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Medium-Scale Liquefaction Technology

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SYNGAS Refiner

Outline

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- Lng market issues
- Industry quotes
- Significant lng projects
- Plant categories by capacities
- Lng liquefier components
- Vendors/liquefaction processes
- Plant/infrastructure economics
- Operating small-scale liquefaction plants
- Planned small-scale liquefaction plants
- Us vehicle fuel lng plants
- Technology innovations & advancements
- Questions?

LNG Market issues

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- Over 5 TCF/year gas flared-E&P trends increase problem next 10 years
  - LNG demand increasing rapidly with consuming countries diversifying supply sources for energy security and to tap markets inaccessible by pipeline. GTL plant development halted. Small-to-medium-scale LNG/GTL plant demand increasing to develop gas from associated reserves, remote locations, pipelines, landfills for distribution and vehicle fuel
  - Growing environmental pressure to reduce flaring that is no longer option for new fields that are increasingly in remote locations. Flaring erodes economic value of field development to resource owner and has lead to global effort to eliminate practice. Re-injection does not maximize economic value. Governments concerned about disposition and national resource use
  - Hundreds of billions barrels oil have greater than 1,000 tcf associated gas as technical reserves. High infrastructure cost for liquefaction, transport, re-gasification make economics favorable for reserves in range of 400+ million standard cubic feet per day (MMscfd). Advancements in process technology, standardized designs and manufacturing efficiencies reduce small to medium-scale plant costs and make additional reserves economical

Industry quotes

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- "We believe the LNG industry will begin to see new plants supplied by stranded natural gas from sources such as landfills and dairy farm waste manure. By liquefying natural gas and getting it to transportation markets, LNG can further evolve into a renewable, clean burning fuel"
  - *Explained Dennis McLaughlin, Earth Biofuels CEO*

- "Natural gas should be used to fuel vehicles and not for power generation"
  - *Boone Pickens, Clean Energy*

- "We have been receiving 10 inquiries a month on building small-scale liquefaction plants"
  - *David Gordon, Kryopak, Salof Companies*

- "We continue to improve our process through the application of new refrigerant compositions and higher compression ratios. These developments have led to progressively lower energy needs and smaller equipment sizes"
  - *Black & Veatch*

Significant LNG projects

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- $3 million plant will liquefy 2.5 MMcfd associated gas to 15.5 tons/day LNG by February 2007 on Nongtom-A platform in Gulf of Thailand. LNG piped onshore to be processed into vehicle fuel
- Praxair subsidiary White Martins started $38 million, 14.5-MMscfd-liquefaction plant in Brazil in August that distributes LNG to regions not serviced by pipelines
- Air Products provides PPMR process w/split MR refrigeration gear configuration & main cryogenic heat exchanger for Peru's first 14.5-MMscfd LNG plant to be onstream in 2009
- Murphy Oil has preliminary board approval for 5-MMscfd flare gas reclamation LNG project offshore Sarawak, Malaysia. Deepwater Kikeh oilfield should be onstream second-half 2007
- Australia considering several more LNG plants after Karratha LNG power plant project
- Kryopak designing 150-X-300 ft, 4.5-MMscfd LNG plant for jackup rig
- China expedites small-scale liquefaction projects to meet growing urban demand

Plant categories by capacities

- Gas found in oil wells, stranded gas wells, landfills, biogas, coal mines. China LNG for distribution and vehicle fuel. Other countries use as transportation fuel or energy source in power plants, heating systems and chemical processes. LNG stored on site - independent pipeline supply.

Plant Type	Capacity (MMscfd/mtpd)
LNG fueling stations	0.5-10
Mini LNG	>1
LNG peakshaving; flare gas	5-20
Small-scale	1-10
Medium-scale	10-200
Small-scale baseload	50-250 (Sonatrach Unit 40; 180/3,500)
Baseload plants	300-1,000 (Sonatrach Units 5&6; 360/7,000)

- **LNG Plant Gas Supply**
  - 3.3-MM-mty-plant: 5-6 tcf feed gas; 550-MMscfd-plant: 5 tcf; 100-MMscfd-plant: 1 tcf.
- Note: Chinese capacity in feed gas rate and not LNG production, can be 10% to 15% difference.

LNG liquefier components

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- For capacity under construction, process cycle will be single-mixed refrigerant or propane pre-cooled single-mixed refrigerant process. Choice of processes will depend on detailed analysis of capital and operating costs of two options. In either case, basic equipment as follows:
  - **Cold Box** – depending on process, one or more cold boxes containing brazed aluminum heat exchangers, separator vessels, cryogenic piping, instrumentation, valves. Propane pre-cooled system may also contain core-in-kettle heat exchangers.
  - **MR Compressor** – electric motor or gas turbine drive centrifugal compressor depending upon site-specific requirements.
  - **Refrigerant System Vessels** – vessels required on compressor suction and discharge.
  - **Aerial Inter-Coolers and Condenser**
  - **Cryogenic Liquid Collection & Vaporizer System**
  - **Heavies Removal Column** – requirement determined by feed composition

Vendors/liquefaction processes

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- Large-scale units tend to use mixed-refrigerant loops (MRL) while smaller units use turbo-expanders. Crossover point from turbo-expander to MRL is about 0.05 million mty. Baseload plants use plate-fin (PFHE) and coil-wound cryogenic heat exchangers
  - **Baseload Liquefaction Processes**
    - **Air Products'** propane pre-cooled MR (PPMR) uses nitrogen, methane, ethane, propane. Gas feed initially cooled by propane chiller to - 35°C. Liquid/vapor streams chilled further before flashed across J-T valves to provide cooling for final gas liquefaction. Used in 82% of baseload plants and APCI also moving into small and medium-scale plants
    - **Phillips'** original optimized cascade LNG process uses propane/ethylene circuits, methane flash circuit, brazed-aluminum heat exchangers and core-in-kettle exchangers
    - **Statoil/Linde** LNG Technology Alliance's mixed-fluid cascade process uses three MR cycles to pre-cool, liquefy, sub-cool purified gas. Linde makes proprietary spiral wound heat exchanger (SWHE)
    - **Shell's** dual MR process has two separate MR cooling cycles using SWHEs and process configuration similar to PPMR process. Shell also has single MR process
    - **IFP/Axens'** Liquefin produces LNG at very high capacities and is two-MR process for new LNG baseload projects of 6 MTPA train sizes

Vendors/liquefaction processes

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- **Small, Mid-Scale Liquefaction Processes**
  - **Black & Veatch's** PRICO process uses single-MR loop/single refrigeration compression system: nitrogen, methane, ethane, propane, iso-pentane. MR compressed/partially condensed prior to entering cold box w/PFHE cores. Used for peakshaving, vehicle fuel supply, gas distribution systems: 4 to >180 MMscfd. MR system used for baseload, peakshaving. BV has 16 operating plants: 4 to 360 MMscfd and nine projects under development.
  - **Linde LE's** advanced single-flow for mid-scale 0.2-1.0-MTPA plants. Liquefaction occurs in SWHE. Basic single-flow for small <0.2 MTPA plants such as peakshaving or mini-LNG. Pre-cooling, liquefaction & sub-cooling occurs in 1 or 2 PFHE(s).
  - **Kryopak's** EXP - single-cycle turbo-expander refrigeration uses inlet process gas as refrigerant. No mixed refrigerant (MR) required. PCMR - pre-cooled MR: nitrogen, methane, ethane, butanes w/ conventional refrigeration circuit for pre-cooling. SCMR - single-cycle MR: nitrogen, methane, ethane, butanes and pentane

Vendors/liquefaction processes

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- **Small, Mid-Scale Liquefaction Processes**
  - **Chart Energy & Chemicals** provides process design thru engineering, construction, startup to meet small-plant requirements. Designed cold boxes for Phillips Cascade Process and provides aluminum plate and core-in-kettle heat exchangers.
  - **Mustang Engineering's** LNG Smart requires no refrigerant production. Eliminates MRs. Uses inlet gas as sole refrigerant medium. Gas enters multistage process via compression, turbo-expansion.
  - **Hamworthy** offers small-scale plant using closed nitrogen expansion loop providing required cold duty to liquefy gas. Mini-LNG plant uses pipeline or landfill gas

Plant/infrastrucutre economics

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- Large-scale plant costs doubling/tripling w/strong LNG demand. Base product costs up 20 to 30% last two years. Small-scale costs only risen 50%. Manufacturing efficiencies reducing plant costs while joint-venture partnerships lowering component costs

- Until 2003, medium-scale liquefiers (0.1-1.0 million mty) built for $300-$400 per metric ton per year (mt/y) of capacity - a premium price/unit of production between 3.0-8.0 million mty. Large-scale plants produced sufficient volumes to cover substantial costs of marine facilities such as long jetties, breakwaters and channel dredging

- Beginning w/economic rebound of 2002 recession, large-scale plant costs increased to near $500/ mt/y of capacity. Medium and small-scale plants have increased just 50%. Producing around six plants per year could significantly reduce costs

Plant/infrastrucutre economics

- Vehicle Fuel Infrastructure Costs

  Med-size liquefiers: $500,000 to >$12 million. Conventional 20-tpd MR plant: $3-$4.5 million; 200-tpd plant: $12 million. Storage: 11,000-750,000 liters: 3.5 $/liter-1.5 $/liter. Loading systems: $50,000-$3 million. Road tankers; US semi-trailer: 13,000 gals (50,000 liters) $350,000. Gas supply station: 15,000-400,000 gal: $210,000-$1.8 million. LNG fueling stations: $300,000.

Operating small-scale liquefaction plants

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Production Facility	Location	Daily Production (g/d)
US		
Clean Energy	Willis, TX	100,000
Earth Biofuels	Topock, AZ	86,000
ExxonMobil	Shute Creek, WY	70,000
Williams	Ignacio, CO	30,000
BP	Evanston, WY	30,000
Pioneer Natural Res.	Satanta, KS	20,000
China		
Guanghui LNG Plant	Xinjiang (Shan Shan)	55 MMscfd (Linde)
Hainan LNG Plant	Hainan Island	10 MMscfd (Propak; EXP)
Xinao LNG Plant	Weizhou Island	6 MMscfd (Kryopak; flare gas)
Germany		
Bayerwerk AG	Gablingen	45 kmol/h
Norway		
Naturgass Vest	Bergen	120 tpd (Linde)

Weizhou Island plant

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Planned small-scale liquefaction plants

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Production Facility	Location	Daily Production (MMscfd)
US		
KeySpan Energy	Brooklyn, NY	8.5 (Expander)
Washington Gas	Chillum, MD	5 (PRICO)
Peoples Gas Light/Coke	Fisher, IL	15 (PRICO)
China		
Erdos-Xingxing Gas Co.	Xingxing	36 (BV; remote gas;Industry/Vehicles)
CNOOC	Zhuhai, Guandong	20 (BV; fast track project; turbine drive; 2007)
Dazhou	Dazhou	34 (BV; clone of Erdos)
Yongda	Yongda	36 (BV; clone of Erdos)
Lanzhou	Lanzhou	12 (BV; municipal gas distribution)
HongKong Towngas CBM	Shanxi	6 (Kryopak, 2007)
Shanxi LNG Ltd.	Shanxi	50 (Kryopak, 2007)
Wuxi Yongda Gas LNG	Congqing, Sichan	37 (2007)
Pacific Asia CBM	Guizhou	30 (Kryopak, 2008)
Australia		
Wesfarmers Gas Ltd.	Kwinana, WA	180 tpd (Linde; 2008)
Norway		
Statoil	Hammerfest	13,000 tpd (Linde; 2007)
Scotland		
Transco National Energy	Scotland	12 (EP)

Planned Chinese small-scale LNG plants

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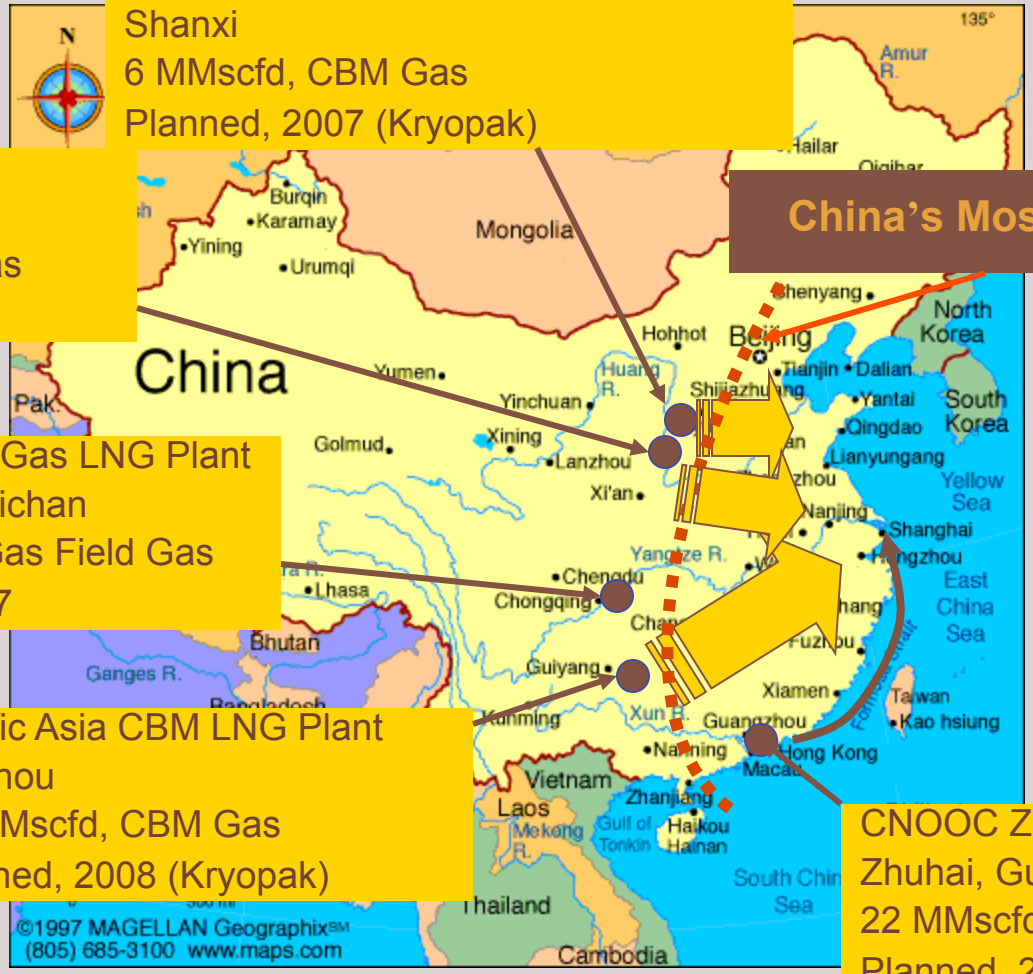
HongKong Towngas CBM LNG Plant
Shanxi
6 MMscfd, CBM Gas
Planned, 2007 (Kryopak)

Shanxi LNG LTD
Shanxi
50 MMscfd, Gas Field Gas
Planned, 2007 (Kryopak)

Wuxi Yongda Gas LNG Plant
Chongqing, Sichan
37 MMscfd, Gas Field Gas
Planned, 2007

Pacific Asia CBM LNG Plant
Guizhou
30 MMscfd, CBM Gas
Planned, 2008 (Kryopak)

China's Most Developed Area



CNOOC Zhuhai LNG Plant
Zhuhai, Guangdong
22 MMscfd, Offshore Gas
Planned, 2007

US vehicle fuel LNG plants

- Clean Energy's 10-MMscfd Boone Pickens Plant, Willis, TX, 60 miles N of Houston produces 100,000 gal/d vehicle-grade LNG from high-pressure pipeline feed. Gas liquefied at -285°C, stored in 1,000,000-gal tank, delivered in 33 cryogenic trailers to vehicle fleet and industrial customers. Purchased plant from Applied LNG Technologies (ALT) in 2005 for $14 million
- Less than a year after Apollo Resources International bought ALT, Earth Biofuels, acquired Apollo LNG and does business as Earth LNG that owns 8-MMscfd Topock, AZ LNG plant producing over 80,000 gals/day w/86,000 gals/day capacity. Apollo LNG's market value is about $36 million.
- LNG sold primarily to municipal fleet customers on US West Coast and in Arizona. Earth LNG owns 14 cryogenic tanker trucks. Customers: municipal fleets, commercial vehicles, refuse haulers.
- LNG business margins effectively locked in. Plant operations cost relatively fixed; contracts are structured such that LNG sales pricing fluctuates proportionately as gas feedstock cost goes up or down. Transaction helps expand and diversify Earth Biofuel's revenues and profitability
- Fuel sold under Willie Nelson's brand name – BioWillie.

Clean energy boone pickens plant, Willis, TX

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Technology Innovations & Advancements

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- Vacuum Insulated Pipe (VIP)
  - Economically viable alternative to mechanically insulated pipe. Cryogenic fluids lose liquid quality, refrigeration by heat transfer thru carrier pipe & insulation. Evacuating annular space between cryogen carrier pipe and jacket pipe, conductive/convective heat transfer nearly eliminated. Multiple reflective insulation layers within annular space minimize radiation heat transfer to cryogen. First VIP for LNG application was in LNG fueling stations
- First VIP LNG Export/Import Terminal Use
  - Atlantic LNG Trinidad Tobago (T1-1998; T4-2004); Distrigas import facility, Boston, MA (2000); ELNG Idku Egypt (2004); Darwin, Australia (2005); Freeport LNG (2006)
- Industry Advancements
  - Reduced jetty size or elimination; smaller line sizes w/external expansion joints; subsea pipeline: low-cost alternative to trestle-based offshore loading/offloading system; vacuum insulated from liquefier to tank, tank to tanker, tanker to tank bringing enormous advantage; cryogenic transfer technologies; VIP proven technology but every new project brings challenges.
- Small/Medium-Scale LNG Competition
  - CompactGTL capital cost $25,000-$35,000/b/d capacity; OPEX: $5 to $6/bbl; for oilfields producing 10,000-50,000 MMscfd; 10-to-20-b/d plant for testing onshore/ offshore Brazil will be onstream 2008; feasibility studies for offshore GTL plants using technology; GTL based on compact, modular syngas and FT reactors enabling GTL plants at 10 to 150 MMscfd.

Questions?

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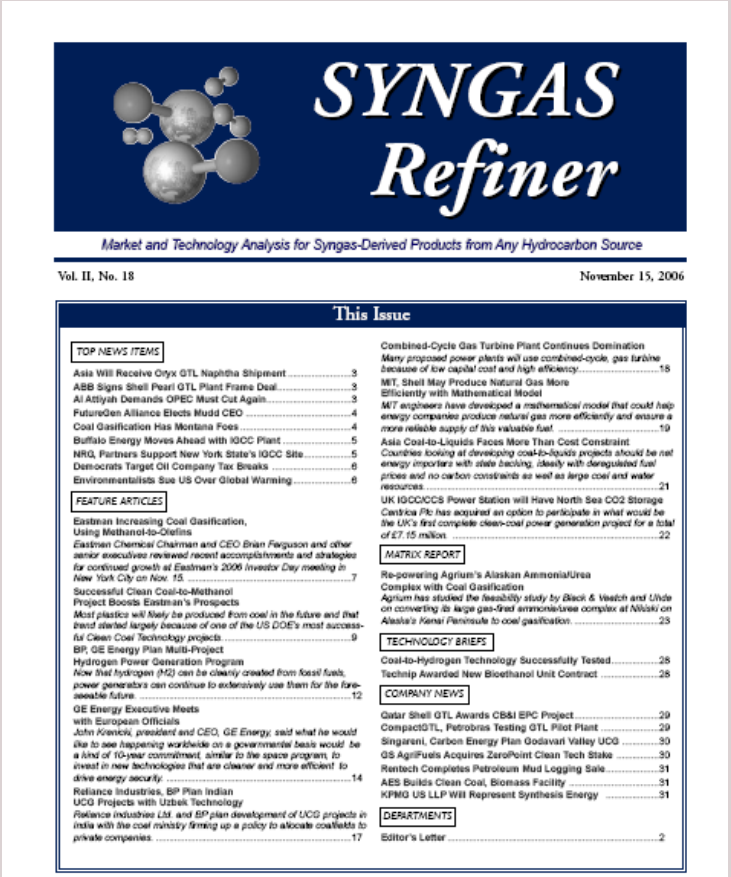
- ZEUS DEVELOPMENT CORP
  - HOUSTON, TEXAS USA



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Market and Technology Analysis for Syngas-Derived Products from Any Hydrocarbon Source

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This Issue

TOP NEWS ITEMS

Asia Will Receive Oryx GTL Naphtha Shipment 3
ABB Signs Shell Pearl GTL Plant Frame Deal 3
Al Attiyah Demands OPEC Must Cut Again 3
FutureGen Alliance Elects Mudd CEO 4
Coal Gasification Has Montana Foes 4
Buffalo Energy Moves Ahead with IGCC Plant 5
NRG, Partners Support New York State's IGCC Site 5
Democrats Target Oil Company Tax Breaks 6
Environmentalists Sue US Over Global Warming 6

FEATURE ARTICLES

Eastman Increasing Coal Gasification, Using Methanol-to-Olefins
Eastman Chemical Chairman and CEO Brian Ferguson and other senior executives reviewed recent accomplishments and strategies for continued growth at Eastman's 2006 Investor Day meeting in New York City on Nov. 15. 7

Successful Clean Coal-to-Methanol Project Boosts Eastman's Prospects
Most plastics will likely be produced from coal in the future and that trend started largely because of one of the US DOE's most successful Clean Coal Technology projects. 9

BP, GE Energy Plan Multi-Project Hydrogen Power Generation Program
Now that hydrogen (H2) can be cleanly created from fossil fuels, power generators can continue to extensively use them for the foreseeable future. 12

GE Energy Executive Meets with European Officials
John Krenicki, president and CEO, GE Energy, said what he would like to see happening worldwide on a governmental basis would be a kind of 10-year commitment, similar to the space program, to invest in new technologies that are cleaner and more efficient to drive energy security. 14

Reliance Industries, BP Plan Indian UCG Projects with Uzbek Technology
Reliance Industries Ltd. and BP plan development of UCG projects in India with the coal ministry firming up a policy to allocate coalfields to private companies. 17

Combined-Cycle Gas Turbine Plant Continues Domination
Many proposed power plants will use combined-cycle, gas turbine because of low capital cost and high efficiency. 18

MIT, Shell May Produce Natural Gas More Efficiently with Mathematical Model
MIT engineers have developed a mathematical model that could help energy companies produce natural gas more efficiently and ensure a more reliable supply of this valuable fuel. 19

Asia Coal-to-Liquids Faces More Than Cost Constraint
Countries looking at developing coal-to-liquids projects should be net energy importers with state backing, ideally with deregulated fuel prices and no carbon constraints as well as large coal and water resources. 21

UK IGCC/CCS Power Station will Have North Sea CO2 Storage
Centrica Plc has acquired an option to participate in what would be the UK's first complete clean-coal power generation project for a total of £7.15 million. 22

MATRIX REPORT

Re-powering Agrium's Alaskan Ammonia/Urea Complex with Coal Gasification
Agrium has studied the feasibility study by Black & Veatch and Linde on converting its large gas-fired ammonia/urea complex at Nikiski on Alaska's Kenai Peninsula to coal gasification. 23

TECHNOLOGY BRIEFS

Coal-to-Hydrogen Technology Successfully Tested 28
Technip Awarded New Bioethanol Unit Contract 28

COMPANY NEWS

Qatar Shell GTL Awards CB&I EPC Project 29
CompactGTL, Petrobras Testing GTL Pilot Plant 29
Singareni, Carbon Energy Plan Godavari Valley UCG 30
GS AgriFuels Acquires ZeroPoint Clean Tech Stake 30
Rentech Completes Petroleum Mud Logging Sale 31
AES Builds Clean Coal, Biomass Facility 31
KPMG US LLP Will Represent Synthesis Energy 31

DEPARTMENTS

Editor's Letter 2