Key success factors for GTL & technology impact

- Oil to gas price ratio – positive trends due to shale gas technology
  - no real impact on GTL technology selection but improvements will enhance profitability
- Site specific capital costs in offsites and infrastructure are significant
  - tends to drive towards larger scale facilities to get economy of scale
- Intrinsic capital cost based on technology selection is important
- Catalyst cost is important
- Project execution potential impact on capital cost is significant and
  this creates inertia for taking technology steps
- Plant ramp-up and reliability are also important and contribute to
  reluctance to change (unless the change is specifically aimed at
  improved reliability based on lessons learnt)
  - Some important lessons learnt at maximum commercial scale
- Departure point is no negative impact on plant reliability
  - this is achievable with the next generation GTL technology
Key Focus Areas

Utilities

ASU → Reforming → Hydro-carbon Synthesis → Product Upgrading

Natural Gas → Water Treatment

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GTL with Hydrocarbon Synthesis

It has now been more than 10 years since the design basis was set for the first commercial GTL facility using slurry phase reactors. Significant technology developments have occurred - together with reforming unit developments and improved utility system design now classified as a next generation of gas-to-liquids (GTL) technology.

Reactor Intensification

- Increased volumetric conversion efficiency with same reactor shell
- 150% reactor capacity available now

Catalyst Development

- Support
- Cobalt application
- Regeneration – new step at commercial scale

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Regeneration as a Catalyst Management Tool

- Regeneration reduces effective catalyst cost
- Effective catalyst management facilitated by on-line catalyst removal and addition
- Allows the process to remain near the optimal operating point

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Successful Demonstration of Regeneration Process

Lab scale regeneration and synthesis testing (spent commercial samples)

Catalyst age [% of commercial life]

% Recovery

(100-200 kg scale)

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Present Commercial GTL Reforming

- Autothermal reforming (ATR) from Haldor Topsøe is well proven at large capacity

- Highly reliable between planned shut-downs

- Present maximum single train sizes were set by the Air Separation Unit (ASU) but in future 2 or 3 reforming trains using 2 or 3 ASU units will be coupled with 2 larger Hydrocarbon Synthesis units – optimal configuration is selected based on investment and plant operation considerations

- Increased utility system efficiency requires opportunities to use excess steam
Sasol demonstrated features for Haldor Topsøe ATR technology using industrial reformers at Secunda.

Next step is to add heat exchange reforming into the flowsheet.
**Synthesis Gas Generation Improvement**

- Haldor Topsøe Exchange Reforming in series (HTER-s)

<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>HTER-s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant-wide GTL carbon efficiency (%)</td>
<td>73-75</td>
<td>80 +</td>
</tr>
</tbody>
</table>

**Parallel layout**

- Steam
- Natural Gas
- Oxydant

**Series layout**

- Steam
- Natural Gas
- Oxydant

- Increase in synthesis gas capacity from the same O₂ capacity
- Increase in plant-wide carbon efficiency

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**Sasol & Haldor Topsøe: Re-cap of Reforming Technology Advances**

- **Benefits**
  - Low steam to carbon operation (0.6) was a step change in ATR efficiency & capex
  - Necessary in GTL for suitable syngas $H_2:CO$
  - Demonstrated in Secunda.
  - Operating in Sasolburg and ORYX GTL
  - Significant advances in burner design and scale-up

- **HTER-p**
  - Major efficiency improvement retrofit
  - Adds steam reforming without requiring a fuel gas.
  - Commercialized successfully in Secunda.
  - 4x additional units being installed
  - Subsequently used to retrofit methanol and hydrogen plants

- **HTER-s**
  - Next major step-change in reforming technology.
  - Builds on HTER-p technology, but inherently more efficient.
  - Simple mechanical design.
  - Metallurgical challenges are manageable

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Gas Turbine Integration

Brayton Cycle integrated efficiency is between 50% and 60% and is far more efficient than the simple steam Rankine cycle.
Reforming Technology Impact (with utility re-optimization)

Base Case ATR 70 bar steam

HTER-s with ASU drives on 120 bar steam

HTER-s with ASU drives on electricity with non-integrated gas turbines

HTER-s with integrated gas turbine design

Carbon Efficiency

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Further Scale Benefits for GTL

- Ingredients for single ASU supporting up to 40,000 bbl/d GTL capacity
  - New axial-centrifugal compressors potentially also with a gas-turbine driven ASU: enables larger ASU capacity

(From an Air Products presentation)

Further Hydrocarbon Synthesis intensification beyond 24,000 bbl/d is possible (Intrinsic advantage for slurry phase reactors)

- Facility target capacity of 120,000 bbl/d supported by 3 or 4 FT & ASU trains (Currently use 6 ASU trains for 100,000 bbl/d plant)

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Some USA Feasibility Study Results

- The next generation results were compared to present generation technology for a US Gulf Coast site location.

- Various next generation technology options were considered:
  - most benefits from a combination of HTER-s with an integrated gas turbine power block together and Hydrocarbon Synthesis reactor intensification with catalyst regeneration.

- Significant capital cost saving in the hydrocarbon synthesis unit, the heart of the GTL process. 50% scale-up of the downstream product recovery and product work-up units to a nominal capacity of about 50 000 bbl/d still allows single units to be connected to two hydrocarbon synthesis units which gives significant economy of scale. All the associated utility units also benefit from this scale-up.

- The air separation unit (ASU) only requires about 20% scale-up because of the reduced oxygen consumption with HTER-s.
## Carbon Efficiency Improvements

<table>
<thead>
<tr>
<th>Case/Comparison parameter</th>
<th>Present Generation</th>
<th>Next Generation (HTER-s with non-integrated gas turbine)</th>
<th>Next Generation (HTER-s with integrated gas turbine)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility carbon efficiency</td>
<td>73 to 75 %</td>
<td>77.5 to 78.5 %</td>
<td>80.5 to 81.5 %</td>
</tr>
<tr>
<td>Achievable relative improvements in CO₂ emissions</td>
<td>20 %</td>
<td></td>
<td>30%</td>
</tr>
</tbody>
</table>
Conclusions

- The next generation GTL plant design has now reached “ready for commercialization” status
- The improved plant design is more or less Capex neutral on the same capacity basis & significantly more efficient
- Carbon dioxide emissions per unit of product are around 30% lower
- Hydrocarbon synthesis technology improvement has enabled a single train capacity increase of 50% - even more upside potential
- Improved GTL economics (per bbl) due to: lower capital cost & lower operating cost (due to catalyst & efficiency improvements) and/or more product can be made from the available natural gas
- This also comes with about a 10% smaller plot & improved operating flexibility/reliability based on previous learning
- Some new features will be demonstrated in the USA project in a manner which avoids potential negative impact on plant reliability