



GLOBAL GAS FLARING REDUCTION PARTNERSHIP

Associated Gas Monetization via miniGTL

Conversion of flared gas into liquid fuels & chemicals

Update January 2014

This report was prepared by Dr. Theo Fleisch for the Global Gas Flaring Reduction Partnership.

The opinions and conclusions expressed in this report are those of Dr. Fleisch and do not represent recommendations or endorsements by the Global Gas Flaring Reduction Partnership or the World Bank.

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1. Glossary

ASU	Air Separation Unit
ATR	AutoThermal Reformer
bpd	barrels per day
BTL	Biomass to Liquids
CAPEX	Capital expenditure
CNG	Compressed Natural Gas
CTL	Coal to Liquids
dbc	Daily barrel capacity
DME	Dimethyl Ether
EPC	Engineering, Procurement, Construction
FEED	Front End Engineering Design
FID	Final Investment Decision
FPSO	Floating Production Storage and Offloading
FT	Fischer Tropsch
GGFR	Global Gas Flaring Reduction Partnership
GTC	Gas to Chemicals
GTL	Gas to Liquids
GTL-FT	Gas to Liquids Fischer Tropsch
gpd	gallons per day
HQ	Headquarters
kscfd	thousand standard cubic foot per day
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MMBTU	Million British Thermal Units
MMscfd	Million standard cubic feet per day
MTG	Methanol To Gasoline
NGL	Natural Gas Liquids
OCM	Oxidative Coupling of Methane
OPEX	Operating Expenditure
POX	Partial Oxidation
SMR	Steam Methane Reformer
STF	Syngas to Fuels
STG	Syngas to Gasoline
TCF	Trillion Cubic Feet
WGS	Water Gas Shift

2. Executive Summary

The large scale conversion of natural gas to liquid fuels (GTL) and chemicals (GTC) – collectively called “miniGTL” for convenience in this report - has been practiced for decades. For instance, a world scale GTL plant can convert 300 MMscfd of gas into 30,000bpd of diesel or gasoline while a world scale methanol plant produces about 2500tpd of methanol from about 75 MMscfd of gas. Over the last few years, miniGTL technologies have been developed to monetize smaller volumes of gas (less than 25 MMscfd) and thereby offer opportunities to extinguish flares. The engineering of such plants focuses on modular design, simplicity, automation and robustness of operation. In our first study reported in February 2012, a small number of companies with commercially viable options were identified, while others needed more time for R&D to demonstrate their technologies. Now, 2 years later, Oberon Fuels, Velocys and CompactGTL are on the brink of multiple commercial plants. The progress of all companies reviewed in our first report will be discussed.

Since the first report, miniGTL has become a booming business opportunity, particularly in North America, with many new entrants mainly because of the large arbitrage between shale gas and liquid transportation fuel prices. Ten new companies offering near term solutions to gas flaring via conversion of the gas into valuable, easy to market products have been identified. A diversification of product options with more technologies aimed at gasoline production has been observed. Proton Ventures offers for the first time a distributed fertilizer option. Among the “new” entrants are companies that have been pursuing GTL technologies for 5 years or more but have only recently gone public with their work. Greyrock, for example, is joining the leaders in offering commercially ready solutions from 100 to 1000 bpd plants which consume about 1 to 10 MMscfd. Other companies, such as MarcellusGTL, do not develop new technology, but develop projects by licensing proven technologies such as ExxonMobil’s MTG process.

This report contains the most comprehensive study of miniGTL technologies available today. Over 24 companies have been reviewed and are described in some detail. The goal of this study is the identification of companies that provide relatively low risk, commercially viable options today in order to simplify evaluation and choice for GGFR members in eliminating flares.

3. Introduction

In the latter part of 2011, a dozen miniGTL technologies were critically evaluated for their application to extinguish and monetize flares by converting them into locally marketable liquid fuels and chemicals. Natural gas is the preferred feedstock for the production of methanol, ammonia, diesel, gasoline and other products. Hundreds of large world scale plants are operational around the world. The term “miniGTL” was created to identify technologies that convert gas flares into such products with gas volumes from sub 1 MMscfd to a maximum of 25 MMscfd, with a “sweet spot” at 15 MMscfd.

Twelve technologies were evaluated:

- CompactGTL
- Velocys
- Gas Techno LLC
- Verdis Fuels
- GRT Fuels
- Synfuels International
- Methion Ltd
- Oberon Fuels
- Carbon Sciences
- R3 Science
- General Methanol
- 1st Resource Group

The conclusions were as follows:

Over one dozen miniGTL technologies are under development that will be potentially useful for the monetization of flared gas. They are at different levels of commercial readiness, ranging from offering commercial units today to research in the laboratory.

The companies behind these technologies have been introduced, the pros and cons of the technologies have been evaluated and the statuses of their commercial development have been described. Some of these technologies will find widespread use, while others will be abandoned. New companies with new options will appear.

In general, miniGTL technologies will be among the more capital intensive AG monetization options. However, the high value of the products and their ready use in local markets will be strong drivers for their application. Most importantly, miniGTL is not just a potential option for the future but is available today for first commercial applications.

About 2 years later, the predictions have been realized. A few technologies have found commercial applications, or are very close to them, while other technologies have been abandoned. In this update report, these previously reviewed technologies will be revisited for any advances that have been made.

Ten new players have been identified with interesting new options for associated gas monetization via miniGTL technologies. The new technologies will be introduced and evaluated.

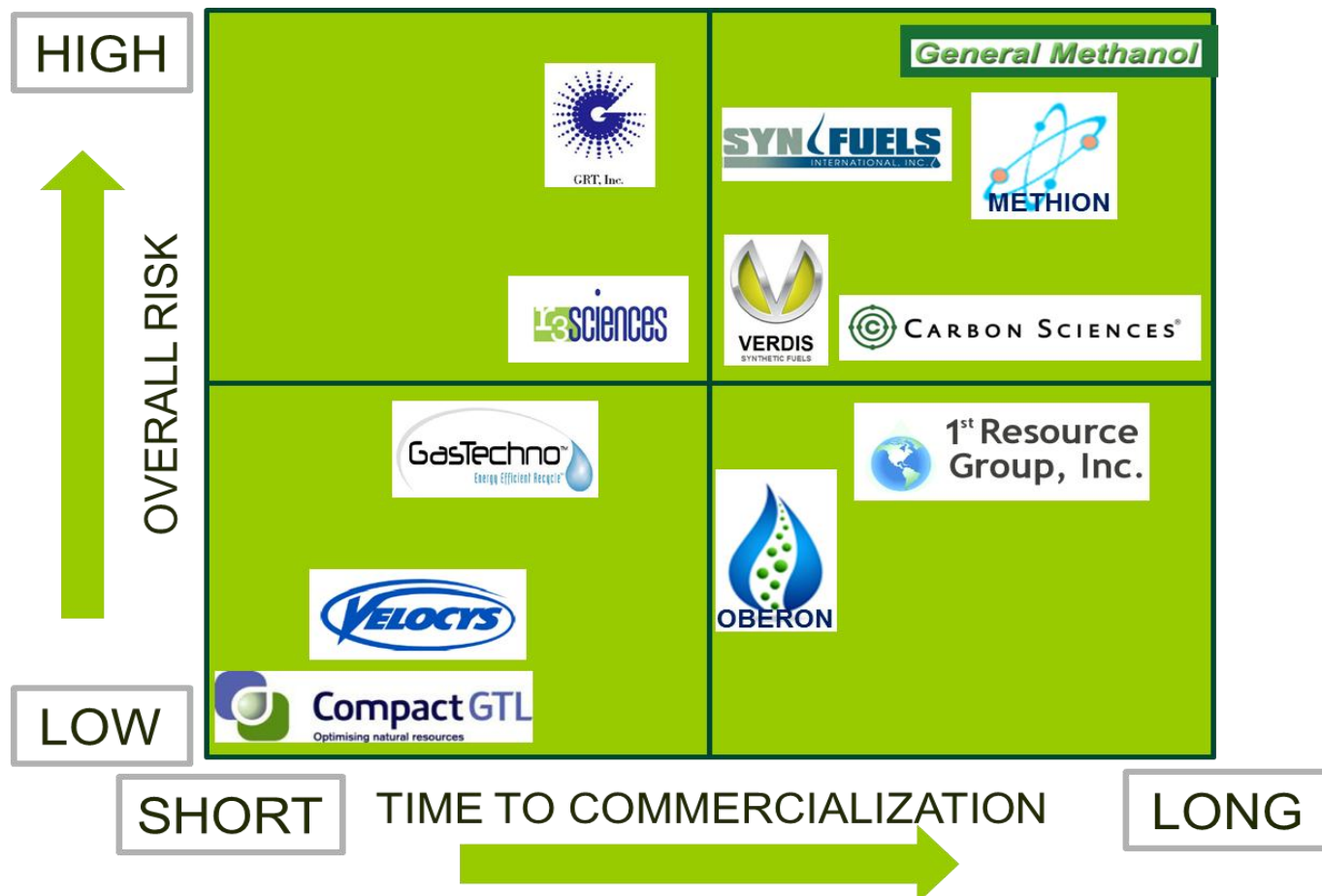
A combined, integrated assessment of the remaining risks and commercial readiness will be presented.

4. Developments in previously reviewed technologies

The key grouping slide of the first report is shown below. The 12 technologies were grouped according to our estimation of remaining technical risks and to time required for commercial applications. These groupings are only semi-quantitative and reflect the best judgment of the author who has 25 years of experience in GTL technologies. CompactGTL, Velocys, Oberon Fuels and GasTechno were judged to have the lowest overall remaining risk and were closest to commercial applications.

All press releases and announcements since the report was issued have been noted, searched all websites for updates and talked to most of the companies for their views on the progress made. The view taken in the previous report - shown in the figure below – has been updated and the current view is shown at the end of this chapter.

Overall risk and time to commercialization: January 2012 report



4.1 CompactGTL

In October 2012, CompactGTL announced an exclusive collaboration agreement with Single Buoy Moorings Inc (SBM) to offer floating GTL plants on FPSOs. Kawasaki Heavy Industries (KHI) became shareholders and entered into agreement for the supply and modularization of the reactors. New on-shore plant designs have been developed incorporating conventional reforming and modular FT technologies. These so-called “hybrid” plants offer lower Capex and the potential to move to larger scale (up to 15,000 bpd). In March of 2013, Tony Hayward, past CEO of BP, was introduced as CompactGTL’s new Chairman. In December of 2013 he led a major refinancing effort for CompactGTL.

CompactGTL continued head to head competition with Velocys as the two leaders in miniGTL-FT technologies. CompactGTL’s demonstration plant in Brazil was approved by Petrobras, and operated stably throughout 2012 with a robust, high level of service. However, a first commercial plant in Brazil has been delayed by Petrobras because of an overall slow-down of its development of new deepwater projects. CompactGTL remain very active as presenters at appropriate conferences around the world. It points to numerous confidential feasibility studies for commercial projects around the world, some of which are moving forward to the FEED stage and with FID’s expected by 2015, but to date have not been able to announce one publicly. Its position on the time to commercialization scale is moved slightly to the right.

4.2 Velocys

While the Company’s technology has been marketed under the name Velocys in North America since its inception, in September 2013 the name of the parent company changed from Oxford Catalysts Group to Velocys.

A global service agreement with Mourik to provide catalyst handling services was announced in November 2012. Velocys became Ventech’s preferred supplier of FT technology in North America. Ventech Engineers International LLC is a global leader in the design and construction of modular refineries. Ventech have since placed an order worth \$8m for FT reactors with sufficient capacity for a 1,400 bpd plant. Two of Velocys’ existing partners, Toyo Engineering Corporation and MODEC have invested further funds to accelerate global technology adoption and, in December 2012, the company also raised about \$50 million through a conditional equity placing, strengthening its balance sheet.

In Petrobras’ refinery in Fortaleza, Brazil, a 6 bpd integrated GTL plant is targeting qualification during the second half of 2013 following the lead of CompactGTL. A 25 bpd reactor has been operational in Thailand since 2012 confirming performance data seen in Brazil. A 125 bpd FT base unit has been engineered and is ready for large scale production, likely in Japan. Overall, the estimated technology risk associated with micro-channel reactors has been somewhat decreased since our last report.

Velocys has made significant progress in commercializing its technology over the last two years. The company’s involvement in five commercial scale projects has been announced:

- In July 2012, Velocys was selected by project developer Solena Fuels as sole FT supplier to GreenSky London, Europe's first commercial scale renewable jet fuel facility, being developed in partnership with British Airways and using biogas as feedstock. This was announced following a formal evaluation of available technologies carried out by Fluor Corporation.
- In September 2012, it was selected to supply FT technology for a 1,000 bpd commercial GTL plant at Calumet's facility in Karns City, Pennsylvania, USA using natural gas as feedstock. Calumet is a specialty petroleum products manufacturer.
- In July 2013, Velocys announced its selection as the FT technology provider for the design and possible construction of a 1,100bpd commercial biomass-to-liquids (BTL) plant in Oregon, USA. The proposed facility is led by Red Rock Biofuels.
- In September 2013, Pinto Energy announced it had selected Velocys as supplier of FT technology for a 2,800 bpd commercial GTL plant it is developing in Ashtabula, Ohio using natural gas as feedstock.
- Finally, in October 2013, a 100 bpd demonstration plant using both micro-channel SMR and FT was announced in Thailand by partner PTT again using natural gas as feedstock.

Velocys seems to have taken the lead in developing commercial GTL-FT projects, but a few projects by others could change this situation quickly. The radically new Velocys microchannel reactor design is however still considered to pose a somewhat higher technical risk than the more conventional reactors offered by others, including those from CompactGTL.

4.3 Oberon Fuels

Oberon Fuels has made tremendous progress over the last 2 years! It was able to raise significant funding from Martin Resource Management, sufficient to build the first commercial plant in California using bio-gas. The first phase of this first DME plant is operational in Imperial Valley, California, producing 4500 gallons per day (110 bpd) of DME from methanol. The fully integrated plant, including a reformer and a methanol production unit, will be completed by 3Q 2014. Future plants will have capacities up to 10,000 gallons of DME per day (about 250 bpd) consuming about 2 MMscfd of natural gas.

On June 6, 2013, a partnership between Oberon Fuels, Volvo Truck and Safeway was announced to introduce DME as a clean diesel alternative for heavy duty trucks. Two Volvo trucks operated by Safeway will run on Oberon DME and will be deployed in Safeway's commercial operations during 2014. Commercial scale production of DME powered trucks will commence in 2015. Volvo has two decades of experience with DME fuel and has identified DME as the cleanest, most promising diesel alternative for the future.

Oberon Fuels is very active on the conference speaker circuit to introduce DME to the US and is working to obtain the permits necessary for use of DME as a transportation fuel. Business development efforts have led to the sale of a number of plants to be located in parts of the US where abundant gas is available for conversion.

Overall, Oberon Fuels is a low risk, albeit low volume, play, with commercialization already underway. The product DME is either blended with propane/butane for heating and cooking, or is used as an ultra-clean, advanced diesel alternative.

4.4 GasTechno

Gas Techno has been promoting its Early Adopter Program since May of 2012, and has been operating its pilot plant since December 2012. The pilot plant was installed on a Michigan oil & gas field and successfully demonstrated that the reactor system is capable of converting C1-C6 hydrocarbons from a flare to alcohols and aldehydes. The gas quality ranged from 1050 BTU/scf to 1300 BTU/scf and had as high as 18% nitrogen in the feed gas stream.

In December of 2012 one of its Early Adopter Customers agreed to finance the construction of GasTechno's second generation portable miniGTL plant. This plant was designed to process 35 to 50 kscfd of associated/flared gas and make up to 4 bpd of refined liquids including methanol, ethanol and formaldehyde. The plant was completed in July 2013 and tested using 99% methane in its fabrication shop, with data gathered to make final modifications before moving it to an oil field in Michigan where operations began in August 2013. The plant has only run sporadically because of the high cost of pressurized oxygen cylinders; oxygen is needed for the partial oxidation process in the GasTechno process.

GasTechno continues to work on improving the marketability of its product mix of methanol, ethanol and formaldehyde. In October 2013, it filed a new diesel patent claiming the conversion of its feedstock into a diesel blending stock. In July of 2013 GasTechno was awarded the highest rating for their basic patents in Michigan out of 100 companies evaluated by Ocean Tomo, a leading intellectual property evaluation firm. Indeed, their technology is a potential game changer, but raises risk concerns among investors and potential early adopters. The major concerns are the limited availability of long term plant performance data, the lack of selectivity of the process and the economic viability. However, GasTechno offers low Capex plants for very small gas volumes, not readily addressed by other technologies.

4.5 R3Sciences

R3Sciences is facing technical issues in its development of a revolutionary homogeneous modular methanol technology. Plans for commercial deployment in 2013 have been delayed, and work has moved back into the laboratory. Some \$ 5 million has been spent on catalyst development over the last few years, and a small 50 gpd pilot plant is now planned in 2014. This pilot plant will be followed by the development of a 2000 gpd prototype in 2015, with planned commercial offerings in late 2015/early 2016. Commercial plants will consist of about 6 modules fitting onto a small footprint of 30x50 feet. They will convert 1 MMscfd into 10,000 gpd of methanol.

Technical and safety risks were noted in the earlier report based on personal experiences with this technology in the nineties. It remains to be seen whether R3Sciences can overcome these challenges. However, the prize is big: the homogeneous methanol process technology offers

many cost saving advantages and could be a long sought breakthrough. The risk remains high and the time to commercialization has moved further into the future.

4.6 Verdis Fuels

There have been no press releases or updates on the website. It appears that no progress has been made, most likely because of lack of funding and of potential customers.

4.7 1st Resource Group

There are no updates on the website and there have been no press releases. However, the 1st Resource Group ("1RG") has made tremendous progress over the last 3 years. It has developed modular GTL-FT designs sized for 500 to 5000 bpd production using conventional technologies; with a conversion rate of 12 kscf of gas per barrel of liquid product, these corresponds to 6 scfd and 60 MMscfd gas feed rates. It claims a Capex of \$52 million and \$130 million for 600 bpd and 2000 bpd plants respectively corresponding to \$87,000/dbc and \$65,000/dbc. These numbers are low and exciting, but are only early engineering estimates. Clearly, they have sacrificed conversion efficiency to save cost needing 12kscf gas to make 1 bbl of diesel rather than the more typical 10kscf.

1RG is targeting the heavy duty diesel, aviation fuel and railroad business. It is also the only company with a vertically integrated business vision with plans to own the gas resources it converts.

1RG's technologies are "off the shelf", with a good FT catalyst from the Sued Chemie division of Clariant International. The author is very familiar with the catalyst which has excellent performance in fixed bed reactors. The plants are designed, engineered and built by Commonwealth Engineering and Construction Company (CEC), a mid-size EPC company with limited credentials in GTL.

The remaining overall risks will be the financing of projects as well as the execution, operability and robustness of the first plants.

4.8 Carbon Sciences

Carbon Sciences is a publicly traded company (CABN). Its foundation was a novel, coke resistant, reforming catalyst that could convert natural gas to syngas using CO₂ (!) and steam. The problem was that the resulting syngas has a low H₂/CO ratio of about 1, unsuited for further miniGTL-FT technology. In November 2012 it issued a press release announcing a new vision for its miniGTL plants using conventional reformer technology, and in December 2012 announced development of a modular plant design (60 modules) with a total capacity of 1000 bpd. In January 2013 it announced a partnership with Fluor to engineer the plant and, in a June 2013 press release, Tulsa Oklahoma was mentioned as the potential site for the plant. All technologies would be licensed-in (reformer, GTL-FT or MTG).

CABN stock has dropped over 99% over the last 2 years. There have been senior management changes, with Bill Beifuss replacing Byron Elton as CEO, and severe cutbacks in R&D funding.

Carbon Sciences is likely to need significant additional funds to continue development of the technology.

4.9 GRT Inc

The GRT technology converts methane into gasoline using bromine to form the reactive intermediate methyl-bromide. Technology development has been underway for more than 15 years without achieving commercialization. No progress has been reported over the last 2 years.

4.10 Synfuels International

The Synfuels technology is another non-syngas process. It converts methane to acetylene in a pyrolysis reactor which is then converted in ethylene. Ethylene is a valuable key chemical and a well-known feedstock to gasoline. Under development for more than 15 years, the technology has not seen the light of commercialization. No new developments have been reported in the last 2 years.

4.11 Methion

There is no news on the website and there were no press releases. However, Alan Richards, the CEO of Methion claims that progress has been made but that, for reasons of confidentiality, nothing new can be disclosed at this time.

Investor economic evaluation reports based on empirical pilot results modeled in a steady state Aspen Simulation have been completed for Methanol. Dimethyl Ether and olefins simulations are now in progress. Reports will be available first quarter 2014. (Statement from Mr. Richards)

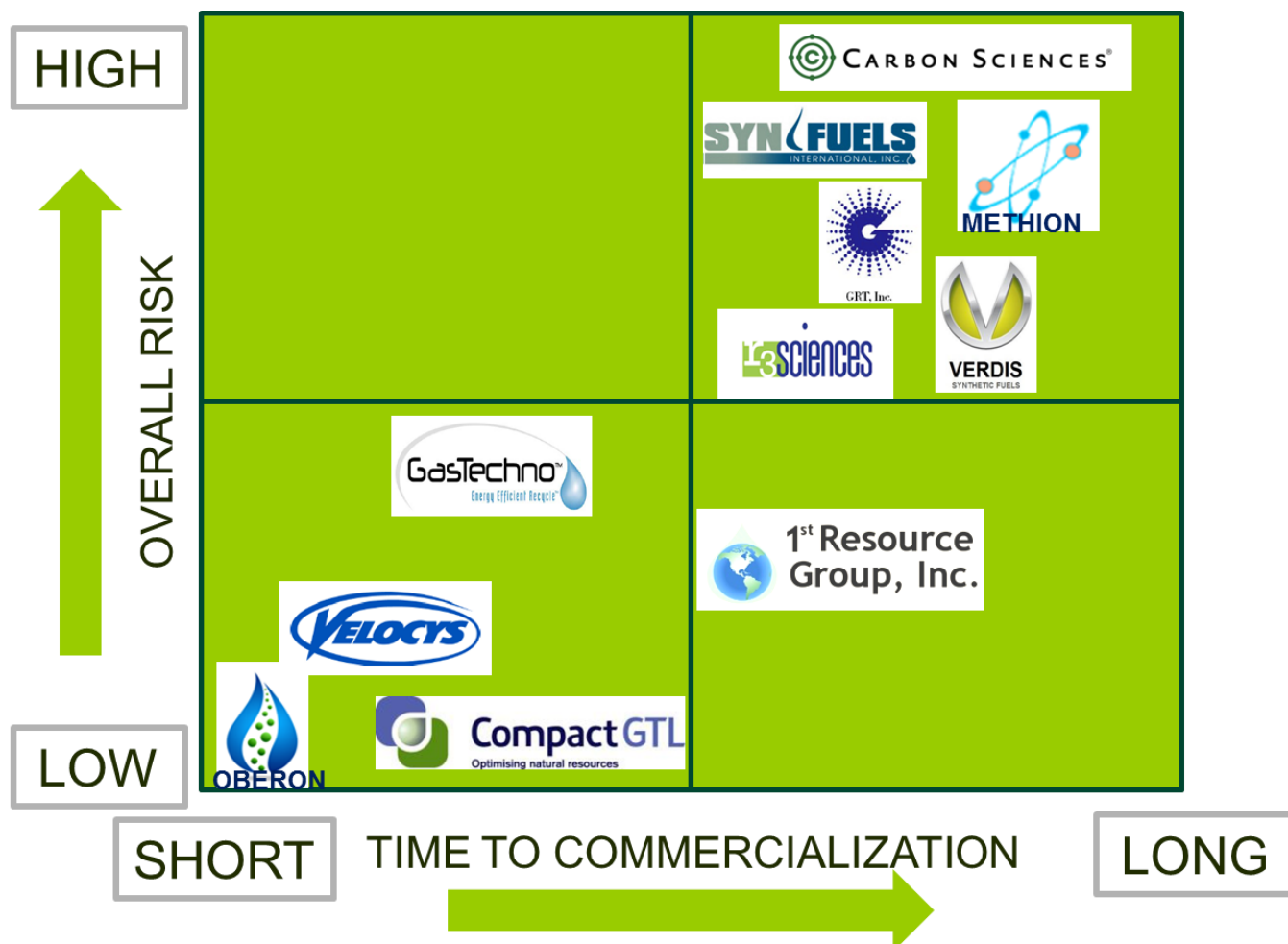
A very high level of risk remains because of the revolutionary approach with sulfuric acid as the methane activation agent. The technology is under development for 8 years and very limited quality process data is available. The reports expected early next year will show the status of the technology.

4.12 General Methanol

General Methanol has ceased operations. It was ranked as the technology with the highest overall risk in our 2012 report.

Based on all the above noted developments, here is the updated assessment of the technologies reviewed in the 2012 report.

Overall risk and time to commercialization:
January 2014 updated position



There are 3 leaders: Oberon Fuels and Velocys technologies are being commercialized in the US and have taken the lead in the construction of the first miniGTL plants. CompactGTL follows with FEED and FID decisions expected in 2014/2015. All 3 companies are well funded with experienced staff and strong strategic partners.

GasTechno and R3Sciences are working hard to deploy first commercial systems, with GasTechno currently in the lead since it has a system in the field and are currently assembling the third system. Both companies target small flares of about 1 MMscfd or less. With respect to overall risk, both companies are developing novel breakthrough technologies with the inherent risks. Both companies will face more hurdles in technology acceptance and project financing.

The 1st Resource Group is considered to pose a smaller overall risk than GasTechno or R3Sciences because of its use of conventional technologies. However, its low staffing level, coupled with limited GTL experience, still poses a significant risk.

The technologies pursued by Synfuels International and GRT are believed to be better suited for large scale applications, and do not see them as aggressive players in the miniGTL arena in the foreseeable future.

Alan Richards of Methion is outspoken in his interest in extinguishing gas flares and his technology is suitable for typical gas flare volumes. However, no records are available that show that the technology actually works.

For Carbon Sciences, the estimated overall risk is financial rather than technical, and when/if its current financial situation improves it could move quickly to a more promising risk assessment position.

5. New Technologies

Over the last 2 years, a number of new GTL technologies and companies surfaced. Most of these companies are looking at the low cost shale gas in the US as their primary feedstock of interest but are also interested in associated/flared gas.

A number of companies such as Nerd Gas (Wyoming based), Emberclear (Toronto based) and G2X Energy (Houston based) plan to develop US based projects using licensed ExxonMobil MTG technology (making gasoline). They focus on larger scale plants and do not offer miniGTL plants for flare reduction. Recently, Nerd Gas announced the potential construction of a 1 bpd GTL FT pilot plant to test its own, modular FT technology. If it moves ahead, while excluded from the current evaluation, it could become another player in miniGTL.

Based on data from the internet, press releases, conference presentations etc, thirteen companies were selected for evaluation as potential miniGTL providers. They are shown in the following figure.

New companies for 2014 update



Air Liquide is a leader in the field of gas conversion through its acquisition of Lurgi. It is however putting no effort in development of small scale applications, and about 5000 bpd (50 MMscfd gas feed rate) is believed to be the smallest scale plant it would build. Similarly, Japan-GTL, who had previously indicated interest in smaller GTL plants, now states that plants of >15,000 bpd are its focus. Syntroleum, one of the GTL leaders in the nineties, recently announced its return to GTL. Its focus is on larger plants ("multiple thousands of barrels") as it believes that

miniGTL plants using its technology would not be economically viable. Air Liquide, Japan-GTL and Syntroleum are, therefore, not options for flare reduction and have been removed from the evaluation.

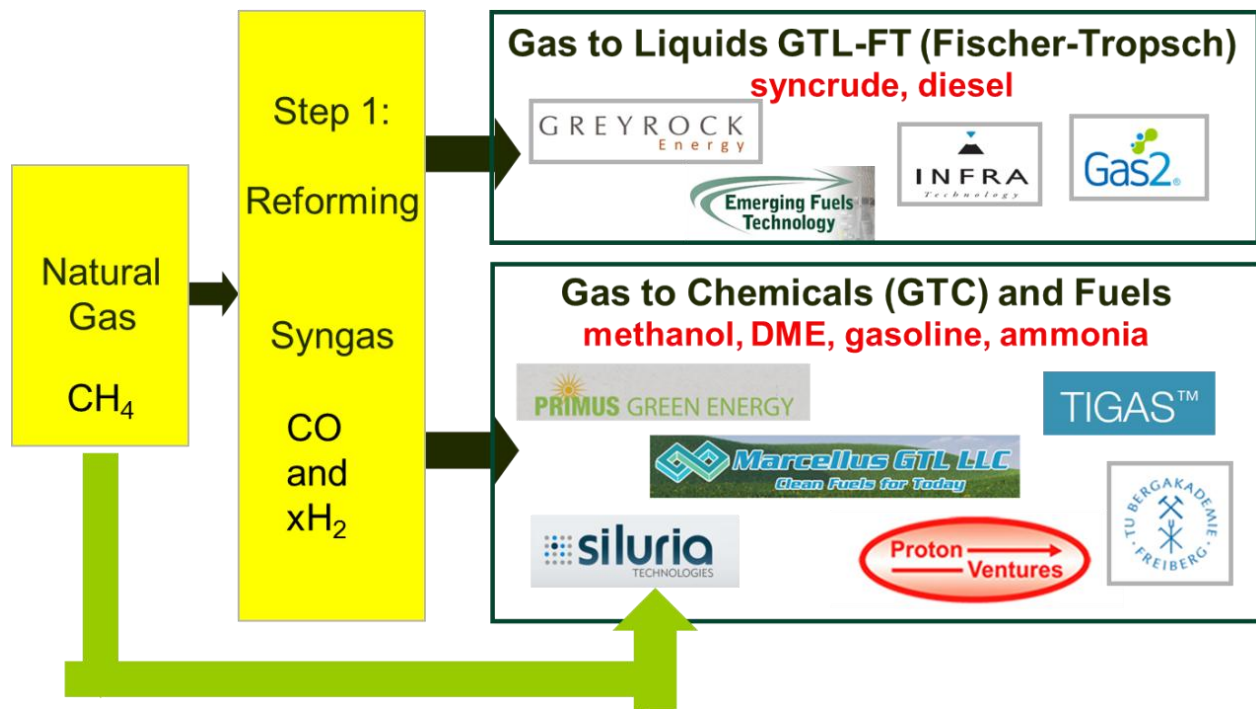
The remaining 10 companies offer exciting new options. Four of them play in the GTL-FT field with syncrude or diesel as the final products. Greyrock distinguishes itself from traditional FT technologies by producing fuels directly from syngas without the need to refine or upgrade wax. INFRA is pursuing the same one step conversion.

The Topsoe TIGAS process produces gasoline, Marcellus GTL licenses ExxonMobil's MTG technology while Primus Green Energy has advanced the MTG technology to "STG+", syngas to gasoline, jet fuel and chemicals. The TU Freiberg has also developed a similar syngas to fuels (STF) technology where the methanol intermediate is converted to gasoline.

The Siluria technology is quite different since it does not go through the conventional syngas route, but proceeds directly to ethylene and then gasoline in a process called "oxidative coupling of methane" (OCM).

Proton Ventures is the first company to offer a mini ammonia (fertilizer) option.

GTL: Gas to Liquids – Fit of new companies



The company websites, along with contact information, are listed in the Table below.

COMPANY	TECHNOLOGY	WEBSITE	CONTACT	E-MAIL
Greyrock	FT	www.greyrock.com	Robert Schuetzle	rschuetzle@greyrock.com
INFRA	FT	www.infratechnology.ru	Dmitry Popov	popov@infratechnology.ru
EFT	FT	www.emfueltech.com	Ken Agee	kagee@emfuelstech.com
Gas2	FT	www.gas-2.com	Mike Fleming	info@gas-2.com
Marcellus GTL	MTG	www.marcellusgtl.com	Paul Hamilton	paul.hamilton@marcellusgtl.com
TIGAS	MTG	www.topsoe.com	Henrik Udesen	hu@topsoe.dk
Primus GE	MTG	www.primusge.com	Nan Li	nli@primusge.com
TU Freiberg	MTG	www.tu-freiberg.de	Ibrahim Kolewole	ibrahim.muritala@iec.tu-freiberg.de
Siluria	OCM	www.siluria.com	Rahul Iyer	rahul.iyer@siluriatech.com
Proton Ventures	Ammonia	www.protonventures.com	Anish Patil	anish.patil@protonventures.com

5.1: Greyrock Energy

Company Profile

Greyrock Energy was founded in 2006 as Pacific Renewable Fuels by Dr. Dennis Schuetzle, previously head of R&D for Ford Motor Company with extensive experience in fuels, catalysis and manufacturing processes. The company is headquartered in Sacramento, California with offices and a demonstration plant in Toledo, Ohio. The CEO is Mr. Robert Schuetzle. Its sole focus is small scale GTL-FT plants for Distributed Fuel Production™ and it has a commercial offer of both a fully integrated 1000 bpd plant consuming about 11 MMscfd, and smaller “MicroGTL” plants (described below). Greyrock’s team has extensive experience from numerous industry leaders including Sasol, Chevron, Jacobs Engineering, Ford and others. This experience has not only led to breakthrough innovations, but also demonstrates the importance of practical elements for commercialization and robust operation.

Technology

Greyrock Energy has developed a proprietary catalyst that directly converts syngas into fuels with high selectivity, completely eliminating the need for the 3rd GTL-FT reaction step, the refining of the paraffinic waxes into fuels. Therefore, its “Direct To Diesel”™ GTL technology has lower CAPEX. The elimination of this reaction step is a key innovation.

Greyrock uses a modular, integrated architecture with an advanced adaptive control system to deliver robust performance. Importantly, it demonstrated its technology at the 30 bpd level in a demonstration plant in Toledo, Ohio in 2011. The technology was scaled up from the laboratory to a 1 bpd pilot plant in 2008 in collaboration with a number of key commercial partners.

Greyrock offers different integrated reforming technologies allowing the production of syngas from flared gas, NGL, bio-gas, cellulosic materials and waste CO₂.

Advantages and Challenges

Greyrock Energy seems to have a strong position in the commercialization of miniGTL plants. Its 1000 bpd plant is similar in scope to current projects announced by Velocys and CompactGTL. It has a proven 2 step process (proven at 30 bpd) to high quality diesel which seems to have low technical risk because of the use of rather conventional technologies such as fixed bed reactors.

In addition to the 1000 bpd plant design, Greyrock has recently announced its “MicroGTL” solution. These plants are designed to process 1.3 - 4 MMscfd leading to about 100 to 300 bpd of finished fuels. The equipment is sufficiently modular to allow it to be moved to a new location should that be warranted.

Status and Path Forward

Greyrock Energy claims to have a strong pipeline of customers for both its larger and MicroGTL systems. It is a relatively unknown player in miniGTL technologies since they deliberately do not showcase their technology at conferences or in press releases. It is a full service company performing feasibility studies and FEED engineering studies, followed by procurement and construction in cooperation with partners. It will also assist in commissioning, start-up and operations. Greyrock Energy has a proven, low risk, ready to commercialize technology. Recently, it began offering its MicroGTL systems with plants of less than 300 bpd capacity, an important development for flare reduction.

5.2 INFRA Technology

Company Profile

INFRA Technology was founded in 2009 and is headquartered in Moscow, Russia, with a US office in Houston, Texas. Its CEO is Andrey Li. It has a very active R&D program headed by its CTO, Professor Mordkovich. Similar to Greyrock Energy, it has a direct syngas to diesel (and/or jet fuel) GTL-FT process. However, its process is still only in the pilot plant phase, with a small plant (0.25 bpd) operational since 2010. A large demonstration plant of 100 bpd is being built.

Technology

INFRA Technology claims tremendous technical improvements over today's 3rd generation GTL-FT technologies practiced by Shell, Sasol and others. Its “4th Generation Technology” is based on much improved catalysts and fixed bed reactors leading to a 3fold higher productivity and direct formation of liquid hydrocarbons in the diesel and jet fuel range with no or only limited hydrotreating required. Conventional reforming technologies are used. INFRA Technology is

firmly focused on small modular plants for flare reduction as its business entry. Larger plants are envisioned for the future.

Advantages and Challenges

INFRA Technology is developing a much improved GTL-FT process. It has an excellent team of researchers and its innovations have been protected through a portfolio of international patents. Its very high productivity catalyst leads to smaller reactors, with less catalyst for the same volume of gas feed. This will lead to lower Capex which INFRA Technology estimates at about \$60,000/dbc compared to numbers closer to \$100,000/dbc for today's plants. These numbers need to be proven in the demonstration plant at scale.

There could be significant challenges in heat management in the FT reactor because of the high catalyst productivity. Commercial grade product quality will be another challenge if the hydrotreating step is to be completely avoided. Direct conversion to diesel fuel also typically leads to lower carbon efficiencies because of higher production of undesirable methane and other lower carbon bi-products.

Status and Path Forward

INFRA Technology has piloted a very promising advanced GTL-FT technology. It is well funded and is now embarking on building a 100 bpd demonstration plant. Its modular architecture is ideally suited for remote gas flare sites. It will take 2 to 4 years before commercial plants can be offered.

5.3 Emerging Fuels Technologies (EFT)

Company Profile

EFT was formed in 2008 by Ken Agee who, in 1984, founded Syntroleum, a leader in GTL-FT from 1990 to 2005. Dr. Kym Arcuri and Dr. Rafael Espinoza are his partners. The company is headquartered in Tulsa, Oklahoma.

Technology

EFT's core competency is GTL-FT technology. It provides services in catalyst development, engineering, plant design and general consulting. It has developed a superior FT catalyst for a fixed bed reactor system that performs "like a slurry system", achieving highest catalyst performance with the excellent heat control typical for slurry reactors. Its engineering designs are focused on smaller plant sizes ranging from 500 bpd to 5000 bpd using about 5 to 50 MMscfd as feedgas.

Advantages and Challenges

EFT has world class expertise in GTL-FT and has created a state-of-the-art facility for FT technology development. Its FT technology has been successfully tested in a 1 bpd pilot plant

for over a year. EFT claims that immediate scale-up to small plants (up to 1000 bpd) is feasible because of its rather standard process design and operating conditions. Its new catalyst has been extensively tested in a single tube reactor and scale-up to thousands of tubes is relatively straight forward. EFT does not have a very active business development effort, which will hamper commercial adoption of its technology.

Status and Path Forward

EFT has developed FEL (Front End Loading) engineering designs for a number of small scale plants with +/-20% cost estimates, and commercial developments are understood to be underway. They claim that their capex estimates show a rather typical \$100,000dbc (\$100 million for a 1000 bpd plant).

5.4 Gas2

Company Profile

Gas2 was formed in 2005 in close collaboration with Robert Gordon University, and is headquartered in Aberdeen, Scotland. Mike Fleming is the Managing Director and Dr. James Bannister is the Technology Manager. Gas2 is developing a novel technology around porous membrane reactors (pMR™) for both the reforming step and the GTL-FT process. It has been successful in raising funding (~\$25 million) to build pilot plants at its Wilton Centre in Teeside, and has built up a good patent portfolio.

Technology

Conventionally, catalyst pellets or extrudates are filled into metal reactor tubes or, more recently, deposited onto metal surfaces (Velocys). Gas2 catalysts are incorporated into 3D porous alumina structures which are part of the reactor design. This provides a number of advantages such as low pressure drops, improved mass transfer and controlled reaction conditions in small pores. Its reforming step is a Catalytic Partial Oxidation (CPOX) process where oxygen and gas react in the small pores to generate syngas. An expensive catalyst based on rhodium, built into the membrane, enables the reaction without carbon formation. It is reported that its “pMR CPOX” pilot syngas plant will come on line in mid-2013, with the GTL step following in 2013/2014.

Advantages and Challenges

While Gas2's three dimensional porous alumina structures will offer some advantages over conventional fixed bed reactors as mentioned above, the extent of the cost savings and efficiency improvement need to be proven; the cost of oxygen for the CPOX technology could offset any cost advantage over competing steam methane reforming technology. The use of an expensive noble metal such as Rhodium is not helpful either. Heat management in the exothermic GTL-FT reaction is key, and the very low-conductive alumina membrane and support is not well suited to remove the heat from the reactor module.

Gas2 is at the “conceptual engineering stage” where engineering realities and early cost estimates will answer these questions soon.

Status and Path Forward

Gas2 is building two pilot plants which will come on-stream in 2013/2014, one for the reforming process and one for the GTL-FT step. These plants will demonstrate the potential technical and economic viability of porous membrane reactors. Based on these learnings, Gas2 will announce technology demonstration and commercial plans in 2014. If the technology continues to look promising, demonstration plants at larger scale are likely required before commercial offerings can be made. This will require significant more funding and a few more years of development time.

5.5 Marcellus GTL (MGTL)

Company Profile

Marcellus GTL is a project development company, based in Duncanville, Ohio, with a business focus on the monetization of cheap shale gas in the US. John Rich Jr. is the CEO and Paul Hamilton the Executive VP.

Technology

Marcellus GTL is licensing the ExxonMobil MTG process where gas is converted into gasoline via methanol and DME. The Haldor Topsoe TIGAS and the Primus Green Energy STG+ technology discussed below are also variations on this technology which was developed and commercialized by Mobil in New Zealand in the nineteen-nineties.

Advantages and Challenges

The MTG technology is proven and carries no technical risks. MGTL is planning its first project in Pennsylvania with a modest and safe capacity of 2000 bpd consuming about 20 MMscfd of pipeline gas. The challenges lie in securing financing and in project execution. The success of this first project will essentially determine the future of MGTL.

Status and Path Forward

MGTL has been successful in advancing its first project with excellent support from local and regional government authorities. It is now in the process of raising the \$200 million required to build this plant, together with negotiating gas supply and product sales agreements.

5.6 TIGAS

Company Profile

The TIGAS technology has been developed by Haldor Topsoe, a 70 year old leader in syngas technologies and syngas based processes. Haldor Topsoe is a world class catalyst manufacturer with annual global revenues of about \$1 billion. Company headquarters is in Lyngby, Denmark.

Technology

TIGAS stood for “Topsoe Integrated Gasoline Synthesis”, a process developed and demonstrated nearly 30 years ago for the monetization of stranded gas via conversion into gasoline. The old TIGAS process involved syngas formation, a novel, combined methanol/DME reaction step, followed by conversion into gasoline. The new and improved TIGAS process (now standing for “Topsoe IMPROVED Gasoline Synthesis”), developed over the past 2 years, no longer requires the formation of the DME intermediate, and is a simpler 3 step process where syngas goes to methanol which is directly converted to gasoline.

Advantages and Challenges

Topsoe has built many world-scale reformers, methanol and DME plants. Topsoe has also sold its methanol to gasoline catalyst to Chinese MTG facilities with great success. It is said that the Topsoe catalyst works better than the original ExxonMobil MTG catalyst! The whole process has therefore been proven at commercial scale. The quality of the gasoline product will be sufficient for blending with oil derived gasoline, but will require some mild upgrading for pure/neat application.

Status and Path Forward

Topsoe is the most experienced technology provider of all companies evaluated for the GGFR miniGTL study. The conversion of natural gas into chemicals and fuels is the foundation of the company. TIGAS is an old technology, but has been significantly improved and demonstrated over the last 2 years. Topsoe understands the potential market for small scale applications and has been developing smaller, modular MiniTIGAS units in the 1000+ b/d (10+ MMscfd) range. In mid-2013 Topsoe signed a collaboration agreement with the Khanty Mansiysk administration, Russian Federation, for application of miniTIGAS for associated gas utilization.

5.7 Primus Green Energy

Company profile

Primus Green Energy is based in Hillsborough, New Jersey, USA. The company is backed by IC Green Energy, the renewable energy investment arm of global investor Israel Corporation.

Robert Johnsen is the CEO of Primus Green Energy and Dr. George Boyajian is the VP of Business Development. There are approximately 50 employees.

Technology

Primus has further advanced the well-known ExxonMobil MTG technology. Primus calls its technology STG+, “Syngas To Gasoline and other products”. The process follows the same standard steps, syngas to methanol reactor, DME reactor, gasoline synthesis, and gasoline treatment. Simplifications and cost reductions come from development of a continuous process where about 35% of the syngas is converted to 93 octane gasoline in a single pass, before the unreacted syngas is separated and recycled. Furthermore, the well-known need for removal of the undesirable durene product is integrated in the process. Other potential products, using different catalysts, are jet fuel and aromatics.

Advantages and Challenges

The basis of the technology is well known and proven. Primus has highly integrated and simplified the process allowing smaller footprint, lower cost plants. However, these process improvements need to be proven in a demonstration plant. This step is underway and Primus has already completed a few hundred hours of continuous operation.

Status and path forward

Primus has a functioning pilot plant at its Hillsborough facility. In October 2013, a 720 hour continuous operation was completed at its new 7 bpd (100,000 gallons per year) demonstration gasoline plant using pipeline gas. A jet fuel production line will be added in 2014, as well as a biomass gasifier. Once its technology is proven and fine-tuned in this plant, Primus will be ready to offer commercial plants. Currently, Primus is planning a 2000 bpd gasoline plant in the USA close to natural gas feedstock.

5.8 TU Freiberg

Institute Profile

The “Technische Universität Bergakademie Freiberg”, Germany, was founded in 1756 with a focus on natural resources. The Institute of Energy Process Engineering and Chemical Engineering (IEC) at the university is headed by Professor Bernd Meyer and has been developing gasification, reforming and syngas conversion technologies for decades.

Technology

The IEC is well known for its R&D on coal gasification technologies. Since 2004 it has been developing an ATR/POX natural gas reforming process together with Lurgi in a plant with a gas feed rate of about 350kscfd. A Syngas to Fuel (STF) gasoline process has also been demonstrated at a very respectable 15 bpd from 2010 through 2012. The IEC is now looking for

partners and funding to integrate and further optimize these two technologies. The goal of the 3 to 5 year effort would be a robust, small scale gas to gasoline process that is well suited for flare gas utilization.

Advantages and Challenges

There is no question that the IEC could deliver a technically sound ATR/STF or POX/STF integrated process. There is however serious competition in this area. The old MTG process is being commercialized around the world, and new technologies are already being offered commercially such as Topsoe TIGAS, or are being demonstrated such as the Primus STG+ process. Any technical or economic advantages that IEC's eventual technology may offer still need demonstration.

Status and Path Forward

The IEC, and its partner CAC Chemitz, are inviting interested parties to work with them to move their technologies toward commercial readiness which is some 3-5 years away.

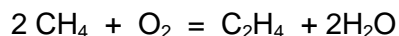
5.9 Siluria Technologies

Company Profile

Siluria Technologies was formed in 2009 and is headquartered in San Francisco. The CEO is Ed Dineen and the VP of Corporate Development is Rahul Iyer. Its Oxidative Coupling of Methane (OCM) technology was developed at the Massachusetts Institute of Technology (MIT) by Professor Angela Belcher, a co-founder of the company. The company is very well funded, with a total of \$50 million raised between 2011 and 2013 to support an aggressive R&D effort at MIT.

Technology

The OCM technology is old. It was the rage of the nineties, given up as non-economic, but has now been resurrected by Siluria with a fresh approach. OCM is a process where 2 molecules of methane are "coupled" to form ethylene, the building block for production of plastics, chemicals and fuels. The conversion of olefins such as ethylene to gasoline is old refining technology. The coupling takes place on catalyst surfaces in the presence of oxygen.



Ethylene replaces syngas as the intermediate to hydrocarbons, a more direct approach avoiding the formation of CO. The Siluria Technologies process takes place in novel, porous, nano-wire catalysts that are grown on bio-material templates. High throughput, automated catalyst testing allows the addition of dozens of new catalysts to its data library every day. Over 40,000 catalysts have been tested so far, and the most promising will be further tested in a 300 tpy (~5 bpd) demonstration plant to be announced soon.

The OCM process has been extensively demonstrated, with thousands of papers published on the subject over the last 3 decades. While the 2nd step, the conversion of ethylene to valuable products is well proven, there have however been significant issues with the OCM process itself. Mixtures of hydrocarbon gas and oxygen can lead to complete combustion (it is what happens in a flare!). The trick of OCM is to control the oxidation process where methane is oxidized to ethylene, but the ethylene is prevented from further oxidation to CO and CO₂. This is not easy since the ethylene is more susceptible to oxidation than the “tough” methane molecule. High ethylene yields were achieved at low conversion rates of less than 10% (“mild” conditions, i.e. lower temperatures), while CO and CO₂ became the major products at higher conversion rates (more aggressive conditions, higher temperatures). The conclusion of the old OCM community was that both better catalysts, active at lower temperatures, and innovative process engineering were needed to prevent the ethylene from over-oxidation.

Advantages and challenges

OCM allows the conversion of gas into fuels without the expensive syngas step. However, an (expensive) air separation unit (ASU) is needed to produce oxygen, the co-reactant. Also, increased ethylene yield at high conversion rates is required. As already mentioned, gasoline production from olefins such as ethylene is old, proven refining technology. However, it remains to be seen how much downsizing can be done in a cost-effective manner.

Status and Path Forward

If successful in achieving acceptable ethylene yields, Siluria Technologies could offer a more direct, relatively low cost GTL process. However, a wealth of R&D in both catalysis and reactor engineering is required to move beyond the past efforts. The technology needs to move from the laboratory into a pilot plant followed by a demonstration plant. The quality of the R&D effort, supported by ample funding, could lead to rapid progress, but more than 4 years are likely needed to come to the point of commercial offers.

5.10 Proton Ventures

Company Profile

Proton Ventures was formed in 2001 and its headquarter is close to Rotterdam, The Netherlands. The CEO is Hans Vrijenhoef, while technical matters are handled by Dr. Anish Patel. It is a small engineering company with a focus on a novel distributed ammonia business from manufacture to storage and distribution. Proton Ventures is very different! First, it offers a mini-ammonia fertilizer technology and second, it offers the smallest, potentially commercial conversion unit with a feed rate of only 0.2 MMscfd.

Technology

Proton Ventures has developed a modular, very small ammonia unit together with Casale, a leader in methanol and ammonia technologies. The process is an optimized Haber Bosch (HB)

process, the standard in world-wide ammonia production, called “Gas2Ammonia”. An air separation unit (ASU) provides the nitrogen (N₂), while hydrogen (H₂) is produced from natural gas via a steam reformer (SMR). Additional hydrogen is produced by a water gas shift (WGS) where carbon monoxide (CO) reduces water (H₂O) generating H₂ and CO₂. The nitrogen and hydrogen are then combined using Proton Ventures' Gas2Ammonia process.

1. ASU: Air separation: N₂ + O₂
2. SMR: CH₄ + H₂O = CO + 3H₂
3. WGS: CO + H₂O = CO₂ + H₂
4. HB: N₂ + 3H₂ = 2NH₃

The process produces 1.8 tons of CO₂ for every ton of ammonia produced since the carbon in the gas is rejected (see formulas above). It must be noted however that in all GTL technologies the carbon in the gas will be converted to CO₂ once the GTL fuel is combusted.

Proton Ventures offers a gas treatment module to accommodate NGLs and contaminants.

Advantages and Challenges

Ammonia is one of the largest commodity chemical in the world. It is produced in world scale plants, then shipped to farmers. Proton Ventures' technology allows production of small volumes of ammonia close to the consumers. Its base plant comes in five standard, 40ft containers, is easily transportable and movable, consumes less than 200 kscfd, and produces 3 tons/day (about 1000 tpa) of ammonia. For larger gas volumes, multiple units can be connected. Proton Ventures claims that the unit is fully automated and does not need any full time operators, leading to very low opex. It claims to “guarantee” the process and the ammonia catalyst for 15 years!

With the limited revenue flow from only 3 tons of ammonia per day there is pressure on economics. Proton Ventures states that very low cost flared gas, the high value of ammonia with a low distribution cost, combined with low capex and opex can make this technology viable today.

Status and Path Forward

The base Gas2Ammonia unit of 1000 tpa has been designed and engineered, and commercial opportunities are being sought. This plant consumes only 0.2 MMscfd! Proton Ventures has been quite active in North Dakota the last year or so to find the right gas flare application. For gas flows > 0.2 MMscfd, multiple units can be combined with economy of scale from “mass production” of modular units. For instance, 5 base units would be deployed for a 1 MMscfd flare. For flares below about 2 MMscfd with nearby fertilizer markets, this technology is worth investigating.

6. Comparisons of New Technologies

6.1 Plant scale applicability

As mentioned earlier, the gas flow range of flares targeted for miniGTL applications has been defined for this study from sub 1 MMscfd to as large as 25 MMscfd.

Furthermore, not all technologies are suitable for offshore applications.

As in our first report, the miniGTL flow range is divided into 3 segments, “Small” for flow ranges below 1 MMscfd, “Medium” for gas flow ranges from 1 MMscfd to 10 MMscfd, and “Large” for gas feed rates from 10 MMscfd to 25 MMscfd. Green indicates good applicability, red no applicability while amber indicates “to be determined”.

Mini-GTL: Project size applicability and business focus

COMPANY	SMALL <1MMscfd	MEDIUM 1-10MMscfd	LARGE >10MMscfd	Offshore Applicable
Proton Ventures	Green	Amber	Red	Red
Greyrock	Amber	Green	Green	Green
INFRA	Amber	Green	Green	Green
EFT	Red	Amber	Green	Amber
MarcellusGTL	Red	Red	Green	Red
TIGAS	Red	Red	Green	Amber
Primus	Red	Amber	Green	Red
Siluria	Red	Amber	Green	Red

Gas2 and TU Freiberg: no information

"Small" miniGTL projects are very challenging, predominantly for economic reasons. The small product volumes (<100 bpd) generate little of the revenue needed to cover both operating costs and payback of Capex with an acceptable economic return. Only Proton Ventures and GasTechno offer potential solutions in this range today. However, Greyrock is moving towards this “small” area with its MicroGTL technology which currently offers solutions in the "medium"

range from 1 to 3 MMscfd. The same is true for INFRA. The INFRA technology is based on small modules, and its demonstration plant will operate at 1 MMscfd, right at the border between "small" and "medium". Thus, both Greyrock and INFRA have the potential to enter the sub 1MMscfd market. R3Sciences and Verdis will also target "small" volumes once their technologies are ready for commercialization. Again, these very small applications face more of an economic challenge than a technical one.

It has been found by many miniGTL providers that "large" scale volumes, above 10 MMscfd (1000 bpd of products), are required to deliver financeable projects with good double digit financial returns at gas feedstock costs of up to \$4/MMBTU. Greyrock's base miniGTL plant offer is at 10 MMscfd feed-rate, while Primus Green Energy and Marcellus GTL both offer first plants consuming about 20 MMscfd. TIGAS reportedly could be scaled down into the "large" range, but plants in the "medium" range are currently not feasible, mainly for economic reasons. The only technology not applicable at this time for "large" volume (>10 MMscfd) miniGTL plants is Proton Ventures.

Gas2 is in the conceptual engineering and testing case and has not yet announced targeted commercial plant sizes. TU Freiberg has also not yet announced project sizes. Therefore neither company is included in the Figure above.

Many flared gas volumes are in the "medium" range and, to target these flares, companies are pushing their technologies to this smaller scale, among them Greyrock, INFRA, EFT and TIGAS. The market size of these medium sized mini-plants will largely depend on specific circumstances such as profit expectations, gas costs, avoidance of flare penalties, availability of flare reduction credits and synergies with existing operations.

Air separation units producing oxygen are not permitted on FPSOs for safety reasons. Thus, technologies that require oxygen are not suited for offshore applications, eliminating Proton Ventures, Gas2 and Siluria. The production of gasoline via methanol/DME looks too complex and requires too much space. Marcellus GTL, TIGAS and Primus are therefore not viable for this market. A simple GTL-FT unit producing syncrude, easily blended into crude oil is the clear technology of choice for such applications. Both CompactGTL and Velocys pursue such projects, as well as newcomers Greyrock and INFRA.

For convenience, the same assessment for the companies reviewed in the original 2012 study is included below.

Project size applicability and business focus: January 2012 report

COMPANY	SMALL <1MMscfd	MEDIUM 1-10MMscfd	LARGE >10MMscfd	Offshore Applicable
VERDIS				
1 st RESOURCE				
OBERON FUELS				
R3SCIENCES				
CARBON SCIENCES				
GASTECHNO				
METHION				
VELOCYS				
COMPACTGTL				
GRT				
SYNFUELS				

6.2 Base (15 MMscfd) Plant Parameter Comparisons

The companies listed in this table returned a questionnaire related to the cost and performance of a plant with a gas feed-rate of 15 MMscfd. The Proton Venture modular ammonia technology cannot be scaled up to this size. Gas2, TU Freiberg and Siluria are not yet at the stage where detailed engineering and cost estimating can be done for such plants. Information from 1st Resource Group (1RG) from our first report has been added, since the data have just become available.

Survey: Parameters for a 15 MMscfd plant

PARAMETERS	GREYROCK	EFT	INFRA	Primus	TIGAS	1RG
Footprint	~1acre	~2 acres	~1 acre	5 acres	~1.5acres	~2acres
Capex	\$100MM	\$150MM	\$100MM	\$250MM	\$150MM	\$110MM
Opex/yr (w/o gas)	\$11MM	~\$11MM	\$3MM	?	?	\$12MM
Product Marketability	1300bpd diesel drop-in	~1500bpd diesel & naphtha	1560bpd diesel or jet	~1500bpd gasoline or diesel/jet	1500bpd gasoline	1250bpd diesel/jet 60/40
Energy Efficiency	>58%	~60%	~65%	>50%	>60%	?
Carbon Efficiency	>60%	~75%	75-80%	~90%	~70%	?
Commercial Readiness for 15MMscfd plant	Now 30bpd demo Since 4/2011	Now? Based on 1bpd pilot & Other techn	No 0.25bpd pilot 100bpd plant being built	Now 7bpd demo In 2013	Now All steps Individually proven	Now? No demo Conventional technologies

The data in this table have different levels of accuracy. Some are based on actual FEED data (Greyrock) while others are early best estimates.

The footprints of the plants are about 1 - 5 acres (~4000 – 20,000 m²), with the actual size being driven very much by provision for utilities, storage and the flare rather than the miniGTL process unit alone.

The product volumes range from about 1300 bpd to 1500 bpd (some measured, some currently estimated) depending on process efficiencies. Process efficiencies of smaller plants are likely 10 to 30 relative percentage points lower than the ones from optimized world scale plants. In all cases, the products are high quality gasoline or diesel drop-in blend-stocks, or high performing neat fuels with some additional, limited upgrading and/or additives.

The rule of thumb for the Capex for large scale GTL plants is about \$100,000 dbc or per 10 kscfd gas feed-rate. Small scale plants should be significantly more expensive per production

volume because of the loss of economy of scale. However, it has been shown by the technology providers that they can build miniGTL plants for about the same unit size cost of \$100,000/dbc. This has been made possible through innovative, modular, low cost designs, sacrifices in process efficiencies and so on. Thus, these plants should have capital costs of about \$150 million as claimed by EFT, TIGAS and MarcellusGTL. However, Greyrock, INFRA and 1RG have significantly lower estimated costs of about \$100 million. Greyrock's estimate is based on detailed procurement estimates, while 1RG's and especially INFRA's are early projected estimates.

The estimates for the operating expenditures (Opex), which include everything except feedgas cost, are remarkably similar at about \$11 million to \$12 million per year or about \$20/bbl. INFRA claims a fourfold lower opex because of smaller volumes of catalyst, longer catalyst life and simpler operation with fewer staff.

In general, with a typical opex of \$20/bbl and a \$4/MMBTU feedgas price (i.e. feedstock cost of \$40 per bbl of product), at an oil price of \$90/bbl, conversion projects could achieve a healthy EBITDA (earnings before interest, tax, depreciation and amortization) of about \$50/bbl.

The data from the 1st 2012 study are shown below for comparison purposes.

Survey: Parameters for a 15 MMscfd plant, January 2012 report

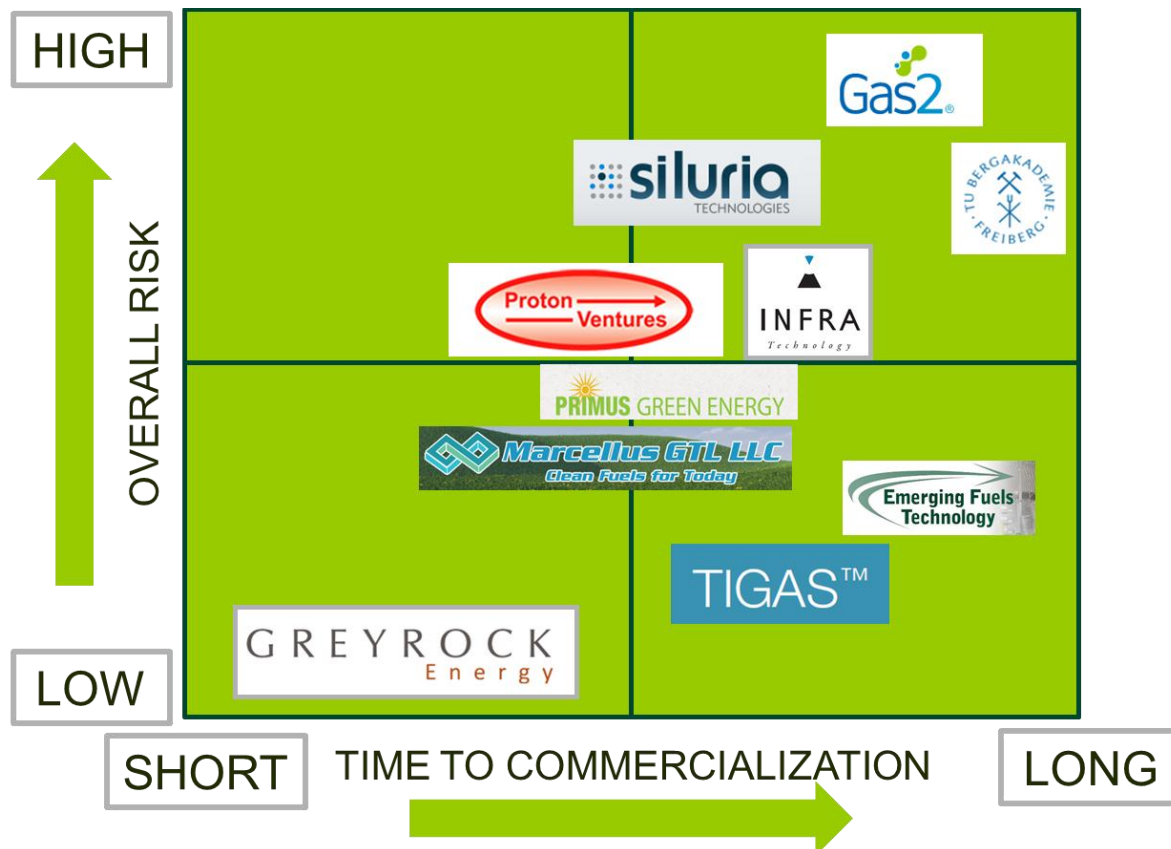
PARAMETERS	GasTechno	Merthion	Velocys	CompactGtl	GRT	SynFuels	
Applicable to 15MM?	YES Phase 2	YES	YES	YES	YES	YES	
Footprint	0.1 acre 5000sqft	<0.1acre <5000sqft	<0.5acre ~15k sqft	0.5acre 25k sqft	2-3 acres >100k sqft	~5 acres ~200k sqft	
EPC cost	\$63MM	\$5-10MM	\$115MM	\$125- 180MM	\$100MM - 164MM	\$85MM	
Opex (w/o feedstock)	\$15-20MM	<\$0.5MM	\$5.5MM	\$8MM	\$2.5MM	\$4MM (estimated)	
Daily product make	~2000bpd methanol, ~2000bpd formalin	99% of methane to methanol >4000bpd?	1250 to 1750 bpd diesel	1250bpd Syncrude & FT wax	1000-1200 bpd gasoline	1000bpd Gasoline Some carbon	
Energy efficiency	<50%	>88%	55-63%*	55-63%*	40 – 46%	36%	
Carbon efficiency	55 – 64%	>99%	70- 75%*	70-75%*	60 – 69%	41-70%	
Commercialization readiness	Basic Engineering Study underway	Need for 20bpd pilot plant	6bpd demo 2011/12	20bpd demo 2011/2012	Need for demo plant	Demo needed; Pilot plant at 0.05bpd	

6.3 Risk and Commercial Readiness

A wealth of information has been provided for the 10 new individual technologies evaluated. All of them provide exciting new options for gas flare reduction. They are at different stages of development with varying remaining risk profiles. The purpose of this GGFR study is not just to alert the GGFR members of the many miniGTL options under development, but to categorize them with regard to commercial readiness and remaining overall risk. The estimated time to commercialization depends on demonstration of the technology at some reasonable scale, business development efforts, along with overall technology attractiveness such as product mix, robustness, provider qualifications, etc. The estimated overall remaining risk is dominated by the technology risk, but also includes an assessment of financial risks associated with the technology provider along with product marketability and other factors..

The only “new” companies with ready to commercialize technologies are Greyrock Energy and Marcellus GTL. Greyrock has proven its integrated GTL-FT process at 30 bpd, while Marcellus GTL uses licensed, proven ExxonMobil MTG technology but does carry a degree of financing and project execution risk. INFRA is currently planning the big step from small pilot plant to 100 bpd demonstration/semi-commercial scale and Primus is starting up its demonstration facility. EFT sees no need for a demonstration plant since its GTL-FT technology, proven in a pilot plant, is a standard, fixed bed technology such as the one used by Shell in Qatar (Pearl plant).

New companies: Overall risk and time to commercialization



Greyrock Energy appears as the most advanced 'new' technology provider included in this study. A 30 bpd fully integrated plant has been operational for about 2 years, and is fully supported by a strong technical team. The technical risk is low because of the use of conventional technologies. The only exception is the use of a novel catalyst formulation that allows the direct production of high quality diesel. However, this catalyst is based on conventional cobalt based GTL-FT systems. Greyrock is working with a number of companies on commercializing its initial 1000 bpd facility; the "MicroGTL" plants with capacities of 100 - 500 bpd (1 - 5 MMscfd feed rate), and even smaller designs (down to 100 bpd), are being evaluated by a number of potential customers. A first commercial plant announcement is expected in 2014. Greyrock joins Velocys, CompactGTL and Oberon Fuels as an early front runner for commercial miniGTL plants.

Marcellus GTL is unique in this group of companies. It is not a technology developer, but a business development company. Initially, it is out to monetize cheap Marcellus shale gas by converting it into gasoline using licensed MTG technology. Its business plan includes further plants in the US and abroad, where it operates under the name, "Novello GTL". The remaining risks are the raising of capital, project execution and plant support.

Primus Green Energy is a well-funded company improving on the old MTG technology. A 7 bpd demonstration plant is operational since 4Q 2013 and is performing very well. Once the technology is completely proven and fine-tuned in a year or less, it will target a first commercial 2000 bpd plant in the US.

EFT, Emerging Fuel Technology, has deep knowledge in GTL-FT. The key owners have been GTL leaders at Syntroleum, Exxon, Sasol and Conoco. They have developed the "best" traditional catalyst with very high activity, excellent selectivity and long life. Tested in a small pilot plant, there are no plans for a larger scale demonstration because of the use of "standard" fixed bed technology. The argument is that the understanding of the behavior in one tube is sufficient to build a commercial plant with thousands or tens of thousands of tubes. EFT is an engineering company with a state-of-the-art laboratory. The customer can choose a procurement and construction company to build the actual plant. Without a business development arm, it remains to be seen how successful it will be in this competitive arena.

TIGAS by Topsoe is a modification of the old MTG technology and was proven at demonstration scale more than 25 years ago. It has recently been significantly improved leading to a 3 step process where all 3 steps have been individually proven. Topsoe is by far the largest and most experienced company in this study. It has the technology and do the engineering. It can do the procurement as well, but is not a construction company. It is not known for business development, and there are some doubts on the speed of commercialization. The technology has been available for 2 decades with no commercial plants so far. However, flare gas customers are encouraged to look at TIGAS if the production of gasoline is of interest.

INFRA Technologies seems to be making step changes in both GTL-FT process performance and also in modularization. Proving its technology in a 100 bpd (!) demonstration plant is very ambitious. It will be 2 to 4 years before such a plant is financed, built and utilized to prove

process components and longer term robustness. Thus, today, it has a higher risk and is a few years away from larger scale miniGTL plants.

Proton Ventures is an exciting addition to the miniGTL options, introducing the first small-scale plants for production of ammonia fertilizer ("Gas2Ammonia" technology). Its radical, very small scale of only about 200 kscfd feed rate makes a first commercial application cheap (from a Capex point of view), but the economic viability is a big question. The technical risk is moderate because of the use of conventional, 100 year old ammonia technology. The extreme modularization, however, does add some risk. Process efficiency is another concern.

Siluria Technologies is a very well-funded new-comer which picks up an exciting technology, OCM, Oxidative Coupling of Methane. OCM was heavily researched in the past but given up as uneconomic. Novel catalyst fabrication and testing procedures allow the screening of about 100 new catalysts a day. Over 40,000 catalysts have been tested so far and the most promising will be further tested in a 300 tpy (~5 bpd) demonstration plant to be announced soon. Siluria targets both large scale and small scale plants (range of 10 to 50 MMscfd feed rate). Technology risk is significant and time to commercialization is a minimum of 4 years.

Gas2 is at the conceptual engineering stage and will announce a plan for demonstration and commercialization in 2014 if the technology works and continues to look promising. Its porous membrane reactor technology for both syngas formation and GTL-FT is currently being tested in pilot plants. If techno-economic feasibility studies based on pilot plant data confirm the drivers for these technologies, an integrated demonstration plant needs to be built to prove technology, robustness and economic attractiveness. The Gas2 technology is considered to have the highest remaining risk among the 'new' technologies evaluated.

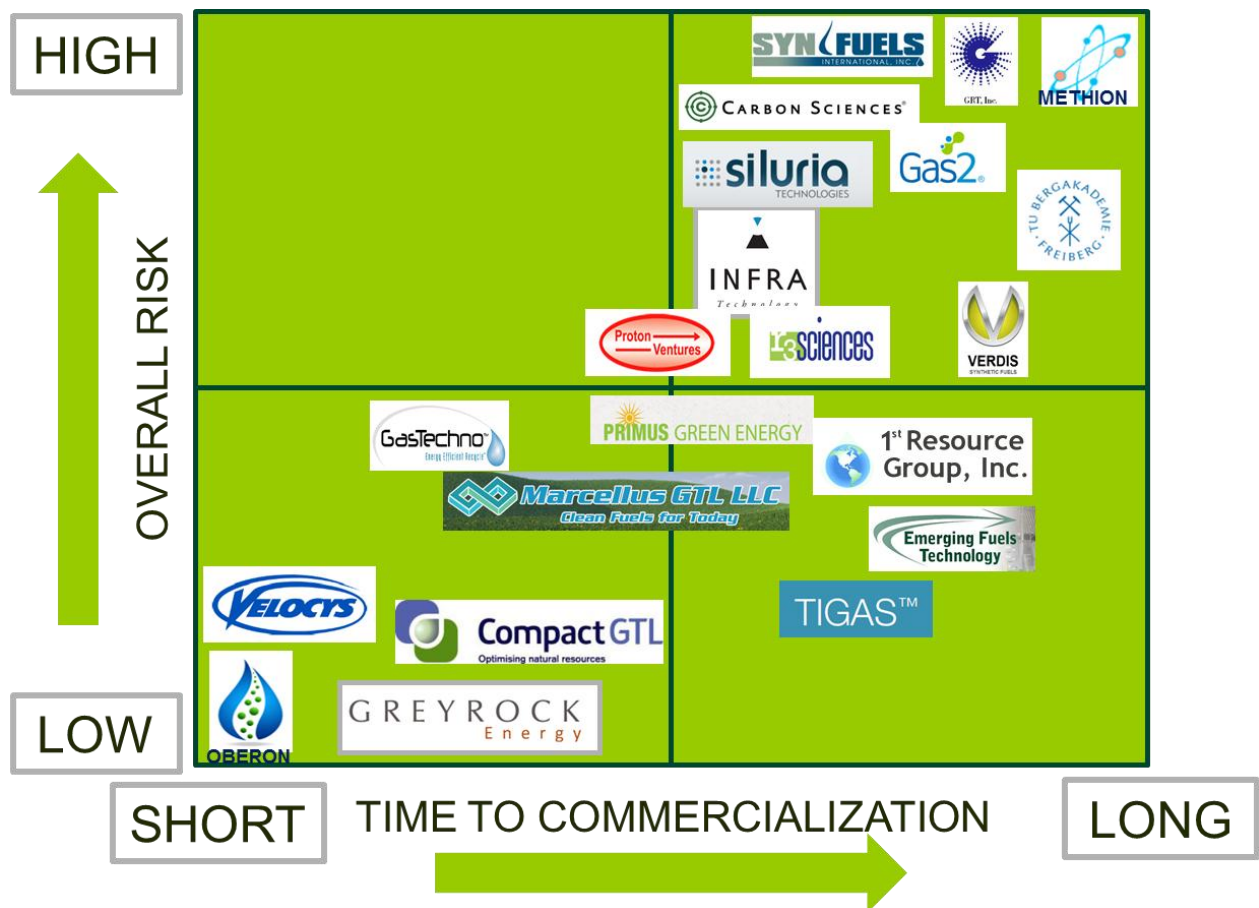
TU Freiberg has a long history of process development in conversion technologies, especially in coal and other solid carbonaceous materials. Over the last few years it has tested gas reforming technologies (ATR and POX) and has worked on a MTG technology. More work is needed to demonstrate an integrated, optimized process. Most importantly, a business development entity is needed to transfer the technology from academia to commercial reality which remains some 3-5 years away.

7. Conclusions

With the advent of cheap shale gas in the USA there has been a tremendous increase in interest in monetizing such gas by converting it into valuable, drop in fuels and chemicals. The development of technologies and plants suited for such application directly benefits the gas flare reduction community. Today, gas flares can often be extinguished by cost-effectively converting the gas into valuable and locally marketable products such as gasoline, diesel, DME, fertilizer and methanol.

To provide an overall view of the currently available miniGTL technologies, the position of the 'new' technologies and the revised position of the technologies reviewed in the 2012 report have been combined in the Table below.

Combined January 2012 and reports 1 & 2:
Overall risk and time to commercialization



Summarizing the technologies at, or close to, commerciality today:

CompactGTL, Greyrock, Oberon Fuels and **Velocys** (in alphabetical order) are the leaders in the miniGTL field. They are all well-funded, well managed companies with solid technologies, experienced staff and strong partners. Plant sizes offered range from about 1 MMscfd gas feed rate (Oberon Fuels), 1 MMscfd to 10 MMscfd (Greyrock) to plants above 10 MMscfd from CompactGTL and Velocys.

Topsoe offers **TIGAS** for gas feed rates of 10 MMscfd or larger. It stands behind its new process from feasibility study through plant start-up. The new process, without DME intermediate manufacture, makes TIGAS the leader in gas to gasoline technologies.

EFT and **1RG** are small companies with limited staff and means. However, EFT has decades of experience in GTL while 1RG has assembled a new team. Their technologies are rather conventional FT processes, EFT with a better FT catalyst, 1RG with a more modular design.

Marcellus GTL is a very small group of business developers targeting a first plant based on MTG technology using Marcellus shale gas. More plants are targeted in the future, both in the US and internationally. The focus is clearly on larger plants, most of them likely to be outside the GGFR flare interest range.

Primus is an ambitious company, well financed and managed. Like Topsoe, it sees potential in improving the old MTG technology with its new STG+ process. With a successful demonstration over the next 2 years or so, it could become a serious player.

For very small scale applications, below 1 MMscfd, interested customers are recommended to take a look at **GasTechno, Proton Ventures** and **R3Sciences**. There are technology risks in all of them with additional product marketability risk in GasTechno. However, the financial risks with these small plants are limited because of their low Capex. **Proton Ventures** offers distributed ammonia, a product of great value in many rural areas with gas flaring.

In summary, miniGTL options to extinguish flares have arrived and are here to stay. This report, which is based on publicly available data, will help interested customers in the evaluation and selection process of the most appropriate technology. The GGFR Partnership stands ready to be of further assistance.