

The trailer loading system consists of two bays that allow for the filling of two trailers simultaneously. A typical 10 000 gal. trailer can be fully filled in less than an hour. The trailer loading system is skid mounted with swing arms. The LNG is delivered to the truck via an LNG transfer hose suspended from the swing arm. The swing arm also holds the LNG vapour hose that sends the LNG vapour from the truck to the LNG storage tank boil off line. The LNG trailer loading skid recycles the LNG back to the LNG storage tank in between trailer fillings to keep the pumps and piping cold. This allows for a quicker and simpler transfer procedure.

All trailer loading functions are controlled from the kiosk located on the south end of the skid. The location of the kiosk allows the truck operator a full view of the connections on the LNG truck, and enables him/her to monitor all aspects of the loading via the Human Machine Interface screen. An in-ground truck weigh scale provides the control point to stop loading. A diesel generator provides back-up power to the trailer loading system.

Plant performance

The plant production can vary from 65 000 – 97 000 gal./d, depending on the plant demand and changes in operating conditions, such as ambient temperature, feed gas composition, and LNG product specification. On average the plant consumes around 0.75 to 1.0 kWh/gal. of LNG produced based on the total power consumed by the complete plant. This is in line with the power consumption of the Willis, Texas plant, which uses the mixed refrigeration cycle.

Project objectives

From the initial conception, operational flexibility was a key requisite in plant design. Since the LNG vehicle market demand during the early stage of the plant life was going to fluctuate, it was imperative for the company to have a plant with a flexible

Table 3. LNG product specification

Composition	Requirement (MOL %)
Methane (CH_4)	97% minimum
Ethane (C_2H_6)	1% maximum
Product temperature	- 263 °F (maximum)

Table 4. Advantages of nitrogen expander cycle

Green refrigerant
Nitrogen is an inherently safe, nonpolluting, corrosion-free, economical refrigerant. It eliminates the added complexity and need for a subsystem for storing and mixing of several hydrocarbons to produce a multi-component refrigerant.
Flexible
It is flexible in minimising the overall effects on efficiency and performance for ranges of ambient/cooling water temperatures, natural gas feed compositions, and customer LNG specification. A wide operating range from 100 to 25% with corresponding power savings is possible.
Simple
The nitrogen is always in the gaseous phase. Less monitoring and control points, and minimal operator intervention is required. The nitrogen expander cycle is straightforward for operating staff to understand, operate and trouble-shoot.
Easy maintenance
No need for purging in and out for maintenance on the refrigeration side. Use of manufacturer's standard equipment for readily available spare parts and support. Simplified and rapid return to production after plant shutdown. Generally shorter cool down times.

operating range, as well as scalability to grow with market demand. In the end, the company selected multiple train designs, even though a single train would have been more economical. The two train option provided a wide turndown range and redundancy during the early years. The smaller multiple train option also allowed for modularised skid mounted design for easier and cheaper installation. Lastly, the multiple train option provided scalability for a simple and economical way to increase the plant capacity by adding identical trains with market growth. This permitted the company to make a smaller initial capital investment with the option to invest in increments as demand increased.

The second important feature was the vehicle LNG product specification control. At the time of the project study there was not an industrial consensus on the LNG fuel specification. The older supply contracts for the company required a supply LNG specification of less than 1% ethane content, while different LNG engine manufacturers had less stringent fuel specifications. Clean Energy decided to purchase the Cosmodyne cold box with demethaniser column to control the ethane and other heavy hydrocarbon (C_2+) in the LNG product. The demethaniser column allows the operator to control the LNG specification to different requirements. As a consequence of this design, Clean Energy selected to use a demethaniser bottoms fractionator (DBF) to deal with a warm heavy hydrocarbon liquid stream coming off the bottom of the demethaniser. The DBF separates the ethane and other lighter hydrocarbon coming off the bottom of the demethaniser column and mixes it with other waste streams as fuel gas for the neighbouring Rio Tinto gas turbines. The rest of the LPG is sent to a pressurised storage tank and is sold.

Lastly, Clean Energy selected Cosmodyne's nitrogen refrigeration process for the reasons stated in Table 4, as well as the fact that the environmentally safe process resulted in easier and faster plant permitting.

Conclusion

Clean Energy currently operates two LNG plants. The Boron plant provides a more robust and simple operation than the mixed refrigeration plant in Willis, Texas. Its operators needed minimal training in comparison to the operators at the Willis plant due to simple monitoring and controls. Additionally, the Boron plant does not need to be tuned with changing ambient temperatures for optimisation, as is the case at the Willis plant. This allows the plant to be frequently monitored and controlled remotely. Other plant owners who operate both types of plants have made similar observations. On a recent plant visit, Greg Schneller of National Grid also agreed that the nitrogen refrigeration plant was an easier plant to operate and maintain than other types of LNG plants. National Grid operates multiple peak shaving plants with different types of processes.

There were some minor modifications made to the plant. For example, an improved switchgear protection system was added after a minor incident. As such, there are a few things the company would do differently. The plant layout would be revised to allow for more than one train addition. Secondly, the evaporative cooling water system would be reviewed since it required a lot of maintenance. A closed loop glycol or direct air fan cooled system will be evaluated since the system requires almost no maintenance while consuming more power.

Overall, the company is very satisfied with the Boron plant, which has delivered over 50 million gal. of vehicle grade LNG since coming online in 2008. The plants availability rate is over 99%. The Boron LNG plant will play a big supply role as the company builds the 'Natural Gas Highway' and the US takes steps towards energy independence. **LNG**