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HOUSTON Gas Processors Association
YOUR MIDSTREAM NETWORK

GTL TECHNOLOGY UPDATE

Presented by:
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MUSE, STANCIL & CO.

- **Independent energy consulting firm founded in 1984, providing industry expertise from wellhead to end-user; www.musestancil.com**

- **Energy Sectors Served**
  - Natural Gas Processing
  - Refining and Refined Products
  - Pipelines
  - Crude Oil
  - Natural Gas Liquids
  - Petrochemicals
  - Biofuels

- **Representative Assignments**
  - Market Studies
  - Asset Valuation
  - Project Development
  - Transactional Due Diligence
  - New Technology Assessment
  - Insurance Claims (Property & Business Interruption)
  - Litigation Support
  - Royalty Negotiation/Auditing
  - Contract Negotiation/ Dispute Resolution

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GTL TECHNOLOGY UPDATE

- **Available gas "liquefaction" pathways**
- **Why GTL?**
- **Gas-To-Liquids Pathways**
- **Fischer Tropsch**
  - R&D work ongoing worldwide to increase efficiency in reaction pathway
  - Engineering design leading to more cost effective process design
- **New market entrants**

GAS LIQUEFACTION PATHWAYS

- **Variety of technology pathways exist for conversion of commercial natural gas to various liquid products**
  - Natural Gas Liquefaction (LNG)
  - Natural Gas Conversion
    - Natural Gas to Methanol (GTM)
    - GTM integrated with Methanol to Gasoline (MTG) or other products such as dimethylether (DME)

- **Comparison of Netback Prices, Basis: 2014 Averages and Henry Hub**

	LNG to Europe	***LNG to Asia***	***Methanol***	***GTL***
Product Sales Price	$9.69/MMBTU	$15.78/MMBTU	$443.35/MT	$104.09/BBL
U.S. Dollars Per MMBTU gas processed				
Revenue	8.73	14.21	13.64	10.41
Shipping	(1.00)	(2.80)		
Tolling	(2.75)	(2.75)	(9.11)	(5.49)
Netback per MMBTU	4.98	8.66	4.53	4.92

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Production of GTL diesel is competitive with other liquefaction pathways; specific project economics can varying significantly

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WHY GTL?

- **"Stranded" Gas**
  - Geographically isolated gas deposits
  - Gas reserves with limited economic market accessibility
  - Gas flaring

- **Diesel Markets**
  - Strong diesel demand world wide
  - Emphasis on increasingly "cleaner" diesel fuel worldwide
  - Significant change in the gasoline/diesel price relationship since 2008

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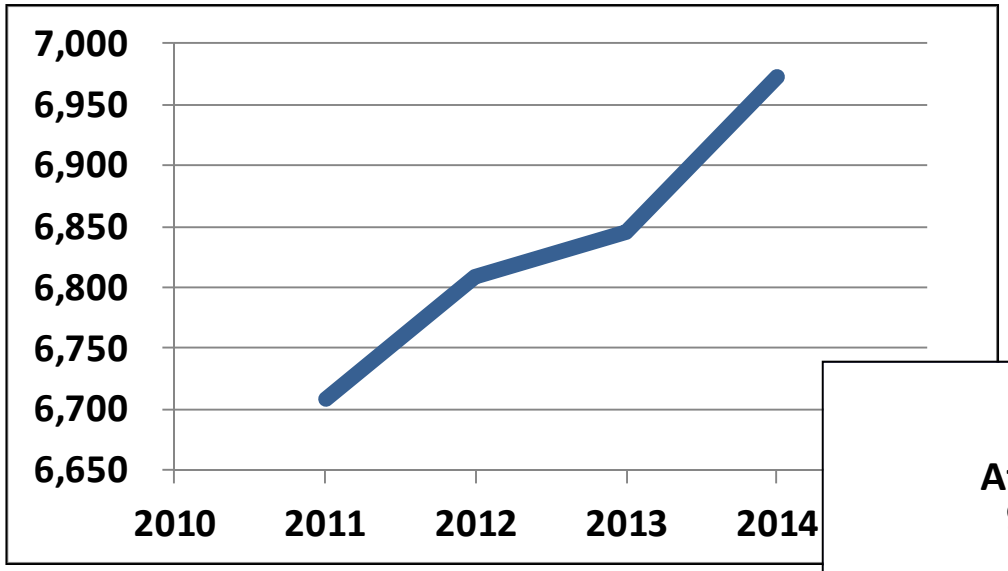
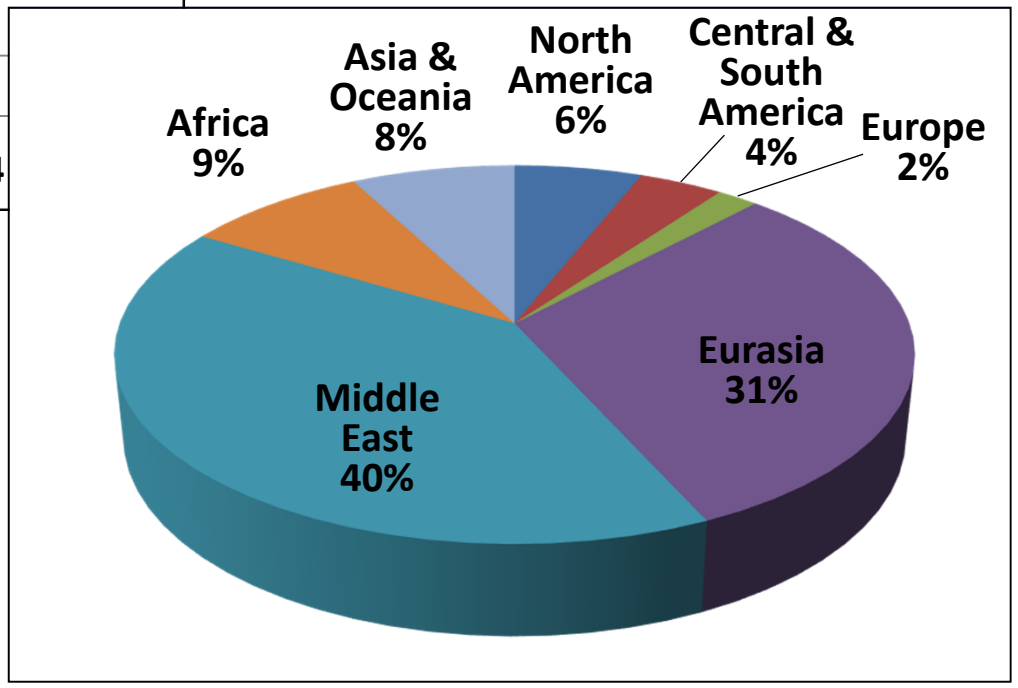
Small-scale, compact and mini-GTL enable project development in a wide variety of locations both onshore and offshore

WORLDWIDE GAS RESERVES





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- LNG projects dominate Asia & Oceania

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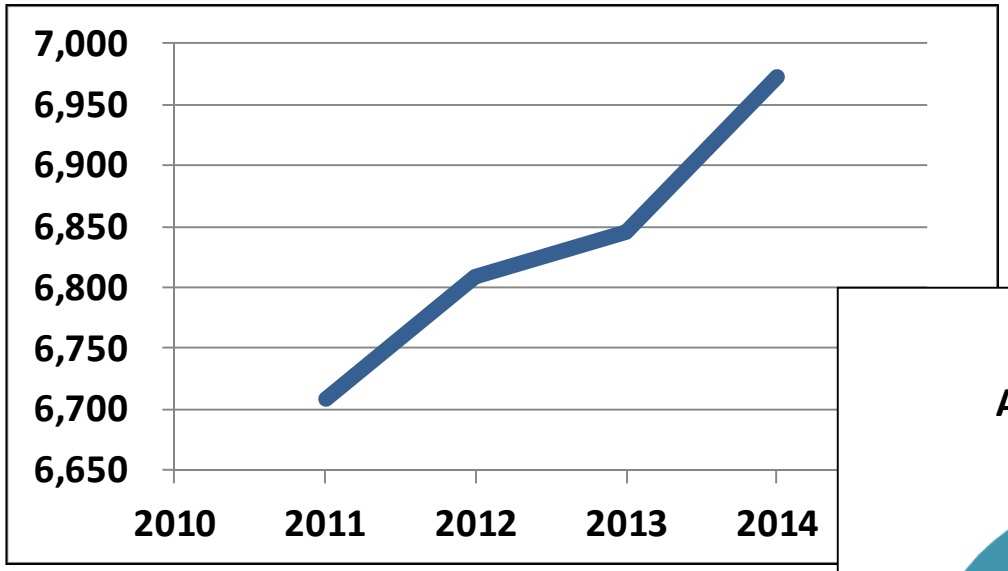

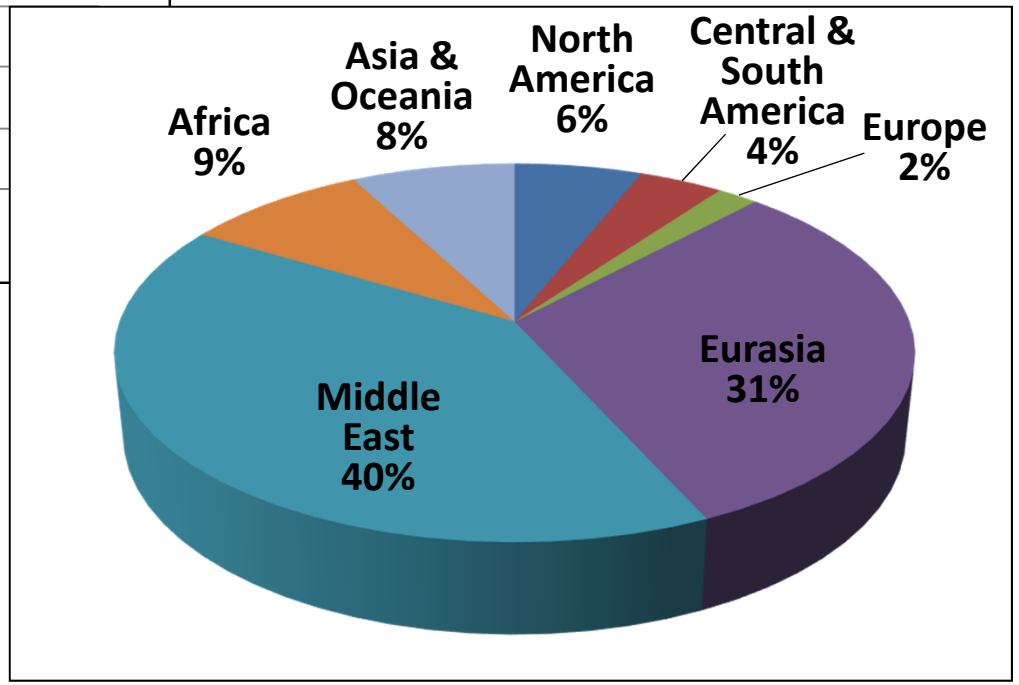

- Large-scale GTL already in service in Qatar
- LNG projects dominate Asia & Oceania

BUT…many opportunities exist to deploy smaller-scale GTL worldwide

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GTL Products Exceed Stringent Quality Requirements

	GTL Diesel	*ULSD*	*CARB Diesel*	*Jet*
Sulfur, ppm max	<1	10	8	3000
Aromatics, max	0%	31.7%	10%	25%
Gravity, API		30+	30+	37-51
Cetane Number, min	74+	40	40	40

Note: ULSD and Jet specifications based on Colonial Pipeline 12/2011 specifications

CARB Diesel specification based on Kinder Morgan Pipeline specification

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GTL produces a perfectly fungible fuel and, therefore, GTL products can be supplied into almost any market

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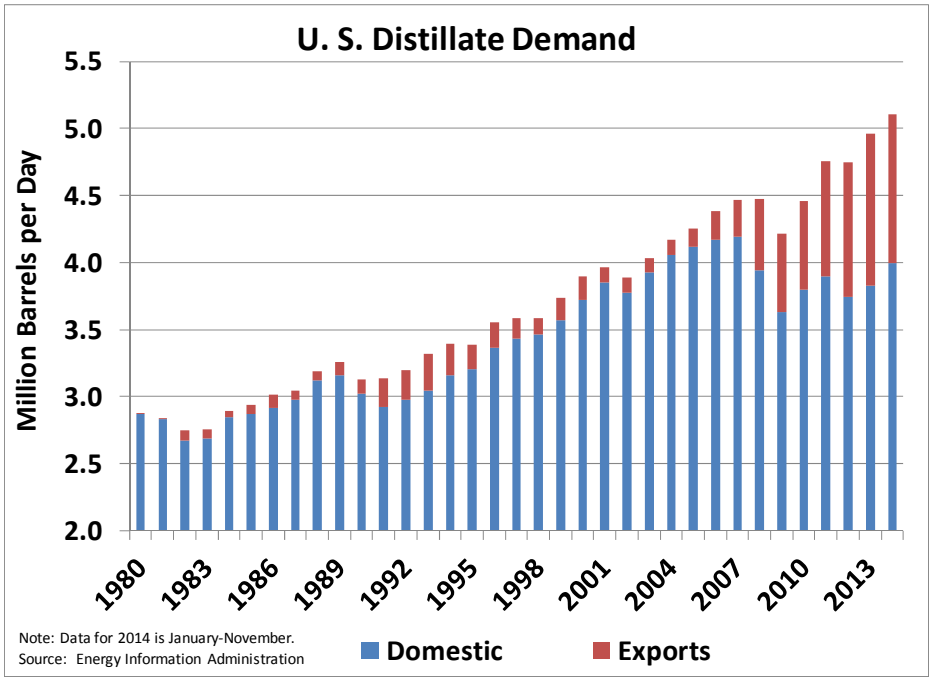
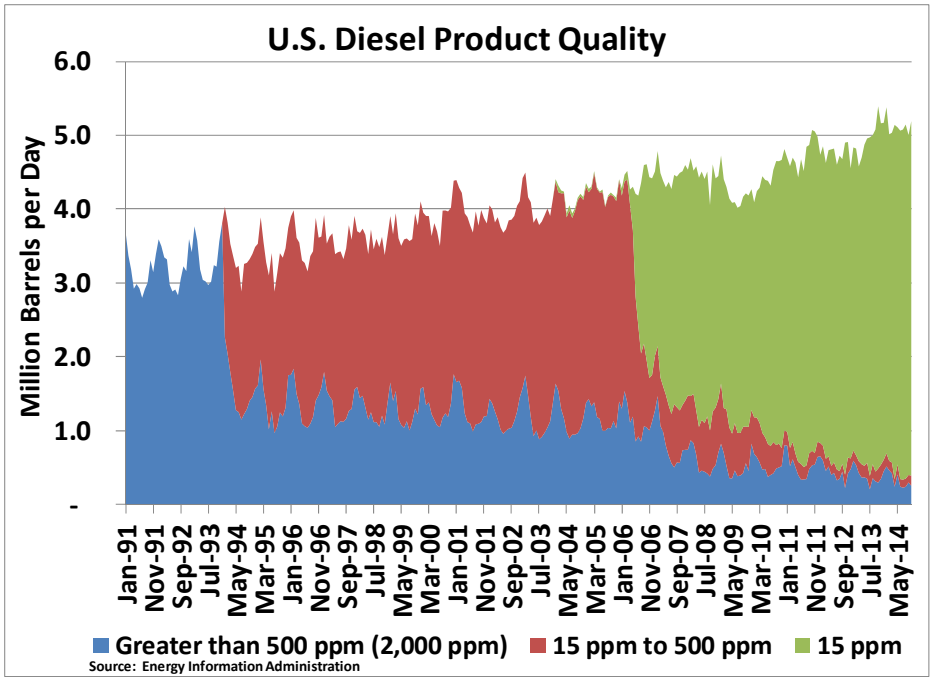
DEMAND GROWTH FOR HIGHEST QUALITY PRODUCT

- Air quality concerns have driven global diesel requirements toward very low sulfur, low aromatic product specifications
- The U.S. demand for diesel is growing and U.S. refiners are also exporting huge volumes of higher quality diesel fuels
- These trends are expected to continue





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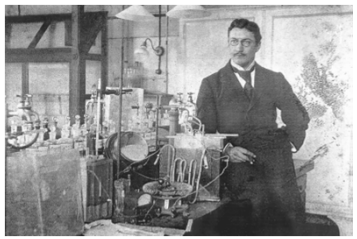
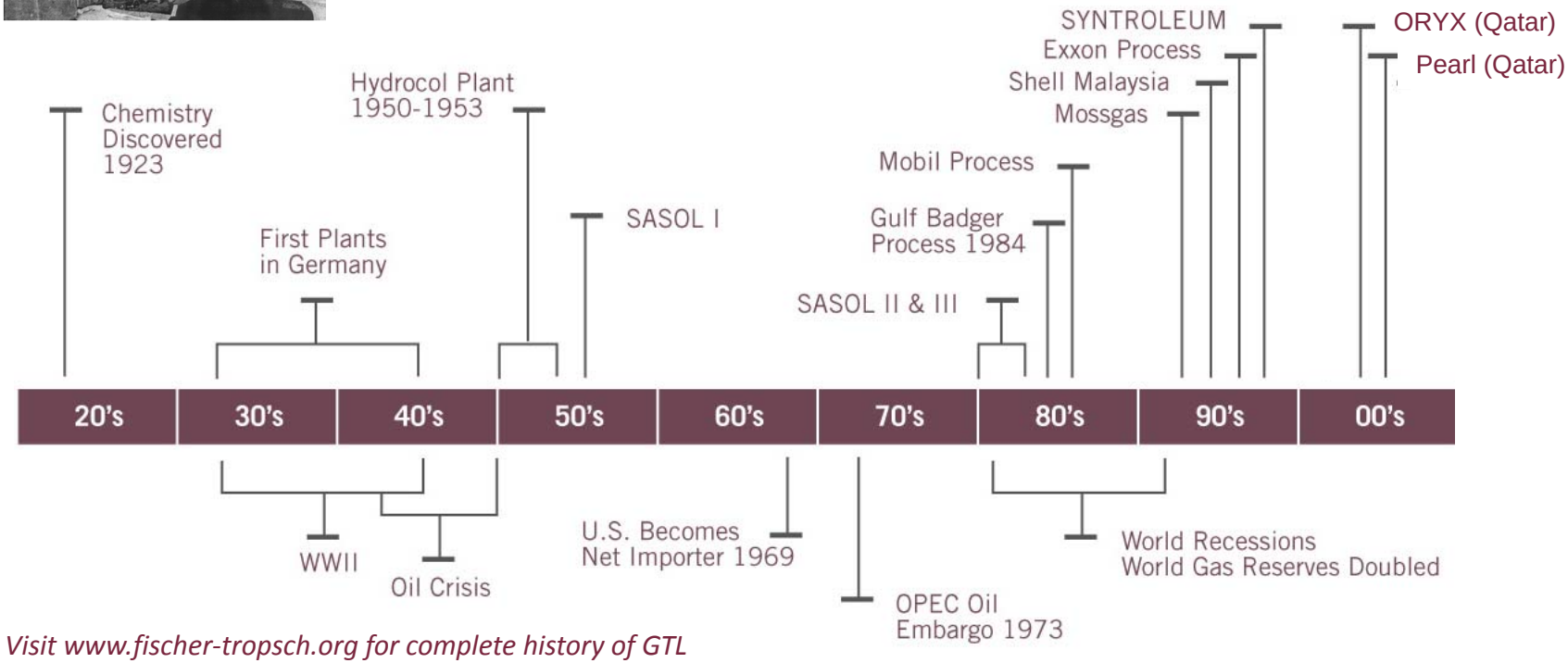
Natural Gas To Diesel (GTL) – Well Established and Proven

History



Franz Fischer
1918 – "Father" of GTL



Visit www.fischer-tropsch.org for complete history of GTL

Advances in catalyst development and process design are fueling expansion in small-scale GTL sector

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Numerous Companies Developing Mini-GTL Technology

General Methanol

Methion

GRT, Inc.

VERDIS
SYNTHETIC FUELS

New Entrants In The Market For Mini-GTL

Company	Technology	Notes
INFRA	FT	100 BPD plant (2015)
Greyrock	FT	1000 BPD plant (2015)
Emerging Fuel Tech. (EFT)	FT	1 BPD pilot plant
Gas2	FT	3 BPD pilot
Marcellus GTL	MTG	2000 BPD (2016)
TIGAS	MTG	Demo plant in Houston
Primus GE	MTG	6.5 BPD plant in operation
TU Freiberg	MTG	15 BPD plant
Siluria	OCM	1 TPD ethylene pilot plant being constructed
Proton Ventures	Small scale Ammonia	0.2 MMcfd feed rate (3 TPD Ammonia)

POSITIVE ATTRIBUTES

- **Proven chemistry**
- **Years of bench-scale testing, industry has "fine tuned" catalyst and commercialized catalyst manufacturing**
- **Scale-up of most of the process components already proven**
  - Production of syngas, front end
  - Hydrocracking of wax and distillation of products, back end
- **GTL-FT diesel product has been tested in many commercial applications**
  - Commercial Aircraft
  - Trucking Industry
  - Military, B52 Bomber
- **Commercial plants have operated in South Africa for many years**

CHALLENGES

- **Capital cost for fixed-bed reactor processing configuration historically dictated larger projects to capture economies of scale; largest world-scale project completed to date far exceeded budget estimate**

- **Margin risk associated with uncorrelated feedstock and product price volatility**

- **Catalyst selectivity for wax production versus direct conversion to diesel or gasoline**

- **Scale-up of high efficiency, fluidized bed reactors not proven thus complicating process technology guarantees and project finance**
  - Physical design, wax separation from catalyst particles
  - Heat balance, highly exothermic reaction requires active control of heat balance to avoid "hot spots"

CHALLENGE – CAPITAL COST

- **Number of companies developing modular process design**
- **Minimize "custom" aspects of project design**
- **Provide for shop fabrication to improve quality control and compress projection execution timeline**
- **With modular approach, smaller projects become economically feasible**
- **In addition, developer are seeking brownfield sites or have partnered with integrated producers to integrate smaller-scale commercial units into existing facilities**

CHALLENGE – MARGIN RISK

- **AGE OLD QUESTIONS – What will oil and gas prices be next week? Next month? Next year? In 5 years? In 10 years?**

- **Commercial viability of small-scale units requires venture capital support; technical advances in reactor design are enabling such projects**

- **Project finance will require positive economic margin outlook in the medium to long term**

- **Opportunities enabled by new reactor design technologies include:**
  - Offshore or floating installations
  - Focus on "portable" nature of the process
  - Remote locations where liquid takeaway infrastructure is available or can be installed at lower cost than can gas infrastructure
  - In many locations worldwide where gas flaring is being severely limited

CHALLENGE – CATALYST DEVELOPMENT

- **All GTL catalysts are proprietary although most GTL companies have one or two catalyst manufactures who are licensed to produce**

- **Most recent leap forward is catalyst for direct conversion of natural gas to diesel, thus eliminating the wax step**
  - Will likely result in reduced capital cost for less complex "back end" of the process
  - May also have implications for reactor design and ultimate reactor scale up, yet to be determined

- **INFRA**
  - Announced investment decision on 100 BPD plant in June
  - Pilot Plant launch in July
  - Will test additional catalysts and plant configurations

- **Greyrock**
  - Direct-to-Diesel™ Catalyst
  - Modular construction of a 1,000 BPD plant
  - Capacity can be increased by adding additional modules
  - "Drop in" fuel which has been tested in heavy duty engines

NON-FT PROCESSES - GAS TO CHEMICALS AND GASOLINE

- **Primus Green Energy**
  - 6.5 BPD pilot plant was commissioned in 2013
  - Currently in third continuous run
  - Producing 93 octane gasoline

- **TIGAS**
  - Conversion to gasoline in a single synthesis loop with no need for methanol storage

- **Proton Ventures**
  - Gas2Ammmonia process

- **Siluria**
  - Conversion of methane and ethane into gasoline and ethylene

CHALLENGE – REACTOR SCALE-UP

- **Process developers have been mindful of the need for measured scale-up with respect to fluidized-bed reactors**
- **Some demonstration scale units have been built and operated to prove aspects of reactor engineering design**
- **To address the issue of clean wax separation from catalyst particles, new catalysts are being developed to eliminate the wax production and directly produce diesel; development work continues and the industry awaits commercially-available data on these new catalysts**
- **Other developers have focused on innovative changes in fixed bed reactor design developing modular, micro channel reactors**
- **Pilot plant and demonstration-scale plants employing micro-channel reactor technology have operated and larger scale commercial projects are being developed**
  - Velocycs
  - Compact GTL

CONCLUSIONS

- **A wide variety of options exist for GTL projects**
- **Large increase in gas supply in North America has increased the attractiveness of these projects**
- **While LNG and large scale GTL projects continue, the newer technology is aimed at mini GTL plants that can be built with smaller gas reserves**
- **The smaller units provides good economics by being modular and skid mounted, so they can be constructed in areas that provide market opportunities**
- **New technologies are in various stages of commercialization, and there are several very promising start-ups competing for investment funds**