Economics Of Steam Generation For Thermal EOR

Highlights from SPE Paper 172004

More than 70% of the world’s remaining oil resources are classified as “heavy oil,” requiring Enhanced Oil Recovery techniques (EOR) to produce. Thermal methods, such as steam injection, represent the majority of global EOR production. The steam generated for thermal EOR consumes 1.7 trillion cubic feet (TCF) of natural gas per year, and this is expected to rise significantly over the next decade as more heavy oil fields are developed. In the Gulf region, projects underway in Oman, Kuwait and the Neutral Zone will represent some of the largest steam flood projects worldwide. With natural gas becoming increasingly constrained and expensive, there is a need to better understand the true economics of steam generation.

Detailed performance and economic models of generating steam were used to calculate the Levelized Cost of Energy (LCOE) and the Fuel Break Even (FBE) price of three steam generation technologies deployed today at Gulf oilfields.

Research found that Solar Steam Generators (SSG) delivered the lowest-cost steam when compared to once-through steam generators (OTSG) and “fully burdened” cogeneration using once-through heat recovery steam generators (OT-HRSG) at the marginal fuel price.

Steam Generators for Thermal EOR

OTSG
Once-Through Steam Generator
Burns fuel, typically natural gas, to generate steam

**PROS**
- Low capital cost per ton of steam produced
- Short construction time
- Flexible and controllable steam output

**CONS**
- Highly dependent on fuel supply and costs
- Releases greenhouse gas emissions

OT-HRSG
Once-Through Heat Recovery Steam Generator
Cogeneration - uses “waste heat” generated from a gas-fired power plant to produce steam

**PROS**
- Low capital cost per ton of steam produced
- Increases system efficiency

**CONS**
- Steam produced linked directly to power capacity
- Indirectly consumes gas
- Duct burning dependent on fuel price
- Releases greenhouse gas emissions

SSG
Solar Steam Generator
Uses concentrated sunlight to generate steam

**PROS**
- Does not consume fuel
- Does not produce greenhouse gas emissions
- Can extend field life

**CONS**
- High capital cost
- Dependent on weather
- High land footprint

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What is the cost of fuel?
Despite experiencing fuel supply shortages, many countries in the Gulf have multi-tiered and subsidized fuel costs, which do not reflect the true economic value.

To expand heavy oil production, these countries will need to import LNG at $13 per MMBtu, not only to fuel EOR projects, but also for power generation and industrialization.

This study considers two fuel prices $6 and $13 per MMBtu.

Levelized Cost of Energy of Steam Produced
The Levelized Cost of Energy (LCOE) represents the cost of building and operating a steam generator over its lifetime. LCOE is a key metric in comparing the real cost of producing steam from different generation technologies.

\[
\text{LCOE}_{\text{real}} = \frac{\text{NPV} (\text{Total Cost Of Ownership})}{\text{NPV} (\text{Total Energy Produced})} \times \frac{\text{nominal discount rate}}{\text{real discount rate}}
\]

The Total Cost Of Ownership includes the capital and operating costs, fuel cost, as well as the cost of economic and environmental burdens.

LCOE Comparison for Steam Generation

The economic burden considered for the OT-HRSG is the opportunity cost of the “waste heat” from the gas-turbine exhaust. The decision maker may assume that waste heat into the OT-HRSG is free. This is not accurate. In reality, the OT-HRSG is dependent on the price of natural gas by its direct connection to power generation. The waste heat has an economic value that is equal to the opportunity cost of producing more power and water in an optimized plant configuration. No economic burdens were applied to the OTSG.

An environmental burden for producing greenhouse gas emissions was applied to the OTSG and the OT-HRSG. A carbon cost of $40 per ton/CO₂ was calculated based on the range of internal carbon prices used by the oil majors.

The analysis shows that at a fuel price of $6 per MMBtu, solar steam generators deliver lower cost steam than fully burdened OTSG and OT-HRSG.

The Fuel Break Even Price (FBE)
The Fuel Break Even (FBE) price is a useful economic indicator that allows a decision maker to compare the economics of various methods of steam generation based on the marginal cost of fuel.

This fuel price is where the total cost of ownership from the fuel-fired steam generation method (either OTSG or OT-HRSG) is equal to that of using solar energy.

The FBE analysis shows that for fuel prices above $2.25 per MMBtu, solar steam generators produce lower cost steam than environmentally burdened OTSGs. When cogeneration is compared to solar steam generators, the FBE when fully burdened is $4.50 per MMBtu.

Fuel Break Even Summary

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>FBE ($/MMBtu)</th>
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</thead>
<tbody>
<tr>
<td>SSG v. OTSG</td>
<td>4.95</td>
</tr>
<tr>
<td>SSG v. OT-HRSG</td>
<td>7.70</td>
</tr>
<tr>
<td>Unburdened</td>
<td>2.25</td>
</tr>
<tr>
<td>w. Power Opp. Cost</td>
<td>4.90</td>
</tr>
<tr>
<td>+ Carbon Cost</td>
<td>4.50</td>
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<tr>
<td>+ Water Opp. Cost</td>
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Solar steam for EOR is cost-competitive with fuel-fired alternatives at a gas price of $6 per MMBtu.

Conclusions
Thermal EOR is an effective method for producing heavy oil fields, but the consumption of fuel is a serious problem. Steam generation projects in Gulf oilfields are on such a large scale that they affect an entire country’s economic position. The field development may entail steam injection for many decades. Thus the power and gas requirements have an important impact at a national level.

- The economic evaluation of steam generation must include all economic and environmental burdens.
- Solar Steam Generators produce the lowest cost steam when compared to alternatives dependent on fuel supply with environmental and economic burdens.
- Governments and national oil companies must consider the macro-economic implications of steam generation, including the true fuel cost and the future impact of gas consumption.

Download the full SPE paper from One Petro for detailed analysis on the performance models and other assumptions.