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One major barrier for clean coal gasification technologies being implemented into conventional energy sectors has been the perception that a large capital investment is required to move away from a natural gas or oil feedstock to a solid feedstock such as coal or biomass, and the conversion thereof. Historically, this has marginally been the case in some places where gasification projects have been implemented to “fuel” chemical, power, fertilizer, and other energy projects. However, projects that can take advantage of the optimal “integration” of gasification and downstream processing technologies and maximize capital effectiveness and efficiency can reap great benefits from gasification technologies. In cases where the lowest cost feedstocks can be used and feedstock flexibility is maximized, again without overspending capital, the projects’ return on investment can be further enhanced.

During the last few decades, many well-established gasification companies have attempted to improve integration with downstream technologies, yielding mixed results. In some instances, the optimized plant configuration resulted in significant cost savings—giving the project a reduced cost of production for its end product. In other instances, the integration was so complex that significant additional capital was required to realize such optimization and the technical difficulties encountered during startup and operation had a negative impact on the project and its economic performance.

Synthesis Energy Systems (SES) has developed, demonstrated, and deployed its advanced fluidized bed SES Gasification Technology, which is able to cleanly convert low-grade, low-cost coal, coal wastes, and biomass into multiple high-value end products without the same level of capital investment required for most gasification projects. Based on the fuel flexibility and lower upfront costs, SES’ fluidized bed gasification technology has been breaking barriers to enter markets previously not considered feasible for smaller-scale gasification projects. The products at such facilities include direct reduced iron steel, transportation fuels, chemicals, fertilizers, coal-derived synthetic natural gas, and power generation—the one market segment where it has been most difficult for gasification to succeed economically.

“Fluidized bed gasification technology has been breaking barriers to enter markets previously not considered feasible for smaller-scale gasification projects.”

HISTORICAL IGCC IMPLEMENTATION

The first integrated gasification combined-cycle (IGCC) facility using coal as feedstock was constructed in the early 1980s in California using General Electric (formerly Texaco) gasification technology in combination with GE’s heavy-duty gas turbines. It was funded partially by the U.S. Department of Energy as a proof-of-concept. At the time of project initiation, the 1970s oil crisis was in full swing, and there was a mandate from the U.S. government to develop homegrown technologies to replace dependence on imported energy sources, especially oil, in an environmentally friendly manner.

Under the Cool Water Coal Gasification Program, an IGCC plant was constructed in Southern California and operated from 1984 to 1989 on four types of bituminous coals using...
have a narrow feedstock quality capability, and allow limited
expensive, high-quality bituminous and sub-bituminous coals,
flow gasification technologies, which require the use of
commercially operating IGCC plants, is the use of entrained
Common to all of the plants listed above, and most of the other
plants were constructed, including:
• Wabash River Coal Gasification Repower Project (1995),
  Indiana – CB&I
• Polk Power Station IGCC Plant (1996), Florida – GE
• Willem-Alexander IGCC Plant (1998), Buggenum, Nether-
  lands – Shell
• ELCOGAS IGCC Plant (1998), Puertollano, Spain – Uhde
  (PRENFLÒTM)
• Duke Edwardsport IGCC Plant (2013), Indiana – GE

During the next two decades, several more commercial-scale
IGCC plants were constructed, including:

“In regions where solid feedstocks
are available, and gas and oil
resources are scarce and expensive,
syngas generated from solid
fuel gasification can enable the
economical production of chemical
and energy products…”

The previously listed large-scale power-producing gasifica-
tions highlight that there is progress being made and
sufficient market drivers to advance the deployment of IGCC.
However, in some less affluent areas, multi-billion dollar capi-
tal investments and reliable access to low-ash coal may not be
practical or feasible. Therefore, we believe that smaller, less
capital intensive, and more fuel-flexible gasification facilities
can serve an important role, often in places where gasification
is needed most—developing countries with access to low-rank
coal or other solid feedstocks, but limited financial resources.

TRANSFORMATIVE TECHNOLOGY

SES licenses its proprietary fluidized bed gasification technol-
ogy into markets where high-value products, conventionally
produced from natural gas and oil, can be produced from
synthesis gas (syngas) via coal, coal wastes, biomass, and
other waste materials. In regions where solid feedstocks are
available, and gas and oil resources are scarce and expensive,
syngas generated from solid fuel gasification can enable the
economical production of chemical and energy products such
as methanol and its derivatives, fertilizers, electricity, hydro-
gen for refining, transportation fuels such as gasoline and
diesel, substitute natural gas (SNG), reducing gas for metals
refining, and fuel gases. SES’ gasification technology, which
has over 40 years of development behind it, is well suited for a
wide range of carbonaceous feedstocks, including the lowest
cost, lowest quality options available. Over the last decade,
SES has implemented and enhanced the gasification system
design from the original U-GAS® technology, developed by the
Gas Technology Institute in Chicago, Illinois.

The SES Gasification Technology includes a dry-feed system
with multiple feed ports, using oxygen, enriched air, or air as
the oxidant, into a single reactor that operates under a bub-
bling-bed fluidization regime. A bubbling bed reactor has a
forgiving operating envelope; the large volume of feedstock in
the gasifier as compared to the feed rate allows the operation
of the gasifier to have reduced sensitivity to feedstock fluc-
tuations and other operating parameter changes. The gasifier
operates with uniform bulk reactor temperatures, which pre-
vents the formation of tars and oils. The syngas leaves the top
of the gasifier through a series of cyclones, which remove the
particulate matter and return it to the gasifier for additional

high-purity oxygen. The plant released just a fraction of
the permitted air-quality-related emissions at the time and
achieved about 90% reliability—exceeding the benchmark
set by conventional coal power generation technologies. Ac-
According to the final report issued by the Electric Power
Research Institute (EPRI), a participant in the program, the
project accomplished the demonstration of low SO₂, NOₓ, and
particulate emissions. No solid waste was generated due to
sulfur removal, the capital and electricity costs were competi-
tive, and feedstock flexibility was achieved. Actual installed
costs for the 93-MW plant were $315.2MM ($3387/kW). EPRI
found that the installation cost of a “mature technology” Cool
Water plant could be as low as $1567/kW, which became the
target for future IGCC plants in the U.S. Although the project
was deemed to be fuel flexible, the coals gasified at the plant
were within 4% of the plant’s designed coal heat content of
11,300 BTU/kWh, which was actually a very narrow feedstock
window.
conversion. The ash is removed through the bottom of the gasifier where it is cooled and depressurized for ease of handling. After the first set of cyclones, the hot syngas is used to raise superheated medium-pressure steam, which is then used as a primary fluidizing media in the gasifier along with the oxidant. The syngas is then further scrubbed to remove any remaining particulate matter before it is ready for additional downstream processing into a multitude of potential energy and chemical products (see Figure 1).

Fluidized beds are cost effective to build and operate reliably, which is why the SES Gasification Technology leads to lower capital investment, lower operating costs, and higher plant availability (compared to other commercialized gasification technologies). Fluidized bed gasification systems have simpler equipment designs, reduced oxidant usage, and increased fuel and operational flexibility that include on-stream fuel switching and gasifier turndown capabilities to 30% of the designed syngas production rates. Additionally, the SES Gasification Technology offers minimal wastewater discharge as compared to many other gasification technologies through the use of dry solids handling processes, and no generation of tars and oils from coal gasification, which can be extremely costly to clean from syngas.

Perhaps one of the most important attributes of the SES Gasification Technology is that it is fuel-flexible—capable of gasifying all ranks of coal, coal wastes, and other solid fuels, thus allowing its end users to secure the lowest cost feedstock for their operations, and further lower the cost of production of the valuable chemical and energy products (see Table 1).

**PAIRING SES GASIFICATION TECHNOLOGY WITH GE’S POWER GENERATION TECHNOLOGY**

In early 2013, SES and GE’s aero-derivative gas turbine group began co-marketing a small- to medium- scale, standardized design, cleaner coal gasification plant for the distributed power market (<300 MW). This plant design is intended to have numerous economic, environmental, and societal advantages.

Chief among the benefits is that the plant enables customers to use the lowest quality, and thereby lowest cost, coals and has the ability to switch coal feedstocks with no plant modifications. It optimizes “reuse” of plant design through use of fuel-flexible gasification technology: The wider the fuel envelope for the gasifiers with little to no impact on the equipment design, the greater the reuse of plant design will be. The plant’s modular design standardizes on 90% of the plant, allowing for modifications only in packaged process units (like air separation) or in coal handling units to accommodate different ash content requirements. Staying smaller and standardizing on a nonutility-scale basis widens the market to distributed power and captive power users like mining operations and stand-alone chemical or refinery applications. The plant also implements World Bank environmental standards into the base design with allowances for modifications to improve on the environmental performance if local permitting mandates it.

Additionally, the new plant design limits the complexity of integration and avoids the temptation to over-optimize and thus drive up project costs; the simple design also allows for utilization of regional partners. Partnering with local EPC

![FIGURE 1. SES Gasification Technology based on a fluidized bed gasifier](image)

**TABLE 1. Range of fuel characteristics tested with SES Gasification Technology**

<table>
<thead>
<tr>
<th>SES Gasification Technology Fuel Flexibility</th>
<th>Tested Range</th>
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</thead>
<tbody>
<tr>
<td>Moisture, wt%</td>
<td>1–41</td>
</tr>
<tr>
<td>Volatile Matter, wt%</td>
<td>3–69</td>
</tr>
<tr>
<td>Fixed Carbon, wt%</td>
<td>6–83</td>
</tr>
<tr>
<td>Sulfur, wt%</td>
<td>0.2–4.6</td>
</tr>
<tr>
<td>Free Swelling Index</td>
<td>0–8</td>
</tr>
<tr>
<td>Ash Content, wt%</td>
<td>&lt;1–55%</td>
</tr>
<tr>
<td>Ash Fusion T, °C (initial deformation T1)</td>
<td>1030–1370</td>
</tr>
<tr>
<td>Heating Value, kcal/kg</td>
<td>3000–7800</td>
</tr>
</tbody>
</table>
contractors and power project developers also improves the likelihood of project success. Today, SES and GE are marketing to regions where large utility-scale plants are not feasible due to lack of grid infrastructure, natural gas is nonexistent or prohibitively expensive, low-quality local coal is unusable in conventional boilers, and/or power is generated from expensive imported LNG or fuel oil/diesel.

INTEGRATION WITH A LITTLE “I”

Whereas previously designed and constructed IGCC plants placed significant focus on maximizing integration with the intent to maximize plant efficiency, SES and GE have taken a different approach on a small- to medium-scale SES Gasification Technology-based power plant design. By limiting and prioritizing the integration of the gasification and power production technologies, the design lends itself to lower capital costs and simplicity with a greater ease of operation including startup sequencing. The ability for the power plant to maximize the use of prepackaged process units (such as air separation, water treatment, acid gas removal, and sulfur recovery units) and reduce the complexity of startup will allow the plant to benefit from simpler operations and process controls. Although the installed cost on a per unit of power basis may be higher than conventional coal-based power generation technologies of the same scale, the reduced complexity does not exacerbate this issue, and still allows the cleaner coal plant to surpass CFB boiler and PC boiler technologies in emissions profile and overall plant efficiency. In other words, at this small scale, the reduced integration does not have the negative impact that would be expected when competing against larger, base-load utility coal facilities. Additionally, as gasification plants produce a high-purity CO$_2$ stream, they are essentially carbon-capture ready.

The integration with a little “i” includes sending syngas to the GE turbines (see Figure 2). Exhaust from the turbines as well as superheated steam is sent to the heat recovery steam generator (HRSG), which is also integrated with a steam turbine.

SES’ DISTRIBUTED POWER PLANT CONCEPT: THE FIRST PASS

In January 2014, the first potential customer for launch of this small- to medium-scale gasification distributed power plant was identified and preliminary engineering efforts were
undertaken. The early work performed by SES, with support from GE and their regional partners Tuten and IstroEnergo Group, yielded the following design components regarding the combined technologies:

1. System Design:
   a. Single SES gasifier system, operating at nominally 50 bar(g), on high-purity oxygen, and consuming 1100–1700 tonnes/day of coal (depending on coal quality) to produce clean syngas that is suitable for GE’s LM-2500 series aero-derivative gas turbines.
   b. Two GE LM-2500+G4 gas turbines in combined cycle with a single steam turbine and HRSG.
   c. SES gasifier system sends excess superheated medium pressure steam to the power plant.
2. Net power output is nominally 80 MW, with projected improvement based on minor modifications to the gas turbine fuel nozzle.
3. Feedstock capability includes lignite, sub-bituminous, and bituminous coals with heat contents as low as 3000 kcal/kg (as received, LHV).
4. Reuse of process units from the SES Gasification Technology system through syngas cooling, fines removal, acid gas removal, sulfur recovery unit, and the gas turbines. The “flex” packaged units would include air separation unit, coal handling and preparation, ash handling, and the bottoming cycle in the power plant.
5. Initial budgetary estimates start as low as $1800/kW installed costs for a China construction basis and are projected to run $2000–2500/kW for a significant portion of the market; these prices can be achieved through maximizing fabrication of packaged units and major process equipment via qualified and internationally accredited Chinese fabricators.
6. The estimated net LHV plant efficiency is 34–38% depending on coal quality, plant site conditions, and elevation.
7. Operating and maintenance costs, excluding coal costs, are estimated to be 2–3% of the total installed cost basis annually.4

A sample of the projected plant economics is provided in Table 2.

**DEPLOYING DISTRIBUTED GASIFICATION POWER ONE PLANT AT A TIME**

Tackling the major barriers to implementing coal gasification projects is SES’ main focus and the SES Gasification Technology’s capability of converting a wide range of low-cost, low-quality coals is the largest factor in achieving good project economics. In addition, SES has developed equipment manufacturing capabilities in China that help it reduce the capital costs required to build projects.

SES has partnered with Zhangjiagang Chemical Machinery Co., Ltd. (ZCM) for its China and select Asia regional business, forming Jiangsu Tianwo-SES Clean Energy Technologies Ltd. (T-SEC), which is intended to enable global-scale implementation of projects using SES Gasification Technology via the lowest cost supplier of process equipment. This partnership is designed to enable SES to pass on savings to its customers, thereby reducing the overall capital expenditure for historically capital-intensive gasification projects.

SES secured the global exclusive rights to this technology more than a decade ago, and has since constructed five of its low-quality coal gasification systems in two methanol-producing plants in China: the Zao Zhuang New Gas Company Joint Venture Plant (ZZ) in Shandong Province and the Yima Joint Venture Plant (Yima) in Henan Province. Both plants convert low-grade coals and coal wastes, with very high ash content regularly exceeding 40 wt%, into syngas which is then converted into refined methanol. The ZZ plant, constructed in

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**TABLE 2. Example indicative plant economic factors based on Indonesian lignite**

<table>
<thead>
<tr>
<th>Fuel Input</th>
<th>35 wt% moisture (as received)</th>
<th>3840 kcal/kg LHV</th>
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<tbody>
<tr>
<td></td>
<td>~1200 tonnes/day</td>
<td>$30/tonne delivered</td>
</tr>
<tr>
<td>Plant Performance</td>
<td>Net Efficiency ~36% LHV</td>
<td>Net Output 80 MW</td>
</tr>
<tr>
<td></td>
<td>Plant Life = 30 years</td>
<td>Availability = 90%</td>
</tr>
<tr>
<td>Financing Assumptions</td>
<td>$240MM Installed Cost</td>
<td>2 yrs construction</td>
</tr>
<tr>
<td></td>
<td>30% Equity/70% Debt (15 yr)</td>
<td>8% Interest Rate</td>
</tr>
<tr>
<td></td>
<td>O&amp;M Costs = 2% Installed Costs (annually)</td>
<td></td>
</tr>
<tr>
<td>Economic Performance</td>
<td>At $100/MWh (net)</td>
<td>At $120/MWh (net)</td>
</tr>
<tr>
<td></td>
<td>22% Unlevered ROE</td>
<td>18% Unlevered ROE</td>
</tr>
<tr>
<td></td>
<td>41% Levered ROE</td>
<td>29% Levered ROE</td>
</tr>
</tbody>
</table>
2007 with commercial operation initiated in 2008, housed the largest U-GAS® based gasifiers ever installed at the time: two SES gasifiers, each with a capacity to produce 14,000 Nm³/hr of syngas.

At the Yima plant, which had its first methanol production in 2012, SES scaled up from the ZZ gasifier capacity and pressure threefold, installing three 1200-tpd SES gasifiers that operate at 10 bar(g), each with the capability to produce 45,000 Nm³/hr of syngas. During the first years of operation at ZZ, SES devised and implemented multiple improvements to the U-GAS® technology, many of which were included in the design of the Yima plant. These improvements increased carbon conversion, overall gasifier efficiency, operability, and heat recovery. These enhancements, along with additional optimizations that are being devised from the larger scale Yima gasifiers, are included in SES’ high-pressure gasification system design—optimized for chemicals and energy production where downstream processes benefit or require high-pressure syngas for end-product manufacturing.

CONCLUSION

Gasification is a global solution for the utilization of the world’s most abundant natural resource—coal—to produce chemical and energy products cleanly and efficiently. The challenge to do this economically and in markets that are not likely to support a large capital investment has been a historic challenge for gasification, and SES is making headway on knocking down the two major barriers to cost effectiveness: large capital investment and required access to expensive, high-quality coals. Through the implementation of a low-cost source for process equipment and the ability to use the lowest cost fuels available, SES believes it can enable projects to proceed in even the most challenging market: distributed power generation from coal gasification. SES is excited to move forward with its project partners to implement its clean coal gasification technology into the distributed power market for the production of clean, efficient, and economic electricity production.

NOTES

A. Only as a cost savings measure for plants which will have known maximum ash contents for their fuel sources.

REFERENCES


For more information regarding SES and its technology, please visit www.synthesisenergy.com