Optimal Construction and Operation of the GCC Regional Natural Gas and Electricity Production and Transmission Systems

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Why Model Natural Gas Systems?

1. To quantify benefits
2. Provide decision support to policy makers
3. Determine least cost or maximum profit
4. Prioritize new construction projects
5. Determine most economically or operationally the most efficient system
6. Avoid weak or unreasonable investments
Why Propose GCC Gas Modeling?

- Major natural gas projects in the GCC region
- Provide analytical long-term planning tools
- Establish gas planning teams within the region
- Integrate a regional gas model with a regional electricity model
- Collaborative planning initiatives with Purdue
- Economic analysis of a regional system beyond the GCC
57% Of The GCC Electricity Generation Uses Natural Gas.
# Gulf Natural Gas Reserves

In the GCC, January 1, 2000

<table>
<thead>
<tr>
<th>Country</th>
<th>Natural Gas (Trillion Cubic Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bahrain</td>
<td>4</td>
</tr>
<tr>
<td>Kuwait</td>
<td>55</td>
</tr>
<tr>
<td>Oman</td>
<td>29</td>
</tr>
<tr>
<td>Qatar</td>
<td>347</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>206</td>
</tr>
<tr>
<td>UAE</td>
<td>211</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>852</strong></td>
</tr>
</tbody>
</table>
Topology of the gas model

Key: Square = Gas Source, Circle = City, Triangle = Power Station
Diamond = Storage Site, Links = Pipelines,
Directed Links = Uni-directional pipeline, Undirected Links = Bi-directional pipeline
Flow from a Gas Source

- **GFSC**\(_{ty, tm, z, gi, gj}\) to city \(gj\)
- **GFST**\(_{ty, tm, z, gi, gk}\) to storage \(gk\)
- **GFSTN**\(_{ty, tm, z, gi, gkn}\) to new storage \(gkn\)
- **GFSD**\(_{ty, tm, z, gi, gd}\) to export \(gd\)
- **GFSP**\(_{ty, tm, z, gi, ni}\) to power plant \(ni\)
Flow of gas out of a gas source is balanced using the following constraint

\[ GP_{ty,tm,z,gi} = \sum_{gj} GFSC_{ty,tm,z,gi,gj} + \sum_{gk} GFST_{ty,tm,z,gi,gk} + \sum_{gd} GFSD_{ty,tm,z,gi,gd} + \sum_{ni} GFSP_{ty,tm,z,gi,ni} + \sum_{gkn} GFSTN_{ty,tm,z,gi,gkn} , \forall ty, tm, z, gi. \]
The gas production capacity constraint is given by:

\[ \text{GP}_{ty,tm,z,gi} \leq \text{GP}_{\text{MAX}}_{z,gi}, \forall ty, tm, z, gi. \]

Like the existing gas sources, new gas sources have balance and capacity requirements. The gas flow from a new gas source is balanced by:

\[
\begin{align*}
\text{GPN}_{ty,tm,z,gin} &= \sum_{gj} \text{GFSNC}_{ty,tm,z,gin,gj} + \sum_{gk} \text{GFSNT}_{ty,tm,z,gin,gk} + \sum_{gd} \text{GFSND}_{ty,tm,z,gin,gd} \\
+ &\sum_{ni} \text{GFSNP}_{ty,tm,z,gin,ni} + \sum_{gkn} \text{GFSNTN}_{ty,tm,z,gin,gkn}, \forall ty, tm, z, gin.
\end{align*}
\]

The gas production capacity constraint for a new gas source is given by:

\[
\text{GPN}_{ty,tm,z,gin} \leq \text{GPMAX}_{N_{z,gin}} \cdot \sum_{\tau=1}^{ty} \text{GSNINV}_{\tau,z,gin}, \forall ty, tm, z, gin
\]
Gas Storage Tank Injection and Withdrawal
Pipelines Entering & Leaving A City.

From source $gi$  
GFSC$_{ty,tm,z,gi,gj}$

From new source $gin$  
GFSNC$_{ty,tm,z,gin,gj}$

From storage $gk$  
GFTC$_{ty,tm,z,gk,gj}$

From new storage $gkn$  
GFTNC$_{ty,tm,z,gkn,gj}$

From import $ge$  
GFEC$_{ty,tm,z,ge,gj}$

From plant $ni$  
GFPC$_{ty,tm,z,ni,gj}$

From city $gjp$  
GFCC$_{ty,tm,z,gjp,gj}$

GFCD$_{ty,tm,z,gj,gd}$  To export $gd$

GFCC$_{ty,tm,z,gj,gjp}$  To city $gjp$

GFCP$_{ty,tm,z,gj,ni}$  To plant $ni$

GFCT$_{ty,tm,z,gj,gk}$  To storage $gk$

GFCTN$_{ty,tm,z,gj,gkn}$  To new storage $gkn$
Gas Flow Entering and Leaving A Power Station

From storage \( g_k \)
- \( \text{GFTP}_{ty,tm,z,gk,ni} \)

From new storage \( g_{kn} \)
- \( \text{GFTNP}_{ty,tm,z,gkn,ni} \)

From source \( g_i \)
- \( \text{GFSP}_{ty,tm,z,gi,ni} \)

From new source \( g_{in} \)
- \( \text{GFSNP}_{ty,tm,z,gin,ni} \)

From import \( g_e \)
- \( \text{GFEP}_{ty,tm,z,ge,ni} \)

From city \( g_j \)
- \( \text{GFCP}_{ty,tm,z,gj,ni} \)

From plant \( n_ip \)
- \( \text{GFPP}_{ty,tm,z,nip,ni} \)

\( \text{GFPD}_{ty,tm,z,ni,gd} \) To export \( g_d \)

\( \text{GFPT}_{ty,tm,z,ni,gi} \) To storage \( g_k \)

\( \text{GFPTN}_{ty,tm,z,ni,gkn} \) To new storage \( g_{kn} \)

\( \text{GFPC}_{ty,tm,z,ni,gj} \) To city \( g_j \)

\( \text{GFPP}_{ty,tm,z,ni,nip} \) To plant \( n_ip \)
Next Steps

1. Interface gas model with Purdue long-term electricity regional model
2. GCC ~ Middle East data collection
3. Demonstrate benefits of greater regional integration
4. Establish collaborative project within region