RTI Warm Syngas Clean Up Technology Demonstration

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RTI Technology Reduces Cost and Improves Efficiency!}

**Value Drivers of RTI Warm Syngas Cleanup Technology**

**RTI热合成气净化技术的驱动力**

**Syngas Cleanup is a Major Cost Driver**

**合成气净化是一个主要的成本来源**

**Efficiency Improvements Reduce All Elements of Cost**

**提高效率可以降低所有的成本**

Graphics Source: Eastman Chemical Co.

**Conversion to clean power, DRI, or chemicals/fuels**

**净化的合成气**

**ASU**

**Cooling Train**

**SRU/TGTU**

**Shift Reactor**

**Coal/Pet Coke**

**Gasification**

**CO2 Compression**

**CO2脱除**

**Sulfur Recovery**

**Sulfur Removal**

**AGR Processes**

**Typical Capital Cost Breakdown**

**2:1 Syngas**
RTI Warm Syngas Cleanup Technology Platform

- Increase efficiency and lower costs 高效率和低成本
- Operate at 250-600°C 工作在250-600°C
- Pressure independent 压力独立
- Effective for all forms of sulfur 对所有形式的硫有效
- Fully compatible with all CO₂ capture 与所有CO₂技术完全兼容

- Flexible modular approach to meet specific syngas purity needs 灵活的模块化方法可满足特定的合成气纯度需求
- Systems tested on actual coal-based syngas 系统已经过实际的煤合成气测试
- Warm desulfurization process (WDP) tested through pre-commercial demo scale 热脱硫工艺 (WDP)通过放大测试
From Lab to Large Scale Demonstration
从实验室到工业放大

**Invention (2001)**
- Proprietary RTI sorbent
- High attrition resistance

**Lab/bench testing (2001-2003)**
- RTI International, NC
- Concept proven & modeled

**Pilot testing (2006-2008)**
- Eastman Chemical Co., TN
- 3000 hr, coal-derived syngas

**Demonstration – Syngas Cleanup & CO$_2$ Capture (2010-2015)**
- Tampa Electric Co., Polk 1 IGCC Plant, FL
- Testing underway, 50-MW$_{equiv}$ scale, coal/petcoke-derived syngas
RTI Desulfurization Sorbent Characteristics

- Supported ZnO-based sorbent 氧化锌负载型吸附剂
  - High attrition resistance (mechanical stability) 高耐磨性（机械稳定）
  - Inert support (chemical stability) 惰性载体（化学稳定）

- Unique highly dispersed ZnO nanostructures 独特的高度分散的氧化锌纳米结构
  - High reactivity (short reactor residence time) 反应活性高（反应器内停留时间短）
  - High sulfur capacity (good operating window) 硫容高（良好的操作性）

- Produced on a commercial scale by Clariant - about 100 tons of sorbent produced to date 至今工业规模的生产约有百吨 (Clariant)

- Covered by extensive US / International patents including several recent improvements 拥有自主知识产权, 包括最近美国和国际专利

- Won 2004 R&D 100 Award

More than 3,000 hours of total syngas operation. Consistent high performance across a wide pressure range.

<table>
<thead>
<tr>
<th>Pressure</th>
<th>20 bar</th>
<th>30 bar</th>
<th>40 bar *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Sulfur Concentration (avg.)</td>
<td>8,700 ppmv</td>
<td>7,000 ppmv</td>
<td>8,400 ppmv</td>
</tr>
<tr>
<td>Effluent Sulfur Concentration (avg.)</td>
<td>5.9 ppmv</td>
<td>10.7 ppmv</td>
<td>5.7 ppmv</td>
</tr>
<tr>
<td>% Total Sulfur Removal (avg.)</td>
<td>99.9%</td>
<td>99.8%</td>
<td>99.9%</td>
</tr>
</tbody>
</table>

Observed attrition rate was lower than commercial FCC catalysts.

* Same pilot unit was tested to 80 bar at ChevronTexaco R&D site with similar (~99.9%) S removal.

Picture Source: Eastman Chemical Company
Demonstrate RTI WDP technology’s ability to reduce capital costs, improve efficiency, and lower carbon footprint for gasification.

Mitigate design and scale-up risks.

Verify capital and operating costs.

Integrate RTI warm syngas cleanup technology with carbon dioxide capture.
Integration of Syngas Cleaning and Carbon Capture Systems at Tampa Site

**Demonstration Project Scope**

- Air Separation
- GE Gasifier (~400 psig)
- Scrubbers
- COS Hydrolysis
- Syngas Cleaning
- aMDEA
- CO₂ Recovery

**Process Flow**

1. Air
2. Oxygen
3. Coal/Petcoke
4. GE Gasifier (~400 psig)
5. Scrubbers
6. COS Hydrolysis
7. Syngas Cleaning
8. aMDEA
9. CO₂ Recovery

**Key Points**

- Currently vented, but could be sequestered or used or recycled.
- Sulfuric Acid Plant
- Acid Gas
- Clean Fuel Gas
- Regenerator Gas

**20% slipstream test (~50 MWₑ) enables direct commercial scale-up from this demonstration scale**
RTI Warm Gas Cleanup (WDP) Demonstration Project Performance

RTI热合成气净化示范工程业绩

- Construction achieved on schedule and under budget
  施工按计划，投资低于预算

- > 500,000 total labor hours with no significant injury
  >500,000小时无明显工伤事故

- Unit performing as expected with >1,200 syngas operation hours
  装置按预期执运行>1200小时

- 99.7-99.9% total sulfur removal from RTI WDP step
  RTI WDP步除去99.7-99.9%的硫

- >99.99% total sulfur removal achieved WDP + aMDEA
  (sub-ppmv levels of total sulfur in cleaned syngas)
  WDP+ aMDEA除硫达到>99.99%
RTI Warm Gas Cleanup (WDP) Demonstration Project Performance

RTI热合成气净化示范工程业绩

- Sorbent attrition rate in line with design expectations
  吸附剂损耗率与设计预期相符

- Sorbent sulfur capacity steady - no sign of deactivation
  吸附剂硫容稳定 - 无失活的迹象

- Successful operation both below and above design rate
  成功运行在低于和高于设计流量

- Demonstration testing continuing through 2015 with goal to achieve > 5,000 total syngas operation hours
  装置验证在2015年继续运行,做到实现>5000小时的总合成气运行时间

- Now seeking suitable partner(s) to help RTI commercially deploy the technology
  RTI现在正在寻求合适的合作伙伴,以协助该技术的全球推广
Demonstration Plant Results: High Total S Removal

工業放大結果：高效脱硫

- Syngas inlet H₂S concentration: 7,500 to 10,800 ppmv
- Syngas inlet COS concentration: 450 to 650 ppmv
RTI WDP is a differentiated warm-temperature, solid-sorbent based syngas cleanup system that simultaneously offers:

- Lower capital costs (up to 30+% less) 较低的资本成本 (省 >30%)
- Lower non-labor, non-feedstock operating costs (up to 40+% less) 较低的非劳动，非原料的运营成本(省 >40%)
- Improved overall process efficiency (up to 10+% better) 提高了整体流程效率 (好 >10%)
- Improved process flexibility by decoupling sulfur removal and carbon dioxide capture 通过分离脱硫和除二氧化碳，提高了流程灵活性
- A capable economic syngas cleanup option for all applications 适合所有应用
**RTI WDP Technology Can Expand Markets for Conventional AGR**

**RTI WDP技术可以扩展传统的AGR市场**

<table>
<thead>
<tr>
<th>Typical/Suitable Applications</th>
<th>Amines</th>
<th>Selexol®</th>
<th>Rectisol®</th>
<th>RTI WDP + CC (e.g., aMDEA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGCC (without CC)</td>
<td>✔️</td>
<td>✔️</td>
<td>✗</td>
<td>✔️</td>
</tr>
<tr>
<td>IGCC (with CC)</td>
<td>✔️</td>
<td>✔️</td>
<td>✗</td>
<td>✔️</td>
</tr>
<tr>
<td>H₂ or NH₃/Urea</td>
<td>✗</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Chemicals (e.g., MeOH, F-T, SNG)</td>
<td>✗</td>
<td>✗</td>
<td>✔️</td>
<td>✔️</td>
</tr>
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RTI WDP + aMDEA works economically across the whole spectrum of applications

* CC = Carbon dioxide capture
Methanol Techno-Economic Analysis Results: 甲醇技术经济分析结果:

Gasification Size: Two 300-MW$_{equiv}$ Shell-type solids-fed gasifiers with Shenhua Mix coal feed
Base Case: Sour WGS + Syngas Cooling + Rectisol$^\circledR$ + Claus/SCOT$^\circledR$ Sulfur Recovery Unit (SRU)
RTI Case: RTI WDP + Sweet WGS + Syngas Cooling + aMDEA + Modified Claus/BELCO$^\circledR$ SRU

[Capital costs (capex) and operating costs (opex) indexed to 100% for Rectisol$^\circledR$ base case]

Cost savings indicated are across the entire block from raw warm syngas exiting the gasifier block through cleaned syngas feed to the methanol conversion step, including the sulfur recovery unit.

投入资金节约 Capex Savings 30+% 运营节约 Opex Savings 40+%
RTI’s warm syngas cleanup technology offers opportunities to both improve efficiency and significantly reduce capex/opex costs of gasification for power generation and chemicals/fuels. RTI的热合成气净化技术的高效率，明显低的资本和运营成本等优点为发电，化工产品和燃料生产提供了机会.

RTI’s WDP has potential to integrate with most CO₂ capture technologies (e.g., amines, Selexol®, Rectisol®, sorbents) to enable them to meet syngas purities for chemicals/fuels. RTI的WDP有潜力与大多数除二氧化碳技术整合(如胺,Selexol®,Rectisol®,吸附剂), 使生产的合成气纯度能够满足化学品/燃料的合成要求.

RTI WDP has been integrated with an aMDEA system for carbon capture and total sulfur levels dropped to sub-ppmv (>99.99% total S removal), performance levels needed for many chemicals/fuels applications. RTI WDP已与aMDEA系统整合用于除二氧化碳, 整合的结果使总硫含量降至低于ppm 水平 (>99.99%全硫去除), 能够满足化学品/燃料的合成要求.

RTI WDP technology performance has been consistently proven at lab, bench, pilot plant, and now pre-commercial demonstration scales. RTI的WDP技术性能已经在实验室, 中试, 放大中证实.

The RTI WDP demonstration plant is expected to run through at least the end of 2015, and will provide critical data and information to support rapid full-scale commercial deployment. 预计RTI的WDP放大测试至少运行到2015年底，在这期间它将提供关键的数据和信息，以支持快速全面商用部署.

RTI is now seeking a suitable partner(s) to assist in global deployment of the technology. RTI现在正在寻求合适的合作伙伴, 以协助该技术的全球推广.
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  - Clariant
QUESTIONS?

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