Energy Payback Ratio and CO$_2$ Emission Associated with Electricity Generation from a Natural Gas Power Plant – Preliminary Findings

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Objective: Net Energy Analysis of electricity generation using a modern natural gas power plant, and development of a Greenhouse Gas Emission Factor for the lifecycle of the system.

Net Energy Analysis:
• A comparison of the useful energy output of a system, with the total input energy consumed by the system in order to produce useful energy.
• Expressed quantitatively as an Energy Payback Ratio (EPR) which can be compared to alternative technologies.

Greenhouse Gas Emission Factor:
• Expressed in terms of tonnes CO₂ emitted per GW-hour electricity produced.
• Can be compared to alternative technologies.

Lifecycle:
• “Birth to Death” of a system including fuel procurement and transportation, plant structural materials and construction, operation, and decommissioning.
REFERENCE NATURAL GAS PLANT

Operating Assumptions:
Gas Turbine ($\eta = 50\%$)
Plant Capacity = 80%

Gross Electrical Power Output: 450 MW$_e$ total from 3 turbines
Annual Electrical Energy Output: 11,352,960 GJ$_e$ (3,153 GW$_e$h)
Annual Natural Gas Input = 22,705,920 GJ$_{th}$ (6 x 10$^8$ m$^3$*)

*1020 BTU/ft$^3$ (38 MJ/m$^3$)

Advanced Gas Turbine

Compressor

Gas Turbine

Combustion System
NET ENERGY ANALYSIS
NATURAL GAS TURBINE ELECTRICITY GENERATION

ENERGY PAYBACK RATIO = \frac{\text{ENERGY OUTPUT}}{\sum \text{ENERGY INPUTs}}
FUEL RELATED AMORTIZATION PROCEDURE
“Paying for the Pipeline”

Reference Plant Fraction:

Reference Plant Fuel Consumption:
6.10 x 10^8 m³/year

Total US Pipeline Natural Gas Delivered*:
5.35 x 10^{11} m³/year

*EIA-0131(97): 1997, Excludes Exports, Imports, & Additions to Storage

Reference Plant Fraction:

6.10 x 10^8 / 5.35 x 10^{11} = 0.114%

Example Calculation for Energy Associated with Natural Gas Pipeline:

\[
\text{Energy Embodied in U.S. Natural Gas Pipeline} \times \frac{1}{30 \text{ years}} \times \text{Ref. Plant Fraction (0.114\%)} = \text{Energy Embodied per year in Pipeline Allocated to Reference Plant}
\]
FUEL RELATED ENERGY INPUTS TO REFERENCE NATURAL GAS PLANT
(includes exploration, production, processing, transmission, etc.)

Materials
- Drilling equipment, wells, processing equipment, pipeline, compressors, measuring and regulating equipment, housing

Labor
- Installation
- Engineering & Administration
- Operation & Maintenance

Fuel
- Natural gas used for drilling, heating, dehydrators, field & transmission compressors
Maximum Energy Payback Ratio (EPR) for natural gas is limited by the fuel used in production, processing, & transmission.

Natural Gas Reservoir
100 Energy Units Natural Gas

Production, Processing, & Transmission consumes
10 Energy Units of Natural Gas*
*Source EIA, 1987-97 Avg

90 Energy Units Natural Gas Delivered to Plant

50% Thermally Efficient Plant

45 Energy Units discharged to environment as waste heat

45 Units of Energy Produced as Electricity

Maximum EPR* = \(
\frac{45}{10} = 4.5
\)

*Accounting for fuel consumed in production, processing and transmission, and plant efficiency only.
# ENERGY INPUT DATA TABLE

## Input (GJ) per Year of Reference Plant Operation

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>GJ\textsubscript{th} / Calendar Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Production Equipment (Installed)</td>
<td>6,889</td>
</tr>
<tr>
<td>Natural Gas Production O&amp;M - Fuel</td>
<td>1,424,632</td>
</tr>
<tr>
<td>Natural Gas Production O&amp;M - Labor</td>
<td>7,417</td>
</tr>
<tr>
<td>Natural Gas Storage and Processing Equipment (Installed)</td>
<td>19,652</td>
</tr>
<tr>
<td>Natural Gas Storage and Processing O&amp;M - Fuel</td>
<td>Included with Production</td>
</tr>
<tr>
<td>Natural Gas Storage and Processing O&amp;M - Labor</td>
<td>32,205</td>
</tr>
<tr>
<td>Natural Gas Transmission Equipment (Installed)</td>
<td>92,574</td>
</tr>
<tr>
<td>Natural Gas Transmission Production O&amp;M - Fuel</td>
<td>917,471</td>
</tr>
<tr>
<td>Natural Gas Transmission Production O&amp;M - Labor</td>
<td>14,897</td>
</tr>
<tr>
<td>Power Plant Materials*</td>
<td>11,205</td>
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<tr>
<td>Power Plant Construction*</td>
<td>18,556</td>
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<tr>
<td>Power Plant Operation</td>
<td>211,750</td>
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<tr>
<td>Power Plant Decommission*</td>
<td>5,047</td>
</tr>
<tr>
<td>Land Reclamation</td>
<td>111</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>Preliminary 2,798,780</strong></td>
</tr>
</tbody>
</table>

*Scaled from 1GW Coal Plant*
Normalized Net Energy Investment in
Natural Gas Electrical Power Plant - Preliminary

<table>
<thead>
<tr>
<th>Component</th>
<th>TJ$<em>{th}$/GW$</em>{e,y}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Related</td>
<td>6,990</td>
</tr>
<tr>
<td>Construction &amp; Materials</td>
<td>147</td>
</tr>
<tr>
<td>Operation</td>
<td>588</td>
</tr>
<tr>
<td>Decommission</td>
<td>12</td>
</tr>
</tbody>
</table>
Normalized Energy Investment Comparison*

** Previous Work by: S. White, University of Wisconsin

** Wind analysis excludes storage
Preliminary Energy Payback Ratio
for Reference Natural Gas Power Plant

Reference Plant Inputs
(GJ\textsubscript{th} per calendar year of operation)

Fuel Related: 2,516,000
Construction & Materials: 66,100
Operation: 212,000
Decommission: 5,160
Total: 2,800,000

Reference Plant Output
(GJ\textsubscript{e} per calendar year of operation)

Net Electrical Output: 11,350,000

\[
\text{ENERGY PAYBACK RATIO} = \frac{11,350,000 \text{ GJ}_{\text{e}}/\text{year}}{2,800,000 \text{ GJ}_{\text{th}}/\text{year}} = 4.06
\]
Energy Payback Ratio
Comparison to Previous Work*

*Previous Work by: S. White, University of Wisconsin
Greenhouse Gas Emissions
Tonne CO₂-equivalent / GWₑh - Preliminary

- **CH₄ - Methane (Excludes Methane Leaks):** 376
- **Fuel Related:** 77
- **Materials & Construction:** 1.3
- **Decommission:** 0.1
Greenhouse Gas Emission Comparison

(Tonne CO$_2$-equivalent / GW$_{eh}$)

Coal data from S. White, University of Wisconsin

- Natural Gas (Preliminary): 454 Tonne equiv. / GW$_{eh}$
- Coal: 974 Tonne equiv. / GW$_{eh}$
- Fission: 17 Tonne equiv. / GW$_{eh}$
- Fusion: 8 Tonne equiv. / GW$_{eh}$
- Wind: 23 Tonne equiv. / GW$_{eh}$

Coal, Fission, Fusion, Wind data from S. White, University of Wisconsin
Conclusions

• The Energy Payback Ratio for Natural Gas Power Plants is low (4) compared to alternative technologies (11-26).

• The EPR is limited by the use of large quantities of natural gas in the production, processing, and transmission phases of the fuel cycle.

• Our preliminary analysis shows the greenhouse gas emissions (GGE) from natural gas to be 46% of those generated from coal.

• A Recent DOE study* reported GGE from modern gas turbines to be 35-44% of those from conventional coal. Our estimate is slightly above this range, due to the lifecycle analysis of the systems.

*SR/OIAF/98-03