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TEXAS A&M ENGINEERING EXPERIMENT STATION

TEXAS A&M UNIVERSITY | TEXAS A&M UNIVERSITY at QATAR

Challenges in Natural Gas Monetization: Qatar Experience

Nimir Elbashir
Director, TEES Gas & Fuels Research Center

Texas A&M University at Qatar

Natural Gas Utilization Workshop
Overcoming Hurdles of Technology Implementation
November 1-3, 2016
Morgantown, WV

CENTER FOR ENERGY INITIATIVES
An AIChE Technological Community

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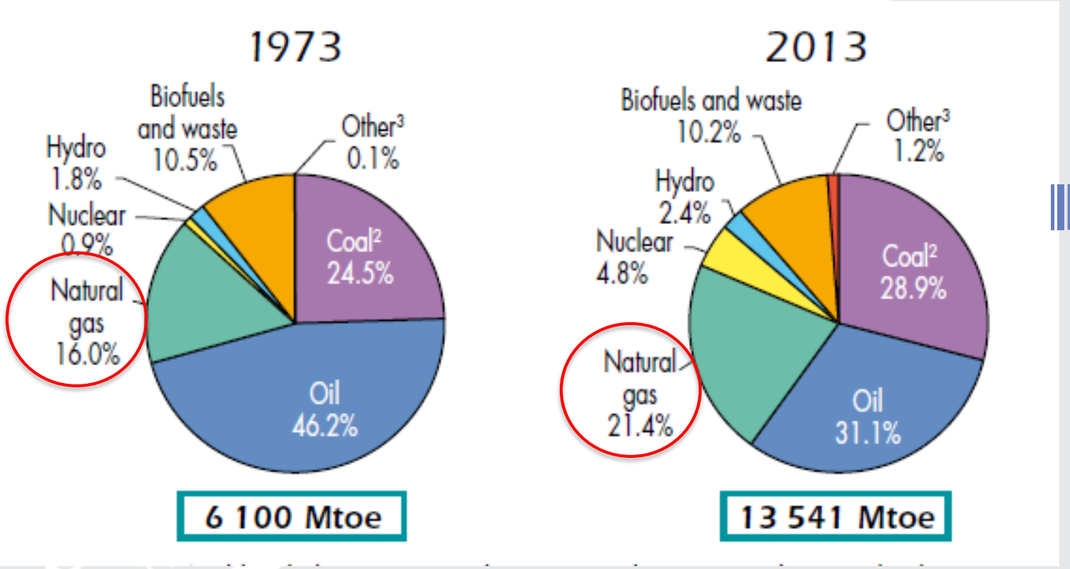
Natural gas role in the energy market

World's Primary Energy Supply



Producers	bcm	% of world total
Russian Federation	677	20.0
United States	651	19.2
Canada	160	4.7
Qatar	151	4.5
Islamic Rep. of Iran	149	4.4
Norway	106	3.1
People's Rep. of China	103	3.0
Saudi Arabia	92	2.7
Indonesia	92	2.7
Netherlands	81	2.4
Rest of the world	1 126	33.3
World	**3 388**	**100.0**

2011 data

Net exporters	bcm
Russian Federation	196
Qatar	119
Norway	99
Canada	63
Algeria	49
Indonesia	46
Netherlands	33
Turkmenistan	29
Nigeria	26
Malaysia	22
Others	152
Total	**834**

2011 data

Source: International Energy Agency
www.iea.org

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State of Qatar

Area: 4,416 sq mi

- ✓ Qatar’s proven natural gas reserves stood at approximately 900 trillion cubic feet.
- ✓ Qatar’s North Field is the world’s largest reserve of non-associated natural gas.

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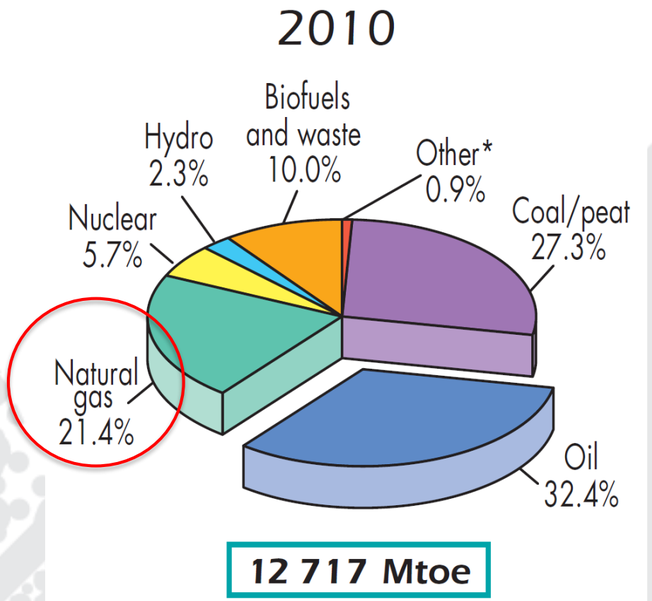
Natural gas monetization in Qatar



Natural Gas

Transportation

Pipeline

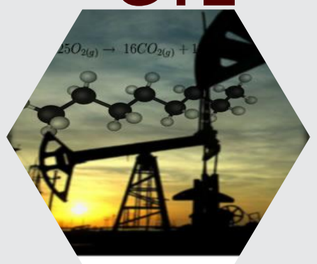
Physical

1/600 volume

LNG

Chemical

GTL



Qatar's aspiration to become the "World Gas Capital" led to the building the largest GTL and LNG plants in the world.

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US & Qatar Natural Gas Milestones

1821	Fredonia, NY supplies residents with gas.
1918	Panhandle field in Texas discovered.
1922	Hugoton Field discovered.
1923	Shell discovery activities of Qatar's NG
1925	3 major pipelines to Houston completed.
1931	Pipeline connects Panhandle to Chicago.
1947	Texas gas piped to California.
1947	Terrebonne, LA: First offshore well.

US Natural and Qatar Gas Milestones – cont'd

1951	Commercial underground storage.
1957	US imports gas from Canada and Mexico.
1972	US energy crisis begins.
1972	Discovery of massive reserve of NG in the Northfield in Qatar
	66% of onshore gas in Qatar was flared
1974	This portion had fallen to less than 5%
1978	Natural Gas Policy Act.
1981	2 NGL plants began operation at Masaeid (500ktons) propane and butane
1984	Qatargas is formed (joint venture with QP)
1991	First project of Northfield ($1.3 billion)

US Natural and Qatar Gas Milestones – cont'd

1996	First shipment of LNG to Japan
2004	Qatargas Operating (Qatargas 1, 2, 3 &4)
2006	The OryxGTL Plant start the production of 34kbb/day of GTL products
2012	The Pearl GTL Plant start the production 140k bll/day GTL Products
2005+	Proposals to build add'l LNG import terminals.
2012	Qatargas produced 42 million tons/annum of LNG
2013+	Conversion of LNG import terminals to liquefaction facilities and EXPORT of natural gas

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Qatargas existing & new LNG facilities

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Companies investing in Qatar's gas

Qatar Petroleum

LNG

QATARGAS

RasGas

ExxonMobil

TOTAL

ConocoPhillips

MAERSK OIL

OXY

wintershall

MITSUI & CO., LTD.

GTL

ORYX GTL

sasol
reaching new frontiers

Chevron

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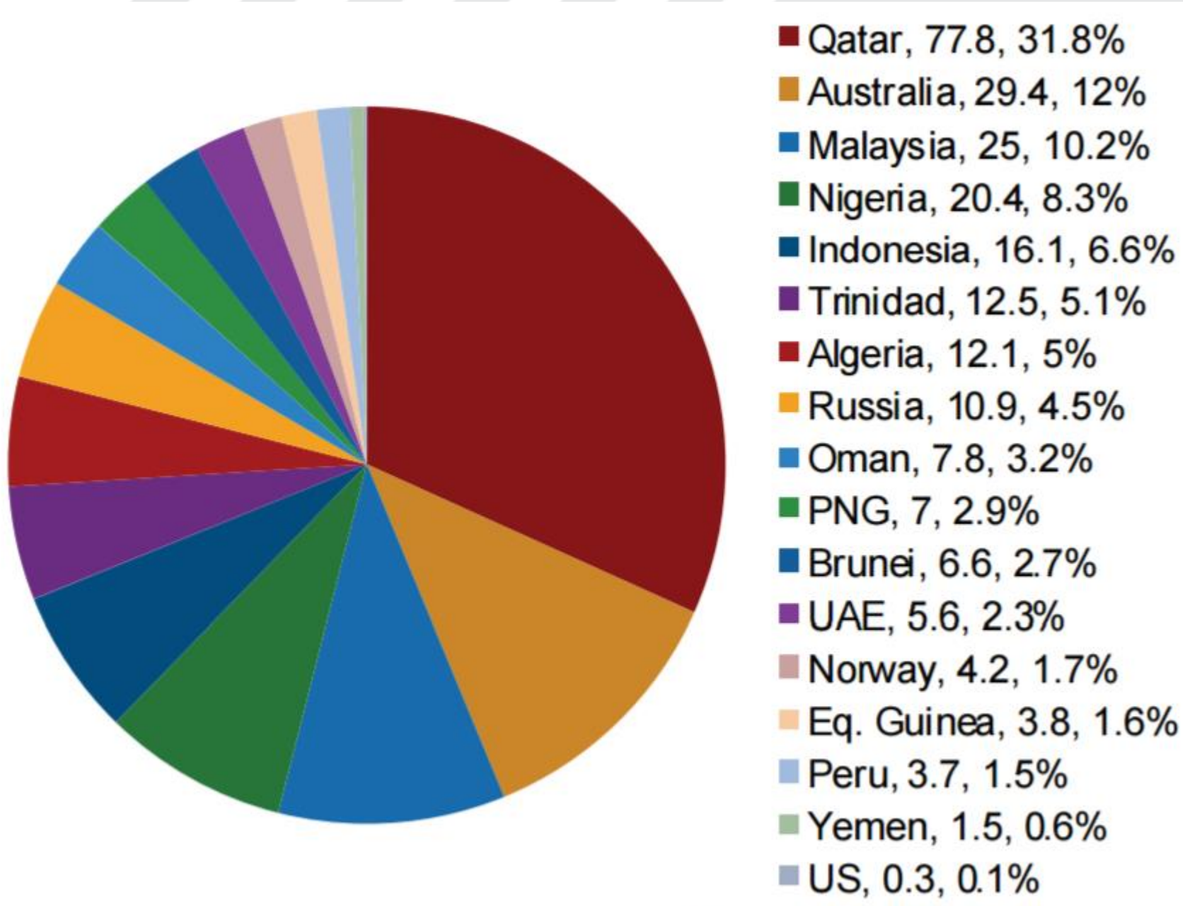
Qatar leading the world in LNG



Note: Numbers in the legend represent total 2015 exports in MT, followed by market share. Sources: IHS, IGU

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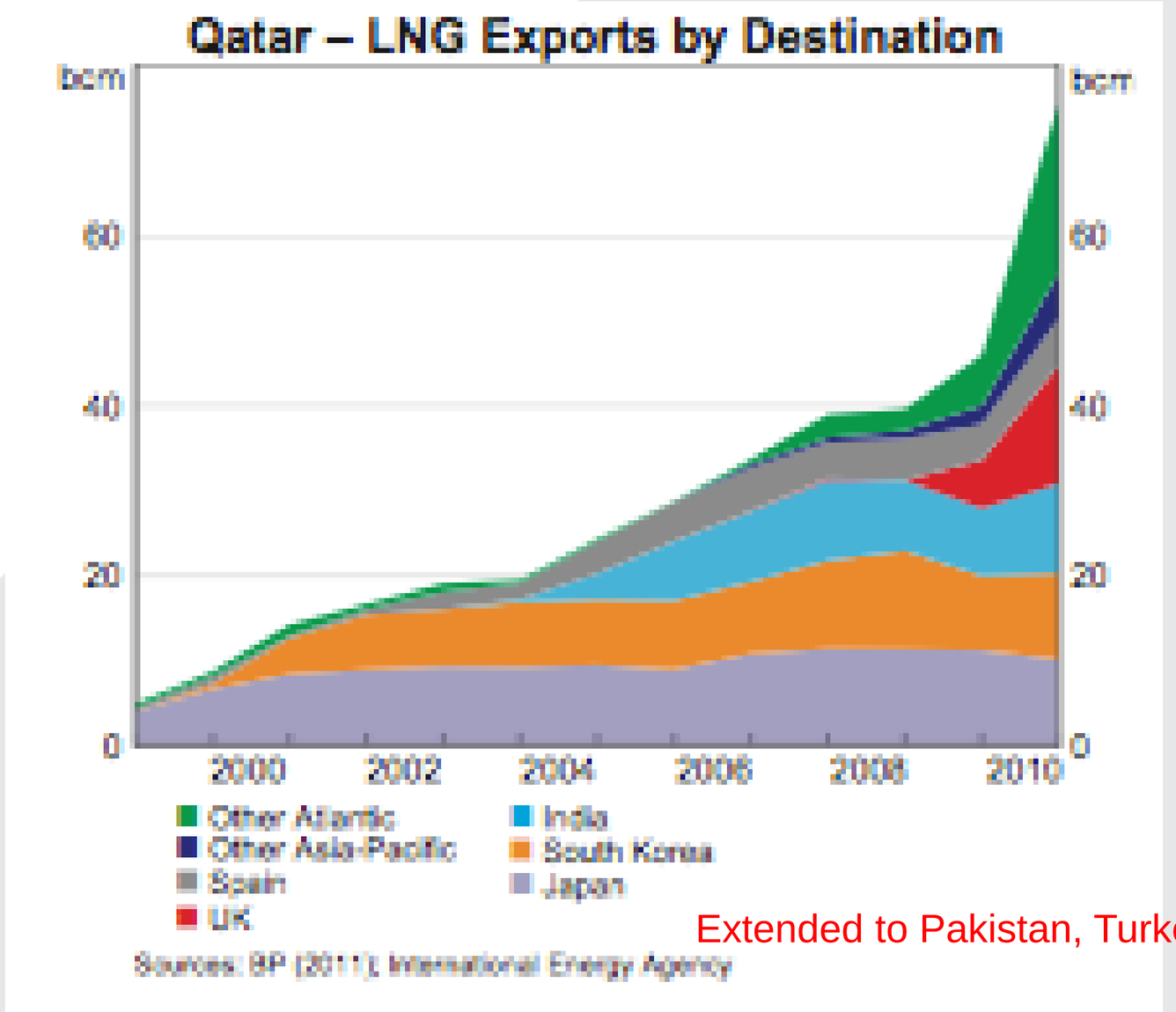
Destinations of Qatar's LNG

77.9 millions metric tons



Extended to Pakistan, Turkey

GTL technology in Qatar

142,000 bpd
1 million tons of kerosene/ year
Gasoil + Base oil

24,000 bpd diesel
+ 9,000 bpd naphtha
+1,000 bpd LPG

sasol
reaching new frontiers

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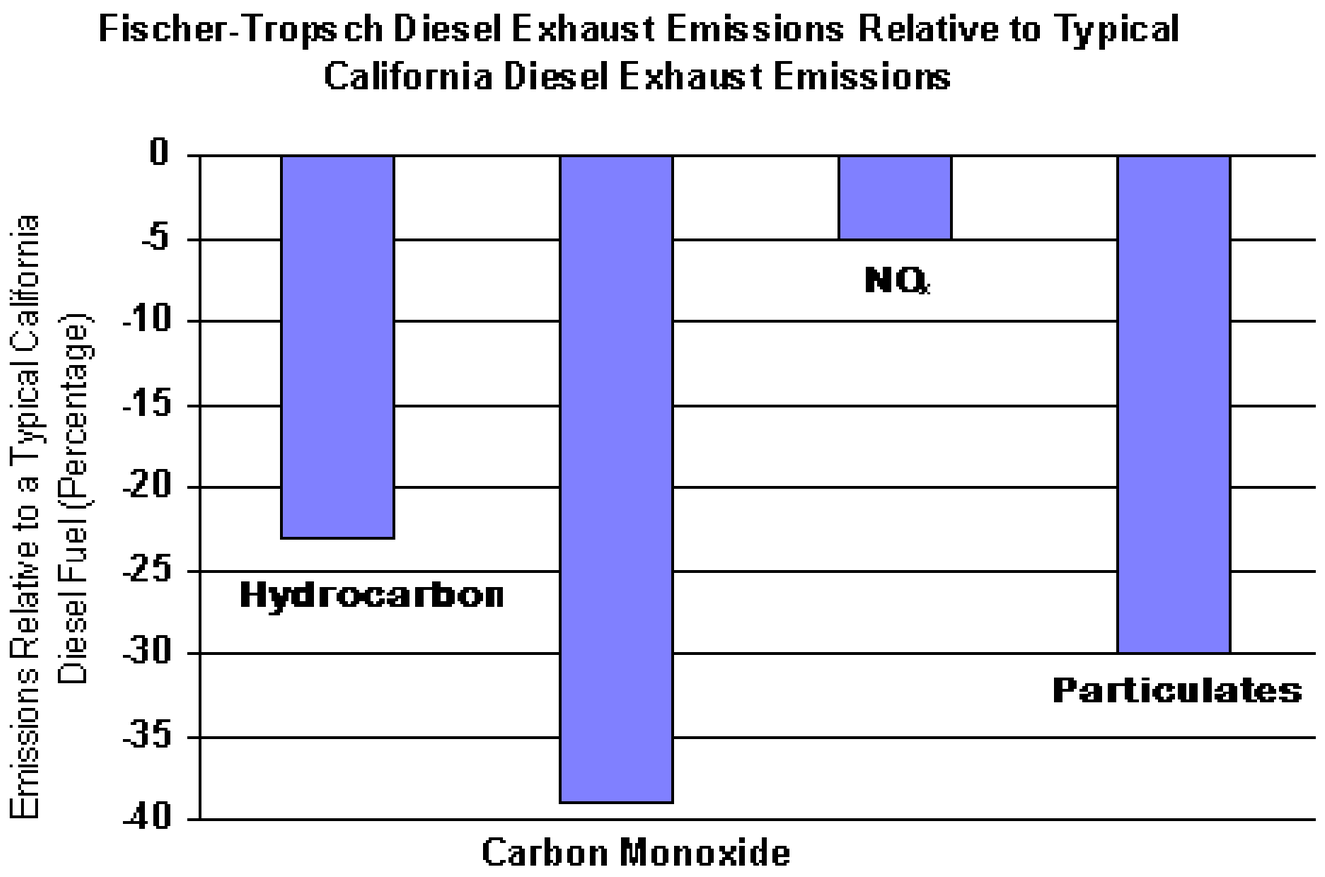
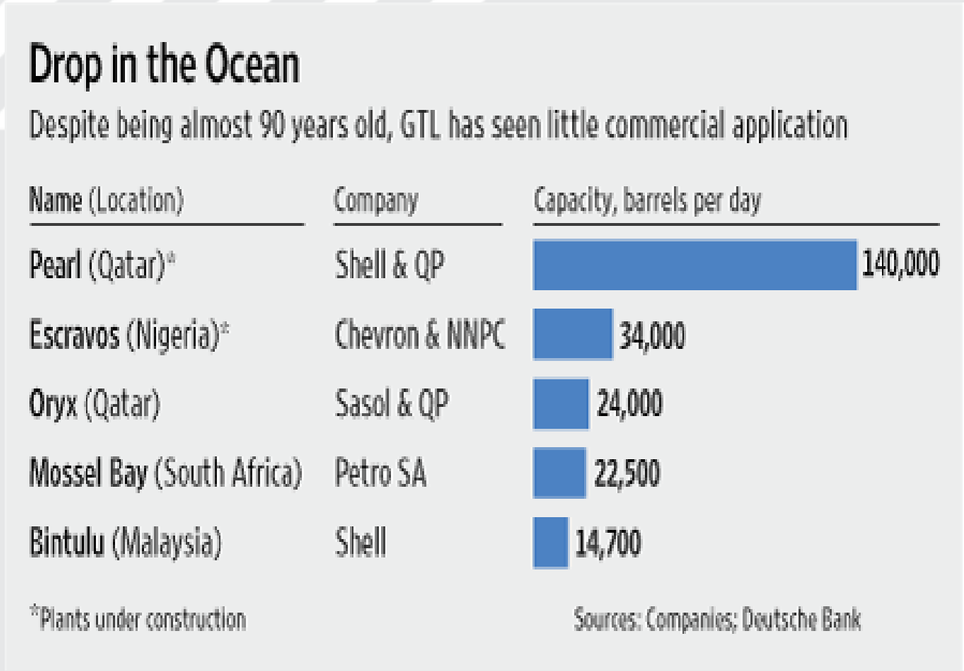
GTL fuels environmentally attractive





Extremely low (0-5-ppm) sulfur, aromatics, and toxics

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Why Qatar prime location for large scale GTL plants?

- Political stability
- Strong economic growth
- Large Gas Reserves (≈15% of world reserves)
- Access to markets
- Strong industry presence
- Future expansion opportunities
- Site synergies & excellent infrastructure
- Modern Harbour
- Committed to industrial development
- Track record with major projects

Qatar: Establishing A world class GTL industry

- The Country
- The Gas
- The Location
- RLIC
- The Government

From ORYX GTL

State of Qatar: Current & Future

- Qatar is an emerging leader in energy, research, politics and human development.

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Qatar Foundation Education City

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Texas A&M Qatar

550 Students in four majors
CHEN, PETE, ELECT, MEEN

since 2003

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Texas A&M supports Qatar's Vision in building up its human capital

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University Ranking: Times Higher Education (THE) Ranking

http://www.timeshighereducation.co.uk/news/mena-snapshot-puts-texas-am-at-qatar-in-top-spot/2018230.article

AT THE HEART OF THE HIGHER EDUCATION DEBATE

Mena snapshot puts Texas A&M at Qatar in top spot

28 January 2015 | By Chris Havergal (URL=/chris-havergal/1254.bio)

Qatar and Lebanon are the top performers in a snapshot of what a new ranking for universities in the Middle East and North Africa could look like

Register now for the *THE* MENA Universities Summit (URL=http://www.cvent.com/events/the-mena-universities-summit/event-summary-ee970f68c9154d1bbeea03fd43aa2b7a.aspx)

Texas A&M University at Qatar took first place in a top-five table for research impact drawn up by *Times Higher*

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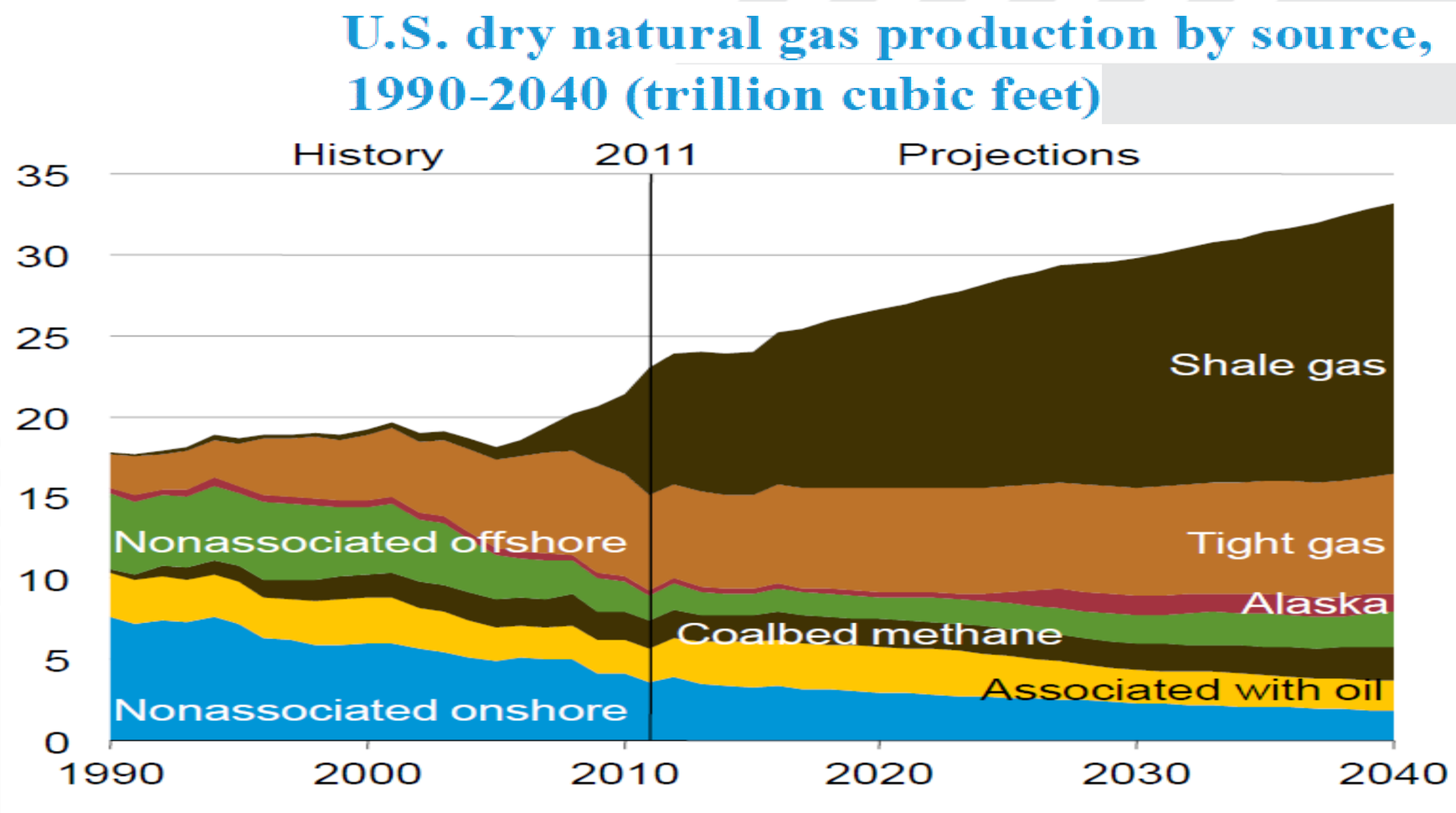
Expectations for natural gas production



U.S. Energy Information Administration | Annual Energy Outlook 2013 Early Release Overview

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Shale gas potentials

What is Texas A&M's expected role in the shale oil and gas revolution?

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Fuels and chemicals formulation, processing, characterization

Processing

Catalysis, reaction engineering, reactor deign

Thermodynamics and phase behavior (experimental and modeling)

Safety

Control

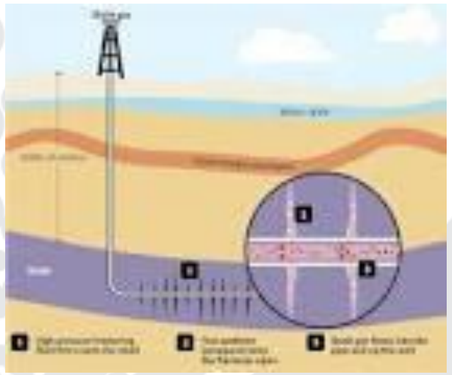
Process integration, synthesis, simulation, design, operation, and optimization, techno-economic analysis, sustainable process design, and molecular/product design

Reservoir simulation and modeling

Design and evaluation of hydraulic fracture treatments

Performance of advanced and stimulated wells

Hydraulic fracture mechanics



Production

Systematic modeling of heat transfer in wellbores

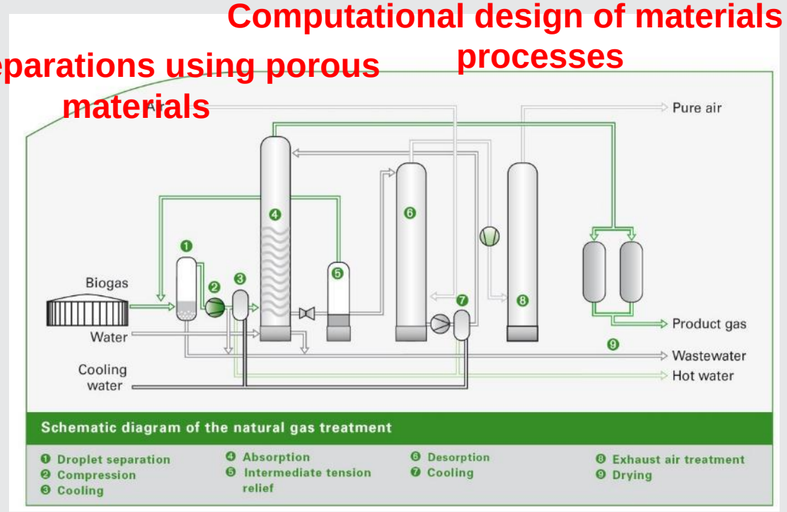
Wellbore integrity analysis

Gas properties

Shale-gas fluid behavior modeling

Computational design of materials and processes

Gas separations using porous materials



Treatment

Monetization

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Texas A&M Gas & Fuels Research Center - Qatar

Professor Nimir Elbashir
Director
Reaction Engineering and Reactor Design
Chemical Engineering

Professor Ioannis Economou
Co-director
Molecular Thermodynamics
Chemical Engineering

Professor Mert Atilhan
Natural Gas Properties
Chemical Engineering

Professor Dragomir Bukur
Catalysis and Reaction Engineering
Chemical Engineering

Professor Marcelo Castier
Thermodynamics and Phase Behavior
Chemical Engineering

Professor Ken Hall
Hydrocarbon Processing
Chemical Engineering

Professor Reza Sadr
Thermofluids and Combustion
Mechanical Engineering

Professor Reza Tafreshi
Engine Testing and Emissions
Mechanical Engineering

Professor Luc Vechot
LNG Safety
Chemical Engineering

Professor Ibrahim Hassan
Heat Transfer, Multiphase Flow CCS
Mechanical Engineering

Texas A&M Gas & Fuels Research Center: CS

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Professor Mahmoud El-Halwagi
Managing Director
Process Integration and Optimization
Chemical Engineering

Professor Jim Holste
Thermodynamics
Chemical Engineering

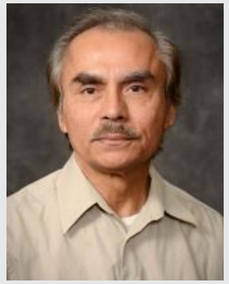
Professor Jorge Alvardo
Fuels Combustion
Mechanical Engineering

Professor Mark Holtzapple
LNG, Fuels and Thermodynamics
Chemical Engineering

Professor Perla Balbuena
Computational Material Design
Chemical Engineering

Professor Maria Barrufet
Reservoir Simulation and Modeling
Petroleum Engineering

Professor Faruque Hasan
Computational Energy Analysis
Chemical Engineering



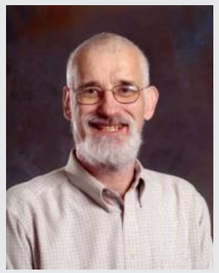
Professor A. Rashid Hasan
Gas Production
Petroleum Engineering

Professor Sam Mannan
Safety
Chemical Engineering

Professor Nazmul Karim
Control
Chemical Engineering

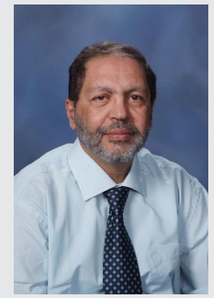
Professor Waruna D. Kulatilaka
Optical Diagnostic
Mevhanical Engineering

Professor Andrea Strezlec
Combustion, Kinetics and Engines
Mechanical Engineering



Professor Peter Valkò
Design of Hydraulic Fracture Systems
Petroleum Engineering

Professor Benjamin Wilhite
Reaction Kinetics and Simulations
Chemical Engineering



Professor Hisham A. Nasr-El-Din
Well Simulation, EOR
Petroleum Engineering

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How GFRC helping Qatar to advance its gas processing technology?

Dolfin Gas Project

QatarGas Project

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Major Industry Collaborations in Qatar & USA

Platinum

ORYX GTL

Synthetic Fuels & Lubricants, Engine Tests; Trainings

GE Oil & Gas

Fuel blends, engine & emissions

sasol
reaching new frontiers

Synthetic Fuels

Reactor, Synthetic Fuels, Lubricants

TOTAL

قطر للبترول
Qatar Petroleum

Catalysts

ExxonMobil

Gas production

RasGas

MAERSK OIL

Gas Production and Process Optimization

وقود
WOQOD

Fuels & Lubricants

Chevron

Gas Processing Technologies

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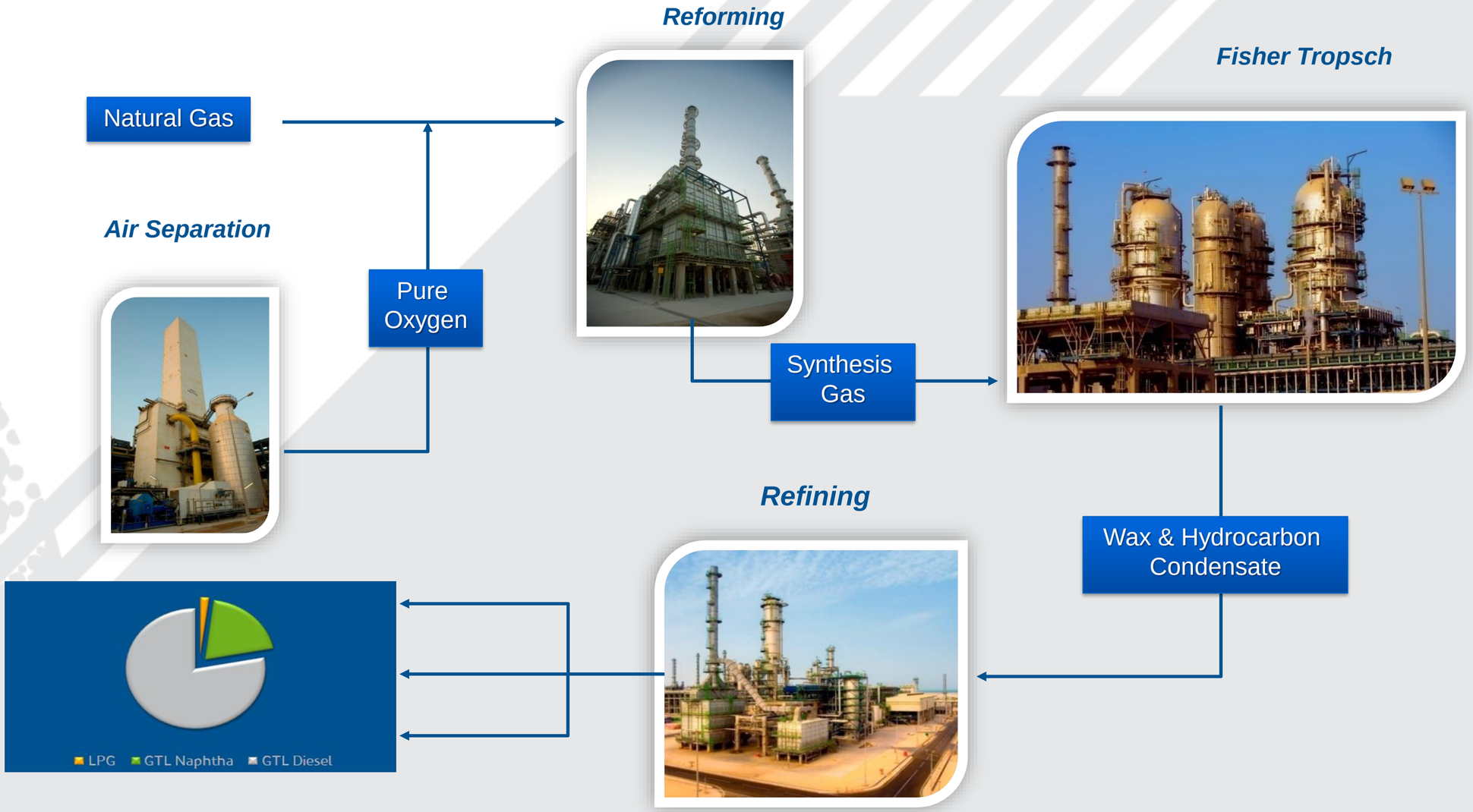
Gas-to-Liquid (GTL) still needs advancement!



ORYX GTL Plant: a joint venture of Qatar Petroleum and Sasol

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Comparison between FTS reactors

Desired Characteristics	Packed bed reactor (gas phase)	Slurry phase reactor (liquid phase)
Operational Consideration	↓	↑
High mass transfer rates	↓	↑
High heat transfer rate	↓	↑
Wide product spectrum	↑	↑

The ideal FTS reactor should combine the advantages of the two major reactor technologies; **fixed-bed reactors** of high reactant diffusivity and reaction rates coupled with steady performance to that of the **slurry reactor** of well-mixed phase and excellent temperature distribution inside the reactor bed coupled with higher overall productivity.

→ **One more feature is the capability of controlling the hydrocarbon product distribution.**

Advantage

Disadvantage

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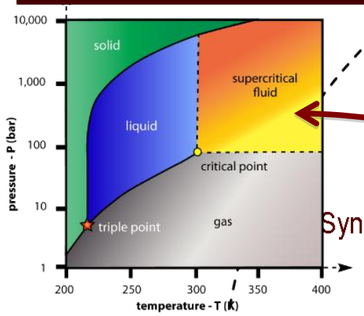
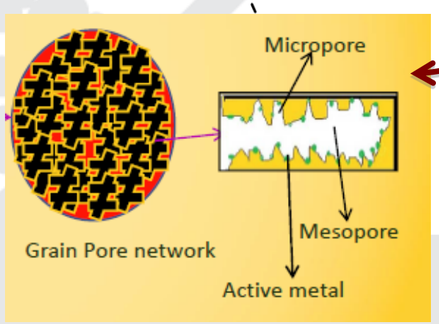
Microscale studies: Simulation & Experimental

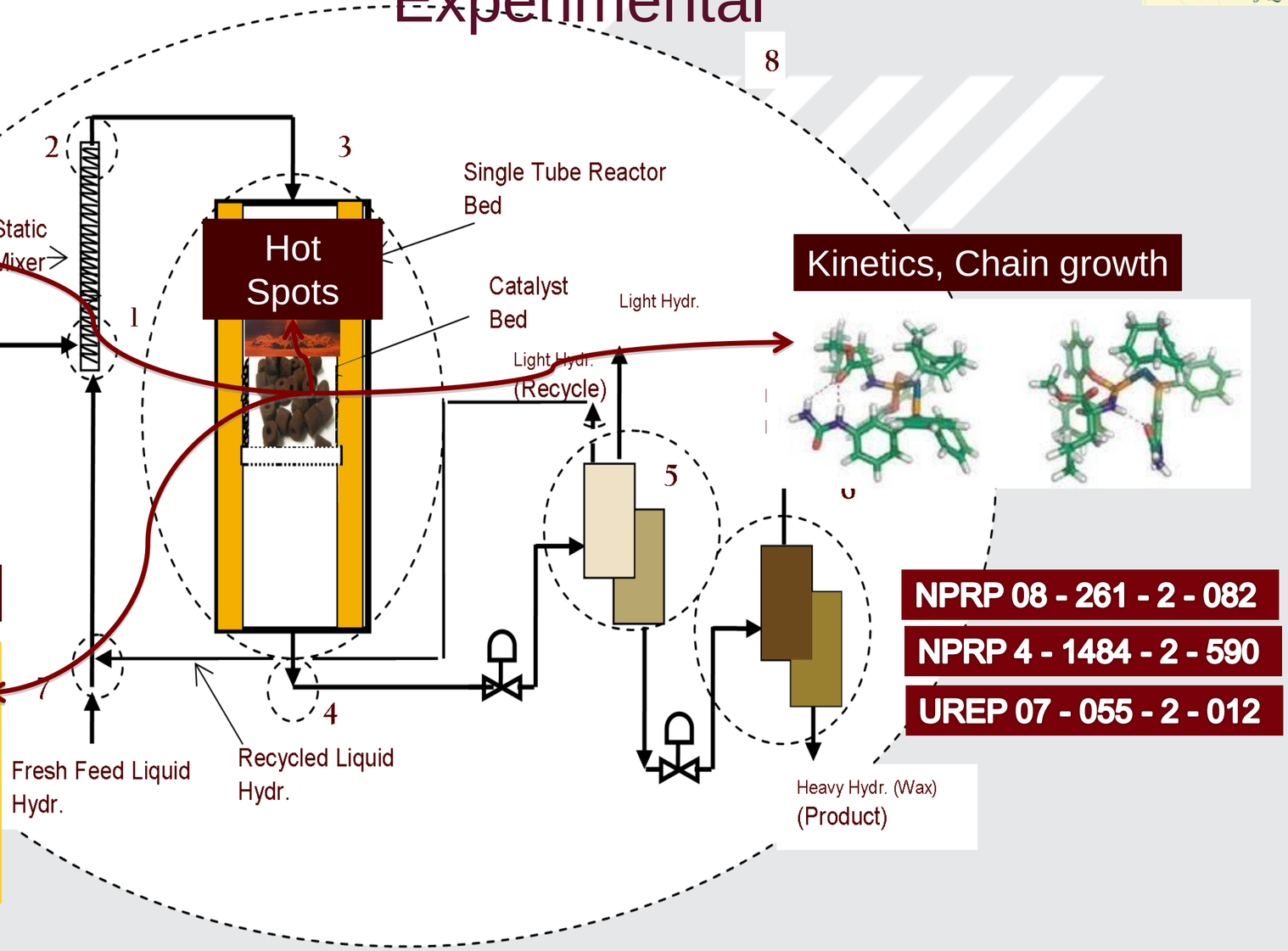
Qatar National Research Fund
Member of Qatar Foundation

Phase Behavior



Diffusion Limitations





Kinetics, Chain growth

NPRP 08 - 261 - 2 - 082

NPRP 4 - 1484 - 2 - 590

UREP 07 - 055 - 2 - 012

Macro-scale studies

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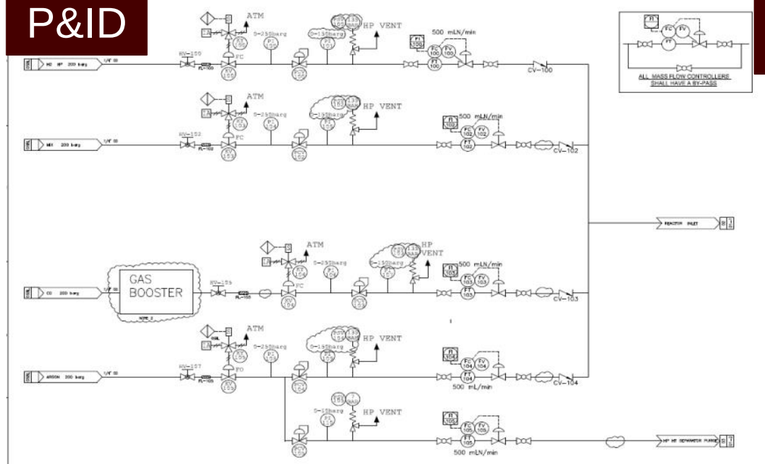
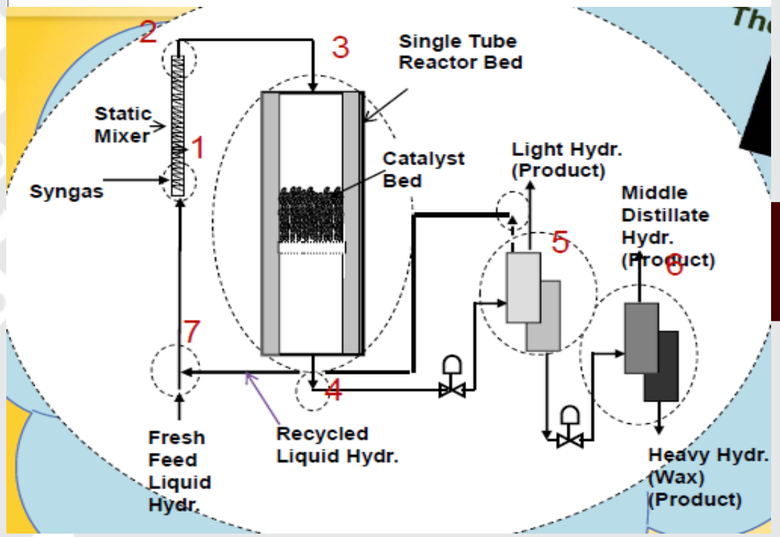
QATAR SCIENCE & TECHNOLOGY PARK
Member of Qatar Foundation
TEXAS A&M UNIVERSITY at QATAR

NPRP 08 - 261 - 2 - 082
NPRP 5 - 066 - 2 - 023
UREP 11 - 151 - 2 - 057

P&ID





Energy Optimization

Process Control

Solvent Recovery

Solvent Selection

Reactor Configuration

Synthetic Fuels Formulation & Characterization

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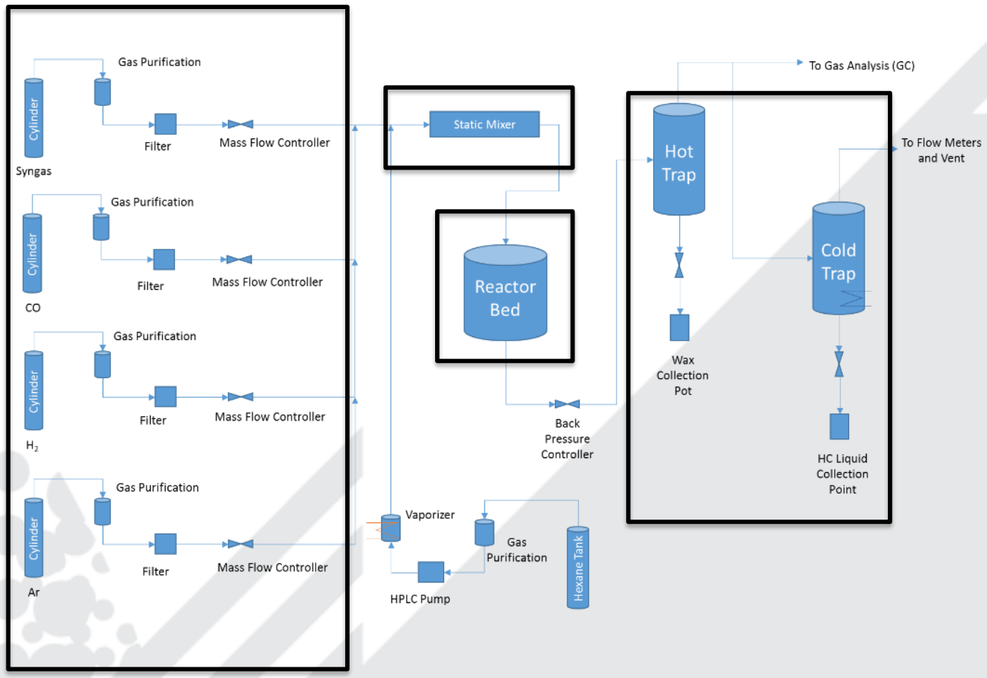
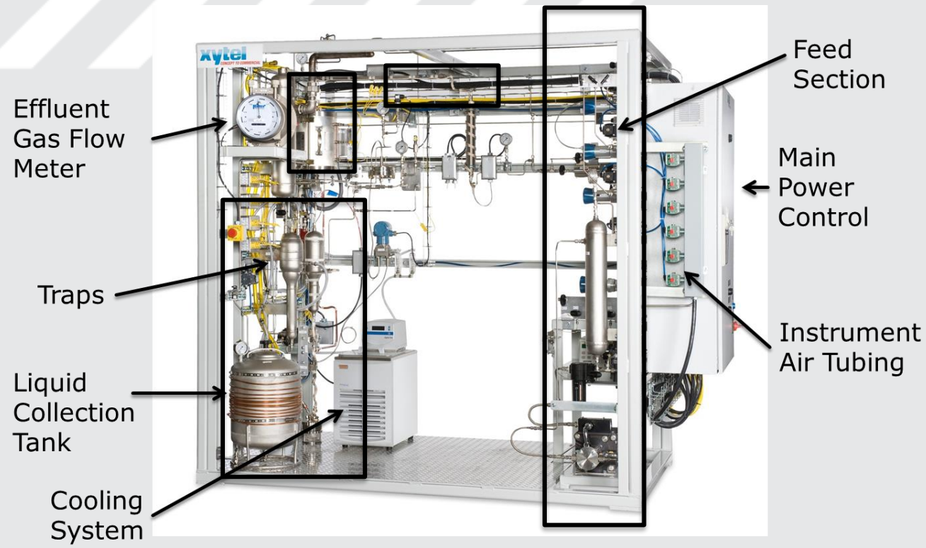
Experimental setup



Block Diagram of High Pressure Fischer-Tropsch reactor unit



Picture of actual High Pressure Fischer-Tropsch reactor unit

Safety Systems : Alarms for abnormal operation, automatic shutdown valves, CO detectors, pressure test conducted prior to operation of unit

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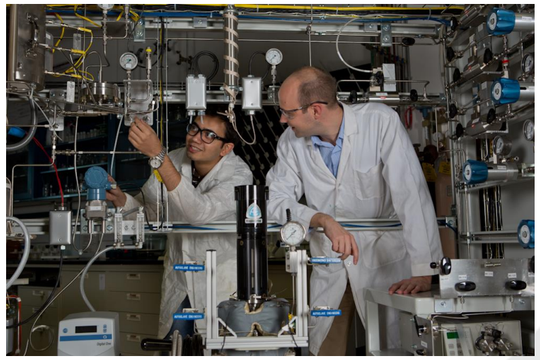
Invention disclosure



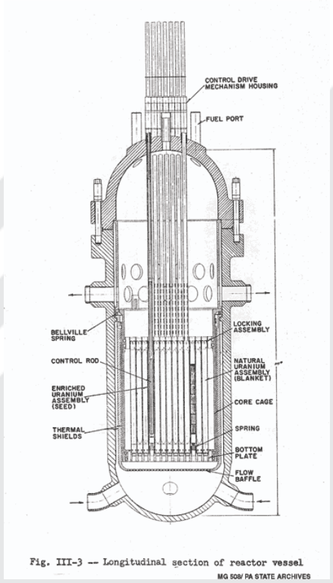


Fig. III-3 -- Longitudinal section of reactor vessel
MG 50W PA STATE ARCHIVES

The Texas A&M University System
Office of Technology Commercialization

OTC USE ONLY
TAMUS # 3861

Commercialization Proposal / Invention Disclosure Form

This form is used to disclose new inventions for assessment and possible commercialization and to meet obligations of disclosure as required under TAMUS Policy 17.01. Before completing this form, please refer to the guidelines at the end of this document. Please send your completed form, inventor data sheet(s), and any additional documentation to disclosures@tamus.edu.

RECEIVED
JUL 25 2013
Office of Technology Commercialization

1. *Title:* **Novel Highly-Integrated Fischer Trsopch Synthesis Reactor of Enhanced in situ Characterstics**
2. *Lead Inventor:* (Inventor Data Sheet required) **Nimir O. Elbashir**
3. *Abstract:* Describe the invention and what it can be used for in 500 words or less. The description should be accessible to a "lay audience" having no special or expert knowledge in your field.

Commercial Fischer-Tropsch synthesis (FTS) reactors have limited room for advancement due in part to the complicated chemistry and economics of the process; for example the temperature profile control of the fixed bed reactor highlights a consequence of the highly exothermic chemical nature of the reaction, whilst the catalyst and its separation on the slurry reactor is technically and financially

This is a schematic <u>but</u> not representing the actual art since it is still under processing.

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Cleaner skies

- *Qatar Airways makes historic journey with first GTL fueled commercial flight from London Gatwick to Doha*
- *New Gas-to-Liquids fuel offers diversity of supply and better local air quality at busy airports*

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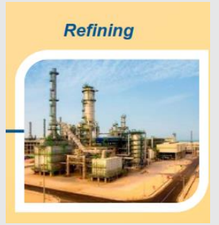
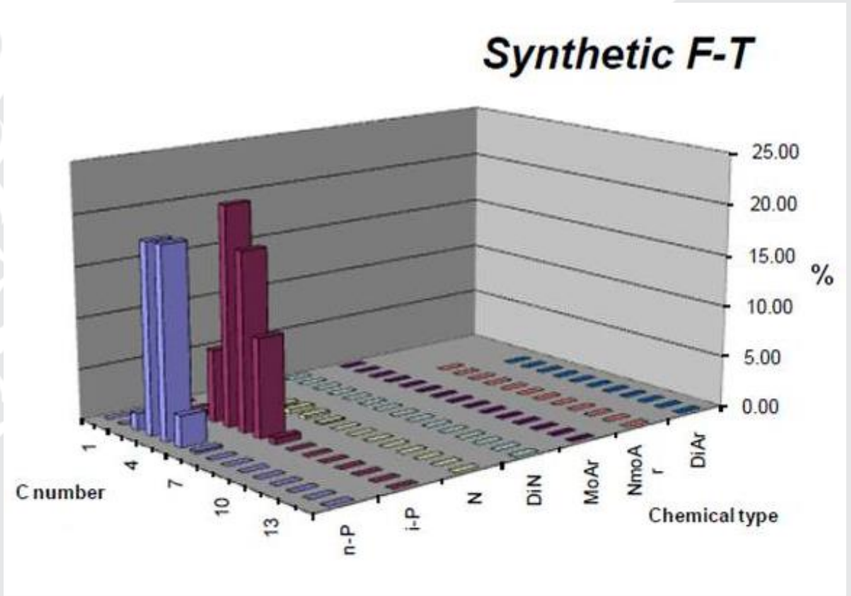
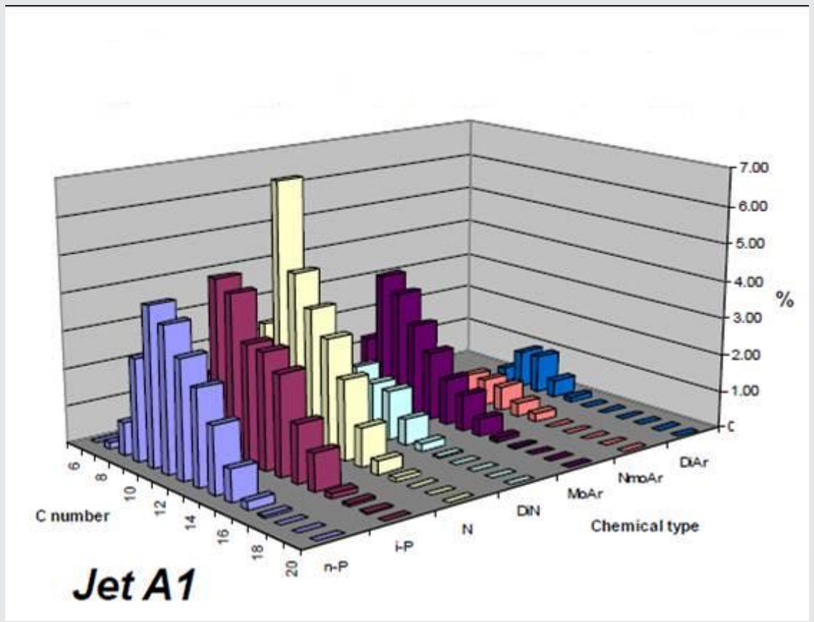
Jet fuels hydrocarbon structure



Species & Carbon Number distribution in a conventional jet fuel (Jet A-1) versus a synthetic GTL kerosene (SPK).





*GCxGC data provided by Shell

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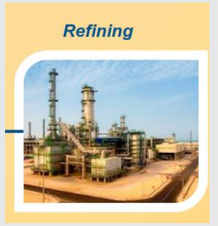
TAMUQ Fuel Characterization Lab



Built a world class research lab to support Fuel Technology of Qatar for Gas-to-Liquid (GTL) processes.

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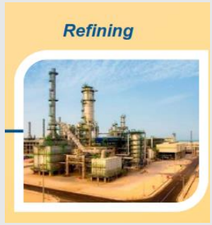
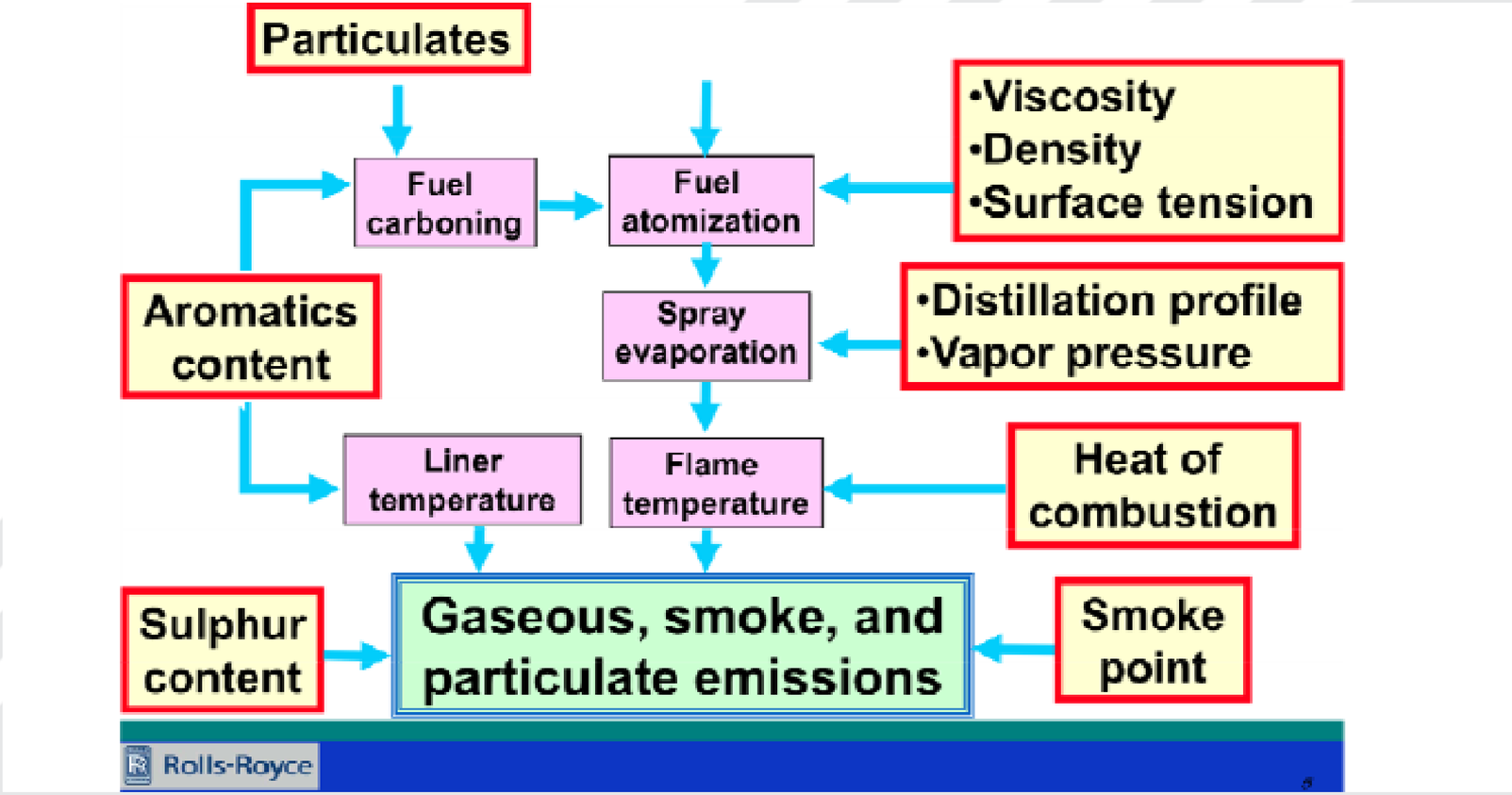
Properties role on fuels' performance





Courtesy of John Moran from Rolls Royce

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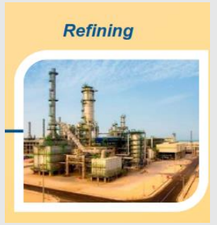
OryxGTL Green Diesel Fuels Campaign!



ORYX GTL
QP - SASOL Joint venture

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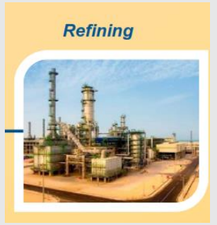
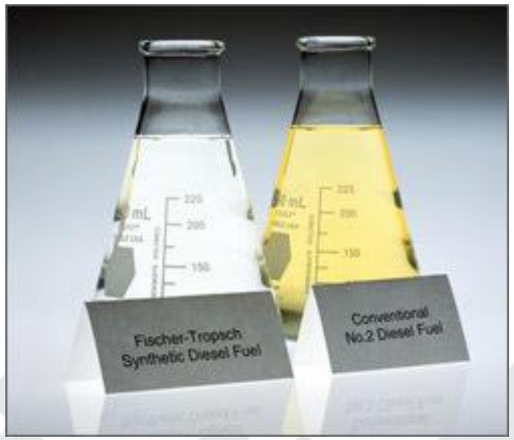
GE (Oil & Gas) Future Blends of Synthetic Fuels





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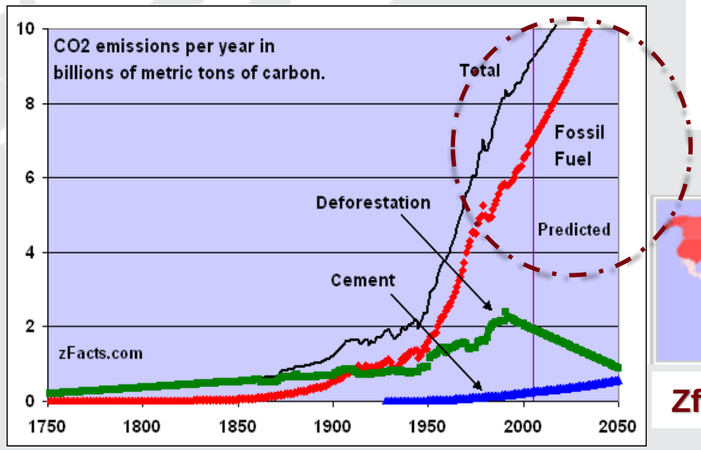
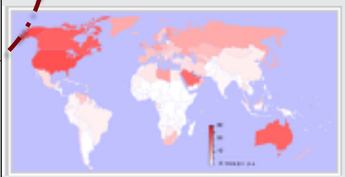
The Challenge: Qatar has the world's largest per capita CO_2 footprint

1

3 or 4

Rank	Country	1990	1991	1992	1993		2004	2005	200	2007	2008	2009	2010
1.	Qatar	25.2	36.7	54.3	60.9	8	58.5	64.2		55.4	48.6	44.0	
2.	Trinidad and Tobago	13.9	17.1	17.0	13.5	2	24.0	23.5		27.9	37.3	35.8	
3.	Netherlands Antilles	32.6	26.9	22.6	35.0	1	31.3	30.7		32.5	31.9	31.0	
4.	Kuwait	19.0	5.1	10.0	16.9	9	31.1	33.3		30.7	31.3	30.3	
5.	Brunei	25.0	22.0	21.4	20.0	4	16.7	15.4		25.3	27.6	23.7	





Zfacts.com

Wikipedia: List of countries by carbon dioxide emissions per capita

Metric tonnes CO2 per capita

DOHA 2012
UN CLIMATE CHANGE CONFERENCE
COP18 | CMP8

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NORTHWESTERN UNIVERSITY

TOTAL

IT'S TIME FOR TEXAS A&M UNIVERSITY at QATAR

QATAR UNIVERSITY

THE TEXAS A&M UNIVERSITY SYSTEM 1876

Design of Novel Catalysts and Processes for CO_2 Conversion from Micro- to Macroscale

~US$ 5,000,000

NPRP X - 100 - 2 - 024

IT'S TIME FOR TEXAS A&M UNIVERSITY at QATAR

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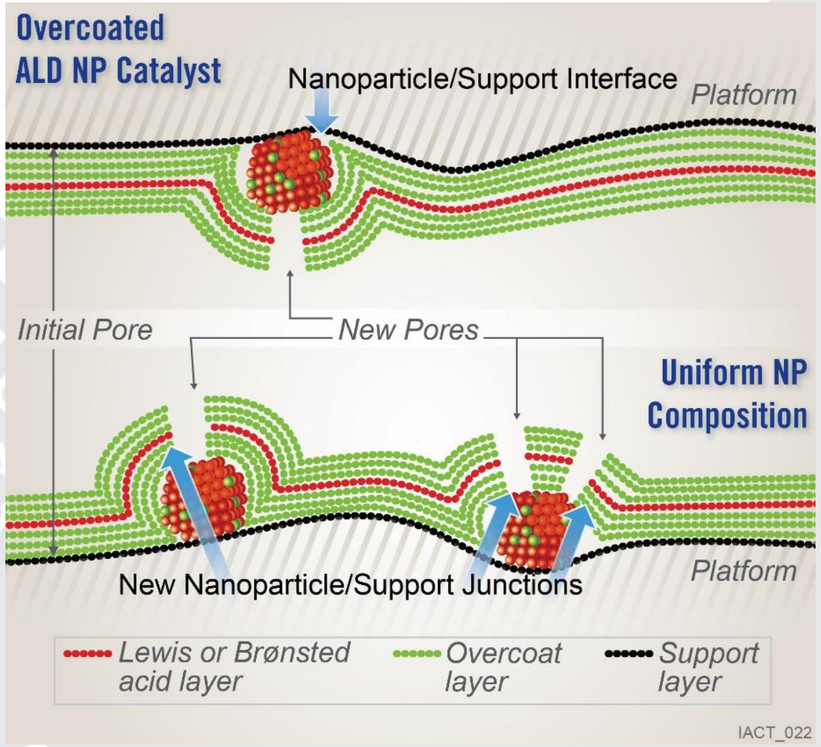
Project Intellectual Merits

Micro scale investigations

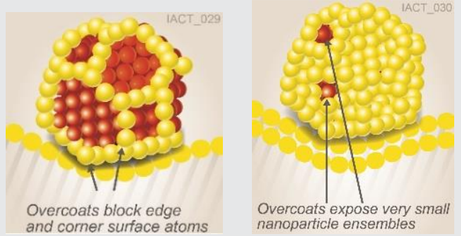
Science 2012, 335, 1205

Prof. Peter Stair team: co-PI

New generations of effective dry reforming catalysts for natural gas + CO_2 conversion to methanol will use novel design concepts based Atomic Layer Deposition (ALD).



- **Provide exceptionally stable transition metal catalysts for CO_2 conversion**
- **Capable of sustained activity under harsh reaction conditions to enhance product selectivity**
- **High-temperature, stable-operation dry reforming reactions should be possible with new generations of oxide over-coated catalysts that resist coking and sintering**



Project Intellectual Merits

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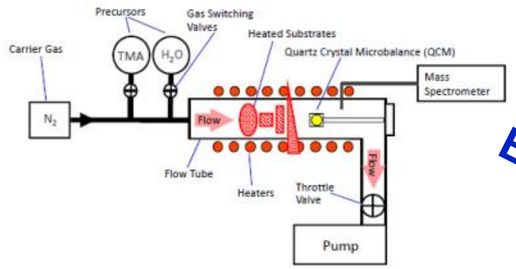
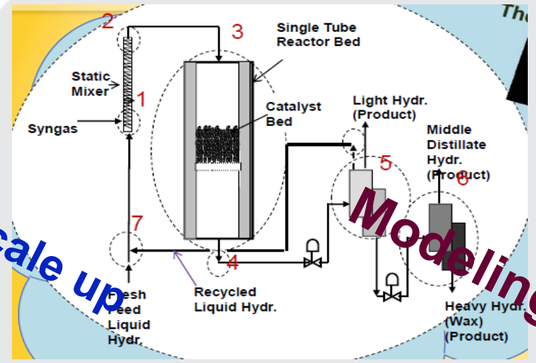
Macro scale investigations

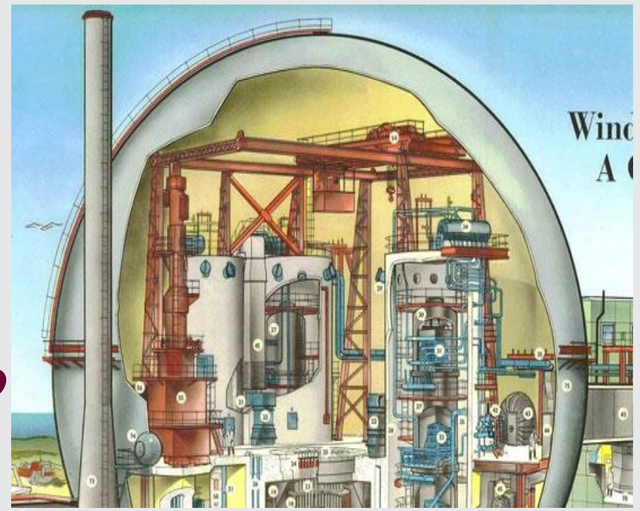
As ALD catalysts are perfected in *Focus 2*, they will be scaled-up in Qatar for bench-scale continuous catalyst testing and characterization. This effort represents a major contribution to ALD catalyst development and R&D infrastructure building in Qatar for new CO_2 conversion catalysts. This activity will be coupled with scaling-up the reactor unit design



Experimental Scale up



Modeling Scale up



- Kinetic measurements
- Thermodynamics & phase behavior
- Fluid mechanics
- Heat & mass transfer

- Energy integration
- Process synthesis & optimization

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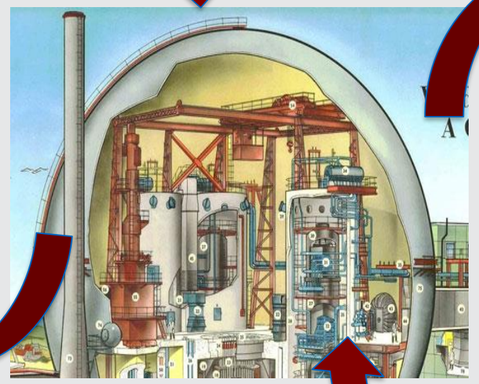
Project Intellectual Merits

Macro scale investigations

Focus 6: **Modeling will be carried out to investigate scale-up potential of a commercial process based on the results of *Focus 5.* Investigate CO_2 fixation scenarios by analyzing the CO_2 life cycle for the process while examining the possibility of integrating the proposed plant in an existing Qatar plant.**



Collaborators

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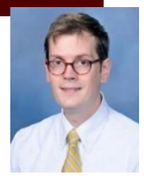

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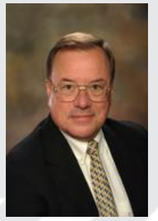
Prof. W. Kulatilaka



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National Priorities Research Program
NPRP

UREP

ORYX GTL
QP - SASOL Joint venture

ORYX GTL Excellence Program in GTL

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Thank you very much!

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