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# A technical and financial analysis of two recuperated, reciprocating engine driven power plants. Part 2: Financial analysis

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ABSTRACT

This paper is the second of a two part study that analyses the technical and financial performance of particular, recuperated engine systems. This second paper examines the financial performance of two hybrid (renewable/fossil), chemically recuperated power plants. One of these plants uses the combustion of biomass as the renewable energy input. The other assumes that solar thermal energy is used.

This financial analysis estimates the so-called Levelized Cost of Electricity (LCOE) of both hybrids using reference data from several sources. Using consistent financial inputs, the LCOE of both hybrid plants is found to be comparable to the LCOE of natural gas combined cycle (NGCC) power generation. Further, the LCOE of the renewable portion of the hybrid plants' total power output is significantly cheaper than that of all the renewable plants examined in the EPRI report, and is competitive with the fossil plants. As a result, the proposed hybrids appear to be a cost-effective form of greenhouse gas mitigation.


## 1. Introduction

Techno-economic evaluations of different power systems are commonly used to evaluate the potential viability of a given technology, e.g. [1–4]. Part 1 of this two part study [5] examined the thermodynamic performance of two chemically recuperated engine systems. One of these systems was a hybrid, in which the combustion of biomass was used in addition to that of natural gas to improve system performance. This study found that the efficiency of biomass use in this hybrid was high, and that it significantly reduced the system's $CO_2$ emissions, potentially resulting in comparable and even lower $CO_2$ emissions than that of natural gas combined cycle power (NGCC) generation. This was argued to be significant result, since NGCCs are commonly considered to have the lowest $CO_2$ emissions of all forms of fossil fuelled, power generation currently in use.

Of course, such performance is less compelling if the cost of operating the hybrid plant is prohibitive. This paper therefore estimates the so-called Levelized Cost of Electricity (LCOE) of two hybrid, chemically recuperated power plants. One of these plants uses the combustion of biomass as the renewable energy input. The other assumes that solar thermal energy is used. Since the performance of both cycles is the same for a given amount of renewable energy input, the financial analysis of both cycles can be based on the thermodynamic analysis of the biomass hybrid studied in Part 1 [5].

This analysis uses reference data from several sources, in particular a well known study of different power generating technologies published by the Electric Power Research Institute (EPRI) [6]. Since there are of course shortcomings of any LCOE method.

Of particular interest is the LCOE of the proposed hybrids relative to that of common fossil and renewable plants. The LCOE of fossil fuel plants ranges roughly between 50 and 80 USD/MW h in most studies, whilst that of renewable technologies can range from 110 to 350 USD/MW h, e.g. [6,7]. Thus, cost remains a challenge for the wide-scale implementation of most renewable plants. The integration of both natural gas and renewable energy inputs in a hybrid may therefore be a viable way to reduce greenhouse gas emissions in a more cost-effective manner.

## 2. Methodology

### 2.1. The Levelized Cost of Electricity (LCOE)

The LCOE is the average price electricity should have over the life time of the plant to achieve a net present value (NPV) of zero. The parameters used to calculate the LCOE are as follows.

1. **Total plant cost (TPC).**
The TPC is the cost of building the plant. It includes not only the basic equipment costs, but also all process and support

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facilities, such as fuel handling and storage, waste treatment, offices, and maintenance. In this study it is accounted for as an initial lump sum.

2. **Total capital requirement (TCR).**
   This is the total capital required to build the plant. It includes all interest incurred during the construction period. In this study the difference between the TCR and the TPC is accounted for as an equal expenditure paid during each year of construction.
3. **Fixed and variable operating and maintenance costs** (FOM and VOM).
   The fixed operation and maintenance costs (FOM) are related to the power capacity of the plant and are normally expressed in [$/kW yr]. They include labor, equipment and overhead charges. Variable operation and maintenance costs (VOM) are usually related to the electric production of the plant, and expressed in [$/MW h]. Throughout this analysis the fuel cost is not included in the VOM and is treated as a separate expense.
4. **Fuel costs** (FC).
   The fuel cost is treated as an annual expense.
5. **Inflation.**
   This study is done in constant dollars (i.e. no inflation rate is applied) to avoid the distortion caused by many years of inflation.
6. **Fixed charges.**
   These are incurred from the moment the plant is placed in service until it has been fully depreciated. In this study they include depreciation, equity return, interest on debt and income tax.
7. **Annual overall power generation (PG).**
   The overall power generation in kW h/yr is calculated as the plant's overall capacity times it capacity factor. The capacity factor is the percentage of time the power plant is generating at its rated capacity. Different technologies have different capacity factors.
8. **Discount rate.**
   The discount rate, also known as the weighted average cost of capital (WACC), is used to calculate the present value of money. It is the product of the debt rate times the percentage of debt financing plus the equity return rate times the percentage of equity financing.

The modelling in this paper was developed using the EPRI report 'Integrated Generation Technology Options' [6]. This report assumes

- the 'optimistic' and 'pessimistic' costs and parameters listed in Table 1;
- the financial parameters listed in Table 2;
- linear tax depreciation over the book life;
- a debt life of 20 years;
- constant US dollars;
- no incentive programs;
- The TCR is equal to the TPC plus the owners cost and the project specific costs;
- $CO_2$ emissions are for power generation only, not the life cycle emissions;
- Biomass emissions can vary significantly based on fuel source and life-cycle emission assumptions [6]. Conventionally, the release of carbon from biogenic sources is assumed to be balanced by the uptake of carbon when the feedstock is grown, resulting in zero net $CO_2$ emissions.

Given the terms 1–8 defined above, the LCOE is then the average price (including the time value of money) over a given period that must be charged to balance the net present value (NPV) of all expenditures, i.e.

$$LCOE\sum_{t=1}^{n}\left[\frac{PG_t}{(1+WACC)^t}\right]=\sum_{t=1}^{n}\left[\frac{I_t+FOM_t+VOM_t+FC_t+IT_t}{(1+WACC)^t}\right] \quad (1)$$

and thus

$$LCOE=\frac{\sum_{t=1}^{n}\left[\frac{I_t+FOM_t+VOM_t+FC_t+IT_t}{(1+WACC)^t}\right]}{\sum_{t=1}^{n}\left[\frac{PG_t}{(1+WACC)^t}\right]} \quad (2)$$

where $n$ is the book life of the plant, $t$ is the year being evaluated and $I_t$ are the investment expenditures. The term $I_t$ may include plant costs (TPC), interest and construction costs (TCR) and debt payments, depending on the year in question.

Prior to calculating the LCOE of the proposed hybrid cycles, the results from the tool developed in the present study are compared to those in the EPRI report [6]. The maximum difference found between them is less than 1% for all technologies in Table 1 operating with optimistic and pessimistic scenarios, thus validating the method.

**Table 1**
Representative cost and performance of power generation technologies [6].

| | Nominal plant capacity [MW] | Capacity factor [%] | Book life [yr] | Heat rate [Btu/kW h] | $CO_2$ emissions [MT/MW h] |
|---|---|---|---|---|---|
| Coal: PC | 750 | 80 | 40 | 8750 | 0.84 |
| Coal: IGCC | 600 | 80 | 40 | 8940 | 0.86 |
| Natural gas: NGCC | 550 | 80 | 30 | 6900 | 0.37 |
| Nuclear | 1400 | 90 | 40 | 10,000 | – |
| Biomass, BFB | 100 | 85 | 40 | 12,900 | 0 |
| Wind: on-shore | 100 | 28–40 | 20 | – | – |
| Wind: off-shore | 200 | 40 | 20 | – | – |
| Solar: CST | 100–250 | 25–49 | 30 | – | – |
| Solar: PV | 10 | 15–28 | 30 | – | – |

| | Total plant cost [$/kW] | Total capital required [$/kW] | FOM [$/kW yr] | VOM [$/MW h] | Fuel price [$/MMBtu] | LCOE [$/MW h] |
|---|---|---|---|---|---|---|
| Coal: PC | 2000–3000 | 2400–2760 | 48 | 2 | 1.8–2 | 54–60 |
| Coal: IGCC | 2600–2850 | 3150–3450 | 74 | 2.3 | 1.8–2 | 68–73 |
| Natural gas: NGCC | 1060–1150 | 1275–1375 | 16 | 2.3 | 4–8 | 49–79 |
| Nuclear | 3900–4400 | 5250–5900 | 110 | 1.7 | 0.4–0.8 | 76–87 |
| Biomass, BFB | 3500–4400 | 4000–5000 | 63 | 5 | 2–6 | 84–147 |
| Wind: on-shore | 2025–2700 | 2120–2825 | 35 | – | – | 75–138 |
| Wind: off-shore | 3100–4000 | 3250–4200 | 105 | – | – | 130–159 |
| Solar: CST | 3300–5300 | 4050–6500 | 64–68 | – | – | 151–195 |
| Solar: PV | 3400–4600 | 3725–5050 | 50–65 | – | – | 242–455 |