# A FUTURE FOR MOLECULES IN THE ENERGY SUPPLY?

Challenges and Opportunities for Sustainable Production of Chemicals and Fuels beyond the Shale Gale

UCSB

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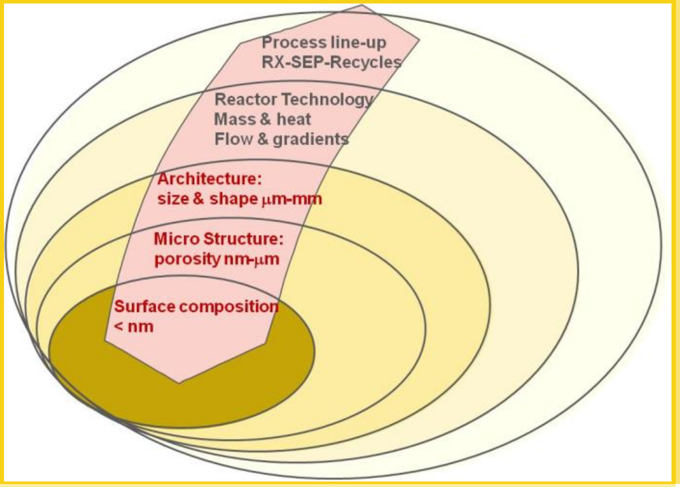



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# DEFINITIONS & CAUTIONARY NOTE

Reserves: Our use of the term "reserves" in this presentation means SEC proved oil and gas reserves.

Resources: Our use of the term "resources" in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves. Resources are consistent with the Society of Petroleum Engineers 2P and 2C definitions.

Organic: Our use of the term Organic includes SEC proved oil and gas reserves excluding changes resulting from acquisitions, divestments and year-average pricing impact.

Resources plays: our use of the term 'resources plays' refers to tight, shale and coal bed methane oil and gas acreage.

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THE WORLD IN 2050 – THE ENERGY CHALLENGE
9 billion people
4-5 times richer
Double the energy
Need to reduce $CO_2$ emissions
Increasing role for Renewables
Hydrocarbons remain indispensible

# MOUNTAINS & OCEANS – OVERVIEW

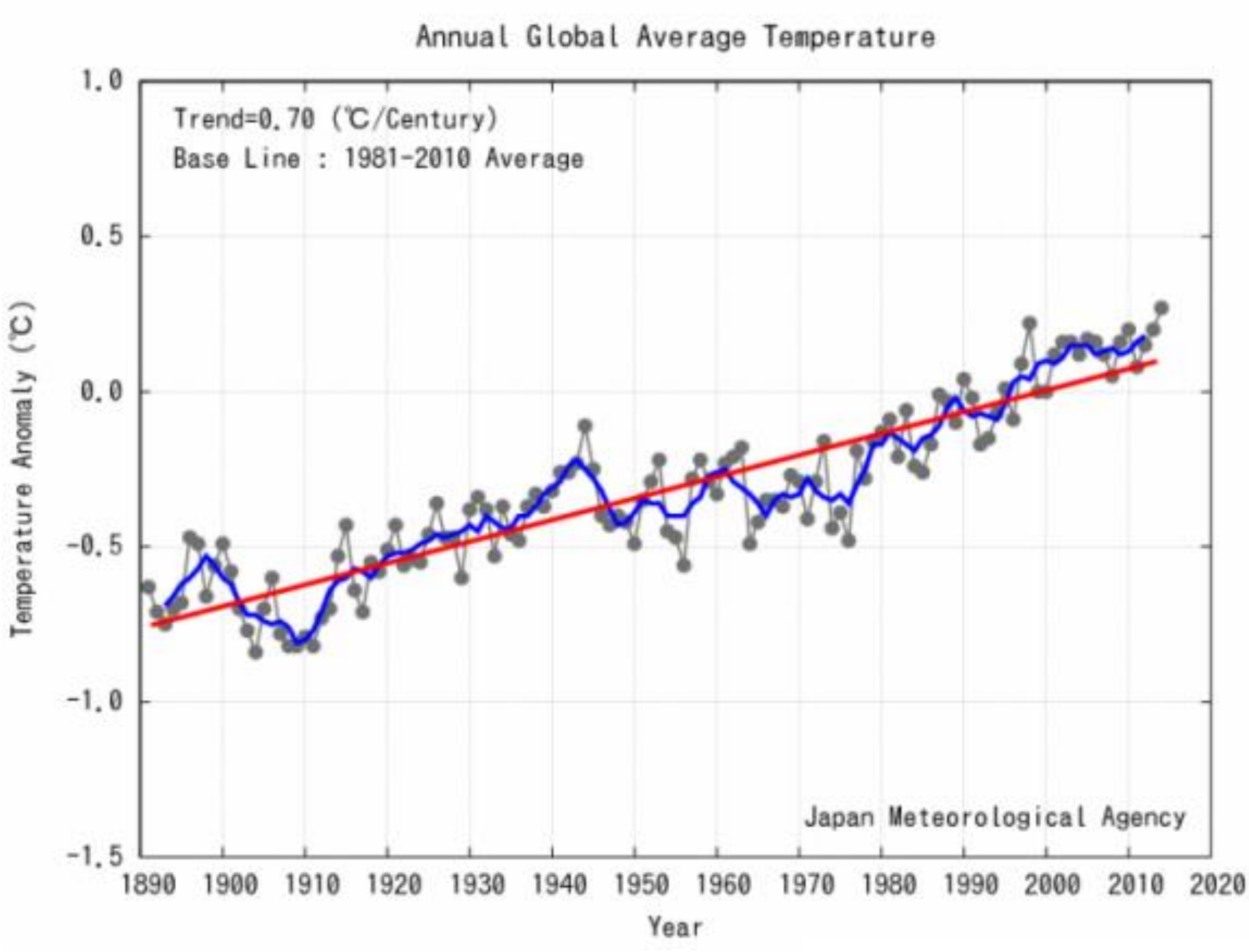
## MOUNTAINS

- Power remains concentrated in economic and political elites/governments
- Top Down policy making in
  - Renewables
  - Hydrogen
  - Gas with CCS as a low carbon alternative to Coal

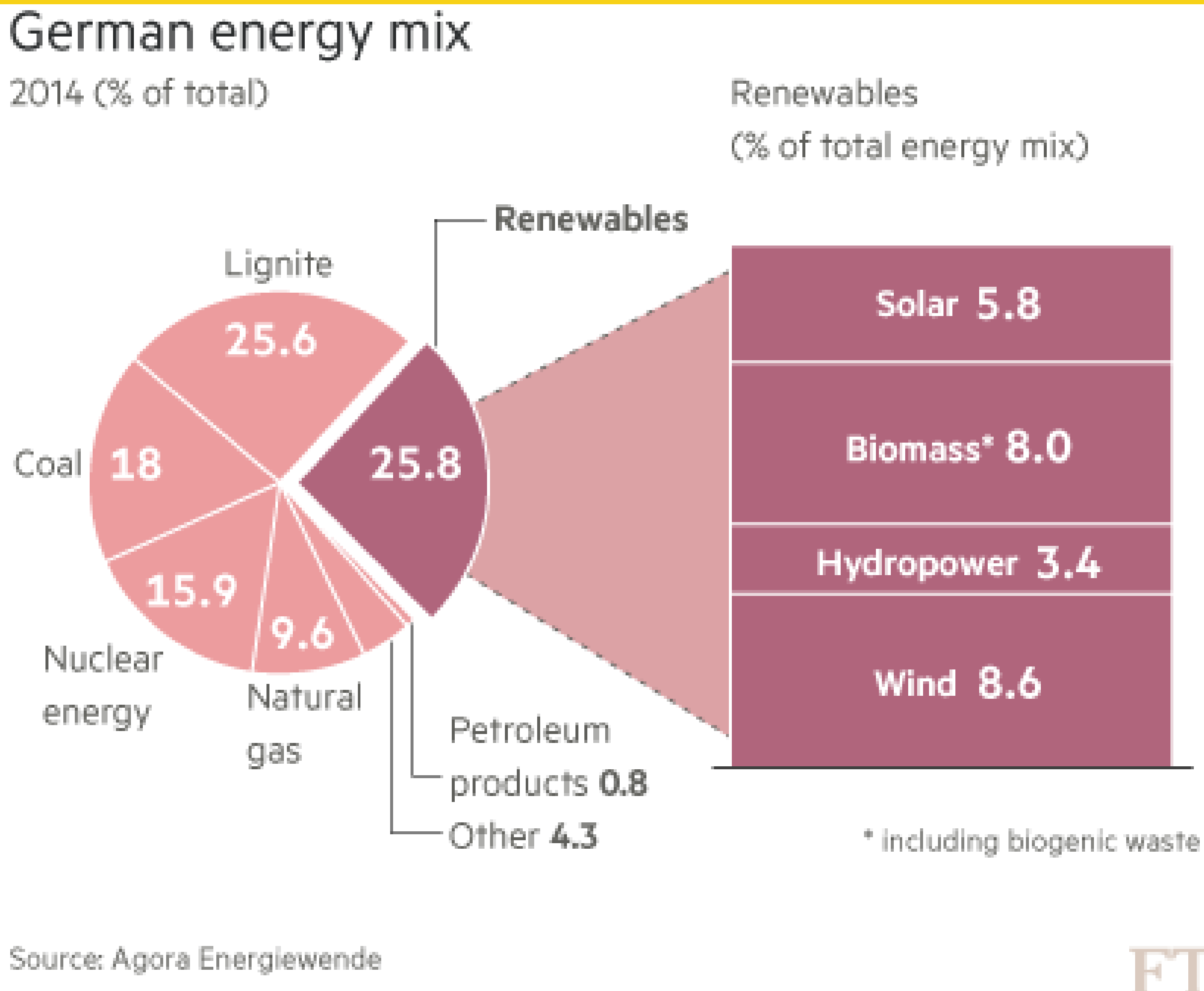
## OCEANS

- Power devolves away from governments and elites
  - Spurs (local) innovation and economic growth
- Less consensus building:
  - Transition from Coal to Gas will be slower
  - Slow adoption to Efficient energy usages measures and CCS

# ANNUAL GLOBAL TEMPERATURE



# GERMAN ENERGY MIX 2014



# $CO_2$ EMISSION PER HYDROCARBON FUEL SOURCE

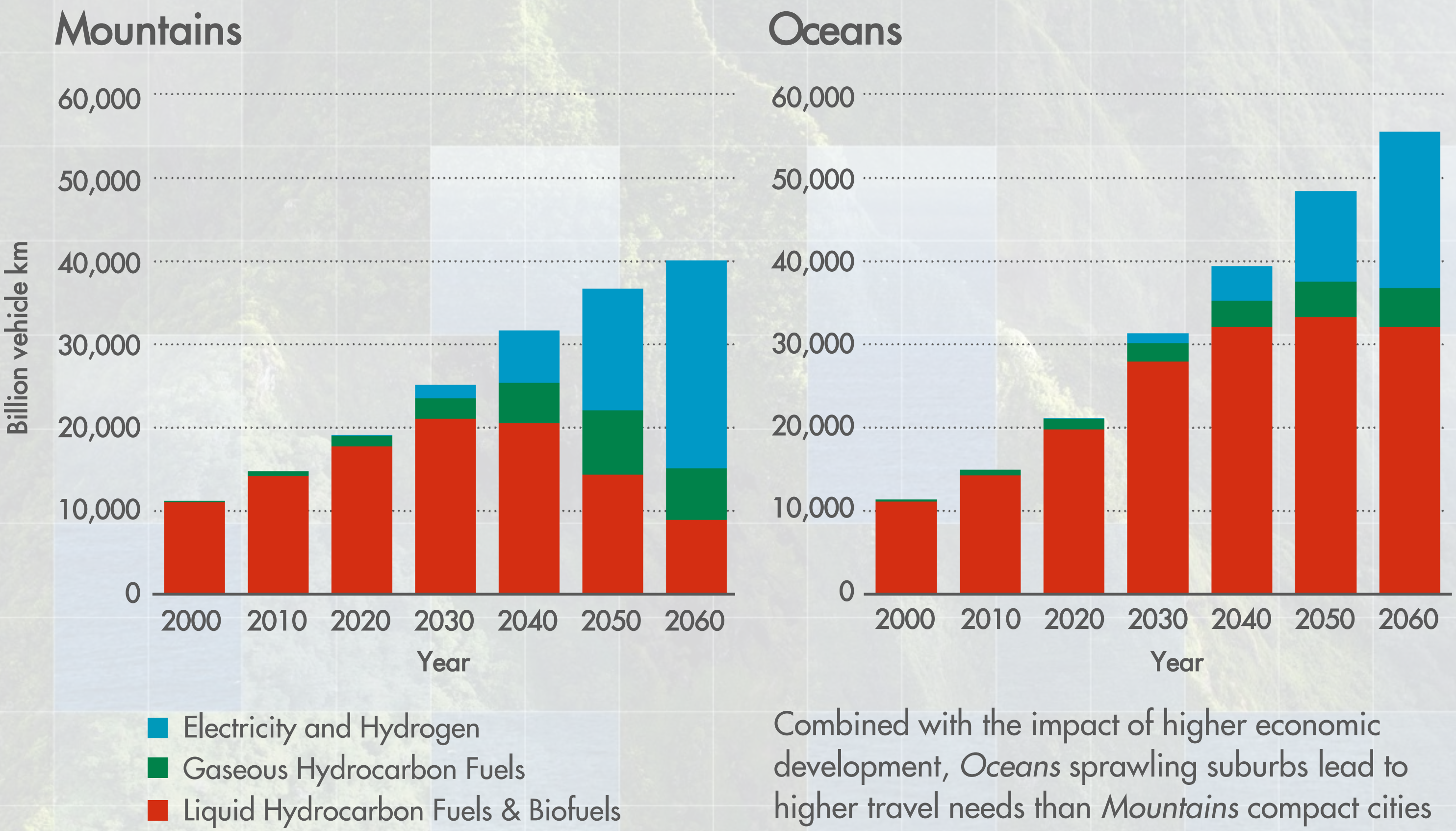
Rational for LNG substituting

- coal (power)
- gasoline/diesel (transportation)

| Fuel Source | $CO_2$ Emission (lb/MM BTU) |
|---|---|
| Coal (anthracite) | 228.6 |
| Coal (bituminous) | 205.7 |
| Coal (lignite) | 215.4 |
| Coal (subbituminous) | 214.3 |
| Diesel fuel & heating oil | 161.3 |
| Gasoline | 157.2 |
| Propane | 139.0 |
| Natural gas | 117.0 |

http://www.eia.gov/tools/faqs/faq.cfm?id=73&t=11

# SCENARIO CONTRAST
# WORLD PASSENGER TRANSPORT




Combined with the impact of higher economic development, *Oceans* sprawling suburbs lead to higher travel needs than *Mountains* compact cities

Source: www.shell.com – new lens scenarios

# SHELL – FUTURE TRANSPORTATION FUELS

'More Gas'

## Premium Fuels

**V-Power fuels:**

**Best performance in Latest engine technology**

- In 60 markets since 1998
- VP-Diesel with unique GTL component
- V-Power racing with 100 Octane and FMT-Technology
- Shell Fuel Save for improved Fuel Economy

## GTL Fuel


**Pioneer in the development of Gas to Liquid technology**

Premium diesel containing GTL Fuel launched in:

Austria, Germany, Greece, Italy, Netherlands, Switzerland and Thailand

## CNG/LNG

**Natural gas will account for over half of Shell's total production in 2012**

- Established CNG offers in dedicated markets
- LNG for large engines (heavy duty on road / off-road, rail, marine)

## Biofuels

**Leading in current and future biofuels**

**First-generation**

- 9,5 billion litres (2010)

e.g. Brazilian Sugarcane Ethanol

(COSAN JV)

**Second-generation**

- Several R&D projects

## Hydrogen


**World's largest public transport joint venture**

Concentration of Demonstration projects in EU/D and USA, China

## Electricity


**Evaluation of Options**

**Performance fuels** | **Energy Diversification** | **… based on $CO_2$ solutions**

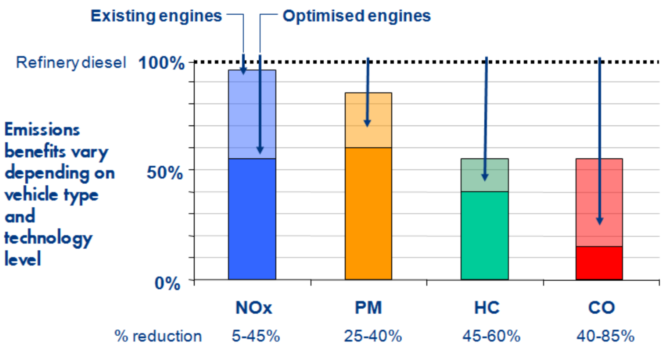
# FUEL OPTIONS FOR MODES OF TRANSPORT

| Mode of Transport | | Liquid Fuels | Gaseous Fuels | | | | Electricity |
|---|---|---|---|---|---|---|---|
| | | | LPG | CNG | LNG | $H_2$ | |
| Car | Short distance | ++ | + | + | – | + | + |
| | Long distance | ++ | + | + | – | + | – |
| Truck | Light | ++ | + | + | – | + | ○ |
| | Heavy | ++ | – | ○ | + | – | – |
| Rail | | ++ | – | ○ | + | – | ++ |
| Ship | | ++ | – | ○ | + | – | – |
| Aircraft | | ++ | – | – | – | – | – |

++ (Fully) compatible + With minor restrictions ○ With major restrictions – Not compatible

# UNIQUE QUALITIES OF GTL PRODUCTS

Emissions reduction in heavy diesel engines





| Mack T 12 | HDDEO low SAPs SAE 5W-30 current | HDDEO low SAPs SAE 5W-30 Shell GTL | API CJ-4 limits |
|---|---|---|---|
| av. top ring weight loss (mg) | 85 | 54 | 105 max. |
| av. liner wear (micro meters) | 21.3 | 14.5 | 24 max. |
| Oil consumption (grams/hour) | 64.3 | 54 | 85 max. |

## GTL Gasoil

GTL Gasoil in new diesel fuel formulations to address market requirements for:

- improved engine durability
- reduced emissions
- less noise and smell


## GTL Base Oils

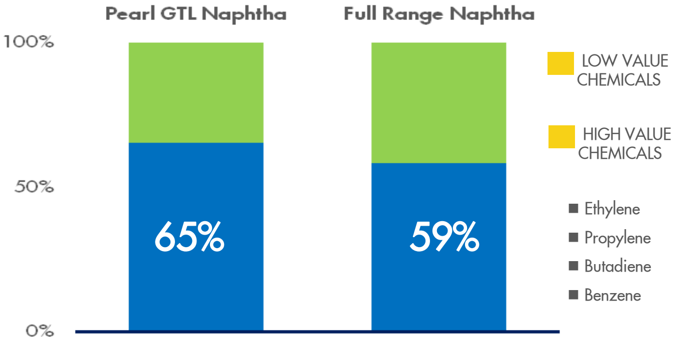
GTL Base Oils in new engine oil formulations to address market requirements for :

- energy conserving/ low viscosity lubricants
- improved engine durability
- reduced emissions
- improved after-treatment device durability

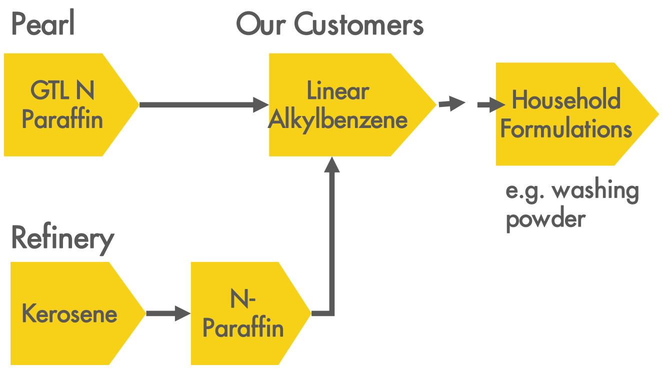
| | Shell G III | Mineral G III |
|---|---|---|
| Vk Kinematic cSt (100°C) - 5.6 to 9.3 | 7.45 | 7.22 |
| Vd Cold Crank m.Pa.s (-35°C) - max. 6200 | 5722 | 6119 |
| Noack % weight | 8.0 | 10.5 |
| Base Oil Viscosity (BoV) cSt (100°C) | 4.59 | 4.45 |

# UNIQUE QUALITIES OF GTL PRODUCTS

## HIGHER VALUE NAPHTHA FEEDSTOCK




## GTL N-PARAFFIN: A COST EFFECTIVE FEEDSTOCK




## GTL Naphtha

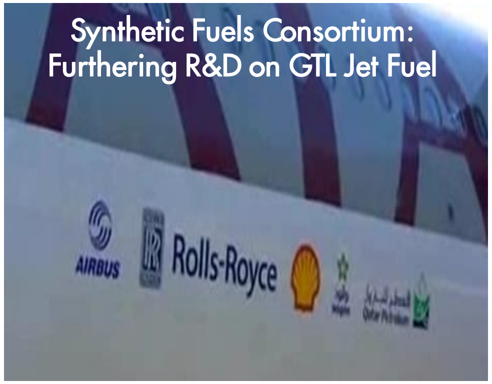
GTL Naphtha is a highly paraffinic premium steam cracker feedstock:

- ➢ Enables feed slate optimization to fully utilize existing hardware

## GTL N-Paraffin

GTL N-Paraffin is a premium feedstock for the production of LAB / LAS, widely used in detergents

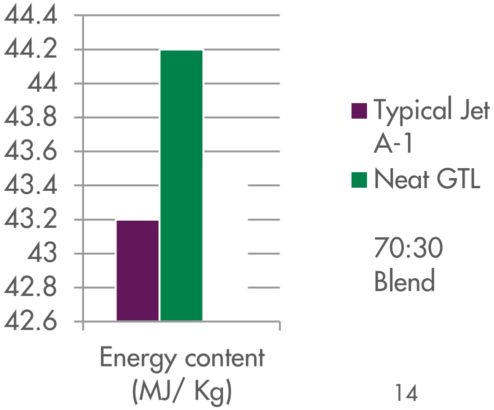
- ➢ More cost effective than from kerosene extraction
- ➢ Allows freedom of location



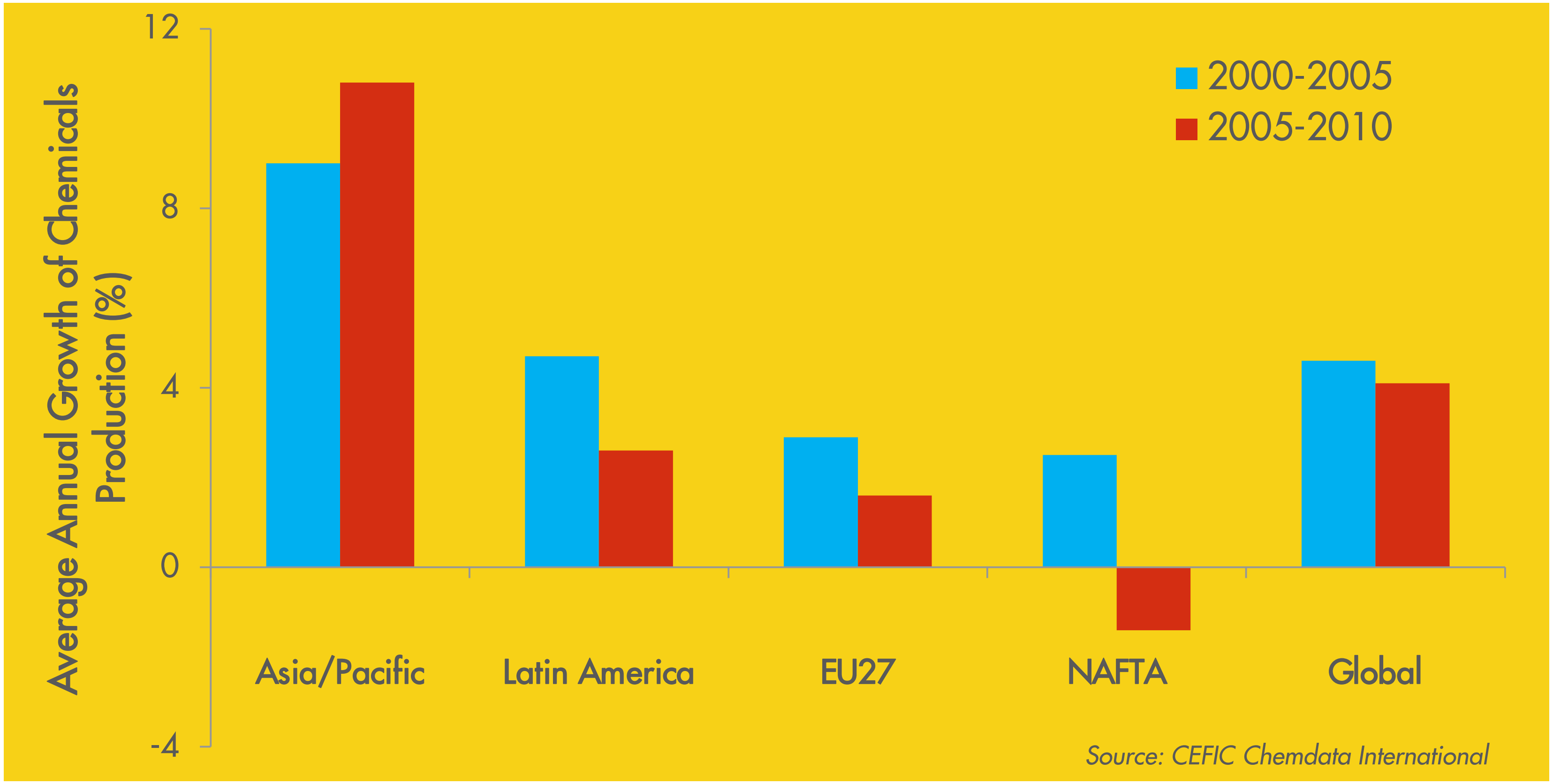

## GTL Kerosene

GTL Jet Fuel is approved for use in commercial aviation, delivering:

- ➢ Lower emissions (Sox, NOx, CO, soot particles)
- ➢ Less smell and smoke
- ➢ Better eco-toxicity
- ➢ Higher take-off load or better fuel economy
- ➢ Better thermal stability and less soot



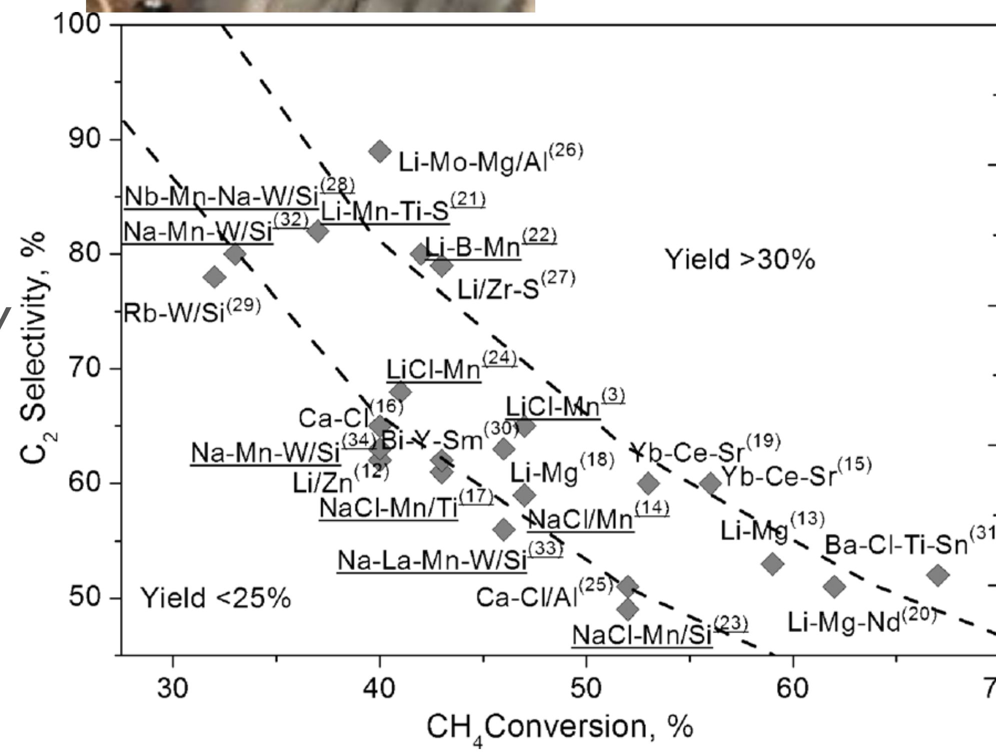
# Average Annual Growth of Chemicals Production (%)



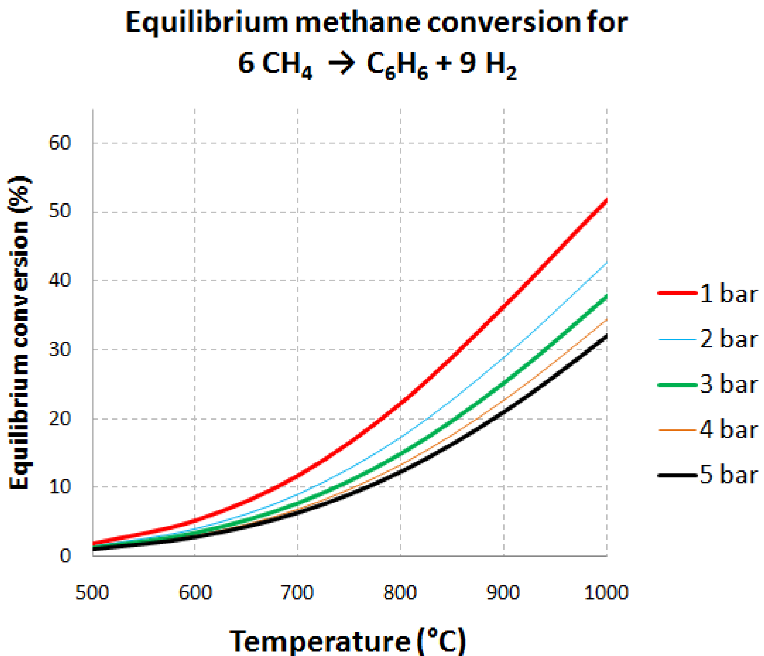

Global average annual chemical production has grown at 1.5 x global energy consumption

# NATURAL GAS-TO-CHEMICALS

- Natural Gas:
  - Affordable-Acceptable-Abundance
- Advantaged feedstock (ref hydrocarbon liquids) for base chemicals
  - Olefins C2= and C3=
  - Aromatics (BTX)
- Alternative C-H activation limited by
  - Reactivity products - Oxidative Coupling
  - Thermodynamics - Methane-to-Benzene



# Methane to Benzene




EMR (3rd Party) Fluidized-bed M2B Testing Rig

Fixed Bed Experimental Results

| T, °C | $CH_4$ Conv*, % w |
|---|---|
| 700 | 11.0 |
| 800 | 23.8 |

* Normalized for Coke. Test Conditions: 100 %v CH4 Feed , Standard M2B Catalyst Pretreatment, GHSV = 1000 h-1, 1 bar, 700-800 deg. C

- Increasing temperature to 800°C increases (doubles) $CH_4$ Conversion
- A Fluidized reactor enables higher operation temperature (short cat cycles)
- Very endothermic ΔH=530 kJ/mole benzene

# Methane to Benzene Program Structure/Activities

Catalyst Development & Experimental Work

STCH M2B R&D

Hazen Research

hte Company EE

Reactor Engineering

CRI Kataleuna

Separations

Process Development

IP

Process Design & Development

Economics Evaluation

Process Integration/ Deployment

Activity Carried out at 4 Locations

# The Future for Molecules in the Energy Supply

## Natural Gas

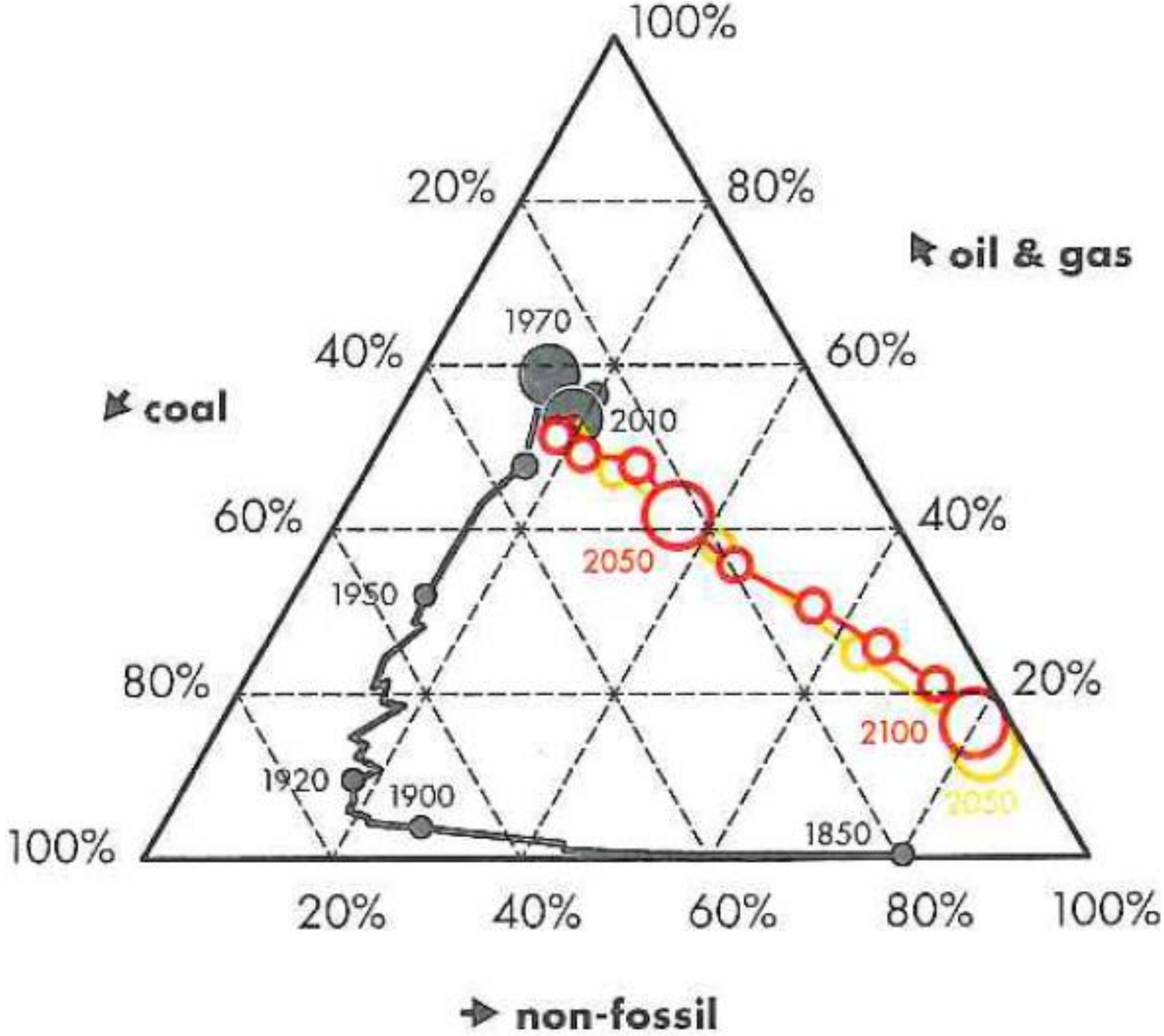
- Transportation Fuel
  - As is (LNG, CNG)
- $CH_4$ activation: no alternative yet for synthesis gas
  - GTL Liquids
- Chemicals: Making C-C bonds from $CH_4$
  - No full conversion routes (except C-products)
  - Limited yield valuable products requires expensive separation & recycles


*Shell Grand Challenges*

**Chemistry & Catalysis :**

Shell needs to continue developing technology that can monetize Natural Gas as a fuel or chemical products and further exploit gas from stranded sources

# Q & A



100%
20%
80%
oil & gas
1970
40%
60%
coal
2010
60%
40%
2050
1950
80%
20%
2100
1920
1900
2050
100%
1850
20%
40%
60%
80%
100%
non-fossil